440177007A

ESTUARINE POLLUTION CONTROL AND ASSESSMENT

Proceedings of a Conference

VOLUME I

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER PLANNING AND STANDARDS
WASHINGTON, D.C.

OVERVIEW

PREFACE

This report is designed to provide information that could be used to establish a national program for the prevention, reduction, and elimination of pollution in estuaries. The Environmental Protection Agency has attempted to identify important estuarine problems by soliciting written state-of-the-knowledge reports from leading scientists working in the field. During April 1974 EPA met with the governing board of the Estuarine Research Federation (ERF), a professional society of some 1,500 estuarine scientists. The purpose of this meeting was to request the Federation's participation in selecting the most knowledgeable contributors.

On May 30, 1974 an interagency ad hoc working group was established to refine the reporting effort approach and to establish the content and format of the report. The group included representatives of EPA, ERF, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration (NOAA), the Smithsonian Institution, and various academic institutions.

From a list of possible contributors, 57 were selected. Their efforts are included in the second part of this report. A set of guidelines, developed by the working group, was distributed to these authors requesting a presentation of approximately 20 pages in a style aimed at a layman audience. In selecting the authors, an attempt was made to provide a balanced representation from the academic, governmental, and industrial communities, including differing or opposing points of view.

Additionally, a letter requesting information was sent to the National Association of Manufacturers, with specific letters to 23 member industries in the Association. Further, those federal agencies with estuarine pollution control programs were formally asked to supply information for inclusion in the study. With all requests for information, guidance in preparation was provided. All materials received are either summarized or included *in toto* as the Individual Contributions section of this document.

Each contribution was examined by a minimum of two outside reviewers selected by the Estuarine Research Federation. Authors were provided with the reviewers' comments and encouraged to revise their manuscripts accordingly; however, revisions were not mandatory. Participating reviewers are listed in Appendix A.

Each contributor was invited to present a summary of his paper during a symposium at Pensacola, Fla., from February 11 to 13, 1975. Numerous government representatives were invited to attend. A complete list of attendees appears in Appendix B.

The meeting was organized to allow as much time as possible for discussion. The intent was to provide contributors with additional information for inclusion in the final version of their papers, and more importantly, to provide the convenors with a basis for preparation of a useful overview report. The symposium was divided into the following sessions:

Research Applications
Estuarine Systems
Other Pollutants
Dredging Effects
Nutrients
Fisheries
Ports
Industry
Power Plant Effects
Public's Role
Legal Aspects
Living and Non-Living Resources
Economics
Concluding Remarks.

In order to capture the essence of the conference, summaries of these sessions were prepared and appear in this report. A committee was chosen from the participants to develop the conference format and prepare the summaries. This committee included:

Dr. Robert Biggs, Assistant Dean, College of Marine Studies, University of Delaware

Dr. David Correll, Rhode River Program, Smithsonian Institution

Dr. John Costlow, Director, Duke University Marine Laboratory

Dr. L. Eugene Cronin, Associate Director for the Research Center for Environmental & Estuarine Studies, University of Maryland

Dr. William P. Davis, Chief, Bears Bluff Field Station, U. S. Environmental Protection Agency

Dr. David Flemer, Office of Biological Services, U. S. Fish and Wildlife Service

Dr. M. Grant Gross, Director, Chesapeake Bay Institute, the Johns Hopkins University

Dr. Thomas Hopkins, Chairman, Department of Biology, University of West Florida

Mr. Kent Hughes, Special Assistant for Marine Science Environmental Data Service, National Oceanic & Atmospheric Administration

Mr. Robert Johnson, Office of Water Planning & Standards, U. S. Environmental Protection Agency

Mr. Edward Langlois, President, Portland Harbor Pollution Abatement Committee, Portland, Maine

Dr. J. L. McHugh, Marine Sciences Research Center, State University of New York at Stony Brook

Dr. Joseph Mihursky, Chesapeake Biological Laboratory, University of Maryland

Mr. Thomas Pheiffer, Annapolis Field Station, U. S. Environmental Protection Agency

Dr. William Queen, Department of Biology, Maryland University

Mr. Kenneth Roberts, Resource Research Specialist, Office of Living Resources, National Oceanic & Atmospheric Administration

Dr. J. R. Schubel, Director, Marine Sciences Research Center, State University of New York at Stony Brook

Dr. Albert Sherk, Office of Biological Services, U. S. Fish & Wildlife Service

Prof. Jerome Williams, Associate Chairman, Department of Environmental Sciences, U. S. Naval Academy

It is important to recognize that only a few of the individual authors had the opportunity to contribute to or review the session summaries. It is hoped, however, that all points of view have been accurately presented by the Committee.

To more effectively popularize some of the concepts expressed in this report, a 28-minute motion picture entitled "Estuary" has been prepared as a joint production of NOAA and EPA. The film illustrates aspects of estuarine pollution, associated problems, and conflicts. It also attempts to describe some approaches that have been, or could be utilized in addressing these problems. The film may be ordered from the NOAA Motion Picture Service, Rockville, Md.

A compilation of all federally funded estuarine research projects is included in the index, prepared by the Technical Information Unit of EPA's National Field Investigations Center in Denver, Colo. The index, on microfiche, is presented as the third volume of this report. The size of the index necessitated this form of presentation to conserve space, paper, and printing costs.

Special appreciation is extended to Dr. Thomas Duke and his staff at the EPA Gulf Breeze Laboratory, Pensacola, Fla., for their assistance in conducting the symposium. Their efforts have contributed significantly to the success of the entire project.

INTRODUCTION

Estuarine systems often are politically, economically, and ecologically complex, and major problems cannot be solved by piecemeal action. Research, planning and management of estuaries should be strongly oriented toward the entire system, with adequate consideration of the total watershed including land use and development as well as future trends.

Estuarine resources are demanded for many alternative uses such as waste assimilation, recreation and esthetic enjoyment. Some uses complement each other, many do not. In order to choose among competitive uses of estuarine resources, the benefits and the costs to society as a whole which arise from alternative uses must be systematically evaluated.

SYMPOSIUM ISSUES

A number of issues discussed at the EPA symposium stand out as being particularly important in terms of effective estuarine management. These issues are discussed in the summaries to follow and are more thoroughly examined in the individual papers included in the second part of this report. The three issues presented below are singled out because a number of the conference participants were motivated to discuss them at length in their written and oral presentations.

DATA SYSTEMS

In few estuaries are the data sufficient to establish historical trends in water quality. In no estuary is our knowledge of the prevailing processes adequate to unequivocally assess the causes of any persistent changes that may have occurred or may be occurring. Therefore, monitoring programs are important and must be continued, but they should be carefully designed to provide data that will also be useful in process-related studies. In light of our present inability to make quick assessments of existing estuarine environmental quality and changes occurring in coastal areas, our present national data storage and analysis systems must be re-evaluated. Additionally, it has become apparent that the utility of national data repositories is questionable when large numbers of users with many different needs are considered. Multiple regional data centers are much more flexible than a single system and therefore should be considered. The smaller size of regional centers would increase availability of regional data, increase the efficiency of the computer systems, and decrease maintenance costs. On the other hand, increasing the number of computer centers necessarily increases the work force, duplication of effort, and probably operating costs.

UTILIZATION OF ESTUARINE RESOURCES

Utilization of estuarine resources was a concern often expressed by the conference participants and attendees. Generally, two areas of concern were evident: (1) consumptive utilization of estuarine waters and (2) discharges of nutrients, thermal loadings, and fresh water to estuaries.

Consumptive utilization of estuarine waters is a necessary support function for numerous industrial processes, and vast quantities are also required for municipal and public use. Adequate water quality must be maintained if this consumptive utilization is to continue.

However, concern was expressed regarding the concept of uniform discharge controls for all estuaries. A suggested alternative to this approach is to base effluent discharge controls on assimilative capacity of the individual estuary. The assimilative capacity must be adequately defined in terms of the total flux of the estuary and the natural background levels of the pollutant being discharged. The objective should be to achieve the optimum use of each estuarine system commensurate with the manner in which the system naturally functions.

DREDGING AND SPOIL DISPOSAL

Although estuaries are natural areas of rapid sedimentation, man has dramatically increased the sediment influx to many of them. Sediment inputs associated with agricultural and construction efforts increase the need for maintenance dredging and therefore should be controlled at the source.

Because of the many different types of dredging and disposal techniques, the different types of dredged material involved, and the great diversity of estuarine environments, present chemical indices for classifying dredged material must be expanded from simple numerical values for adequate nationwide application.

RESEARCH NEEDS

Particular research areas considered by the contributors to require increased emphasis:

1. *Estuarine Models*—A review of estuarine modeling programs, both mathematical and hydraulic, identifying both their limitations and the circumstances in which they can be most profitably utilized, is necessary. Greater emphasis should be placed on the formulation of conceptual models and on attaining a better understanding of the processes that characterize the estuarine environment.

2. *Identification of Toxic Materials*—An increased effort is needed to identify the toxic substances introduced into the estuarine environment as a result of man's activities. An assessment of acute and chronic effects of these substances and their behavior in the estuarine environment is required.

3. *Natural Abundance Variations*—The effects of pollution on estuarine living resources cannot be determined unless natural abundance changes are known. An accelerated effort to make these determinations is therefore required.

4. *Microbial Populations*—Research should be supported to develop rapid techniques for detection of pathogens and for identification of more descriptive microbial indicator organisms.

5. *Natural Filters and Non-Point Sources*—The effect of natural ecological filters such as marsh areas on estuarine processes is not well understood. The possibility of practical application of this process in waste treatment, especially with regard to non-point sources, should be more fully investigated.

6. *Population Distribution Planning*—A critical assessment should be made of the need to recommend new types of controls required for population density in estuarine areas through appropriate zoning and land use management. Zoning and land use planning may not be adequate to control population pressures in estuarine areas.

SESSION SUMMARIES

ESTUARINE SYSTEMS

Each estuary is unique and is a complete, complex and unusually dynamic system, influenced by geographic location and seasonal variations. While much useful knowledge has been gained from research on the individual parts of estuaries and on the separate processes which occur, some of the most serious past failures in effective estuarine management have been caused by attempting to deal with problems as isolated events. Rather, the total estuarine system must be considered.

Recent research has made substantial contributions to our ability to analyze estuarine systems, and important progress is being made at several study sites. Despite the diversity of estuaries, a study of principal types, supplemented by local investigations to identify special problems can aid management of all estuarine systems.

Both estuarine management and estuarine system research are hampered frequently by the political, economic, and ecological complexity of the estuary. Piecemeal approaches are not as useful as a total approach, but cooperative attitude between governments and business can produce beneficial estuarine management programs. Increased research on estuaries as systems will prove to be of exceptional practical value in our efforts to achieve a balance among the ever-increasing uses.

LIVING AND NON-LIVING RESOURCES

Serious public concern exists regarding the fate of the nation's estuaries, and their attendant resources. During the period 1965–1975, legislative and administrative bodies in coastal states acted to protect living and non-living resources of estuaries by banning indiscriminate destruction of estuarine marshes; by considering fish and wildlife values equally with economic, social and legal issues in Federal decisions affecting estuaries; and by recognizing living and non-living resource values in coastal zone planning.

Even though governmental authority to consider living and natural resources of estuaries has been strengthened, problems remain. As yet minimal consideration has been given to aesthetic values when the potential impact of proposed actions within estuarine systems are evaluated. These aesthetic qualities of the shore zone (mixtures of land and seascapes) are as important in attracting people to the coastal estuaries as marine fish and shellfish, waterfowl, and marsh furbearers. Potential aesthetic impacts must be considered as well as biological, water quality and economic impacts. The conference participants recommend that regulatory agencies further develop criteria and guidelines to be used in aesthetic assessments and institute research projects designed to provide information essential to these criteria (see Fig. 1).

Environmental protection policies and programs are, for the most part, designed to prevent or minimize further environmental degradation. Unfortunately, many estuarine areas became degraded before these policies and programs were implemented. Recently, efforts have been made to rehabilitate some derelict areas. The participants suggest that these rehabilitation efforts be continued and extended when possible, along with associated research on habitat rehabilitation.

FISHERIES

Estuaries are an important part of the fishery resource of the United States. Estuarine environments generally are biologically more highly productive per unit area than the open sea. About two-thirds of the commercial and recreational fish and shellfish of the United States spend important parts of their lives, or their entire lives, in estuaries. Thus, management of these resources depends in large degree on maintenance of the quality of the estuarine environment.

Despite the acknowledged importance of estuaries to the fisheries of the nation, the effects of estuarine pollution on the living resources are not well understood. One complicating factor is that, although the estuarine environment is rich biologically, it is also a highly variable environment—a harsh environment at times. This variability produces wide fluctuations in abundance of estuarine resources brought about by natural causes, and these variations usually are impossible to distinguish from those caused by human activities such as engineering works and fishing, as well as water pollution. As an example, Fig. 2 illustrates fluctuations in the abundance of starfish in Long Island Sound for the years 1937 to 1961.

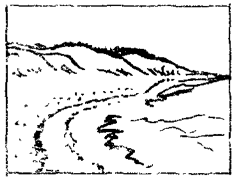
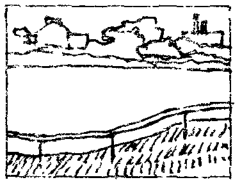
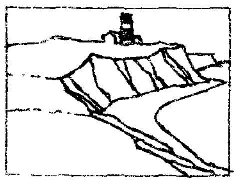
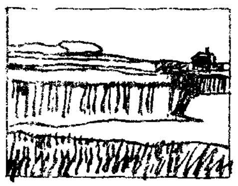
	Resource Type	(Selected) Visual Attribute(s)	(Selected) Intangible Attribute(s)	Managerial Implications	Institutional Implications
	beach	-sand qualities -forms -sweep	-molding by sea energy -primordial state, geological record	-exclusion or regulation of structures -debris, trash, dune buggy regulation -user-capacity determinations	-town exclusionary use vs. open public use (visual access) -public use of private beaches -maintenance funding
	riverbank	-landform configuration -vegetative characteristics -space/closure patterns	-order given to rural and urban land use -natural corridor provides physchological linkage to both source region and sea	-bank erosion protection -vegetative edge protection -clearance and planting management -urban area rehabilitation	-conciliation of split jurisdictions over riverbank areas -administration of public access and access acquisition
	bluff	-landform face -crest patterns -height	-impressiveness -sense of geological process -sense of hazard	-exclusion or regulation of use on or near crest and face -cautionary use of erosion protection measures	-development of legislative and administrative regulation of bluff areas
	tidal marsh	-vegetative infrastructures -seasonal change -wind imprints -tidal changes	-sense of (urban) endangerment -sense of significance in estuarine ecosystem	-prohibition of dredging, filling -regulation of permitted, compatible use	-development of legislative and administrative regulation of marsh areas

FIGURE 1.—Selected aesthetic resource and problem definitions.

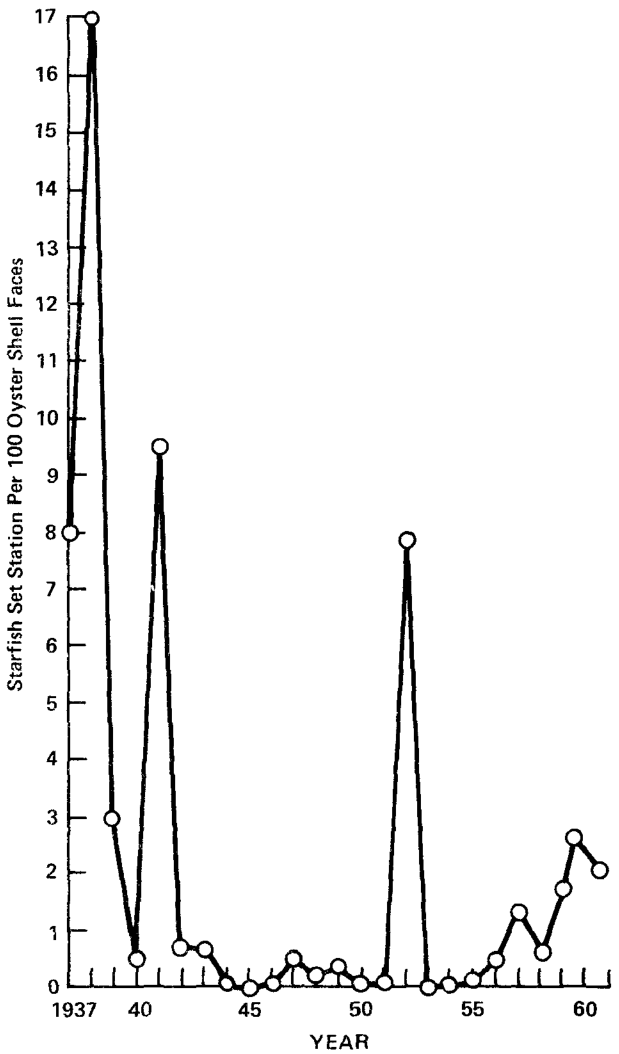


FIGURE 2.—Variations in Long Island Sound sea star abundance, 1937–61.

At the same time, the marked variability of this highly productive environment illustrates the resilience of living resources and underscores their ability to recover from catastrophic events occurring naturally or of human origin. Only by examining sessile resources like oysters and clams can we assess the adverse effects of environmental degradation. Existing knowledge must be fully utilized in this assessment and supplemented with estimates of standing crop, commercial and recreational catches, renewal rates, and natural mortality for most of these resources.

Despite the lack of data concerning the effects of estuarine pollution upon living marine resources of commercial and recreational value, the net effects of water pollution can be presumed to be adverse. Undeniable direct proof probably will never be available. Results of experimental studies indicate that every possible effort must be made to control and, where possible, to mitigate estuarine water pollution.

DREDGING EFFECTS

Although estuaries are areas of naturally rapid sedimentation, man has dramatically increased the sediment influx to many estuaries through his activities, not only within the estuarine zone, but throughout the estuarine drainage basins. Increased sediment inputs largely reflect increased erosion rates resulting from poor soil conservation practices associated with agricultural, strip mining, and construction activities. Local production of biologically produced sediment within the estuary has been stimulated by discharges of nutrient-rich waste water and runoff from agricultural and urban areas. Coupled with this ever increasing sediment input is the continuing requirement for deeper harbors to accommodate the newer, larger ships. The net effect has been a continual increase in dredging activity and cost as shown by Figure 3.

While construction of reservoirs and other engineering works occasionally has decreased the sediment inputs to some estuaries, the net effect has definitely been an increase in sediment loads. Significant progress has been made in controlling soil erosion in agricultural activities. Similar efforts

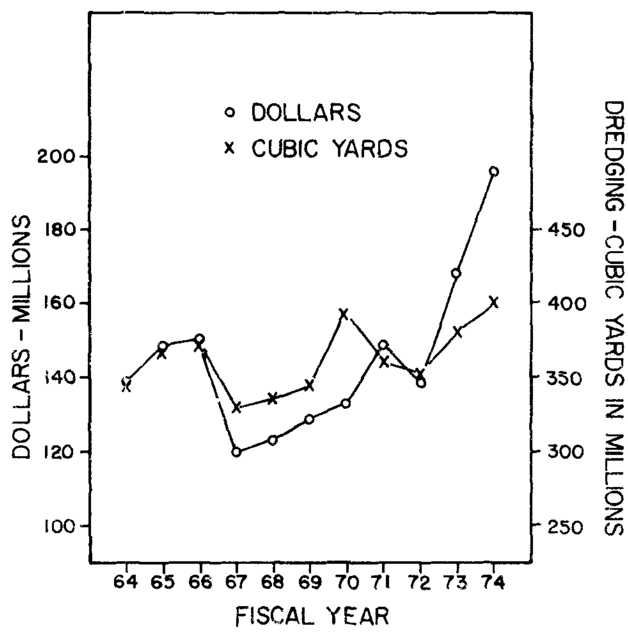


FIGURE 3.

in other areas must be intensified so that sedimentation may be reduced significantly within two decades. Until the influx of sediments can be curbed, maintenance dredging still must be employed; however, disposal of these dredged spoils is also a problem compounded by the difficulty in defining "acceptable" spoil for appropriate disposal sites.

Because of the many different types of dredging and disposal techniques, the different types of dredged material involved, and the great diversity of estuarine environments, present chemical indices for classifying dredged material must be expanded from simple numerical values for adequate nationwide application.

The conference participants advise that criteria for classification of dredged materials should not be based on concentrations of contaminants—neither total concentrations, nor reactive fractions. Rather the guidelines should be based on the total amounts of contaminants actually available for biological uptake—i.e. the concentration of the reactive fractions multiplied by the quantity of material to be dredged for any particular project. The suite of biological contaminants considered must be extended to cover all potentially toxic substances and pathogenic organisms.

NUTRIENTS

Most estuarine ecosystems are considered natural nutrient storehouses. When the capacity of estuaries to assimilate nutrients is exceeded, over-abundance of nutrients can cause nuisance accumulations of algae and rooted plants resulting in degradation of water quality. Natural sources of nutrients are mainly from upland drainage, while freshwater streams are a source of dissolved and particulate forms of nutrients. Major manmade point sources of high nutrient concentrations include domestic sewage and industrial wastes. Non-point sources typified by farms, forests, and urban runoff provide a high net yield of nutrients, adding significantly to the total. More work is required to define the relative importance of point and non-point nutrient sources as an aid in management control decisions.

A realistic nutrient management program should be based on factors that control the individual capacities of estuaries to assimilate nutrient inputs. These factors include physical processes such as the rate of flushing and biological processes such as nutrient cycling. A countrywide application of standards to control maximum permissible nutrient concentrations may be a counterproductive approach, because estuaries are highly diverse in their assimilative capacity.

Nitrogen and phosphorus are considered the most important nutrients (see Fig. 4), but their relative influence varies within an estuary, both spatially and temporally. Some geographical areas (notably Alaska) are relatively free of nutrient problems, but complacency can lead to future complications as experienced in many areas of the coterminous states and isolated estuaries of Hawaii.

Denitrification-nitrification, natural ecological filters (marshes and farm green belts), methods of fertilizer application, and processing of urban runoff are important research areas; however, drainage basin needs must be dealt with on a regional or individual basis.

INDUSTRIALIZATION EFFECTS

As the United States evolved into an industrialized society, our ports became the hubs of industrial activity in coastal regions. We now find ourselves with major industrial centers dependent on water transportation but located on estuaries neither deep enough for modern ships, nor large enough to assimilate associated wastes. At the same time these estuaries are incredibly valuable as a biological-recreational natural resource.

Industry depends on the estuary for waterborne transportation, for process water, or for products derived from estuarine waters or bottom sediments. Refineries and petrochemical plants, crude oil handling, power utilities, iron and steel production, paper manufacturing and sand and gravel extraction are the more important industries, most of which project increased production during the next several decades. Up to the present time, control of industrial effluents has been through the adoption of water quality standards and/or daily load limitations.

Another equally important consideration requires that we reduce the impact of industrial pollution in our estuaries by assisting industrial centers to find new, more environmentally acceptable sites. Regional groups must initiate work on the identification of the areas that can better accept the industrial wastes now discharged into our estuaries. The Coastal Zone Management Act, P.L. 92-583, may serve as an excellent vehicle to achieve this long-term objective.

POWER PLANT EFFECTS

Electrical energy production from the steam electric station (SES) industry results in the need to dissipate large quantities of heat. On the average,

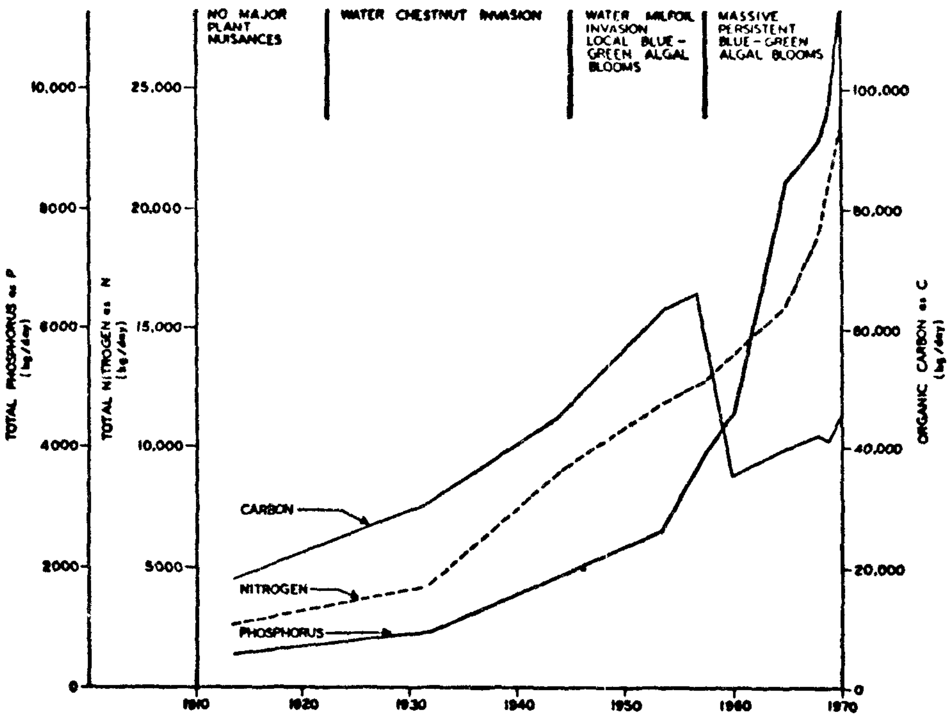


FIGURE 4.—Phosphorus, nitrogen and organic carbon in the upper Potomac River from 1913–70. The top line gives plant nuisances (from Jaworski, Lear and Villa, 1972, Fig. 7).

for every 1 megawatt of electricity produced, 1.7 megawatts of heat are rejected by an SES. This corresponds roughly to a 33 percent energy conversion efficiency for a typical fossil fuel plant. Efficiency of new fossil units is somewhat better, about 40 percent, while nuclear units achieve efficiencies around 32 percent.

Eventually, all of this heat must enter the atmosphere. Due to its large heat capacity water traditionally has been the "middle man" used to carry away the heat. Water requirements for a single power plant installation have increased greatly in the last decade, due primarily to the increased size of new plants.

Research has documented a number of undesirable site-specific, environmental and socio-economic impacts from SES operations. These impacts have been produced by a multiplicity of factors in addition to temperature. The following factors have been identified:

1. Temperature
2. Heavy metals leached from the power plant heat exchangers
3. Biocides used to prevent fouling of the heat exchangers
4. Changes produced by the effect of large volumes of water being discharged at high speeds.
5. Pumped-entrainment, pumped-entrapment problems.

Experience has indicated that at any given site, one design or operating feature may be responsible for the most undesirable effects while at a different site an entirely different design or operating feature is the problem. To achieve the best solutions and most effectively address the recognized problems, the minimal acceptable impact must be determined.

In order to quantify any undesirable changes and assess impacts, a standardized methodology for measurement and evaluation must be developed and used. These quantitative effects and predictions must also be considered from a cost-benefit standpoint. Such predictions, incorporated into an economic model, would provide a powerful tool for decision makers. The data also must be readily retrievable or the major portion of its usefulness will be lost. These step-by-step methodologies must be designed to achieve siting and operational procedures with the best environmental and socio-economic compatibilities (Fig. 5).

OTHER POLLUTANTS

A toxicant is any compound present in sufficient concentration to interfere with normal biological

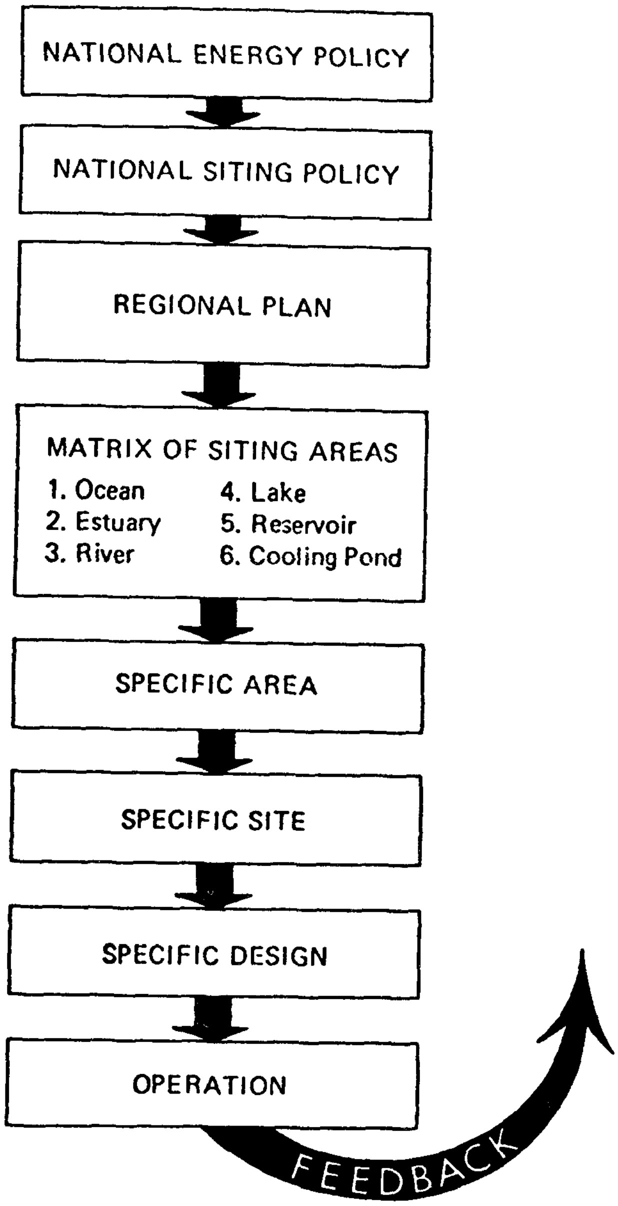


FIGURE 5.—Flow diagram for power plant siting considerations (after Committee on Power Plant Siting, 1972).

functions. One of the major toxicant groups, the organochlorine compounds, enters the estuarine environment primarily as a result of pest and weed control activities. Recent restrictions imposed on specific pesticides have triggered increased rates of new herbicide and pesticide development and use. Unfortunately, the result has been that the production and application of these organochlorides has outpaced research to identify their harmful effects.

Additionally, the significance of organochlorine compounds resulting from the use of chlorine as an antifouling biocide or as a disinfectant in waste treatment still represents an area requiring additional research effort.

Another group of toxicants is represented by petroleum products which include a wide variety of complex substances with an equally wide variety of impacts on estuarine systems (Figure 6). These impacts, aside from obvious aesthetic effects, range from immediate smothering to more subtle, chronic genetic modification of marine organisms. The estuary is most vulnerable to extreme impacts from petroleum because of bioaccumulation through the food chain.

In addition, oils act to concentrate other pollutants such as metals and pesticides, thereby increasing the ecological hazards. Field studies must be done in conjunction with laboratory investigations to determine the importance of these synergistic effects.

The potential threat of carcinogenic petroleum substances transmitted into the human food chain from contaminated seafood products remains to be scientifically demonstrated. The rates of transfer and long range fate and effect of water soluble components of petroleum are also poorly known.

Metals, too, pose complex problems in marine ecosystems, especially the estuaries. Although the sediments can sometimes act as a sink for entrapment of metals, many times man's activities, dredging for example, release metals back into the marine ecosystem potentially contaminating fisheries' resources and possibly entering the human food chain.

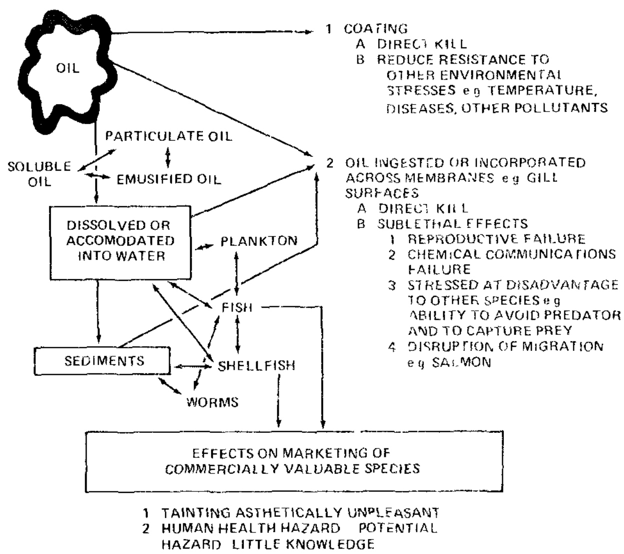


FIGURE 6.—Pathways of oil incorporation into marine life and effects on marine life.

Fate and effect studies of metals and toxic compounds must be complemented with effective monitoring efforts in the marine environment for conclusive results. Only then can "safe levels" be established for elements in sediments, sludges, effluents, and edible species.

RESEARCH APPLICATIONS

Since microbial indicators are an "early-warning" system of changes in an ecosystem, presently known microbes should be more efficiently utilized while additional indicator organisms are investigated. Early or chronic environmental effects may be detectable if the microbial indicators are employed wisely and carefully. Increased emphasis should be placed on the development of methods for the direct measurement of pathogens. Combinations of indicator organisms might be employed. The advantages and disadvantages of each indicator organism should be determined so that each may be applied more intelligently to environmental assessment. This is only one facet of a complex problem involving such mechanisms as genetic transfer of resistance factors to potential human pathogens. Additionally, improved methods for virus isolation and identification and an understanding of virus survival in estuarine and coastal waters and sediments is required to determine their usefulness as indicators.

Another aspect of understanding estuarine systems involves identifying the interrelationship of the physical, biological and chemical processes within the system. Once understood, incorporation of these factors into numerical models would allow the prediction of trends and the effect of various abatement procedures, along with the establishment of appropriate monitoring sites. Unfortunately, at present our computational capabilities far exceed our knowledge of many of the required input parameters. Much research, therefore, is necessary in the area of the fundamental processes for characterization in the models. Short-term efforts should be directed toward field testing of the validity of existing models.

Assessment of the significance of persistent chemical residues in estuaries necessitates monitoring their existence, magnitude, and seasonality in the environment. At the same time, information on the effects of various chemicals on significant species must be determined under controlled laboratory conditions.

The data of systematics form the essential foundation of all other biological disciplines, but the inadequate number of taxonomists in the country is crucial. Thus it is important to support and encourage further development of taxonomists while carefully conserving the human and material systematic resources already existing.

PORTS

Ports must meet environmental demands during a period when they are faced with abrupt changes in terminal design and operations. While increased costs affect the economic productivity of our ports, port development will affect estuarine environmental quality.

An abundance of legislation with resulting guidelines, policies and regulations, is specifically focused on port and estuarine areas. In fact, 53 federal agencies and bureaus administer the 69 different port-related activities. This partition of administrative responsibility can require up to 550 individual steps in a permitting procedure. This tedious permitting process often causes confusion, delays and additional expense.

Studies indicate marked increase in port traffic, as shown in Figure 7. This fact, coupled with changes in ship and terminal design has increased the need for dredging with its associated environmental impacts. Therefore, environmental concerns associated with ports are increasing and a study of the regional port concept and the impact of offshore deepwater ports is essential.

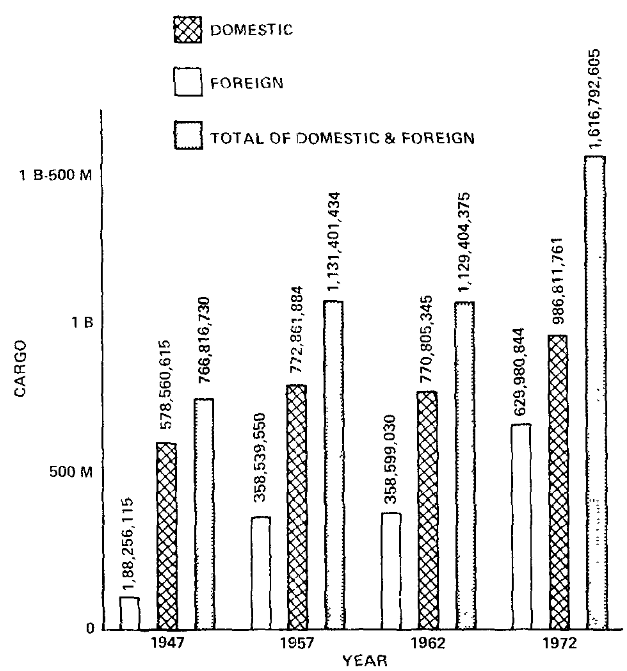


FIGURE 7.—Waterborne commerce in U.S., calendar years 1947–72 in million of tons (2,000 lbs.).

The participants and attendees at the conference expressed appreciation of the importance of the National Environmental Policy Act and the value of the environmental impact statement required therein. However, the following administrative areas were identified as needing clarification:

1. Permit application process—eliminate duplication of effort for the applicant.
2. Coordination among agencies administering the permitting program
3. Analysis of cost-benefit relationship—evaluation of the economics and environmental impact.

Where ports and ships are involved and the issue is clean water, the continuing problem involves proper disposal of ship generated oily waste, ballast water, and sanitary waste. Additionally, oil spills plague port operations and continue to degrade estuarine ecology. This situation will continue so long as vessels transport petroleum products within the estuarine area. In spite of efforts to regulate vessel traffic and train oil spill response teams, more research on methods and operational procedures for spill prevention and control is necessary, including the development of criteria for disposal of collected oil spill residues.

THE PUBLIC'S ROLE

An important aspect of the total effort in decreasing estuarine pollution is the active participation of the public. They not only are an integral part of any attempt to maintain the health and usefulness of estuaries, but also their health and welfare are the keystone on which the entire anti-pollution program is constructed.

The public performs three important functions in support of the estuarine environmental program. The first of these is to make their wants and needs known to those who can translate these requirements into action. The second is to help in the setting of priorities in the use of estuarine resources. The third is to accept the role of responsible citizens in reporting violations to the proper authorities and demanding appropriate response.

Two basic problems face the public. One is in the area of education and communication, while the other involves money. However, most public interest groups seem to be able to raise some funds when an important issue develops. Educating the public to the important issues may be the greater problem, since some of the issues are not well understood.

LEGAL ASPECTS

Over the past decade, the population of the United States has been rapidly shifting to the coastal areas of the nation. This movement, coupled with changing life patterns and progressive industrialization, urbanization, and development have influenced the quality of estuaries along much of the coastal margin. Efforts should be made to develop a set of national population distribution guidelines which would serve as a framework for regional, state, and local planning and development of land use management.

An improved level of coordination and planning among all levels of government could be effected by the establishment of a federal interdepartmental estuarine task force, conceivably as an adjunct to the federal coordination responsibilities of the Department of Commerce as provided for within the U.S. Coastal Zone Management Act. This task force would be expected to identify existing federal laws and policies affecting estuarine management and to synthesize them into a single federal policy for uniform application throughout the federal establishment.

This is especially true with respect to the present method of granting permits. A thorough examination of the present system should be implemented with an eye to the possible substitution of an interagency-state-federal panel that reviews the permits at all activity levels simultaneously.

The task force should further examine the current administratively established federal wetland policy and determine the need for legislative programs for wetland protection applicable to all federal activities, grants-in-aid and regulatory programs. Investigation should be made of the need for more specific legislation to provide federal impact aid assistance to coastal states, primarily in minimizing adverse environmental effects and providing some degree of control over the associated social and economic impact caused by the development of federal energy resources.

Concurrently, effective research and analytical support must be continued. This could still come from private institutions which have developed expertise on the dynamics of entire estuarine systems, or specific portions, and are thus in a position to present specific information on proposed projects. The regulatory agencies, however, should not be entirely dependent on the presentation and analysis of facts by outside parties. There also should be a continuing use of regulatory agency laboratories to produce an articulate program for the protection of estuarine systems.

ESTUARINE ECONOMICS

One aspect of management resulting in continued degradation of the estuarine environment is that the major portion of the estuary is common property. Since there is no individual ownership, there is no individual responsibility for protection and each user tends to consider his needs to the complete disregard of all other users. This situation can be improved by establishing an appropriate set of controls to bring the private costs of using estuarine resources into line with their social costs, thus preventing the estuary from being abused and overstressed.

An effective set of management techniques can be established by applying environmental standards. Implementation could be effected by either rezoning or by legal regulations and ordinances. Another possibility, however is to levy an emission charge. It can be demonstrated that the establishment of an appropriate level of emission charge is a potentially effective device for limiting the discharge of waste residuals into the estuary. A clear understanding that the polluter must pay in proportion to the amount of waste discharged is a strong incentive to prevention of damage.

A national policy on estuarine management is based upon the principle that the federal government establishes minimum environmental standards, but that local areas should be encouraged to establish environmental quality standards more stringent than the federal minimum. In keeping with this premise an attempt should be made to restrain irreversible estuarine development and to keep open as many options as possible for the future. Changing technology plus increasing demand for recreation areas will probably increase the future value of unspoiled recreational resources and reduce the present value of technology-intensive activities.

The value of estuaries to U.S. commercial and sport fisheries cannot be overestimated. Despite this important life support function, estuaries have lost more than 7 percent of their fish and wildlife habitat to commercial and housing development over the last two decades. In many coastal areas these developments proceeded without any evaluation of the socio-economic impact. Examination of the large number of estimates of commercial and recreational benefits associated with U.S. estuaries, reveals that practically all are conceptually invalid since they measure private rather than public welfare gains. It is misleading and unjustified from the perspective of economic theory to value estuarine resources solely in terms of market prices and not the public welfare cost.

CONCLUDING REMARKS

One of the products of the Federal Water Pollution Control Act, Amendments of 1972, is the National Pollution Discharge Elimination System, a permit system designed to control the flow of harmful wastes into the nation's waters and eliminate the introduction of all pollutants by 1985. Because the issuance of permits has begun only recently, and since all permits contain compliance schedules to reduce waste flows, no evaluation can be made at this time of the immediate impact of this program.

Of equal significance in this nation's effort to control the degradation of estuarine areas is the development and implementation of coastal zone management programs and procedures. This course of action has been effective in certain areas, but again, due to the recency of the program, there is not enough information available to quantitatively evaluate its impact.

To ensure that environmental protection efforts initiated over the past decade retain public support, the impact of the programs must be well publicized with concrete, understandable evidence. Aggressive educational programs, using all available media, must be recognized as a fundamental and top-priority need. The wide gap between science and public policy in all environmental matters is most likely to be closed, or at least narrowed, by an educated and public-spirited constituency, oriented logically rather than emotionally toward environmental management.

The general consensus of the workshop was that uniform application of water quality standards is impractical and from an economic point of view, undesirable. The participants support the viewpoint that water quality standards, when developed from existing criteria and information, should be based on specific locational parameters. These should include important biological species, climatological and hydrological features, hydrodynamic characteristics of estuaries, and the existing quality of the environment.

In order to develop a multiple-use management program within an estuarine area, it is essential that the impact of pollution on one use be evaluated as it affects other possible uses of the area. Figure 8 presents, in general fashion, a description of impacts arising from multiple usage. The table is intended as a management tool strictly from the standpoint of making early decisions with regard to evaluating potential usage of an estuarine area and defining some of the possible conflicts arising therefrom. It could also assist significantly in the development

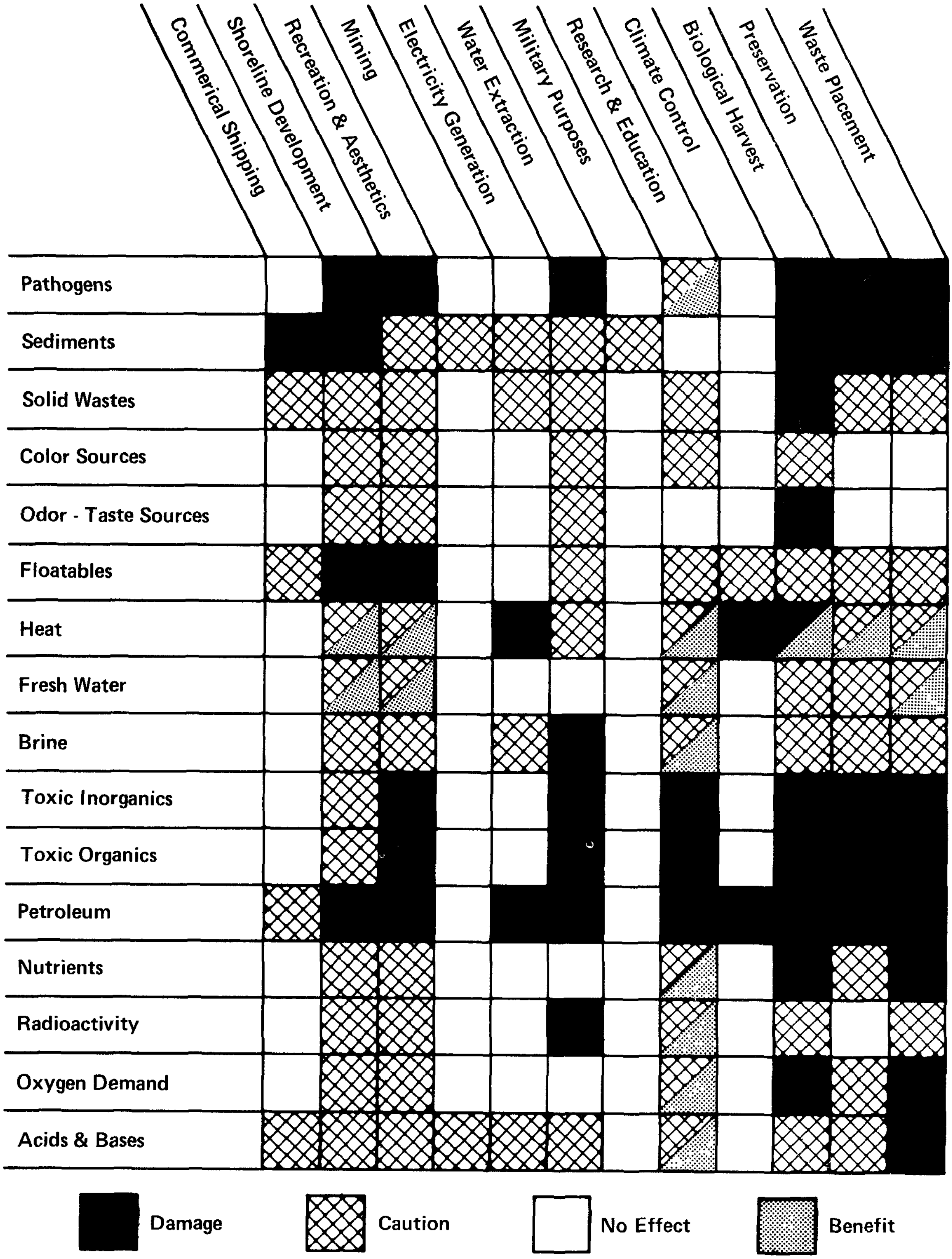


FIGURE 8.—Probable effects of pollutants.

of adequate water quality standards specific to a geographic location.

In the final analysis, the participants agreed that the Nation has been partially successful over the past 5-year period in retarding degradation of our estuarine zone. This has largely been accomplished through the application of new waste treatment technologies, and the implementation of newly written environmental regulations, standards, criteria and guidelines at both the state and federal levels. Every effort must now be made to assess current conditions and capabilities and to use potential resources and existing legislative tools to effect a national program for the prevention, reduction, and elimination of pollution in estuaries.

APPENDIX A

LIST OF REVIEWERS

Abbott, Marie—Marine Biology Labs, Gray Museum
Abbott, R. Tucker—Delaware Museum of Natural History
Able, Robert—Director, National Sea Grant Program (NOAA)
Alexander, Timothy—Office of Coastal Zone Management
Armstrong, Neil—University of Texas
Bailey, Wilfrid C.—University of Georgia
Banta, John S.—The Conservation Foundation
Baptist, John P.—U.S. National Marine Fisheries Service
Bardach, John—Hawaii Institute of Marine Biology
Bauer, Ernest T.—U.S. Maritime Administration
Becker, Paul—Waterways Experiment Station, Mississippi
Bender, M. E.—Virginia Institute of Marine Science
Bennett, Harry—Louisiana State University
Bodovitz, Joseph—California Coastal Zone Conservation Commission
Bookhout, C. G.—Duke University
Boyer, Walter C.—Port of Maryland
Bromley, Daniel—University of Wisconsin
Bruce, Herb—Auke Bay Laboratory, Alaska
Bunting, Robert—Texas A & M University
Burbank, William—Emory University
Butler, Philip A.—Environmental Protection Agency, Gulf Breeze Laboratory
Carpenter, Edward—Woods Hole Oceanographic Institute
Chave, Keith—University of Hawaii
Chestnut, A. F.—University of North Carolina
Clark, John—The Conservation Foundation
Copeland, B. J.—North Carolina State University
Costlow, John D.—Duke University Marine Laboratory
Coull, Bruce C.—University of South Carolina
Coutant, Church—Oak Ridge National Laboratory
Cronin, Eugene—Chesapeake Bay Marine Laboratory
Dame, Richard—Coastal Carolina
Davis, Jackson—Virginia Institute of Marine Science
Davoren, William—California Coastal Zone Conservation Commission
de la Cruz, Armando—Mississippi State
Douglas, Peter—State Capitol Center, California
Edwards, Robert L.—North Atlantic Fisheries Research Center
Evans, Evan C.—Kanohe, Hawaii
Ferguson, Randolph L.—U.S. National Marine Fisheries Service
Fisher, Anthony C.—University of Maryland
Flemer, David A.—Deptartment of Interior
Fruh, Gus—University of Texas at Austin
Gross, Grant—Johns Hopkins University
Hansen, Peter J.—U.S. Atomic Energy Commission
Hartman, Michael R.—Bechtal Power Corporation, Maryland
Hedgpeth, Joel—University of Pacific
Henry, Vernon—Skidaway Institute
Hersh, George—Berkeley, California
Herz, Michael—Fort Mason
Herzog, Henry W., Jr.—University of Tennessee
Higgins, Robert P.—Smithsonian Oceanographic Commission
Ho, Clara L.—Louisiana State University
Holland, A. Fred—Martin Marietta Laboratories
Hubbell, David—U.S. Geological Survey, Denver
Huggett, Robert J.—Virginia Institute of Marine Science
Hunt, John M.—Woods Hole Oceanographic Institute
Huntsman, Gene R.—U.S. National Marine Fisheries Service
Huntsman, Susan—Duke University Marine Laboratory
Jennings, Anne R.—South Carolina Environmental Coalition, Inc.
Jones, Galen—University of New Hampshire
Jones, James I.—Florida State Division of Planning
Ketchumn, Bostwick—Woods Hole Oceanographic Institute
Kirby, Conrad J.—U.S. Army Corps of Engineers
Kjerfve, B.—University of South Carolina
Kuenzler, Edward J.—University of North Carolina
Lammie, James L.—Harding-Lawson Associates, California
Lewis, Robert—Bonneville Power Commission, Oregon
Lippson, Robert—U.S. National Marine Fisheries Service
Liston, John—University of Washington
Litsky, Warren—University of Massachusetts

McErlean, Andrew—Environmental Protection Agency, Washington, D.C.
Maturo, Frank J.—University of Florida
Menzel, R. Winston—Florida State University
Metcalf, T. G.—University of New Hampshire
Morita, Richard—Oregon State University
Murphy, Donald G.—National Institute of Health
Nadeau, Royal J.—Edison Water Quality Resources Center, New Jersey
Nakamura, Eugene L.—U.S. National Marine Fisheries Service
Nichols, Maynard—U.S. Geological Survey, Denver
Olcoh, Harold—University of California at Davis
Pacheco, Anthony—U.S. National Marine Fisheries Service
Pilkey, Orrin—Duke University
Power, Garrett—University of Maryland
Pritchard, Don—Johns Hopkins University
Reese, Charles—Environmental Protection Agency
Ropes, John—U.S. National Marine Fisheries Service
Rosenfield, Aaron—U.S. National Marine Fisheries Service
Ruzecki, E. P.—Virginia Institute of Marine Science
Schubel, J. R.—State University of New York
Scott, Carleton—Union Oil Center, California
Sharp, James M.—Gulf University Research Consortium
Slanetz, L. W.—University of New Hampshire
Smith, Roland F.—U.S. Department of Commerce
Stead, Frank M.—Environment Management, California
Stinner, John E.—California Department of Fish and Game
Stone, Richard B.—U.S. National Marine Fisheries Service
Storrs, Phil—Engineering/Science Inc.
Stutzman, Carl—U.S. Fish and Wildlife Service
Thayer, G. W.—National Marine Fisheries Service
True, Howard—Environmental Protection Agency, Athens Laboratory
Watling, Leslie—University of Delaware
Wilce, Robert—University of Massachusetts
Williams, Austin B.—U.S. National Marine Fisheries Service
Windom, Herbert—Skidaway Institute of Oceanography
Wolfe, D.—U.S. National Marine Fisheries Service
Zaneveld, Jacques S.—Old Dominion University

APPENDIX B

LIST OF ATTENDEES

EPA CONFERENCE ON ESTUARY POLLUTION CONTROL

February 11–13, 1975

Ken Adams
Environmental Protection Agency
401 M St., S. W. (WH-448)
Washington, D. C. 20460
(202) 245-3045

A. Spence Autry
Tampa Electric Company
P. O. Box 111
Tampa, Fla. 33601
(813) 876-4111

Alston C. Badger
P. O. Box 368
Johns Island, S. C. 29455
(803) 559-0371

Yates M. Barber
National Marine Fisheries Service
NOAA
Washington, D. C.
(202) 634-7490

Richard J. Barlow
State of Connecticut
Department of Environmental Protection
Hartford, Conn.
(203) 566-3282

Bert H. Bates, Jr.
2318 Center Street
Dear Park, Tex.
(713) 479-5981

John C. Belcher
Dept. of Sociology
University of Georgia
Athens, Ga. 30602
(404) 542-2706

Peter Bibko
Westinghouse Envir. Systems
P. O. Box 1899
Pittsburgh, Pa.
(412) 256-5919

Robert B. Biggs
College of Marine Sciences
University of Delaware
Newark, Dela. 19711
(302) 738-2842

John W. Blake
United Engineers'
421 Old State Road
Berwyn, Pa. 19312
(215) 422-3880

Lawrence Blus
Patuxent Wildlife Res. Ctr.
Laurel, Md.
(301) 776-4880

Frank C. Boerger
San Francisco Dredging Committee
World Trade Club, Room 303
San Francisco, Calif. 94111

Frank H. Bollman
Development & Resources Corp.
455 Capitol Mall, Suite 675
Sacramento, Calif. 95814
(916) 444-6540

Patrick Borthwick
EPA-Gulf Breeze Lab.
Sabine Island
Gulf Breeze, Fla. 32561
(904) 932-5326

Gordon C. Broadhead
Living Marine Resources, Inc.
11339 Sorrento Valley Road
San Diego, Calif. 92121
(714) 453-4871

Lewis R. Brown
Assoc. Dean, College of Arts and Sciences
Mississippi State College
P. O. Drawer CU
Mississippi State, Miss. 39762
(601) 325-2644

W. D. Burbanck
Dept. of Biology
Atlanta, Ga.
(404) 377-2411

Philip A. Butler
EPA–Gulf Breeze Lab.
Sabine Island
Gulf Breeze, Fla.

Clyde S. Carman, Director
Energy Technology Center
University of Arkansas
(501) 575-2853

James H. Carpenter
University of Miami
10 Rickenbacker Causeway
Miami, Fla. 33149
(305) 350-7211

Melbourne R. Carriker
University of Delaware Marine Laboratory
Lewes, Dela. 19958
(302) 645-6674

James Cating
EPA Headquarters
401 M St., S. W.
Washington, D. C. 20460
(202) 245-3040

Michael Champ
Department of Biology
The American University
Washington, D. C. 20016
(202) 686-2177/2091

Rita R. Colwell
Department of Microbiology
University of Maryland
College Park, Md. 20752
(301) 454-5377

Gary Cook
EPA–Gulf Breeze Lab.
Sabine Island
Gulf Breeze, Fla.

B. J. Copeland
N. C. Sea Grant Program
N. C. State University
1235 Burlington Labs
Raleigh, N. C. 27606
(919) 737-2454

David L. Correll
Chesapeake Bay Center for Environmental Studies
RR#4, Box 622
Edgewater, Md. 21037

Robert Corey
Chesapeake Bay Center for Environmental Studies
RR#4, Box 622
Edgewater, Md. 21037

John Costlow
Duke University Marine Lab.
Beaufort, N. C. 28516

John A. Couch
EPA–Gulf Breeze Lab.
Sabine Island
Gulf Breeze, Fla.

Allan M. Crane
Bears Bluff Field Station
Johns Island, S. C. 29455

L. Eugene Cronin
University of Maryland
Chesapeake Biological Lab.
Bay Ridge
Annapolis, Md. 21403
(301) 326-4281

John Clark
The Conservation Foundation
1717 Massachusetts Ave., N.W.
Washington, D. C. 20036
(202) 265-8882

John H. Cumberland
Bureau of Business & Economic Research
University of Maryland
College Park, Md. 20742
(301) 454-2304

Earl Walter Davey
EPA Lab.
Narragansett, R. I. 02882
(401) 789-3346

William P. Davis
Bears Bluff Field Station
Johns Island, S. C. 29455

William S. Davis
EPA Headquarters
401 M St., S.W. (WH-449)
Washington, D. C. 20460
(202) 245-3030

Carole L. DeMort
University of North Florida

Thomas W. Duke
EPA–Gulf Breeze Lab.
Sabine Island
Gulf Breeze, Fla.

William H. Espey
Espey, Houston & Assoc., Inc.
500 West 16th Street
Austin, Texas 78701

Fred S. Farr
℅ Horan, Lloyd, Dennis & Farr
Camino Aquajito at 5th Street
Monterey, Calif. 93940
(408) 373-4131

Hans A. Feibusch
Environmental Impact Planning Corporation
319 11th Street
San Francisco, Calif. 94103

John H. Finucane
National Marine Fisheries Service
Panama City, Fla.

Hugo B. Fischer
Dept. of Civil Engineering
412 O'Brien Hall
University of California
Berkeley, Calif. 94720
(415) 642-6774

David A. Flemer
US Fish & Wildlife Services
Department of Interior
Washington, D. C. 20240
(202) 343-8032

Paul L. Fore
EPA–Gulf Breeze Lab.
Sabine Island
Gulf Breeze, Fla.

Jerrold Forester
EPA–Gulf Breeze Lab.
Sabine Island
Gulf Breeze, Fla.

Robert C. Foster
Bureau of Land Management
1001 Howard Avenue
New Orleans, La.

Gary Gardner
EPA–Region III
6th & Walnut Sts.
Philadelphia, Pa. 19106
(215) 597-9390

Joe Gill, Jr.
Mississippi Marine Resource Council
P. O. Box 497
Long Beach, Miss.

Robert C. Glassen
Dept. of Oceanography
Florida State University
Gainesville, Fla.

Philip S. Goodman
411 West End Avenue
New York, N. Y.

Seymour P. Gross
Delaware River Basin Commission
Willingboro, N. J.

M. Grant Gross
Johns Hopkins University
Baltimore, Md.

Bartlette Hague
EPA–Region I
2203 J. F. Kennedy Bldg.
Boston, Mass. 02203

John B. Hall, Jr.
NASA Langley Research Center
217K Hampton, Va. 23665
(804) 827-2717

John R. Hall
National Marine Fisheries Service/EAD
P. O. Box 4218
Panama City, Fla.

Roy W. Hann, Jr.
Texas A&M University
College Station, Tex. 77843
(713) 845-3011

William Hargis, Director
Virginia Institute of Marine Science
Gloucester Point, Va. 23062
(804) 642-2111

Ivan Harjehausen
Fish & Wildlife Service
19th & C Sts., N.W.
Washington, D. C.
(202) 743-4397

Tom Hart
Florida Coastal Coord. Council
1823 Wales Drive
Tallahassee, Fla.

Jeff Havel
3830 Forest Drive
Columbia, S. C.

Joel W. Hedgpeth
256 Alma Avenue
Rohnert Park, Calif. 94928
(707) 475-8734

Tom Heitmuller
Bionomics Marine Lab.
Pensacola, Fla.

Marc J. Hershman
56 Law Center
Louisiana State University
Baton Rouge, La.

D. Heyward Hamilton, Jr.
U. S. Atomic Energy Commission
DBER-ERDA
Washington, D. C.

Jeff Kirkpatrick
P. O. Box 13246
Cap. Station
Austin, Tex. 78711
(512) 475-6331

Terry Hofstra
EPA–Region VI
1600 Patterson St.
Dallas, Tex. 75201

C. George Hollis
Memphis State University
Memphis, Tenn.

Terry Hollister
Bionomics Marine Lab.
Rt. 6, Box 1002
Pensacola, Fla.

Donald W. Hood
Institute of Marine Science
University of Alaska
Fairbanks, Alaska 99701
(907) 479-7531

Mary A. Hood
University of West Florida
Pensacola, Fla.

Sewell Hopkins
Texas A&M University
Bryan, Texas 77801
(713) 845-6131

Thomas S. Hopkins
Dept. of Biology
University of West Florida
Pensacola, Fla. 32504

Kent Hughes
Environmental Data Services
Room 555
Department of Commerce
Washington, D. C. 20235
(202) 634-7393

Harold D. Irby
Texas Parks & Wildlife Dept.
John H. Reagan Bldg.
Austin, Tex. 78736

Loren Jensen
Ecological Analysts, Inc.
600 Wyndhurst Avenue
Baltimore, Md. 21210
(301) 435-4000

Freia K. Kershow
RFD, Box 419
Annapolis, Md. 21403

C. E. Kindsvater
U. S. Geological Survey
Reston, Va. 22092

Edward Langlois
Maine State Pier
40 Commercial St.
Portland, Maine 04111
(207) 773-5608

G. Fred Lee
University of Texas at Dallas
P. O. Box 688
Richardson, Tex. 75080
(214) 690-2111

Eldon Levi
National Marine Fisheries Service
Route 11, Box 318
Pensacola, Fla.

Larry Lewis
Mississippi Marine Resources Council
P. O. Box 497
Long Beach, Miss.

Robert C. Lewis
P. O. Box 3621
Portland, Oregon
(503) 234-3361 Ext. 5124

Jeffrey L. Lincer
Mote Marine Lab.
9501 Blind Pass Road
Sarasota, Fla. 33581
(813) 921-6661

Mark Lindberg
Bionomics Marine Lab.
Pensacola, Fla.

James E. Lipe
Monsanto Textile Co.
P. O. Box 12380
Pensacola, Fla. 32575

Robert J. Livingston
Dept. of Biological Science
Florida State University
Tallahassee, Fla. 32306
(904) 644-1466

Norman Lovelace
EPA Headquarters
401 M St., S.W.
Washington, D. C. 20460

Jack I. Lowe
EPA–Gulf Breeze Lab.
Sabine Island
Gulf Breeze, Fla.

John Ludwigson
Nautilus Press
1056 National Press Bldg.
2020 F St., N.W.
Washington, D. C.
(202) 347-6643

Maurice P. Lynch
Virginia Institute of Marine Science
Gloucester Point, Va. 23062
(804) 642-2111

Angus MacBeth
Natural Resources Defense Council
15 West 44th St.
New York, N. Y. 10036

Victor T. McCauley
EPA (WH-449)
401 M St., S.W.
Washington, D. C. 20460
(202) 245-3030

Andrew McErlean
EPA–OES
401 M St., S.W.
Washington, D. C. 20460

J. L. McHugh
Marine Science Research Center
State University of New York
Stony Brook, L. I. 11790
(516) 246-3449

R. Merrill McPhearson
P. O. Box 158
Dauphin Island, Ala.

Ming-Yu Li
Department of Environ. Tox.
University of California
Davis, Calif. 95616
(916) 752-2562

Elliot A. Macklow
National Oceanographic and Atmospheric Administration
6010 Executive Blvd.
Rockville, Md. 20852
(301) 496-8921

Kumas Mahadevan
Department of Oceanography
Florida State University
Tallahassee, Fla.
(904) 644-6700

Roy Mann
Roy Mann Associates, Inc.
180 Franklin Street
Cambridge, Mass. 02139
(617) 492-2050

Norman Meade
EPA, CM #2
401 M St., S.W. (RD-690)
Washington, D. C. 20460
(202) 557-7480

Winston Menzel
Dept. of Oceanography
Florida State University
Tallahassee, Fla.
(904) 644-6700

William B. Merselis
707 E. Vermont Avenue
Anaheim, Calif. 92803
(714) 772-2811

Joseph Mihursky
Chesapeake Biological Lab.
University of Maryland
Solomons, Md. 20678

D. K. Mitchell
Monsanto Company
P. O. Box 12830
Pensacola, Fla.
(904) 968-6311 Ext. 7803

James C. Moore
EPA–Gulf Breeze Lab.
Sabine Island
Gulf Breeze, Fla. 32561
(904) 932-5326

Robert E. Moore
State of Connecticut
Dept. of Environmental Protection
Durham, Conn.
(203) 566-5760

Frank Moseley
P. O. Box 2121
Corpus Christi, Tex.

Alan I. Mytelka
Interstate Sanitation Commission
10 Columbus Circle
New York, N. Y.
(212) 582-0380

Eugene L. Nakamura
National Marine Fisheries Service
P. O. Box 4218
Panama City, Fla. 32401
(904) 234-6541

Frank P. Nelson
3830 Forest Drive
Columbia, S. C.

Gary L. Nelson
National Marine Fisheries Service
P. O. Box 4218
Panama City, Fla. 32401

Larry Olinger
EPA–Gulf Breeze Lab.
Sabine Island
Gulf Breeze, Fla. 32561
(904) 932-2204

Rod Parrish
Bionomics Marine Research Lab.
Rt. 6, Box 1002
Pensacola, Fla. 32507
(904) 453-4339

Sam R. Petrocelli
Bionomics Marine Lab.
Rt. 6, Box 1002
Pensacola, Fla. 32507
(904) 456-4579

Thomas H. Pheiffer
Annapolis Field Office
Annapolis Science Center
Annapolis, Md. 21401
(301) 268-5038

Harriette Phelps
1331 H St., N.W.
Washington, D. C. 20005
(202) 727-2744

Frank X. Phillips
Fla. Dept. of Pollution Control
Tallahassee, Fla.
(904) 488-6221

J. T. Pittman
N. C. Dept. Admin.
217 W Jones St.
Raleigh, N. C.
(919) 829-2290

Stephen Purvine
U. S. Coast Guard
400 7th St., S.W.
G-WEP
Washington, D. C.
(202) 426-9573

William H. Queen
Dept. of Botany
University of Maryland
College Park, Md. 20752
(301) 454-3824

Ben Ribelin
325 John Knox Road
Suite C-135
Tallahassee, Fla.
(904) 488-8281

Stanley Riggs
Dept. of Geology
East Carolina University
P. O. Box 2751
Greenville, N. C. 27834
(919) 758-3636

Kenneth R. Roberts
Living Marine Resources Office
(MR-2)
NOAA
6010 Executive Blvd.
Rockville, Md. 20852
(301) 496-8471

Reginald G. Rogers
EPA–Gulf Breeze
Sabine Island
Gulf Breeze, Fla. 32561
(904) 932-2204

Pete Rogerson
EPA–Marine Water Quality Lab.
Narragansett, R. I. 02882
(401) 789-7604

William Seaman, Jr.
Florida Sea Grant
2001 McCarty Hall
Gainesville, Fla. 32011
(904) 392-1806

Douglas B. Seba
EPA-NFIC
Box 25227
Denver Federal Center
Denver, Colo. 80225
(303) 234-4884

Robert Schoen
U. S. Geological Survey
Reston, Va. 22092

William W. Schroeder
University of Alabama
Dauphin Island Sea Lab.
Box 386
Dauphin Island, Ala. 36528
(205) 861-3702

Jerry R. Schubel
Marine Sciences Research Center
State University of New York
Stony Brook, N. Y. 11790
(516) 246-6543

Jay Shapiro
University of Alabama
Dauphin Island Sea Lab.
Box 386
Dauphin Island, Ala. 36528

Leonard W. Shaw
Bureau of Outdoor Recreation
Dept. of Interior
Washington, D. C. 20240
(202) 343-7554

J. Albert Sherk
U. S. Fish & Wildlife Service
Office of Biological Services
Dept. of Interior
Washington, D. C. 20240
(202) 343-8032

Bill A. Simco
Department of Biology
Memphis State University
Memphis, Tenn. 38152
(901) 454-2955

Joseph L. Simon
Dept. of Biology
University of South Fla.
(813) 974-2686

Vernon Smylie
902 600 Building
P. O. Box 1414
Corpus Christi, Tex. 78403
(512) 882-2762

J. Kevin Sullivan
Rt. 4, Box 622
Edgewater, Md. 21037
(301) 261-4190

Dennis P. Tihansky
EPA Headquarters
401 M St., S.W.
Washington, D. C. 20460
(202) 557 7480

Howard A. True
Surveillance & Analysis Div.
EPA–Region IV
Athens, Ga. 30601
(404) 546-3139

Bruce Turner
Conrad Bldg.
Florida State University
(904) 644-3700

George Valiulis
Westinghouse Environ. Systems
P. O. Box 1899
Pittsburgh, Pa. 15230
(412) 256-5858

Charles P. Vanderlyn
EPA Headquarters
401 M St., S.W.
Washington, D. C. 20460
(202) 245-0581

Peter Van Slyke
EPA Headquarters
401 M St., S.W.
Washington, D. C. 20460
(202) 245-0581

John Vernberg
University of South Carolina
Belle W. Baruch Institute
Columbia, S. C. 29208

William W. Walker
EPA–Gulf Breeze Lab.
Sabine Island
Gulf Breeze, Fla. 32561

David C. White
310 Nuclear Science
Florida State University
Tallahassee, Fla.
(904) 644-5027

Robert D. Wildman
425 13th St., N.W.
Washington, D. C.
(202) 967-4562

Jerome Williams
Environmental Sciences Dept.
U. S. Naval Academy
Annapolis, Md. 21402
(301) 267-3561

Sam Williams
EPA Headquarters
401 M St., S.W.
Washington, D. C. 20460
(202) 245-3012

John Winn
P. O. Box 2288
Mobile, Ala. 36628

James F. Wright
Delaware River Basin Comm.
Willingboro, N. J.
(609) 883-9500

John R. Yearsley
EPA–Region X
1200 Sixth Avenue
Seattle, Wash. 98101
(206) 442-0887

William T. Young
Fla. Dept. of Poll. Control
1384 Shoreline Drive
Gulf Breeze, Fla. 32561
(904) 932-3161

Program Manager

Robert J. Johnson
EPA (WH-449)
401 M Street S.W.
Washington, D. C. 20460
(202) 245-3030

APPENDIX C

LIST OF CONTRIBUTORS

A. Spencer Autry
Tampa Electric Company
P. O. Box 111
Tampa, Fla. 33601

John C. Belcher
Dept. of Sociology
University of Georgia
Athens, Ga. 30602

Robert B. Biggs
College of Marine Studies
University of Delaware
Newark, Dela. 19711

John W. Blake
United Engineers
421 Old State Road
Berwyn, Pa. 19312

Lawrence J. Blus
Patuxent Wildlife Research Center
Laurel, Md. 20810

Frank Boerger
San Francisco Dredging Comm.
World Trade Club, Room 303
San Francisco, Calif. 94111

Frank Bollman
Development & Resources Corp.
455 Capitol Mall, Suite 675
Sacramento, Calif. 95814

John J. Bosley
8412 McGruder Court
Bethesda, Md. 20034

Morris L. Brehmer
Virginia Electric Power Company
P. O. Box 2666
Richmond, Va. 23261

Gordon C. Broadhead
Living Marine Resources, Inc.
11339 Sorrento Valley Road
San Diego, Calif. 92121

Ralph H. Brooks
Pacific Gas & Electric Co.
77 Beale Street
San Francisco, Calif. 94106

Lewis R. Brown
College of Arts & Science
Mississippi State College
P. O. Drawer CU
Mississippi State, Miss. 39762

Philip A. Butler
EPA Gulf Breeze Lab.
Sabine Island
Gulf Breeze, Fla. 32561

R. J. Callaway
Coastal Pollution Branch
Pacific Northwest Environmental
Research Laboratory (EPA)
Corvallis, Ore. 97330

James H. Carpenter
10 Rickenbacker Causeway
University of Miami
Miami, Fla. 33149

Melbourne Carriker
University of Delaware Marine Laboratory
Lewes, Dela. 19958

Michael A. Champ
Department of Biology
The American University
Washington, D. C. 20016

John Clark
The Conservation Foundation
1717 Massachusetts Ave., N.W.
Washington, D. C. 20036

Rita R. Colwell
Department of Microbiology
University of Maryland
College Park, Md. 20752

B. J. Copeland
North Carolina State University
1235 Burlington Labs
Raleigh, N. C. 27606

David Correll
Chesapeake Bay Center for Environmental Studies
RR #4
Box 622
Edgewater, Md. 21037

L. Eugene Cronin
12 Mayo Avenue
Bay Ridge
Annapolis, Md. 21403

John H. Cumberland
Bureau of Business and Ecological Research
University of Maryland
College Park, Md. 20742

William P. Davis
Bears Bluff Field Station
Johns Island, S. C. 29455

William H. Espey
Espey, Houston & Assoc., Inc.
500 West 16th Street
Austin, Tex. 78701

Fred S. Farr
℅ Horan, Lloyd, Dennis & Farr
Camino Aquajito at 5th St.
Monterey, Calif. 93940

John W. Farrington
Woods Hole Oceanographic Inst.
Woods Hole, Mass. 02543

Hans A. Feibusch
Environmental Impact Planning Corporation
319 11th Street
San Francisco, Calif. 94103

Hugo B. Fischer
Dept. of Civil Engineering
412 O'Brien Hall
University of California
Berkeley, Calif. 94720

J. J. Goering
Inst. of Marine Science
University of Alaska
Fairbanks, Alaska 99701

Roy W. Hann
Environmental Engineering
Civil Engineering Dept.
Texas A&M
College Station, Tex. 77843

William J. Hargis
Virginia Institute of Marine Sci.
Gloucester Point, Va. 23062

Joel W. Hedgpeth
256 Alma Avenue
Rohnert Park, Calif. 94928

Marc J. Hershman
56 Law Center
Louisiana State University
Baton Rouge, La.

J. E. Hobbie
North Carolina State University
1235 Burlington Labs
Raleigh, N. C. 27606

Donald W. Hood
Institute of Marine Science
University of Alaska
Fairbanks, Alaska 99701

Sewell H. Hopkins
709 Garden Acres
Bryan, Tex. 77801

Thomas S Hopkins
Box 615, Rt. 3
Clear Creek Drive
Pensacola, Fla. 32504

Harold D. Irby
6907 Grove Crest Drive
Austin, Tex. 78736

Loren D. Jensen
Ecological Analysts, Inc.
600 Wyndhurst Ave.
Baltimore, Md. 21210

Robert J. Kalter
Cornell University
445 Warren Hall
Ithica, N. Y. 14850

J. A. Kerwin
Patuxent Wildlife Research Ctr.
Laurel, Md. 20810

Edward Langlois
Maine State Pier
40 Commercial St.
Portland, Maine 04111

G. Fred Lee
University of Texas at Dallas
P. O. Box 688
Richardson, Tex. 75080

Ming-Yu Li
Dept. of Envir. Tox.
University of California

Jeffrey L. Lincer
Mote Marine Lab.
9501 Blind Pass Road
Sarasota, Fla. 33581

Robert J. Livingston
Dept. of Biological Science
Florida State University
Tallahassee, Fla. 32306

Maurice P. Lynch
Virginia Institute of Marine Sci.
Gloucester Point, Va. 23062

J. L. McHugh
Marine Science Research Center
State University of N. Y.
Stony Brook, N. Y. 11790

Angus MacBeth
Natural Res. Def. Coun.
15 West 44th Street
New York, N. Y. 10036

Roy Mann
Roy Mann Assoc., Inc.
180 Franklin Street
Cambridge, Mass. 02139

Norman F. Meade
EPA Headquarters
401 M Street., S.W. (RD-690)
Washington, D. C. 20460

Robert H. Meade
U. S. Geological Survey
Water Resources Division
Denver Federal Center
Denver, Colo. 80220

D. F. Middaugh
Bears Bluff Field Station
Johns Island, S. C. 29455

Joseph A. Mihursky
University of Maryland
Chesapeake Biological Lab.
Solomons, Md. 20678

Letha F. Miloy
3503 Spring Lane
Bryan, Tex. 77801

Frank N. Moseley
Central Power & Light Co.
P. O. Box 2121
Corpus Christi, Tex. 78403

H. N. Ohlendorf
Patuxent Wildlife Res. Ctr.
Laurel, Md. 20810

Erman A. Pearson
University of California
Dept. of Civil Eng.
Berkeley, Calif. 94720

Sam R. Petrocelli
Bionomics Marine Lab.
Route 6
Box 1002
Pensacola, Fla. 32507

Stanley Riggs
Dept. of Geology
East Carolina University
P. O. Box 2751
Greenville, N. C. 27834

J. R. Schubel
Marine Science Res. Ctr.
State University of New York
Stony Brook, N. Y. 11790

Stephen V. Smith
Hawaii Inst. of Marine Bio.
P. O. Box 1346
Kaneohe, Hawaii 96749

Vernon Smylie
600 Building
P. O. Box 1414
Corpus Christi, Tex. 78403

R. C. Stendell
Patuxent Wildlife Res. Ctr.
Laurel, Md. 20810

L. F. Stickel
Patuxent Wildlife Res. Ctr.
Laurel, Md 20810

Dennis P. Tihansky
EPA Headquarters
401 M St., S.W.
Washington, D. C. 20460

F. John Vernberg
Belle W. Baruch Inst.
University of South Carolina
Columbia, S. C. 29208

S. L. Wiemeyer
Patuxent Wildlife Research Ctr.
Laurel, Md. 20810

CONTENTS

VOLUME I

ESTUARINE ECONOMICS

CONCLUDING REMARKS

ESTUARINE SYSTEMS

RESOURCE MANAGEMENT AND ESTUARINE FUNCTION WITH APPLICATION TO THE APALACHICOLA DRAINAGE SYSTEM

ROBERT J. LIVINGSTON
Florida State University
Tallahassee, Florida

ABSTRACT

Problems encountered in the management of an estuarine system in north Florida are discussed with respect to existing programs and laws in Florida. The often difficult decisions concerning resource development depend on the availability of baseline scientific and socio-economic data. Information is needed concerning the basic energy relationships of estuaries and the long-term effects of pollution on such systems. Realistic estuarine management practices involve an interdisciplinary approach at both the local and regional levels. Federal programs should be aimed at the translation of scientific information into the planned development of the entire drainage area of a given estuary. Based on successful and unsuccessful attempts of resource management in the Apalachicola drainage system, a generalized plan for estuarine development is given.

INTRODUCTION

Florida is presently a major growth area with respect to residential and tourist development. In addition to a population of more than 8,000,000 people, as many as 25,000,000 tourists visit this state each year. The population pressure, extreme in southern and western portions of the state, is concentrated in coastal areas where up to 75 percent of the people actually reside. Since estuarine areas provide the environmental basis for tourism, sports and commercial fisheries, and other related industries, there has been increasing interest, both at the local and regional level, in the development of workable resource management programs for the major drainage systems in Florida. Although there have been serious environmental problems in a number of estuaries such as Escambia Bay, Apalachee Bay, Hillsborough Bay, Tampa Bay, and Biscayne Bay, the variability of contributing factors (e. g., population size, industrialization, natural estuarine functions) has precluded a uniform approach to the problem. This paper will describe various problems of one estuarine system in north Florida, and, based on such experience, will attempt to develop a realistic approach to estuarine management.

The Apalachicola Drainage System

The Apalachicola system includes an area of over 19,500 square miles (Fig. 1), and is composed of four major rivers (Flint, Chattahoochee, Chipola, Apalachicola) and numerous creeks, streams, and marshes.

Drainage from Lake Seminole, an impounded reservoir formed from the Flint and Chattahoochee, becomes the Apalachicola River in Florida. This river, together with the Chipola, is the major source of fresh water for the Apalachicola Bay system (Fig. 2).

This is the largest river system in Florida with monthly mean discharge rates of approximately 25,000 cubic feet/second (cfs) and seasonal highs approaching 100,000 cfs. The drainage area includes a multifold complex of interlocking wetland systems (rivers, creeks, marshes, swamps) bordered by hardwood floodplain forests which provide habitats for a variety of organisms. The naturally high turbidity of the water reflects significant levels of nutrients and detritus that form the basis for the highly productive Apalachicola Bay system (Estabrook, 1973; Livingston et al., 1975A). During periods of high flow (usually late winter or early spring), submerged area becomes extensive due to river flooding. It is thought that massive exchanges of various elements occur between terrestrial and aquatic systems at this time. Nutrients and detritus are flushed into Apalachicola Bay (Estabrook, 1973; Livingston, 1974). The river influence can be detected 160 miles to the south in the Gulf of Mexico (Curl, 1959).

The Apalachicola Bay system, roughly 212 square miles, is a shallow lagoon-barrier island complex situated along an east-west axis. Around 500 square miles of swamps are located above the bay; approxi-

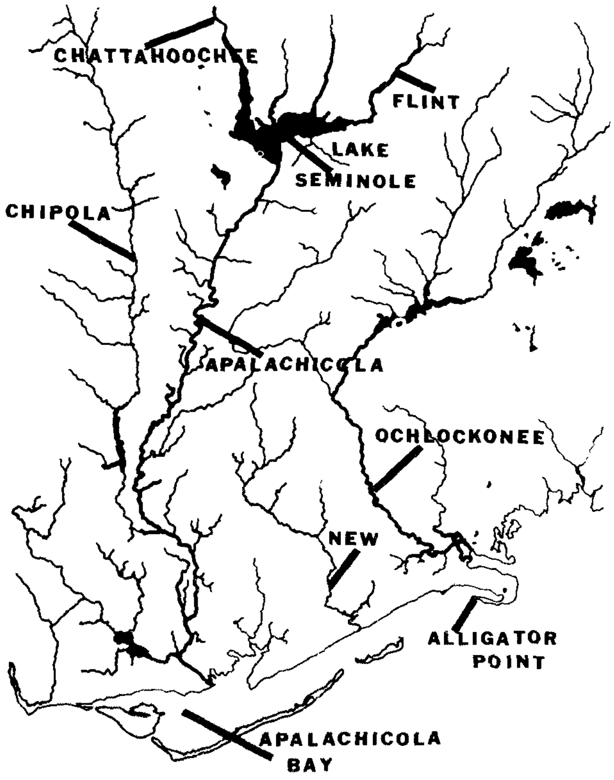


FIGURE 1.—The lower half of the Apalachicola drainage system showing the major rivers contributing to Apalachicola Bay in North Florida.

mately 20 square miles of marshes are associated with the bay. Much of this region is too wet in its natural state for traditional forms of agriculture without the use of diking, ditching, and draining. A series of barrier islands enclose the bay, and this thin line of land, together with the freshwater runoff from upland areas, provides the ecological basis for the very productive estuary (e. g., numerous oyster bars). The major connection of Apalachicola Bay with the Gulf of Mexico is St. George Sound, with lesser outlets consisting of a dredged pass (Sike's Cut) and two natural openings (Indian Pass, West Pass). The bay bottom consists of a sandy-shell mixture and silty sand (Menzel and Cake, 1969) with little development of benthic macrophyte growth.

Apalachicola Bay is a primary source of income for the people of Franklin County, Fla., (Colberg et al., 1968; Rockwood, 1973; Livingston et al., 1974A). A representative list of organisms, including various species of commercial and sport fishing importance, is shown in Table 1.

The Apalachicola oyster industry ranks high in the state (Table 2), and is the fifth most valuable fishery in Florida. It has been estimated that over 75 percent of the commercial landings for the county depend on species which utilize this estuary as a nursery or feeding ground (Menzel and Cake, 1969). Such organisms depend directly or indirectly on detritus, nutrient supplies, and reduced salinities provided by freshwater runoff. The entire watershed system is interconnected; the estuarine functions depend on upland drainage features and a complex series of energy exchanges and feedback reactions within the bay system itself.

Table 1.—Representative organisms found in the Apalachicola Bay System

Fishes	Invertebrates
Gymnura micrura (Butterfly ray)	Crassostrea virginica (Oyster)
Dasyatis sabina (Atlantic stingray)	Callinectes sapidus (Blue crab)
Sphyrna tiburo (Bonnethead)	Penaeus aztecus (Brown shrimp)
Anchoa hepsetus (Striped anchovy)	Penaeus duorarum (Pink shrimp)
Arius felis (Sea catfish)	Penaeus setiferus (White shrimp)
Bagre marinus (Gafftopsail catfish)	Palaemonetes vulgaris
Eucinostomus gula (Silver Jenny)	Palaemonetes pugio
Eucinostomus argenteus (Spotfin mojarra)	Rhithropanopeus harrisii
Mugil Cephalus (Striped mullet)	Neopanope texana
Lagodon rhomboides (Pinfish)	Tozeuma carolinense
Bairdiella chrysura (Silver perch)	Periclimenes longicaudatus
Micropogon unculatus (Atlantic croaker)	Palaemonetes intermedius
Leiostomus xanthurus (Spot)	Pagurus bonairensis
Cynoscion arenarius (Sand seatrout)	
Cynoscion nebulosus (Spotted seatrout)	
Sciaenops ocellata (Red drum)	
Brevooria patronus (Gulf menhaden)	
Menticirrhus americanus (Southern kingfish)	
Orthopristis chrysoptera (Pigfish)	
Lagodon rhomboides (Pinfish)	
Centropristis melana (Black sea bass)	
Lucania parva (Rainwater killifish)	
Synodus foetens (inshore lizardfish)	
Lutjanus griseus (Gray snapper)	
Monocanthus hispidus (Planehead filefish)	
Syngnathus scovelli (Gulf pipefish)	
Syngnathus floridae (Dusky pipefish)	
Syngnathus louisianae (Chain pipefish)	
Sphoeroides nephelus (Southern puffer)	
Lactophrys quadricornis (Scrawled cowfish)	
Cheilomycterus schoepfi (Striped burrfish)	
Paralichthys albigutta (Gulf flounder)	
Paralichthys lethositigma (Southern flounder)	
Symphurus plagiusa (Blackcheek tonguefish)	
Prionotus tribulus (Bighead searobin)	
Caranx hippos (Crevalle Jack)	
Scomberomorus maculatus (Spanish mackeral)	
Microgobius gulosus (Clown goby)	
Gobiosoma robustum (Code goby)	
Hypsoblennius hentzi (Feather blenny)	

FORMS OF POTENTIAL IMPACT

One of the important questions related to estuarine management concerns the long-term (chronic)

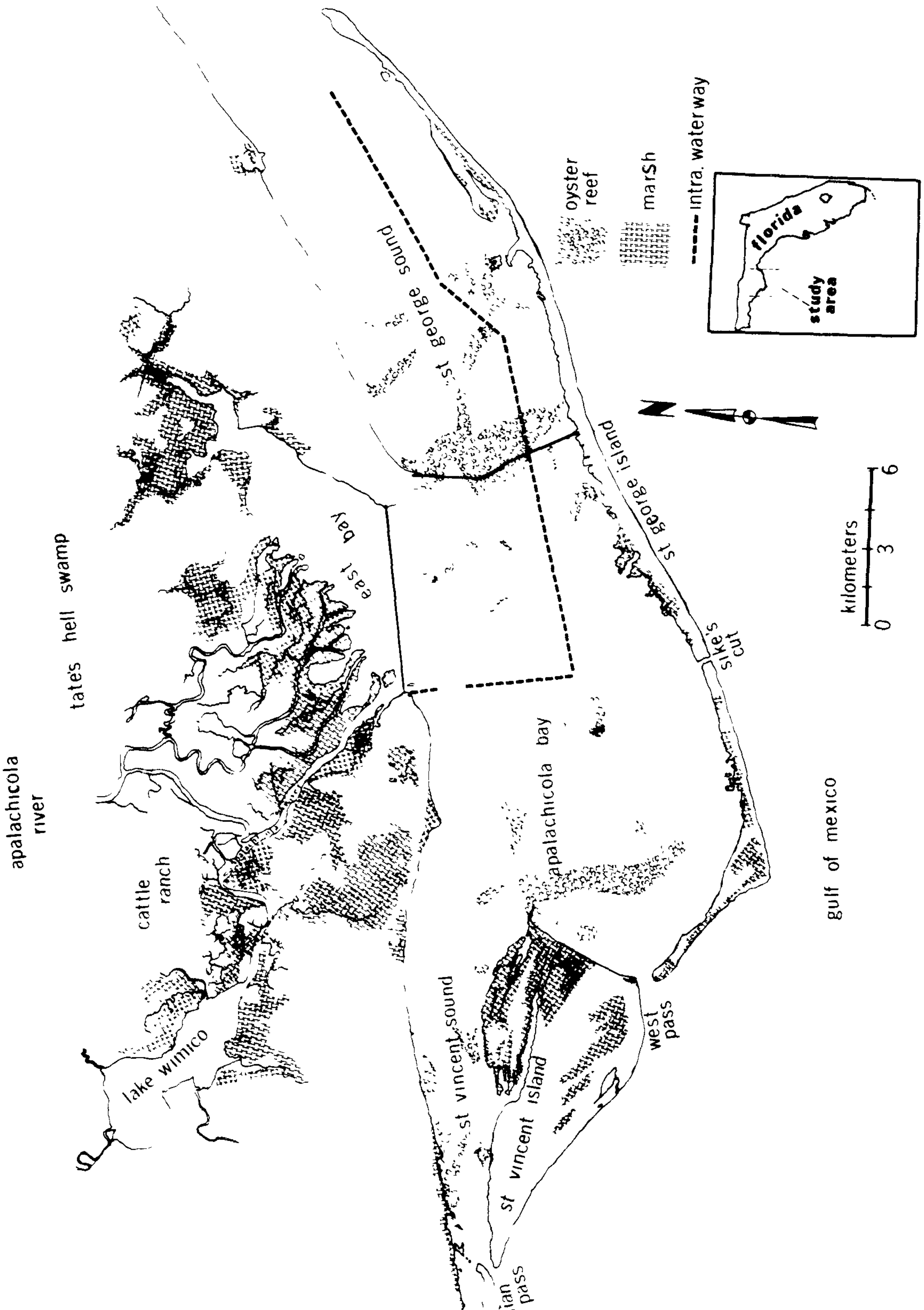


FIGURE 2.—The Apalachicola Bay system showing the distribution of major oyster bars, upland swamps and marshes.

Table 2.—Oyster landings in Franklin County and the State of Florida (1950–70) and percent contribution (County/State)

Year	Franklin County (1000 lbs)	State of Florida (1000 lbs)	Ratio County/State × 100
1950	696.0	895.2	77.7
1951	546.6	735 3	74.3
1952	451.1	563.0	80.1
1953	459.2	585 4	78.5
1954	553.9	685.5	80.8
1955	542 9	649.6	83.6
1956	722.0	888.7	81.2
1957	624.2	734.9	84.9
1958	713.2	824.7	86.5
1959	1,268.8	1,455.0	87.2
1960	1,744.8	1,975.4	88.3
1961	2,947.1	3,326.6	88.6
1962	4,366 7	5,019.8	87 0
1963	3,810.5	4,362.8	87.3
1964	2,252.4	2,885.1	78.1
1965	2,377.5	2,954.7	80.4
1966	3,809.9	4,291.9	88.8
1967	4,195.9	4,761.1	88.1
1968	4,825.7	5,568 8	86.7
1969	4,350.4	5,125.7	84.4
1970	3,044.4	3,786.5	80.4

effects of individual and collective upland development on estuarine systems. This includes toxic effects, habitat destruction, and changes in nutrient and detritus relationships. Synergism and interactions of pollutants with natural modifying factors such as temperature and salinity complicate evaluation of potential impact (Livingston et al., 1974b). The extreme variability from one estuary to another precludes broad generalizations concerning natural estuarine functions. Thus, it is generally recognized that each estuarine system should be approached on an individual basis with such factors as latitude, drainage area, river flow, offshore circulation, and depth taken into consideration.

Physical Alterations

Maintenance dredging has contributed to local habitat destruction, simplification of the fauna, and low productivity in some portions of the Apalachicola River (Cox, 1969, 1970; Cox and Auth, 1971, 1972, 1973). It is possible that dredging of the intracoastal waterway and the opening of Sike's Cut in Apalachicola Bay has altered salinity relationships by directing surface runoff out of the bay and by allowing saline (subsurface) water of gulf origin into the bay (Livingston, 1974). Such salinity increases can lead to reduction of oyster crops due to predation by organisms that are normally prevented entry to the bay because of low salinity (Menzel et al., 1957; Menzel et al., 1966).

Another concern is a proposal by the U.S. Army Corps of Engineers to improve the navigability of the Apalachicola River by the construction of a series of four dams. Serious questions have been raised concerning local habitat destruction by flooding, interruptions of migrations by anadromous fishes such as shad and striped bass, reduced nutrient and detritus flow, and alteration of the temperature and salinity regimes in Apalachicola Bay.

During the past three years, thousands of acres of swamps and marshes have been altered by various agricultural interests (Fig. 3).

About 10 miles up-river from the bay, a 33,000 acre cattle ranch has been established. This has involved clearing, ditching and draining the land and the construction of an extensive system of dikes to prevent periodic flooding (Fig. 4).

In addition to periodic pumping of turbid, low quality water into surrounding creeks, the natural interactions between terrestrial and aquatic systems

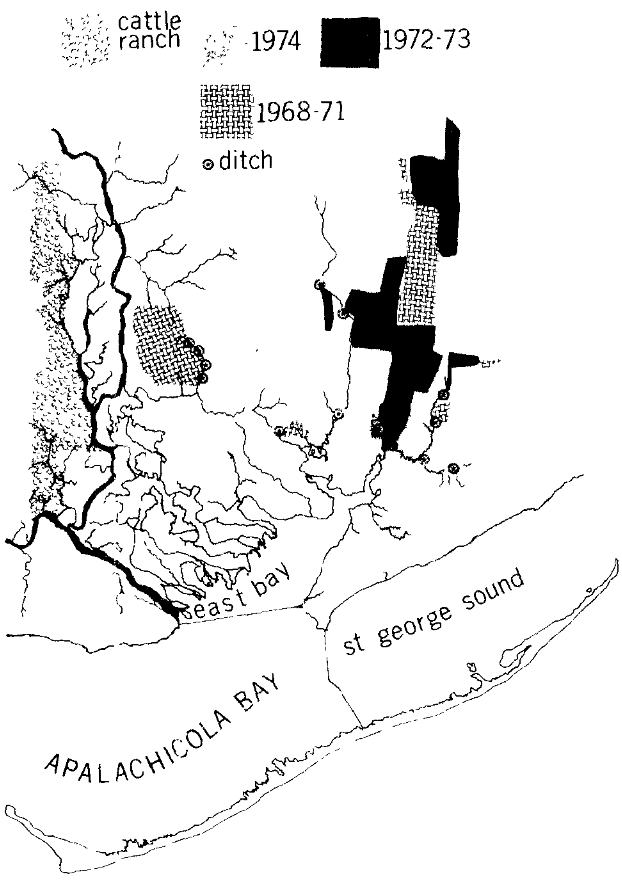


FIGURE 3.—Wetlands areas recently cleared by cattle and pulp mill interests in an attempt to utilize the lower Apalachicola valley for agricultural purposes. The lower portions of the cattle ranch have been cleared, ditched, and diked while pulp mill areas have been cleared, ditched, and drained into East Bay.


DRAINAGE DITCHES


DITCHED AREA


DIKE

FIGURE 4.—Cattle ranch activities include digging of an extensive system of drainage ditches and the diking of the lower portions of the property to prevent flooding

have been interdicted. Recently, thousands of acres of upland timber above East Bay (Fig. 5) were clear-cut by local paper mills.

After removal of trees, the land is plowed, ditched, and drained into creeks that empty directly into the nursery areas of East Bay. During periods of heavy rainfall, highly colored water washes into the bay (Fig. 6). This water, characterized by low pH and altered physical and chemical characteristics, is avoided by shrimp in laboratory experiments (Livingston, 1974). This corresponds to reports by commercial fishermen that shrimp no longer enter areas of "black" water runoff. Questions remain concerning alterations in the salinity structure of the bay and long-term changes caused by the introduction of various chemical agents such as tannins, humates, and fertilizers.

Industrialization

The ultimate aim of dredging and damming the Apalachicola River is to provide a corridor for logistic support and maintenance of upland industrial interests in Florida, Georgia, and Alabama. According to a report by the Northwest Florida Development Council and Economic Development District (1974), the Apalachicola River could serve as a major functional transportation route for industrial concerns in Alabama and Georgia. A dam and lock system would be utilized and adjacent corridors would be strengthened; this would lead to increased barge traffic and expansion of industrial interests along the river. Plans for an industrial park just below the Woodruff Dam have been activated. According to the Tri-Rivers Waterway Development Association, over 5,000 jobs in Florida, Georgia, and Alabama are dependent on navigation along the Apalachicola-Chattahoochee-Flint waterway. These jobs are associated with paper mills, fertilizer factories, construction activities, sand and gravel operations, and barge facilities. By 1976, it is estimated that 1,700 new jobs will be created by such activities. Problems associated with increased turbidity and heavy metal concentrations, petrochemical spills, and municipal wastes could be anticipated with such industrialization.

Residential Development

St. George Island is an integral part of the Apalachicola Bay System (Fig. 7). Development of this barrier island is considered the most important single factor in the growth of Franklin County (Colberg et al., 1968). With the construction of a bridge connecting the island to the mainland, St. George has essentially been opened for development.

The Northwest Florida Development Council has proposed an expansion of the financial base of Franklin County by the development of a tourist/retirement community around Apalachicola Bay.

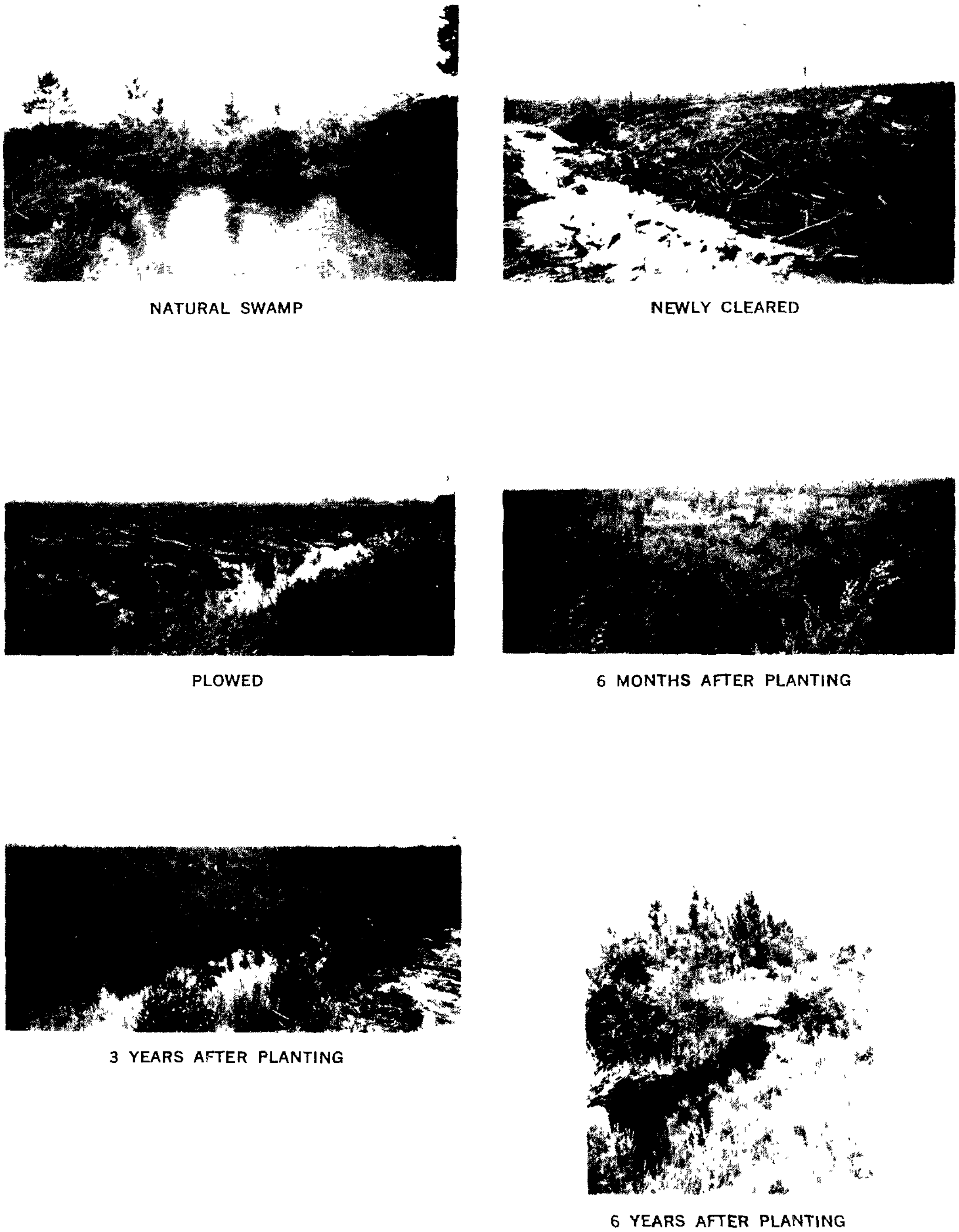


FIGURE 5.—Pulp mill activities in Tate's Hell swamp. Areas are cleared, ditched, plowed, and replanted with slash pine monocultures. Growing trees are fertilized periodically. Highly colored water, characterized by low pH, is drained directly into the bay *from the cleared areas. The potential impact of such drainage on the bay organisms remains unkoown.*

However, the narrowness and relatively limited drainage capacity of St. George Island presents a difficult situation for residential development if the ecological integrity of the bay is to be maintained. The productive oyster beds proximal to the island in St. George Sound would be vulnerable to contamination from septic tank drainage, storm water runoff, and pesticides. Public health standards for approved oyster growing areas set a limiting (MPN) value of 70 for group coliform organisms. With

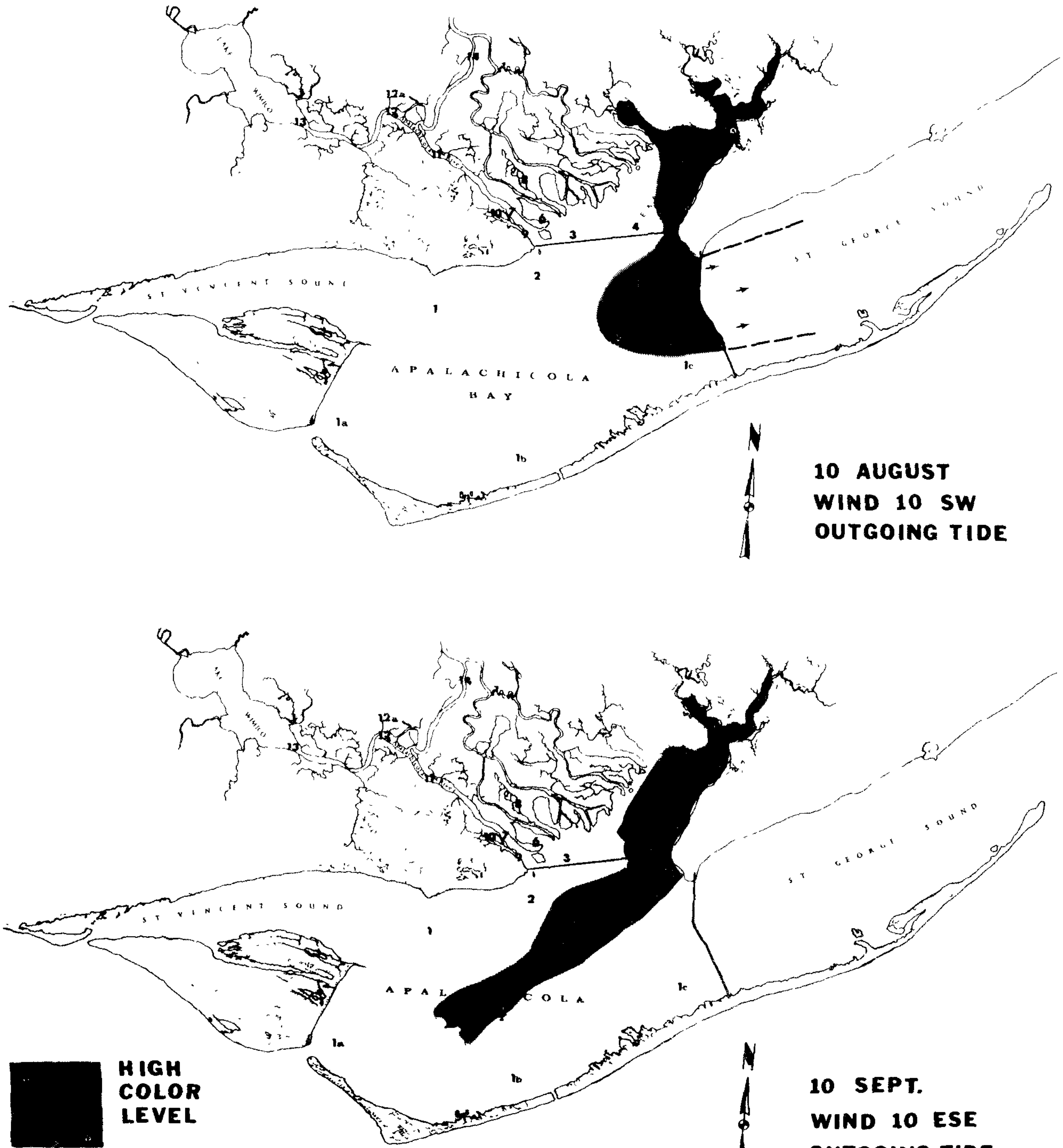


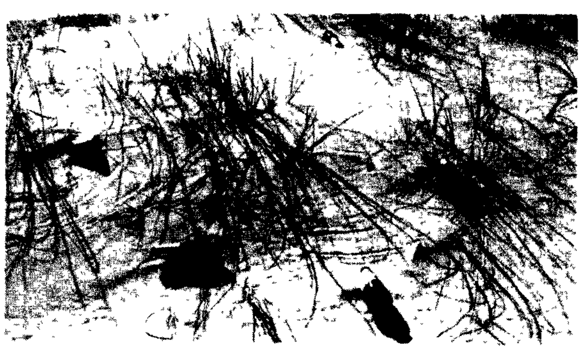
FIGURE 6.—Observations of drainage from the upland ditched areas in East Bay after periods of heavy rainfall. Highly colored water from drainage ditches can be traced as it moves into the bay.

increased numbers of people in the bay area, pest control (dogflies, sandflies, mosquitoes) would increasingly become a problem. Pesticide programs and other methods such as ditching and biological control (e.g., mosquito-eating fishes) would have to be developed as the population of the area increased. Tourist-oriented development is not without serious problems for the oyster-based economy of Franklin County. Before the population grows to an unmanageable size, strict controls of such development

SOLID WASTE

NICK'S HOLE

DEVELOPMENT



BEACH

FIGURE 7.—St. George Island: Solid waste disposal near the bay with increased residential development in already platted portions of the island. Such problems often accompany residential development of coastal areas. Marshes (Nick's Hole) and beaches are sensitive portions of island systems that should be protected from destructive land development practices.

should be adopted if the seafood industry is to remain viable.

The Apalachicola drainage system is presently at a critical stage of development. In this respect, the magnitude and complexity of the social, economic, and environmental problems are typical of various other estuaries in the United States. As yet, Apalachicola Bay is relatively unpolluted. Studies have shown that there is relatively little contamination of the bay from pesticides and other forms of contamination (Livingston, 1974). Nutrients and phytoplankton studies have shown comparable levels of productivity with other areas of the Gulf of Mexico; there are no signs of cultural eutrophication (Estabrook, 1973; Livingston et al., 1974A). Oyster contamination appears to have remained stable over a considerable period with no significant difference between present coliform group MPN values and data taken during the 1940's (Livingston et al., 1974). The epibenthic fauna appear stable (Livingston, 1974). Overall, the Apalachicola drainage system represents an important natural resource that is coming under increasing developmental pressure. An equitable solution to the inevitable conflict over resource development would rest in a management program based on objective scientific investigations. Some approaches to this problem have been made through the Florida State University System Sea Grant Program.

ESTUARINE MANAGEMENT

A growing number of laws and administrative regulations are being designed to promote management and conservation of aquatic systems. The State of Florida has developed a sophisticated system of legal and administrative procedures regarding development in wetland and coastal areas. A list of environmental laws and regulations (federal and state) along with the agencies responsible for their implementation is shown in Table 3. Several of these laws have been used by Florida Sea Grant investigators in applying management practices to the Apalachicola system.

Land Conservation Program

The Florida Land Conservation Program involves the procurement of endangered lands by the state without eminent domain power. During the course of a monitoring program in Apalachicola Bay it was found that during certain periods of excessive overflow of the Apalachicola River into associated wetland areas, considerable quantities of terrigenous detritus (leaves, branches, and so forth) were deposited in Apalachicola Bay (Livingston, 1974). Leaf matter from various types of trees that grow along the river (oak, pop ash, river birch, water hickory, et cetera) accumulated in certain areas of the bay. The importance of allochthonous detritus to other estuarine systems has been established (Darnell, 1961; Teal, 1962; Heald, 1969; Odum, 1971). Two

Table 3.—Partial annotated list of laws and regulations (federal and state) pertaining to environmental problems in navigable and tidal waters and the lands beneath them

1. **Federal**

A. **Rivers and Harbors Act of 1899** (33 U.S. Code, Sections 401, 403, 404, 406–417)

Applies to filling, excavating, or altering navigable waterways, also regulates discharge of pollutants, refuse, and dredge spoils into navigable waters. U.S. Army Corps of Engineers is responsible for permitting (in cooperation with Florida Board of Trustees and Department of Pollution Control).

B. **Federal Water Pollution Control Act** (33 U.S. Code, Section 1141 et seq.) **—amendments of 1972.** (Title 33, U.S. Code, Section 1251 et seq.)

Aims to restore and maintain chemical, physical, and biological integrity of all waters of U.S. Calls for elimination of pollutant discharges by 1985 and achievement of water quality for protection and propagation of fish, shellfish, and wildlife by 1983. Responsible agencies include U.S. Environmental Protection Agency (EPA), U.S. Army Corps of Engineers, U.S. Coast Guard, with help from Florida Department of Pollution Control.

C. **National Environmental Policy Act of 1969** (42 U.S. Code, Sections 4332, 4344)

Establishes environmental protection and restoration as national policy with provisions for generation of environmental impact statements concerning any actions of federal agencies that may impinge on the environment. The Council on Environmental Quality, established by NEPA, provides guidelines for such impact statements. U.S. Environmental Protection Agency is primary agency involved in enforcement although most federal, state, and local agencies operate within NEPA.

D. **Marine Protection, Research and Sanctuaries Act of 1972** (33 U.S. Code, Section 1401 et seq.)

Concerned with protection of oceans from pollutants discharged from vessels including dredge spoils, chemicals, etc. Responsible agencies include U.S. Environmental Protection Agency and U.S. Army Corps of Engineers.

E. **Fish and Wildlife Coordination Act of 1958** (16 U.S. Code, Section 661–666C)

Requires consideration of effects of work in navigable waters on fish and wildlife. U.S. Army of Engineers coordinates with other federal and state agencies.

F. **Endangered Species Act of 1973** (Public Law 93–205)

Provides conservation measures for endangered and threatened species. Administrated by U.S. Department of the Interior.

2. **State**

A. **Florida Air and Water Pollution Control Act** (chapter 403, 011, Florida statutes)

Public policy to conserve quality of state air and waters, provided that no wastes are discharged into water without proper treatment, et cetera. Administered by the Florida Department of Pollution Control with help from the Division of Health of the Florida Department of Health and Rehabilitative Services.

B. **Florida Water Resources Act of 1972** (chapter 373, Florida statutes)

Relating to all state waters (except with respect to water quality), conservation and control programs for management and conservation of such related resources (fish, wildlife, et cetera). Utilization of surface and ground water, prevention of damage by flooding, soil erosion, excessive drainage, et cetera. Administered by Florida Department of Natural Resources with delegation of powers to five regional water management districts. Presently involved in generation of a state water use plan.

C. **Florida Environmental Land and Water Management Act of 1972** (chapter 380, Florida Statutes)

Establishment of an Area of Critical State Concern (ACSC) program and the developments of regional impact (DRI) evaluation process. Areas of critical concern qualify for such designation by having environmental, historical, or archeological importance, or being affected by major development. The purpose is to formulate state decisions establishing land and water management policies for the guidance and coordination of local decisions concerning growth and development. This does not apply to more than 5 percent of the land of Florida as an ACSC, and agricultural activities are exempt from its provisions. A DRI is a report filled out by the developer according to specified questions that are to be answered concerning the overall impact of the development on the region's environment, natural resources, economy, et cetera. The Division of State Planning, Department of Administration implements this act, review of DRI's are considered by the appropriate regional planning agency with the local government conferring final approval, approval with conditions, or denial. The overall purpose of this act is to promote the creation of principles to guide development on the local level within specified state-sanctioned guidelines so that any major development in a given area is compatible with the local environment.

D. **Florida State Comprehensive Planning Act of 1972** (chapter 23, Florida Statutes)

Provides plan for long-term guidance for staff growth by establishing goals, objectives, and policies. This includes coordination of planning efforts among local, state, and federal agencies. Division of state planning is responsible for implementation of this act

E. **Land Conservation Act of 1972** (chapter 259, Florida Statutes)

Environmentally Endangered Lands Program (EEL Program) based on analysis of available ecological information to determine priorities of environmentally endangered land. An EEL plan will be developed to guide the purchase by the state of endangered lands. In such purchases, there is no eminent domain power to implement land acquisition; this precludes identification and priority listing of endangered lands. The choice between acquisition and regulation depends on level of protection necessary to achieve the desired environmental aims. Emphasis is on ecological significance, the importance of submerged lands, and appropriate evaluation Administration is by the Department of Natural Resources with input from other state agencies and a panel of experts on environmental and planning concerns. This includes interagency planning and advisory committees with final approval by the Governor and cabinet.

F. **Beach and Shore Preservation Act** (chapter 161, Florida Statutes)

Provides for beach nourishment, erosion control, regulation of coastal construction, and establishment of setback lines along beaches Administered by the Department of Natural Resources.

3. **Applications to Apalachicola Bay**

A Resolutions designating Apalachicola Bay as an aquatic preserve in accordance with management policies governing such areas.

B. St. Vincent Island is a National Wildlife Refuge that is controlled by the Department of Interior.

C. Endangered lands along the Apalachicola River have been approved for purchase by the Governor and Cabinet.

D. The area is bordered by the Apalachicola National Forest and several parks.

E. A coastal setback line (state) has been established for the gulf side of St. George Island. A county wide setback line (Franklin County) for all lands bordering aquatic areas is presently under consideration.

F. The Apalachicola drainage system is presently under consideration for designation as an Area of Critical State Concern.

years of experiments were carried out in which baskets of leaves were dropped into different parts of the bay and checked regularly for possible association with assemblages of estuarine organisms (Livingston, 1974). The leaves were found to be associated with various food webs in the bay. Although little was known concerning the exact origin of the leaf matter and its actual quantitative contribution to the bay energy budget, the potential importance of such a source had to be recognized.

Deciduous hardwood forests border the river; such swamps, in addition to providing a habitat for a wide variety of terrestrial organisms, are considered to be a focal point for exchanges of nutrients and detritus which eventually become part of the estuarine energy system. In addition to serving as filters for various inorganic and organic substances, such swamps are thus an integral part of the ecological balance of the lower Apalachicola wetlands. Activities such as clear-cutting, ditching, diking, and draining could interrupt such exchanges; in addition, changes in the form of available leaf matter could have an effect on the water and energy budgets of local aquatic areas as well as downstream estuarine systems. This has been shown in various studies (Egglishaw and Mackay, 1967; Woodall and Wallace, 1972). Recent evidence (Swank and Douglass, 1974) indicates that replacement of deciduous forests by coniferous monocultures can seriously alter the water budget of upland areas. Woodall and Wallace (1972) considered that watershed vegetation is a major determinant of aquatic species composition and abundance.

Comprehensive quantitative determination of nutrient and detritus exchanges in bay systems is not available; the nutrient-detritus budget of the Apalachicola bay system remains unknown. However, the leaf data supplied by the Florida Sea Grant project (Livingston, 1974) provided the scientific support for the purchase of $4.4 million of river swamp along the lower Apalachicola river (Fig. 8). Soil analysis contributed to the identification of flooded areas; this was used in the determination of the endangered areas.

At this time, while much of the land is designated for immediate purchase, negotiations are under way for other lands that border the Apalachicola river (Fig. 8). State agencies are presently considering the trade of less sensitive upland areas (above the drainage system) for hardwood swamps (owned by pulp mills) bordering the river. In this way, under the Land Conservation Act of 1972, sensitive portions of the lower Apalachicola river valley will eventually be set aside by the state of Florida as a preservation area to remain in a natural state. Some

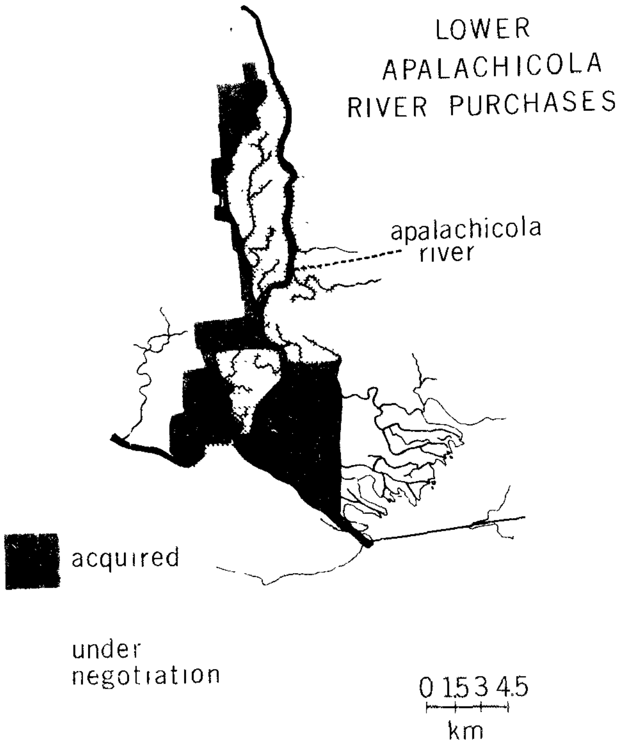


FIGURE 8.—Purchases of portions of the lower Apalachicola River basin by the state of Florida under the Land Conservation Act of 1972. Those listed as "acquired" have been approved by the Florida Cabinet and now await resolution of legal boundary lines and actual purchase. Those listed "under negotiation" are still being considered as part of a trade with less sensitive upland areas.

difficulties have been experienced with this program. Removal of the land from local tax rolls has stirred some opposition. Without eminent domain powers, bargaining can become difficult, with higher prices, bureaucratic confusion and delays often accompanying the deliberations. On the whole, however, this program has been successfully carried out and is presently a powerful (though limited) method for the preservation of sensitive endangered lands.

Areas of Critical State Concern

The Apalachicola drainage system is presently being considered for designation as an area of critical state concern (Table 3). Although this would allow more state involvement in the management of the system with respect to specific forms of development such as municipal waste, drainage programs, and industrialization, agricultural practices such as massive clearing and drainage operations (cattle ranch, pulp mill operations, et cetera), and fertilization programs would remain exempt from control. However, the ACSC program and the DRI Evaluation process (Table 3) have promoted an effective means of control at the local level. In addition to the provision of a legal means of implementation of county-wide planning programs, the expertise of various state agencies is made available to local governments. All too often, such governing bodies are inexperienced in zoning and subdivision regulations that promote orderly growth. Franklin County, for instance, has recently taken steps in this direction by soliciting and passing a county-wide plan. In addition, at the urging of Sea Grant investigators and local seafood interests, a group is presently looking into the development of county zoning regulations to promote protection of the bay system. Such activities are not without considerable opposition. Reaction includes demands for reimbursement by property owners in such state or county controlled areas, requests for more specific scientific information concerning designation of critical areas, and the establishment of tax relief provisions for counties with high percentages of setback lines and critical lands.

Negotiations With Individual Developers

Another approach has been attempted by the Florida Sea Grant Program (Livingston, 1974). Sea Grant scientists are presently initiating a research effort in conjunction with pulp mill interests (the Buckeye Cellulose Corp.). A cooperative research program has been developed whereby all clear-cutting, roadbuilding, and drainage operations in the East bay system have been suspended. In addition to indepth, long-term field monitoring operations in this area to determine potential impact (Livingston, 1974), experimental ecological research will be carried out in conjunction with a comprehensive terrestrial-aquatic sampling program. An experimental area will be cleared and ditched and the physicochemical and biological factors in adjacent areas will be continuously monitored to determine the potential impact of storm water runoff on the aquatic biota. Also, new ways of land utilization will be tested: this includes the setting aside of extensive fringe areas, direction of runoff to holding ponds before release into surrounding areas, and so forth. It must be pointed out that this is due in large part to the enlightened environmental policies of the Buckeye Cellulose Corp.; it does emphasize a growing willingness among private concerns to experiment with alternate methods of development when such efforts are based on objective scientific data. The importance of local contact should not be underestimated.

Barrier Island Development

The situation on St. George Island is a classical case of the dilemma of residential development within estuarine systems. St. George Island is one of three barrier islands that form the Apalachicola bay system (Fig. 2). The island is 30 miles long (7,340 acres of land; 1,200 acres of marshes) and averages less than ⅓ mile in width. It conforms in geological and biological terms to classical barrier island characteristics (Fig. 9) and is an integral part of the bay system (Livingston, 1974).

It is entirely surrounded by salt water, and any freshwater runoff comes entirely from rainfall which filters through the sandy soil and undergoes discharge. This water eventually ends up in the bay or the Gulf of Mexico. The proximity of oyster bars in St. George Sound to the island adds to the sensitivity of this situation. In other words, because of its length, position, and unique ecological features, St. George Island is a key to the continued viability of the Apalachicola bay system. Several years ago, a bridge from the mainland was constructed; this added to the prospects of residential development on the island. There has already been a relatively rapid rate of growth although this has occurred without zoning restrictions, sewage treatment facilities (septic tanks are generally used), solid waste disposal, and storm water runoff control. The island is presently in a state of flux with various interests vying for its use.

The major landowner on the island (Leisure Properties, Ltd.) proposed a test area for development of about 800 acres which would be carried out under the developments of regional impact (DRI) guidelines provided under the Florida Environmental Land and Water Management Act of 1972 (Table 3). This law places control of development solidly in the hands of local (county) interests. There are both positive and negative features to this approach. Local control is favored because it allows more immediate feed-back to those who will be most affected by the proposed development. On the other hand, county commissions in Florida rarely have the expertise at their disposal to evaluate the DRI, and consequently must depend on state agencies, regional planning agencies, and local experts for guidance. This can be confusing, especially when there is little scientific data on which to base a far-reaching zoning or subdivision plan. In the case of St. George Island, scientists associated with the Florida Sea Grant Program in Apalachicola Bay have worked with county and state agencies, and the developers to provide a plan for the long-term management of St. George Island. Included in

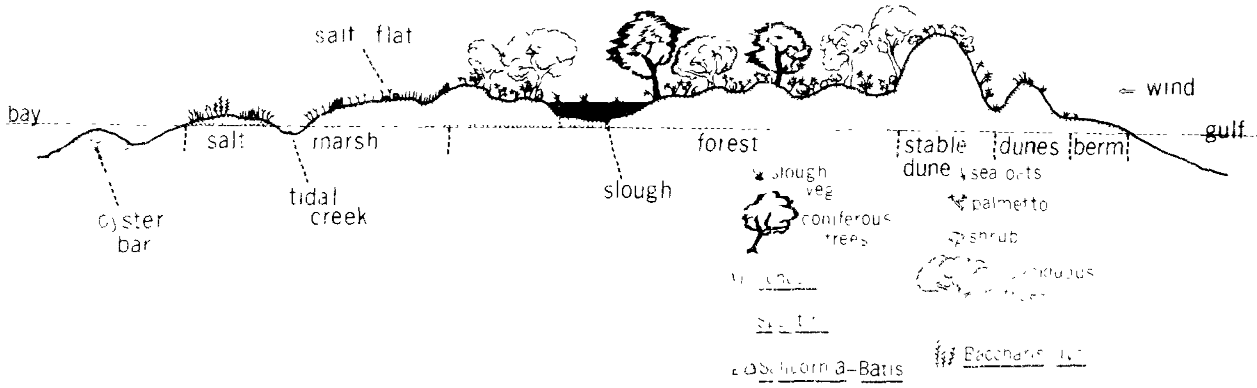


FIGURE 9.—Idealized cross section of a barrier island with special application to St. George Island (modified from Clark, 1974).

this plan would be the provision of an advanced sewage treatment plant, storm water runoff and nutrient control, a regulated pest control program, protection of sensitive portions of the island-bay system, and so forth (Livingston, 1974). A baseline study would precede any development and would continue throughout the various phases. Any impact determined by the scientific studies would be reported to state and county officials and the source of the problem would be eliminated before development could proceed. The DRI would make this a legal necessity. Funds for such studies would be provided by the developer and administrated by the county commission to avoid conflicts of interest. Such a plan is not without liability. It is possible that chronic pollution such as heavy metal contamination could escape detection and build up to levels that would eventually have an impact on the bay ecosystem. Another possibility is that increased development would lead to other forms of expansion that are not as susceptible to control. Such a program also depends on the economic viability of the developers, which is not always assured.

An alternative to this plan would be a restrictive zoning ordinance that would severely reduce the population on the island. In this case, there still would be no support facilities (sewage plant, storm water control, et cetera), although the population increase would not be as rapid. Whether or not such a plan would work over the long run is also doubtful. Another possibility is the purchase of large portions of the island by private foundations and/or municipal and state agencies. Presently, all these alternatives are being examined by various groups. This is a good example of the difficult types of decisions that must be made in any comprehensive planning program.

The Role of Research and Education in Resource Management

There is a growing realization of the importance of long-term scientific monitoring programs in the management of estuarine systems. Such research should be coordinated with state and local administrative bodies so that such knowledge can be utilized in the planning process. This should involve local interests so that control remains realistic and compatible with user concerns. Such research can be coordinated with educational processes to accelerate this process. For instance, local high school classes have been taken on field trips by Sea Grant researchers in the Apalachicola bay project and undergraduates from Franklin County (enrolled at Florida State University) are presently employed in the research effort (Livingston, 1974). As part of the program, the principal investigator also acts as an advisor to the board of county commissioners and serves as a member of several committees that formulate county and city ordinances to protect the Apalachicola system. The interaction of estuarine scientists and county personnel has also resulted in the generation of county funds for the research effort. Thus, using the federal Sea Grant Program as a base of support, matching funds have been provided by local, private, and municipal interests for baseline studies so that answers can be found to the problems of the bay. The research and educational effort should not be underestimated in any management program, and actually forms the basis for understanding that is fundamental to the success of any planning effort. There should be increased incentives for scientists to interact with local interests and state agencies to apply basic biological research to the problems associated with development in natural drainage areas.

The Future of the Apalachicola System

The Apalachicola drainage system is presently the focal point of development by various interests. On the one hand, it is still in a relatively natural state with Apalachicola Bay providing the basis for extremely productive sport and commercial fisheries. On the other hand, various agricultural, commercial, and industrial interests are beginning to utilize the system in ways that will eventually come into conflict with present usage. The Apalachicola system is actually a microcosm of what is occurring in the estuaries all over the country, with conflicting interests competing for the use of terrestrial and aquatic resources. A number of state and federal agencies, responsible for the administration of a welter of new environmental laws and regulations, are also involved in this situation. There are indications that long range planning and resource management based on extensive scientific data will be necessary if such systems are to remain productive. However, despite a serious promotional buildup by industrial interests and the Army Corps of Engineers to promote damming and industrialization of the Apalachicola River, no move has been made to fund a research program to answer the serious questions concerning the effects of such actions on the aquatic system and those who depend on it. Various approaches have been attempted to promote the planned usage of the Apalachicola drainage system. Land that is considered environmentally sensitive and endangered has been purchased by the State of Florida for preservation while land swaps of upland forested areas for endangered wetlands are presently under consideration. An estuarine management program, funded by the Florida Sea Grant program, has served as a platform for the development of an educational and research program designed to promote an orderly approach to the development of the Apalachicola aquatic system. Various private interests such as pulp mills and land developers have contributed to this effort to determine sensible ways of utilizing the wetlands without having an impact on the bay productivity. Various actions by the State of Florida have aided in this effort. Preservation, conservation, and development areas have been determined, and new laws and regulations have enabled a new approach for planning at the local level. County governments can now utilize various state and federal resources to help them in the effort to plan for future development. When combined with scientific research teams from various disciplines, these interactions can lead to constructive action. In spite of all this, major unresolved problems exist. Non-point sources of pollution and activities relating to an impact on the aquatic energy systems have not been adequately researched. The imminent determination to industrialize the river and develop broad new residential areas on the barrier island system of the bay will demand considerable planning if the Apalachicola Bay system is to remain productive. Increased cooperation and interaction of federal, state, and local agencies will be necessary to develop successful management schemes.

APPLICATIONS AND CONCLUSIONS

1. The successful development of an estuarine resource management plan would depend on a complete environmental resource analysis. This would include baseline scientific data, and comprehensive economic and land inventory information so that decisions can be made concerning resource utilization by conflicting interests.

2. Based on the available information, decisions should be made concerning how the system is to be utilized. This would depend on population distribution, the extent and form of industrialization, importance of sports and commercial fisheries, aesthetic considerations, and so on. Thus, at an early stage of development, the actual functional use of the system should be determined (industrial, sports or commercial fisheries, recreation, et cetera).

3. Following the initial determination of use, critical or sensitive areas in the system should be identified. This would include an assessment of the impact of point and non-point sources of pollution. Equally important should be the protection of the basic energy system of the estuary. Although various forms of pollutants can harm an estuarine ecosystem, it is possible that through improper land use, the sources of energy for such a system are altered. This can ultimately be translated into a decrease in useful productivity. The significant relationship of the estuary with its associated upland drainage system should be determined so that basic productivity at all levels remains intact.

4. Based on a scientific assessment of the entire drainage system, a broad management scheme should be developed whereby critical areas are preserved. This should be done through the purchase of such areas by state and federal agencies, this could be patterned after the Florida Land Conservation Act of 1972 where public funds are used to purchase environmentally endangered land. Other areas that are considered important should come under some form of conservation and management program This could be approached in various ways such as areas of critical state concern, state and local set-

back ordinances, and restrictive zoning programs. The federal government should promote advisory services on the local level so that various concerned interests are involved at the decisionmaking level. It is not a matter of doing basic or applied research. Significant questions should be asked, and sound scientific data should be used in the development of an overall management scheme.

5. Because of the individual nature of the ecological functions and problems of each estuarine system, no uniform or generalized scheme of resource management is possible. Administrative functions should be regional and interdisciplinary in nature. The regional approach would be based on the extent of the individual drainage system. In addition to representation of the various local interests within the decisionmaking process, an administrative mechanism should be developed for the translation of scientific data into management and planning concepts. Again, the federal government should provide programs that encourage scientists to participate at the local and regional levels so that information is readily available when needed. This would include educational training programs and coordination of resource inventory analysis.

The ultimate goal of a resource management program for any given estuarine system should thus provide a plan that would be based on objective scientific data and would allow the application of intelligent alternatives to a given local or regional situation. Only in this way can the often difficult decisions be made which concern resource use in our estuaries.

REFERENCES

Clark, John. 1974. Coastal Ecosystems: Ecological considerations for management of the coastal zone. The Conservation Foundation; Washington, D. C

Colberg, M. R., R. S. Dietrich, and D. M. Windham. 1968. The social and economic values of Apalachicola bay, Florida. Final report to: Fed. Water Poll. Cont. Admin.

Cox, David T. 1969. Stream Investigations. Annual progress report, Florida Game and Fresh Water Fish Commission (1968–1969).

Cox, David T. 1970. Stream Investigations. Annual Progress report, Florida Game and Fresh Water Fish Commission (1969–1970).

Cox, David T. and Dennis Auth. 1971. Stream Investigations Annual Progress Report, Florida Game and Fresh Water Fish Commission (1970–1971).

Cox, David T. and Dennis Auth. 1972. Stream Investigations. Annual Progress Report, Florida Game and Fresh Water Fish Commission. (1971–1972).

Cox, David T. and Dennis Auth. 1973. Stream Investigations. Annual Progress Report, Florida Game and Fresh Water Fish Commission (1972–1973).

Curl, Herbert Jr. 1959. The hydrography of the inshore northeastern Gulf of Mexico. Publ. Inst. Mar. Sci. 6: 193–205.

Darnell, Rezneat M. 1961. Trophic spectrum of an estuarine community, based on studies of Lake Pontchartrain, Louisiana. *Ecology* 42(3): 553–568.

Egglishaw, H. J. and D. W. MacKay. 1967. A survey of the bottom fauna of the streams in the Scottish highlands. Part III: Seasonal changes in the fauna of three streams. *Hydrobiologia* 30: 305–334.

Estabrook, Robert J. 1973. Phytoplankton ecology and hydrography of Apalachicola bay. M. S. Thesis, Florida State University, Tallahassee, Fla.

Heald, Eric J. 1969. The production of organic detritus in a south Florida estuary. Ph.D. Dissertation, University of Miami. Miami, Fla.

Livingston, Robert J. 1974. Field and laboratory studies on the effects of pollution on north Florida estuaries. Final report, Florida Sea Grant.

Livingston, Robert J. 1976. Diurnal and seasonal fluctuations of estuarine organisms in a north Florida estuary: sampling strategy, community structure, and species diversity (in press).

Livingston, Robert J., Thomas S. Hopkins, John K. Adams, Michael D. Schmitt, and Laura M. Welch. 1972. The effects of dredging and eutrophication on Mulatto Bayou (Escambia Bay; Pensacola, Florida). Report for Florida Department of Transportation.

Livingston, Robert J., Richard L. Iverson, Robert H. Estabrook, Vernon E. Keys, and John Taylor, Jr. 1974A. Major features of the Apalachicola bay system: Physiography, biota, and resource management. Fla. Acad. Sci. 37: 245–271.

Livingston, Robert J. et al, 1974b. Synergism and modifying effects: interacting factors in bioassay and field research. Publ. Mar. Tech. Soc.

Menzel, R W., N. C. Hulings, and R. R. Hathaway. 1957. Causes of oyster depletion in St. Vincent Bar, Apalachicola Bay, Florida. Proc. Natl. Shellfish Assoc. 48: 66–71.

Menzel, R. W., N. C. Hulings, and R. R. Hathaway. 1966. Oyster abundance in Apalachicola Bay, Florida, in relation to biotic associations influenced by salinity and other factors. Gulf Res. Rep. 2(2): 73–96.

Menzel, R. W. and E. W. Cake, Jr. 1969. Identification and analysis of the biological value of Apalachicola Bay, Florida. Report to F.W.P.C.A.

Odum, William E. 1971. Pathways of energy flow in a south Florida estuary. Sea Grant Tech. Bull. #7, University of Miami Sea Grant.

Rockwood, Charles E. 1973. A management program for the oyster resource in Apalachicola Bay, Florida. Res. Rept. Florida Dept. Nat. Res.

Swank, W. T. and J. E. Douglass. 1974. Streamflow greatly reduced by converting deciduous hardwood stands to pine. Science 185(4154): 857–859.

Teal, John M. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology 43(4): 614–624.

Woodall, W. R. Jr., and J. B. Wallace. 1972. The benthic fauna in four small southern Appalachian streams. Am. Midl. Nat. 88(2): 393–407.

THE RHODE RIVER PROGRAM

DAVID L. CORRELL
Smithsonian Institution
Edgewater, Maryland

ABSTRACT

An intensive study of the interactions of the Rhode River, a subestuary of Chesapeake Bay, with its watershed and airshed is being conducted at the Chesapeake Bay Center for Environmental Studies. Rainfall is a major source of nitrogen nutrients for the watershed and the estuary. Very little of the nitrogen in the rain falling on the watershed or that applied to cultivated croplands reaches the estuary. Almost all of the phosphorus loading of the estuary is from watershed runoff. Using land use analysis and watershed runoff studies, seasonal area yield loading rates have been calculated from land use categories. Freshwater wet areas are effective traps for nitrogen, phosphorus and mineral suspended matter, while residential areas and cultivated croplands are major non-point sources of these parameters. Neither the upland soils, nor the tidal marsh sediments can be considered long term sinks for phosphorus. Most of the organic matter which fuels the food chains of the estuary is produced by the phytoplankton, rather than upland forests, tidal marshes, or mud flat benthic plants. The phytoplankton productivity peaks in an area of the estuary in which the ratio of nitrogen to phosphorus is between 5 and 20. Net productivity also peaks in this zone.

Thus this estuary, which has no point sources of pollution, is maintained in a eutrophic situation by nitrogen loading from rainfall and distant sources of water pollution in the bay, and from phosphorus loading from residential and agricultural diffuse sources. Where the ratio of these nutrients is maintained within a biologically useful range intensive phytoplankton blooms develop.

INTRODUCTION

The Chesapeake Bay Center for Environmental Studies, established in 1965 by the Smithsonian Institution, is a 2,600-acre research facility on the Rhode River. This subestuary on the western shore of the Chesapeake Bay just south of Annapolis was chosen for a long-term research program because it is small enough (two square miles of open water) to be studied in detail, yet large enough to have the characteristics of an estuary.

Although the estuary is near major research centers, its shoreline had not been completely developed when the Center was established. Portions had been bulkheaded or filled and developed for marinas and suburban housing, but large areas are still relatively undisturbed. The land in the watershed of the river still falls into a mixture of land use categories typical of the western shore of Chesapeake Bay.

The research program at the Center is concerned largely with the interaction of the Rhode River estuary with its watershed and man's impact on this system. The effects of air pollution from the Baltimore-Washington metropolitan area, land use practices, and the disposal of sanitary waste waters generated by a rapidly growing population are being studied. The research program is being conducted by scientists from the Smithsonian Institution, the U.S. Geological Survey, and from nearby universities, principally The Johns Hopkins University and the University of Maryland. The broadly based interdisciplinary effort begun in the mid-1960's, has grown to a major research program during the last four years.

The research at Rhode River has been concerned with (1) gaining an overview of the current status of the estuarine-watershed system, and (2) attempting to dissect the system in order to understand the function and quantitative importance of each component.

The components have been considered from two points of view:

Spatial components.—Airshed and weather, uplands, tidal marshlands and mud flats, open water tidal creeks, the main basin of Rhode River proper, and the spine of Chesapeake Bay.

Functional components.—Physical-chemical conditions (temperature, nutrients, soil or substrate, et cetera), primary producers, primary consumers, secondary consumers, and decomposers.

Each spatial component will have a series of functional components. In the case of tidal marshes, for example, we have asked the following questions: What is the primary productivity per unit of surface area? What organisms carry out this productivity at each season of the year? How much of this productivity is used to support the primary consumer and decomposer components of the marshes, and how much is exported to the Rhode River basin spatial component?

The purpose of this report is to summarize the more important research results of the program, i.e., those relevant to "The National Estuary Study," and to outline research which I anticipate will be carried out at Rhode River in the next few years.

STATEMENT OF PROBLEM AREAS

We lack intensive, long-term measurements of the key parameters on which to base a better understanding of the functional role and significance of each component of an estuarine ecosystem.

We also lack sufficient data processing and data utilization from ongoing estuarine research programs.

As a result of problems above, we do not possess the perspective necessary to see the relationship of each component to the system as a whole. Until we obtain this perspective, efforts towards optimum management of estuaries are certain to be arbitrary and often counterproductive.

REVIEW OF RESEARCH RESULTS FROM RHODE RIVER PROGRAM

Airshed Interactions

Rain falling on the Rhode River and its watershed contributes significant amounts of nutrients, especially nitrogen. A network of rain gauges has been established on the watershed and rainwater is collected routinely in a special receiver for chemical analysis (Correll, 1973).

In the 1973-74 hydrological year rainfall on the Rhode River watershed deposited 0.40 lb of phosphorus per acre year, mostly as free phosphate, the form most biologically available. This is a relatively small amount compared to an average fertilizer application rate of 29.5 lb/acre year on the cultivated crops of the watershed (Correll, 1973). However, the rainfall also deposited 6.6 lbs. of nitrogen per acre year (2.84 lb nitrate-N and 3.79 lb organic plus ammonia-N/acre year). Most of this nitrogen came down in forms readily utilized biologically. The average fertilizer application rate on cultivated crops on the watershed is 57.3 lb N/acre year (Correll, 1973).

The daily rainfall area loading rates for each season are given in Table 1. Of course, it must be remembered that the rainfall loading is applied to the entire watershed and the Rhode River itself, while fertilizer is not.

Table 1.—Nutrient loading rates from rainfall on the Rhode River watershed (1973–74 hydrological year)

Season	Total-N (lb/acre day)	Total-P (lb/acre day)	N/P (wt ratio)
Winter (Dec., Jan., Feb.)	0.0133	0.00049	27.0
Spring (Mar., Apr., May)	0.0277	0.00183	15.1
Summer (June, July, Aug.)	0.021	0.00160	13.0
Fall (Sept., Oct., Nov.)	0.0106	0.00046	23.1
Entire year	0.0182	0.00110	16.6

Upland Interactions

The watershed of the Rhode River is composed of many small drainage basins, some of which drain into discrete creeks that can be monitored by instrumented sampling stations. Five such stations have been in operation for one year. Water discharged from each of the five basins is recorded, and volume-integrated water samples are taken automatically for analysis of sediment and nutrient concentrations. Each of these drainage basins contains a different proportion of five land use types: cultivated cropland; wet areas such as ponds, swamps, and marshes; pasturelands; natural areas such as forest and brushland; and residential areas plus roads and bare areas. The average land use on these watersheds was 23.5 percent cultivated crops, 0.5 percent wet areas, 57.2 percent natural areas, 13.6 percent pasturelands, and 5.2 percent residential, plus others. The total watershed area monitored was 2,100 acres. The data gathered on water discharge and concentrations of sediments and nutrients have been used to determine mathematically the area loading rates delivered from each of the five land use categories to the Rhode River at different times of year. Some of these rates are given in Table 2. Although they are subject to refinement in precision as the project acquires a larger data inventory, these rates are of considerable interest in predicting the effects of land use change upon the turbidity and nutrient loading of an estuary on a seasonal basis. Equivalent data has not yet been processed for the fall season.

The area yields from cultivated cropland are consistently higher than from natural areas for all three parameters. The ratios of area yields for nitrogen to phosphorus for cultivated croplands decreased from 21 in winter to about three in late spring and summer. Wet areas such as swamps and marshes obviously trapped large amounts of all three components per acre and are therefore very important with respect to estuarine pollution. (A negative value in the table indicates the removal of the material from runoff water and shallow groundwater as it flows through land in this category.) In general, loading from

Table 2.—Nonpoint source area loading rates from upland land use categories to the Rhode River estuary

Land use category	Total-N (lbs/acre day)	Total-P (lbs/acre day)	Mineral suspended matter (lbs/acre day)
Winter			
Cultivated cropland	+0.0052	+0.00036	+0.31
Wet areas [a]	−0.095	−0 014	−4.6
Natural areas [b]	+0.00033	+0.00021	+0.088
Grasslands [c]	+0.016	+0.0020	+0.087
Residential and others [d]	−0.0034	−0.0025	+0.44
Spring			
Cultivated cropland	+0.0080	+0.0026	+0.80
Wet areas [a]	−0.38	−0.088	−26
Natural areas [b]	+0.0029	+0.00054	+0.026
Grasslands [c]	−0.0087	−0.0051	+0.41
Residential and others [d]	+0.031	+0.026	+3.3
Summer			
Cultivated cropland	+0.023	+0 0098	+1.4
Wet areas [a]	−0.36	−0.16	−36
Natural areas [b]	+0.00085	+0.00021	−0.080
Grasslands [c]	−0.014	−0.0098	−0.023
Residential and others [d]	+0.014	+0.018	+1.2

[a] Includes open water, freshwater, marshes and swamps.
[b] *Includes forest and brushlands.*
[c] Includes primarily pastureland.
[d] Others include bare areas, paved areas, dumps, roads.

grasslands tends to shift from high positive values in winter to negative values in summer. In spring and summer, the land categorized residential was a major source of nitrogen and phosphorus.

Residential land was always a major source of mineral suspended particulates. In contrast, natural areas usually had area loading rates of nearly zero for nutrients and low rates for mineral suspended matter. Rainfall area loading rates for nitrogen and phosphorus (Table 1) usually exceeded area loading rates from natural area uplands (Table 2).

Stream samples were taken at times of known water discharge and analyzed for total and fecal coliform bacteria as indicators of potential pollution with human pathogens. Not enough data has been obtained to calculate reliable area yield rates for each land use, but some conclusions seem justified for the watersheds overall. Progressively higher average area discharge rates for coliform bacteria were observed on February 21, March 18, May 13, and June 17, 1974 (1.9×10^3, 4.5×10^3, 4.5×10^4, and 7.7×10^4 total coliforms/acre min, respectively). This was despite the fact that progressively lower water discharge rates were measured for the same time periods. No one watershed had obviously different emission rates.

Radioisotope studies were conducted of the phosphorus cycling and flux occurring in natural woodlands subjected only to rainfall loading or to increased mineral loading designed to simulate land application of sewage effluents (Correll and Miklas, 1974). Phosphorus loading rates of up to 3.8 lb/acre day were used. Neither the leaf litter zone nor the soil column were able to bind and store significantly greater amounts of phosphorus than were present initially. Applied phosphate was rapidly assimilated by microorganisms in the leaf litter zone and then moved into the soil column. Within the soil, the phosphorus, still packaged within microbial cells, moved laterally in the interstitial waters and was lost from the forest as shallow groundwater runoff in the local streams.

Tidal Marshes and Mud Flats

Many of the tidal marshes and mud flats bordering the Rhode River today are located in or adjacent to Muddy Creek, a headwaters tidal channel. These areas function as filters and thereby alter the water quality of the tidal waters. It is estimated that the Muddy Creek system, which drains 66 percent of the watershed, discharges about 16 tons of suspended particulates per year into these mud flats. Most of this load is precipitated as a result of aggregation and reduced water velocities before it passes into the Rhode River proper. Thus the mud flats and tidal marshes act as sediment traps.

The tidal marshes also assimilate phosphorus and nitrogen nutrients at a high rate. These marshes have large surface areas in contact with the tidal waters. These surface areas are covered with periphyton, a community dominated by algae and bacteria. The bacteria in this surface microbial film are responsible for most of the nutrient uptake (Correll, Faust and Severn, 1973; and, Bender and Correll, 1974), following which the nutrients are transferred down or laterally in the interstitial waters of the sediments by the pumping action of the tides until they reemerge in the water draining into the tidal channels at low tide. No significant net accumulation of mineral nutrients occurs under natural or increased mineral nutrient loading in the high or low tidal marshes of the Rhode River (Correll, Faust and Severn, 1973, and, Bender and Correll, 1974), but many organic forms of phosphorus and nitrogen are mineralized in the overall process. Thus, incoming tides contain a higher proportion of organic and particulate forms of mineral nutrients than ebbing tides.

Experiments with periphyton on artificial substrates in the mud flats indicated average phosphorus uptake rates of 0.18 ton P/acre year and an average turnover time for total periphyton phosphorus of 29 hours. The primary production of tidal marshes and mud flats is due to the activities of submerged and emergent higher plants and the periphyton microbial community on the underwater surfaces.

The productivity of tidal marsh emergent plants (commonly called grasses) is usually considered to be high. In the Rhode River, the productivity of various marsh communities, as estimated from standing crop at the end of the growing season, varied from 1.4 to 5.0 ton dry wt/acre year (Correll, 1973). The most prevalent communities had productions of about 2.6 ton dry wt/acre year. Actual carbon dioxide uptake measurements in high marsh communities gave values which ranged up to 222 lb/acre day as a maximum during the peak of the growth season, but that season only lasts about two months. Thus, these figures are within a factor of 2 of the standing crop values. In the mud flats the productivity of the beds of submerged vascular plants as judged by standing crop in July, was 0.18 to 0.23 ton dry wt/acre year.

The underwater surfaces of both marshes and mud flats are covered with periphyton. Studies of periphyton growth on artificial substrates gave an average rate of 0.18 ton of ash-free dry wt/acre year (Correll, 1973). Actual rates of periphyton net primary production, as determined by radioisotope methods, averaged 1.1 tons ash-free dry wt/acre year (Correll, 1973). Because this value does not account for losses due to grazing, death, et cetera, it is much higher than the biomass growth rate value on artificial substrates. Even so, the productivity of the mud flats (submerged vascular plants plus periphyton) was lower than the productivity of the tidal marshes (about 1.3 vs 2.6 tons dry wt/acre year, respectively). Periphyton carries out primary production in the marshes all year, but the rates within the marshes have not been measured at Rhode River. This primary production has the potential for making two significant contributions to the Rhode River: (1) providing a food supply for spawning and nursery grounds, and (2) providing the estuary with dissolved and particulate organic matter carried by tidal currents.

There is little doubt that the first is a bona fide role for this component of the system. However, experiments at Rhode River tend to deny the importance of the second. Carbon dioxide exchange measurements on one meter square experimental plots in high marsh communities indicate that, due to the metabolism of the microorganisms within the bottom sediments and the surface litter layer, most of the organic material produced in these marshes is respired away again while still in the marsh. Thus, most of the grass productivity actually fuels the food chains of the marsh, rather than being exported by tidal currents to the estuary.

Another question concerning the role of tidal marshes and mud flats is, how effective are they at removal of bacteria carried into this area by the runoff from the Muddy Creek system? Preliminary data suggest that once the bacteria are discharged into tidal waters, most of them survive until they are exchanged into Chesapeake Bay proper.

Rhode River

The chemical and physical properties of the estuary have been studied extensively. Gradients exist for the concentrations of most parameters due to freshwater runoff from Muddy Creek at one end of the estuary and the exchange of brackish water from the bay at the other. These gradients undergo seasonal changes which must be understood if the biological components of the estuary are to be analyzed.

The surface water of the bay adjacent to Rhode River typically reaches a minimum salinity (4–5 percent) in May or June due largely to flushing by the Susquehanna River. It then increases steadily to about 12–13 percent by November or December (Correll 1973). This cycle controls the rate of exchange of the waters in the lower Rhode River. Local watershed freshwater runoff is usually highest in winter and spring, while it often reaches values of essentially zero in late summer or fall.

The total load of suspended particulates in the estuary varies from about 60 tons in the fall to 300 tons in the spring and summer, of which organic matter comprises an average of about 60 percent (Correll, 1973). The turbidity decreases from upstream to downstream. These particulates are important as sites for microbial attachment and for binding of organic matter and phosphorus compounds. They are also important because they severely limit light penetration and thus primary production.

The nutrients (P, N, organic matter) also decrease toward the mouth of the estuary. An exception is nitrate nitrogen, which in the spring has a minimum concentration in the middle of the river (Table 3, and Correll, 1973). Thus, phosphorus in the estuary derives almost entirely from the watershed and decreases in concentration toward the bay due to exchange-dilution with waters of lower phosphorus content. Phosphorus also is deposited in bottom sediments through sedimentation of particulates during normal conditions when bottom waters are not anaerobic. Massive pulsed releases of phosphorus from bottom sediments occur when bottom

Table 3.—Mineral nutrient concentrations in Rhode River surface waters

	Sta.	Total-P (ug P/1)	Dissolved Ortho-P (ug P/1)	Nitrate + Nitrite (ug N/1)	Org-N + Ammonia (ug N/1)	Weight ratio (N/P)
			April 17 (1973)			
Toward Chesapeake Bay ↑	14	26	3	625	669	49.8
	13	28	6	483	684	41.3
	12	32	3	357	769	35.2
	11	37	3	78	838	24.8
	10	56	2	10	931	16.8
	9	70	2	13	808	11.7
	8	111	43	319	362	6.1
			August 9 (1973)			
	14	187	12	6	1381	7.4
	13	134	10	4	1141	8.5
	12	166	43	6	910	5.5
	11	166	43	5	894	5.4
	10	184	45	2	1011	5.5
	9	195	50	2	1076	5.5
	8	469	126	1	1658	3.5

waters go anaerobic occasionally in the summer. A single such release of about one ton of phosphorus into Rhode River was documented in 1973 (Correll, 1974). The occasional occurrence of transfers of phosphorus from anaerobic, phosphorus-rich deep layers of the bay into Rhode River are also suspected but not well documented. Nitrogen enters the Rhode River from the watershed and airshed in high concentrations most of the year and from the bay in the winter and spring.

Phytoplankton is responsible for most of the primary production in the Rhode River. The plankton blooms usually result from bay phytoplankton being exchanged into Rhode River, where growth conditions are more favorable and their populations increase despite the continuous dilution with bay water. The average net productivity of this phytoplankton in the Rhode River, as determined by radioisotope methods, was about 9 tons dry wt/acre year (Correll, 1973). This value is very high, when compared with 1.3 for mud flats or 2.6 for tidal marshes.

Since very little of the carbon fixed in the marshes is exported to the estuary, and since the surface area of the estuary is greater than that of the mud flats and marshes, most of the organic matter which drives the food chains of the Rhode River is probably also produced in the river. Loading rates for Rhode River for organic matter contained in runoff were estimated to be 25-35 tons dry wt/year on the basis of extrapolation from currently available watershed runoff data. Since the surface area of the Rhode River is 1,236 acres, the average loading rate from watershed runoff is only 0.020-0.028 tons dry wt of organic matter acre year.

The primary production, supplemented with exogenous organic matter, drives a complex and very productive food chain in the estuary. This food chain has two other components important to the dynamics—primary consumers and decomposers. They assure efficient utilization of the energy stored by the primary producers and the rapid recycling and reuse of mineral nutrients (N and P). Another important component, from man's point of view, is the secondary consumers.

First, let us consider the primary consumers. These consist of filter feeders of all sizes from ciliate protozoans to shellfish. In terms of energy flow and recycling, the most important of these are the smallest, for their metabolic rates, which are related to the ratio of the organism's surface area to its weight, are extremely high. Rhode River supports high populations of ciliate protozoans, rotifers, and shellfish.

Equally important, if high productivity is to be maintained, are the decomposers (predominantly bacteria). A high correlation has been found in Rhode River between phytoplankton populations and bacterial populations. Animals can eat only particulate organic matter, whether bacteria, phytoplankton, detritis, or other animals. They never completely assimilate that food, but release large proportions as dissolved organic matter. This dissolved organic matter can be utilized only by bacteria and thereby made into particulate matter again. Thus, carbon is recycled continuously by the phytoplankton, filter feeders, and bacteria.

Mineral nutrients are also rapidly recycled. In the case of phosphorus, the bacteria are responsible for over 95 percent of the phosphate uptake in Rhode River (Correll, Faust and Severn, 1973). These bacteria are attached to aggregated suspended particulates (Correll, Faust and Severn, 1973). Total phosphate uptake rates in Rhode River average about 1.2 tons of P/acre year. However, since most of this phosphorus is recycled repeatedly, it is not removed from the system at this rate. Apparently all the phosphorus which comes into Rhode River, from a variety of sources, eventually moves on out into Chesapeake Bay proper. This phosphorus movement probably occurs partly as infrequent pulses (Correll, 1974) rather than at a steady rate.

Phosphorus loading of Rhode River from land runoff in tons/year was estimated to be 0.67 from cultivated crops, 0.22 from natural areas, and 1.4 from residential areas. On the other hand, it was estimated that 0.46 tons P/year were trapped in wet areas and 0.36 tons P/year were trapped in grasslands. This phosphorus would otherwise have reached the estuary. The total loading from land runoff was about 1.5 tons of P/year. The direct

Table 4.—Nutrient sources for the Rhode River

Source	Organic matter (tons dry wt/acre/year)	Phosphorus (tons P/year)	Nitrogen (tons N/year)
Uplands	0.020–0.028	(1.5)	(3.7)
Cropland		+0.67	+2.2
'Wet' areas		−0.46	−1.3
'Natural'		+0.22	+0.90
Pasture		−0.36	+0.36
Residential		+1.4	+1.5
Rainfall		+0.25	+4.1
Phytoplankton	9.2		
Mud flats	low	0	0
Tidal marshes	low	0	low
Chesapeake Bay	0	low	high

loading of the estuary from rainfall was about 0.25 tons P/year. Therefore, the total annual phosphorus input to Rhode River is estimated to be on the order of 1.7–1.8 tons. These sources are summarized in Table 4. A pulsed release of one ton need occur only very infrequently to be important. A slow continuous release of phosphorus into Chesapeake Bay also occurs normally due to the exchange of water masses along a phosphorus concentration gradient (Table 3).

Nitrogen loading of Rhode River from land runoff in tons/year was estimated to be 2.2 from cultivated cropland, 0.90 from natural areas, 0.36 from pasturelands, and 1.5 from residential areas. Wet areas are estimated to have removed 1.3 tons of nitrogen, which otherwise would have reached the estuary. Thus, the total loading from land runoff was about 3.7 tons nitrogen/year. The direct loading of the estuary from rainfall was about 4.1 tons of nitrogen/year. These loadings are summarized in Table 4. In addition, some loading occurred in winter and spring through exchanges of water masses from the bay with a higher nitrate content (Table 3). Without this input from the bay, nitrogen loading would have been only 7.8 tons.

Biota require 10 times as much nitrogen as phosphorus for maximum growth, according to generally accepted estimates. The ratio of nitrogen to phosphorus loading in Rhode River, excluding bay exchange, is only about 4.5, indicating a short fall of 9 or 10 tons of nitrogen per year or an excess of about one ton of phosphorus. However, bay water with a high nitrate content contributes the needed nitrogen, and plankton blooms typically peak in the middle of Rhode River where the phosphorus to nitrogen ratio is optimum. The times and locations of this occurrence vary due to a number of factors, including rainfall and the rate of change in the bay's salinity.

In Table 3, nutrient gradient data, which illustrate these principles, are presented for two days. On April 17 a combination of rapid exchange of high nitrate bay water and local watershed runoff had created a nitrate gradient with a minimum at station 10, while total phosphorus showed the normal decrease toward the bay. The weight ratios for nitrogen to phosphorus also increased from upstream to downstream and were well over 10 for most of Rhode River. This resulted in a depletion of the pool of available orthophosphate.

On August 9, the bay water was no longer high in nitrate. Total phosphorus levels had increased in Rhode River (normal for summertime), but were still decreasing toward the bay. Although nitrate levels were now very low, available orthophosphate levels had increased due to lowered demand. Ratios of nitrogen to phosphorus were now less than 10 throughout Rhode River. The presence of a zone with an optimum ratio of nitrogen to phosphorus is at least one explanation for the fact that productivity is currently higher in Rhode River much of the year than in the main spine of Chesapeake Bay.

Is the Rhode River a reasonably closed system, using most of its primary productivity internally to produce primary and secondary consumers, or does it export substantial amounts of primary productivity to the open bay? Several approaches have been followed in answering this interesting question. One utilizes the diurnal change in dissolved oxygen to measure overall community metabolism. An excess of photosynthetic oxygen production over respiratory oxygen consumption would indicate the system produces more than it consumes.

The results for 1973 (Table 5) indicate that section 2 of Rhode River, in which blooms often occur, did produce about 10 percent more than it utilized. The other portions of Rhode River seemed to be a nearly balanced, or closed, system. This data also indicated a net community production for the main portion of the estuary of about 6 tons dry wt/acre year. Since this includes heterotrophic daytime respiration it is in good agreement with the 9.2 ton estimate of net phytoplankton production.

A second method of examining productivity is to

Table 5.—Rhode River productivity as measured by open-water oxygen metabolism in 1973

Rhode River segment (↑ Toward Chesapeake Bay)	Daytime net productivity (tons dry wt/acre year)	Nighttime respiration (tons dry wt/acre year)	Difference available for export (tons dry wt/acre year)
1	4.43	4.22	+0.21
2	6.62	6.09	+0.53
3	6.01	6.33	−0.32
4	3.65	3.86	−0.21

measure the ratio of net photosynthetic carbon uptake to total community phosphorus uptake. This ratio is called the autotrophy index (atoms inorganic carbon reduced per atom phosphorus assimilated). It should be about 100 for a population consisting entirely of primary producers and 0 for a population consisting of consumers and decomposers only. This ratio had an annual average of 68 for the Rhode River plankton community, compared to an annual average of 25 for mud flat periphyton on artificial substrates (Correll, 1973) indicating a greater proportion of autotrophy in the plankton. Under the conditions prevalent in Rhode River the productivity is normally dominated by nannophytoplankton (algae in the 5 to 10 μm size range) (Correll, 1973). In the summer and fall, however, dense localized dinoflagellate blooms often occur. These organisms are not utilized efficiently as food by filter feeders and are commonly associated with massive fish kills. These blooms are closely correlated with high bacterial populations and high levels of organic phosphorus in the water. The mechanism of the fish kills is not clear. No clear proof of toxins has been demonstrated. Low dissolved oxygen levels in bottom waters at night are also associated with the blooms. The actual causal relationships of these many factors are still not known.

The survival characteristics of coliform bacteria in Rhode River have been studied. In the spring and early summer, when land runoff is occurring, a strong correlation exists between fecal coliform concentrations throughout Rhode River and the factors for dilution of Muddy Creek water by bay water in the various sections of Rhode River ($r = 0.95$ to 1.00). The correlation is much lower for total coliform data ($r = 0.5$ to 0.6). Since Muddy Creek drains most of the watershed, there is a clear indication that the bacteria which give positive fecal coliform assays originate from the watershed at those times. Conversely, many of the bacteria assayed as total coliforms did not originate from the watershed. Survival experiments indicated that high water temperatures and high salinity decreased the survival times of *Escherichia coli* while the presence of suspended Montmorillonite increased their survival.

A search for pathogenic bacteria in Rhode River revealed the presence of fecal *Streptococci* at average levels of 225, 130, and 1,050 per 100 ml of surface water at the mouth, center, and upper end of the river, respectively (Correll, 1973). The numbers present per 10g bottom sediment were usually over 2,400. *Clostridium botulinum* was present in the bottom sediments in three cases out of 24. No *Salmonella* were found. *Vibrio parahaemolyticus*-like organisms were abundant in the water column and sediments except in the winter. These results provide a factual basis for concern over the effects of pathogens on shellfish harvested in Rhode River.

EVALUATION OF PREVIOUS RESEARCH PROGRAM AT RHODE RIVER

The research program at Rhode River has been based on three basic assumptions: (1) An estuarine study must include investigations of the interaction of the aquatic system with its watershed and airshed if the system is to be understood or intelligently managed. Once pollutants have been introduced into the tidal waters, not much can be done. Unless we find the sources and magnitudes of these pollutants we cannot attempt to control them. (2) An estuarine research program must include contributions of information from many scientific disciplines if an overall understanding of the estuary is to emerge. (3) This information must be digested, and the conclusions must be made available to a broad spectrum of people. Otherwise, the problems of managing the estuary will not be alleviated. The scientific community, management people at each level of government, citizens' organizations concerned with the environment, and the general public must have access to these conclusions.

The three programs of the Chesapeake Bay Center for Environmental Studies are responsive to these assumptions. The research program focuses on the Rhode River, its watershed, and its airshed. An information transfer program is underway to relay results of the research to managers and other potential users. The Center's education program is also designed to inform the public about the functioning of the Rhode River ecosystem. In addition, the Center's membership in the Chesapeake Research Consortium helps to insure that its efforts will be coordinated with those of other research facilities concerned with the bay.

So far, I have stressed the positive side of our past effort. We have also encountered many problems. We have accepted the necessity for maintaining an interdisciplinary interorganizational program in which data is gathered in a well planned, spatially and temporally coincident manner. This has been very difficult to achieve, but we have made progress towards this goal. We also have realized the need to demonstrate the applicability of the findings at Rhode River to other estuaries and their watersheds and airsheds. Some progress has been made in this direction. For example, a one-year study is now underway which compares the Rhode River with the South River, a larger subestuary of the Chesapeake Bay. We have realized the need to test how much stress different sections of the estuary can absorb without serious deliterious modification. Although some work has been done along these lines, more is needed. Finally, we have encountered severe problems in funding such an ambitious research program. So far, sufficient funds have been found to maintain a viable, but not optimum, program.

Overall, the program has just begun to produce the type of results it was initiated to produce—information which could not have been obtained by individual scientists working alone or in groups on a short-term basis or by studies of only one component of an estuarine ecosystem.

RESULTS WHICH APPLY DIRECTLY TO ESTUARINE MANAGEMENT

Although preliminary, the area loading rates in this report from the airshed and watershed to the Rhode River are available to serve as a powerful tool for management (Tables 1 and 2). They provide an overview of total nutrient and sediment loading on a seasonal basis from rainfall and five types of land use. The effects, with respect to total loadings, of land use changes resulting from development can now be predicted more accurately. The effects on the estuary of a shift from the sewage disposal methods currently used to methods involving application of sewage to land can also be predicted (Correll and Miklas, 1974). On the basis of our research, the use of tidal marshes for spray irrigation of sanitary waste waters does not seem advisable (Bender and Correll, 1974).

The productivity of an estuary has been quantified and compared with the relative amounts of biologically useful energy it receives from land runoff, mud flats, and tidal marshes (Table 4). The role played by nutrients in the very high biological productivity of Rhode River has been outlined (Table 5). Any management decisions concerning nutrient sources or the modification of tidal marshes or mud flats can therefore be discussed in a quantitative manner on a per acre basis with respect to these parameters.

FUTURE TRENDS AND NEEDS IN RESEARCH AT RHODE RIVER

Because of the need to generate data more directly useful to a growing number of scientists and more easily adaptable to systems analysis and model construction, the research at Rhode River will probably become progressively more programmatic. The participants already are becoming thoroughly aware of the complexity of the system and of the limited usefulness of isolated data.

In general, more research is needed on the cycling of nitrogen, the role of toxins in the system, and the dynamics of the primary and secondary consumers.

RECOMMENDATIONS FOR IMPROVEMENT OF THE ESTUARINE ENVIRONMENT

A systems analysis approach to the management of the overall ecosystem is necessary. We need to be able to predict the impact of overall nutrient, sediment, pathogen and toxin loading from all sources upon various sections of and types of estuaries. These waters have to be characterized with respect to their salinity regimens, flushing rates, and depths. The impacts will be calculated in terms of effects upon biological productivity, balance of oxygen production and utilization, presence or absence of noxious species (such as pathogens, dinoflagellates and blue-green algae, jellyfish, and asiatic milfoil). We need to determine the acreage and types of mud flat and tidal marshes which should be preserved as spawning and nursery grounds for fisheries. We need to be able to predict the effect that these areas exert upon estuarine water quality through their function as biological filters. Not until we can do these things can we make intelligent, maximum use of our estuaries.

REFERENCES

Correll, D. L. and Miklas, J. J. 1974. Phosphorus cycling in a Maryland deciduous forest subjected to various levels of mineral nutrient loading. Symp. Mineral Cycling Southeastern Ecosystems, Augusta, Ga. (in press).

Correll, D. L., M. A. Faust, and D. J. Severn. 1973. Phosphorus flux and cycling in estuaries. Second Internatl. Estuarine Res. Conf., Myrtle Beach, S.C. (in press).

Bender, M E. and D. L. Correll. 1974. The use of wetlands as nutrient removal systems. Chesapeake Res. Consortium Publ. No. 29.

Correll, D. L. 1974. Indirect effects of tropical storm Agnes upon the Rhode River. Symp. Effects Tropical Storm Agnes on the Chesapeake Bay Estuarine System, College Park, Md. (in press).

Correll, D. L. (Ed.) 1973. Environmental Monitoring and Baseline Data, Temperate Studies, Rhode River, Maryland. Publ. Smithsonian Institution, Washington, D. C.

ACKNOWLEDGMENTS

The following sources of research data were used in preparing this report (unless otherwise noted, they are employed by the Chesapeake Bay Center for Environmental Studies):

Rainfall and Land Use Maps, Daniel Higman; Fertilizer Practices, David Miller; Suspended Particulates, Dr. Jack Pierce, National Museum of Natural History, Washington, D.C.; Coliform, Total Bacterial and Phytoplankton Populations, Dr. Maria Faust; Marsh Grass Standing Crops and Marsh Community Carbon Dioxide Exchange, Dr. Bert Drake, Smithsonian Radiation Biology Laboratory, Rockville, Md.; Submerged Vascular Plants Standing Crops, Dr. Charles Southwick, The Johns Hopkins University, Baltimore, Md.; Open Water Oxygen Metabolism, Robert Cory, U.S. Geological Survey (stationed at the Chesapeake Bay for Environmental Studies); Pathogenic Bacterial Populations, Dr. Rita Colwell, University of Maryland, College Park, Md. I would like to thank Dr. Eugene Small, University of Maryland, College Park, Md.; Dr. Howard Seliger, The Johns Hopkins University, Baltimore, Md.; and Dr. J. Kevin Sullivan (all members of the Rhode River Scientific Advisory Committee) for their stimulating discussions over the last several years. The detailed data upon which this summary is based can, in general, be found in the literature cited. The research referred to in this report was funded in part by the Smithsonian Institution's Environmental Sciences Program and by a series of grants from the Program For Research Applied To National Needs of the National Science Foundation (administered through the Chesapeake Research Consortium). I would like to thank Mrs. Dorothy Kinsman, Dr. Francis S. L. Williamson, Dr. J. Kevin Sullivan, and Robert Cory for their comments and suggestions on this manuscript. This report was published with the approval of the Secretary of the Smithsonian Institution.

CHARACTERIZATION OF THE NATURAL ESTUARY IN TERMS OF ENERGY FLOW AND POLLUTION IMPACT

F. JOHN VERNBERG
University of South Carolina
Columbia, South Carolina

ABSTRACT

An estuary is a complex ecosystem which is subjected to a wide range of environmental fluctuation in "normal" parameters, such as salinity, temperature, and rhythmical tidal action. In today's world more and more estuaries are being assaulted by man-induced factors. Many factors make estuaries an important biological and economic resource, but perhaps the most important of all is the amount of energy in these systems. In order for man to manage this habitat for the greatest benefit to man and the earth's ecosystem, a thorough understanding of the energy budget of estuaries is vital. Society has learned the necessity of "dollar" budget planning; it must now recognize the need and applicability for developing energy budget models of ecosystems for purposes of planning and management decisionmaking.

Attempts have been made to develop these models for a few estuaries, but because of their complexity and relatively high cost, these studies are only in their early developmental stages.

Comparative models must be developed for characteristic types of estuaries to assess their essential common and distinctive features. This will enhance the ability of man to predict the effects of a proposed environmental change in other estuaries without the need for excessively costly environmental impact investigations.

The computer and modeling techniques and the scientific-socio-economic expertise exist to initiate comprehensive studies. What is needed is recognition and continuing support to develop this potentially powerful scientific tool for predictive and management purposes.

INTRODUCTION

Our earth is a dynamic, complex, interacting system of plants and animals living together in a non-living, physical-chemical environment. Like all dynamic systems—whether it be a factory, a city, or a living organism—planet earth needs energy to survive and maintain itself. The basic input of energy is from the sun, and this energy is used by plants to photosynthetically produce organic material (food). This production of organic material forms the primary food source for all life. Thus, a knowledge of how the environment influences both food production and the utilization of food and energy by all living organisms is fundamental to human society.

One geographically small, but extremely important ecological segment of our earth, is the estuary. An estuary is a discrete ecological habitat where sea water rhythmically ebbs and flows within a semi-enclosed coastal body of water. A variable amount of fresh water derived from land drainage enters estuaries; some have relatively little freshwater run-off, while others receive tremendous quantities of fresh water from large river systems. This fresh water may dramatically reduce the salinity of sea-water and influence numerous other ecological factors. Hence, the estuary may represent a relatively unstable, dynamic environment.

Great diversity in kinds and shapes of estuaries has been reported in the scientific literature (Lauff, 1967; Odum et al., 1974). However, estuaries typically have certain characteristics in common. Briefly, the principal similarities are: 1) tidal fluctuation, 2) salinity changes, 3) high concentrations of nutrients, and 4) a decrease in numbers of marine species as salinity is decreased. In general, organisms inhabiting estuaries are adapted to live in a dynamic habitat where salinity, temperature, oxygen, and other environmental factors change markedly with time (Remané and Schlieper, 1971; Vernberg and Vernberg, 1972). Although not typical of all estuaries, most have human population centers associated with them. These strategic regions represent an excellent commercial site because they offer a safe harbor for ocean-going ships and a terminal for river traffic as well as being a highly desired recreational area.

Despite the basic similarities common to all estuaries, it is necessary to realize that each estuary has its own specific characteristics. These differences between estuaries may be quantitative, such as the amount of freshwater runoff, the amount of wetlands bordering the estuarine waters, and length and width of estuaries. Qualitative differences also exist. For example, some estuaries are bordered by rocky shores, others by salt marshes. Differences in physical-chemical-geological characteristics have a pronounced effect on the kinds and number of organisms living in estuaries. As an illustration, a low salinity estuary will typically have fewer marine species than a high salinity estuary. Since pollutants may affect brackish water organisms differently than marine species, water quality standards and management procedures might be different in these estuaries.

To understand estuaries and to be able to predict the environmental impact of man on these critical regions, similarities and differences must be carefully considered. The view that "if you've studied one estuary you've studied them all" is dangerous scientifically and is unfounded from a management and legislative viewpoint Pollution control regulations must be based on a sound scientific basis incorporating knowledge of similarities and dissimilarities between estuaries.

ECOSYSTEMS

In recent years, sharp public focus on environmental problems has popularized the long held view of ecologists that the environment is extremely complex and difficult to study on a short-term "crisis-by-crisis" basis. However, rather than being overwhelmed by the complexity of natural ecological systems, ecologists have proposed the somewhat simplified concept of the ecosystem which can be studied by systems analysis techniques and modeling procedures.

Various definitions of an ecosystem exist, but all include the concept that certain plants and animals regularly interact as a unit called a community and that this community exists in an abiotic (non-living) environment. Together the biotic community and the abiotic factors constitute an ecosystem which has a specific characteristic structure (anatomy) and function (physiology). The structural anatomy of an ecosystem is based on such features as the kind and number of species present at different times of the year. In contrast, the functional characteristics include the rate at which the ecosystem functions, such as food production levels and energy flow rates to various ecosystem components.

Our planet is an example of an ecosystem. But, for greater ease of study, this large ecosystem is subdivided into subunits by establishing artificial, but well-defined, boundaries. However, we must remember these subunits interact with each other and do not exist alone. Even by creating these discrete subunits, analysis is still complex, and to be studied properly a multidisciplinary team of scientists and sophisticated computer technology must be involved. Although the general aspects of ecosystems are fairly well understood, the important step of developing refined models for various kinds of ecosystems having predictive and management capabilities is not yet a reality. A generalized scheme of an ecosystem is graphically represented in Figure 1.

The essential feature of an ecosystem is the presence of organisms that are responsible for the production of organic compounds by photosynthetic activity using energy derived from the sun. This process produces most of the food (energy) necessary to support the other biological components of the ecosystem and is called *primary production*. In addition, some bacteria (chemotrophs) can produce complex organic compounds from simple inorganic matter in the absence of sunlight. Herbivores eat primary producers and energy is derived in this manner to sustain the herbivore. In turn, some of this energy is incorporated into organic matter which is available to carnivores who feed on herbivores. The production of organic matter by herbivores is called *secondary production*. In turn, carnivores may be devoured by other carnivores, which represent still another level of organic production and exchange of energy. Parasites extract their required energy from organisms at every level of production. Scavengers feed on food scraps wherever available, while other organisms are responsible for the decomposition of dead biological material. Decomposition products may serve as nutrients for many different types of organisms including primary producers. In estuaries, one of the important food sources is detritus, the debris resulting from the breakdown of biological material which represents potential energy for consumer species. Organisms feeding on detritus are called detritivores.

All of these biological activities take place in a complex non-living environment which has a profound influence on plants and animals. For example, temperature affects most physiological functions. Extremely high or low temperatures may kill an organism, while non-lethal temperatures may influence the rate of photosynthesis or the reproductive cycle. In brief, the ecosystem represents a complex interacting system which is dependent on an external source of energy from the sun and whose functional

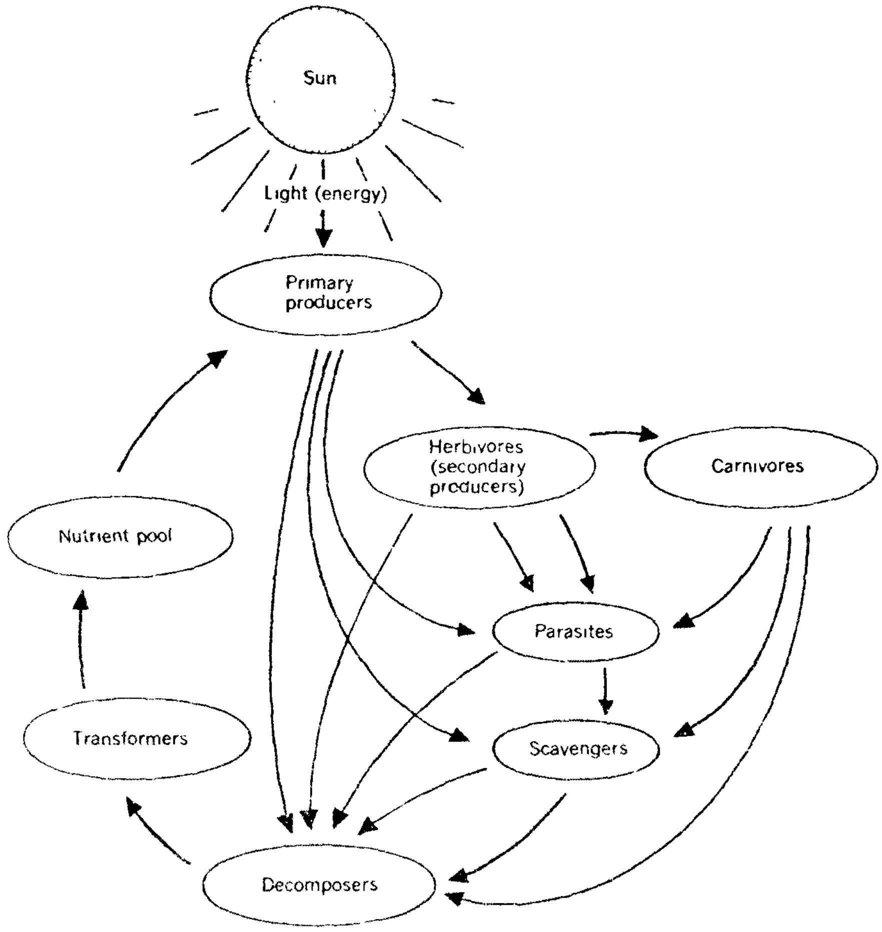


FIGURE 1.—Generalized scheme of an ecosystem. Arrows represent directional flow of nutrients and/or energy (Vernberg and Vernberg, 1970).

activities tend to be cyclic in nature, involving biological, chemical, geological, and physical features.

For an ecosystem to exist and to function, energy is required. An important aspect of studying natural estuarine ecosystems is to determine the input of energy into the system and where and how this energy is transported to and used by the various components of the system. H. T. Odum (1967) has proposed a system of graphically representing the flow of energy by using specific symbols, while other workers use different methods (specific examples presented later). An accounting of the energy within an ecosystem is called an energy budget and reflects input and output of energy from the entire system as well as partitioning of energy within the various components of the ecosystem. Energy may be expressed in various units, such as kilogram-calorie (Kcal), BTU, or grams of carbon, but all are interconvertible.

To analyze complex systems, scientists develop conceptual models which can graphically illustrate the system in simpler terms. Such a model, the "universal" model of ecological energy flow, was suggested by E. P. Odum (1968) (Fig. 2). This model can be used whether analyzing the energetics of an ecosystem or that of an individual organism. Energy flow from one organism to another is represented in Figure 2 by coupling two units of the model. Because of energy loss due to such functions as egestion, respiration, reproduction, and excretion, the first unit is larger than the second. This relationship is of importance and illustrates the obvious fact that the amount of primary production of energy will determine the ultimate size of the ecosystem. Energy input (I) is either assimilated (A) or returned to the environment and not used (NU). Assimilated energy is used for respiration (R) or production (P) of new organic matter. Respiration results in a loss of energy from the system. Production energy may be used for growth (G), stored (S)

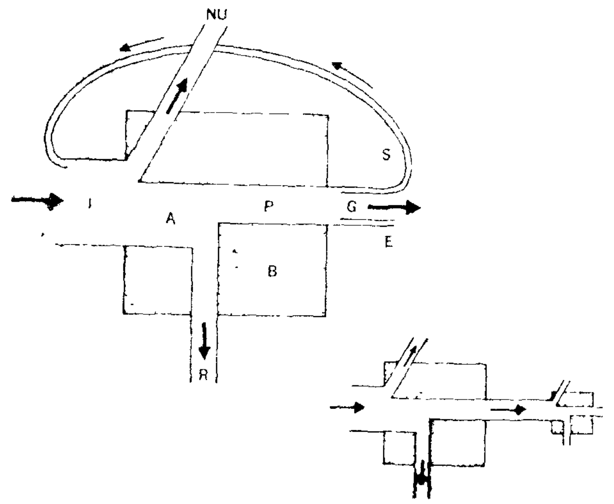


FIGURE 2.—A "universal" model of energy flow through biological systems (from Odum, 1968).

as a reserve for future use, excreted (E) as wastes of metabolism, or energy as used to search out new energy sources.

A basic similarity between economic systems and ecosystems can be readily observed. Economists use some monetary unit, i.e., dollars, francs, or peso, as the source which drives their system, whereas the basic ecosystem unit used by the ecologist is energy. To understand economic systems, the input and distribution of money is analyzed, and the ecologist studies the input and flow of energy through an ecosystem. One obvious difference between the two systems is that an economic system is a manmade entity which depends on a monetary unit which may be changed; in contrast, the energy required to drive an ecosystem is derived from an outside source, the sun, and is not a renewable resource.

Three main types of energy input are important in estuaries: 1) light, 2) organic compounds, and 3) mechanical energy (Odum et al., 1974).

Light energy from the sun is of paramount importance in the production of organic compounds by plant photosynthetic activity (primary production). Phytoplankton (small green plants living in the water), attached large and small algae, and various species of flowering plants living underwater and in marshes and wetlands bordering estuarine waters are the principal primary producers. Not all of the organic matter produced in an estuary is retained; some is exported to adjacent ecosystems.

Organic compounds are introduced into the estuary by rivers, water runoff from adjacent land areas, and from the sea. Some of these compounds provide energy for various groups of organisms. In estuaries associated with human habitation, organic materials resulting from man's activities are frequently added directly to the neighboring estuaries through sewage or industrial discharges. These organic materials represent an energy source for some organisms, but are toxic to others.

The input of mechanical energy may result from various activities associated with winds, tides, and waves. Tidal energy is a principal factor in determining the high degree of productivity of salt marshes. Its turbulence aids in mixing and distributing nutrients. Thermal additives as a result of man's activities, such as heat from thermal nuclear plants, represent still another source of energy.

Energy export from estuaries results from a number of processes such as river flow, tidal circulation, and sedimentation. Water exchange between the ocean and the estuary or between the estuary and freshwater streams may cause a net translocation of organic matter (energy) dissolved or suspended in the water. Energy may flow from the estuarine-wetland ecosystem to the surrounding terrestrial system by terrestrial organisms feeding in the marshes. Man removes energy from estuaries whenever he takes oysters, shrimp, fish, or other organisms. Also, migrating oceanic animals and birds periodically invade estuaries to feed and thus they utilize the estuarine energy reserves. An estuarine energy flow study will analyze the dynamics of where, how, how much, and how fast the energy flows through the estuary-wetlands ecosystem.

In recent years the ecologist has profitably adapted the techniques of systems analysts to the study of ecosystems (Watt, 1966, 1968; Patten, 1971). Rapid strides in computer technology, cybernetics, information theory, and mathematical modeling have permitted a greater arsenal of tools to be available for analyzing complex segments of the earth, such as estuaries. Specific examples will be presented demonstrating attempts to express the functional qualities of estuaries in terms of energy flow models. It should be noted that these studies are in the preliminary, embryonic stage of development as is the entire field of ecosystem analysis. Further, experimental data will be presented which will serve as a basis for predicting the possible impact of environmental manipulation of energy flow in estuaries.

Estuaries are important ecologically and economically because of their naturally high level of energy productivity. For example, estuaries serve as nursery grounds for both migratory oceanic species, such as shrimp, blue crabs, and menhaden, and resident commercially important animals, such as oysters and clams. An important research problem which has great implications for environmental management is the need to analyze the flow of energy through the estuarine ecosystem. Once known, estuarine energy flow patterns could be manipulated and managed to permit their maximum utilization for man's activities and still prevent the destruction of an estuary as a biologically productive ecosystem. Since man is an integral part of this ecosystem, destruction of ecosystems is not to his ultimate advantage. Energy flow studies have another important function in that energy flow values could be converted into monetary units so that an ecologic-economic basis could exist for making environmental management decisions rather than depending on political or emotional factors.

THE ESTUARINE–MARSHLAND ECOSYSTEM

One of the first attempts to construct an energy flow diagram for an estuarine-marsh ecosystem was that of Teal (1962) involving the marshes of Sapelo Island, Ga. Based on the data of various investigators, Teal proposed the energy flow diagram represented in Figure 3. During a year the input of sun energy is 600,000 kcal/meter^2. This energy was estimated to be partitioned as follows. Most of the energy (93.9 percent) was lost in photosynthetic activity. The gross production was 6.1 percent, and the net production was about 1.4 percent of the incident light energy. Of the energy available to secondary consumers, 55 percent was expended in respiration, while 45 percent of net production was exported to feed estuarine organisms. Since this study was published more detailed energy budgets have been published for various individual species found in the estuarine-marsh ecosystem (Dame, 1972; Hughes, 1970).

Recently a detailed study of a New England salt marsh by Nixon and Oviatt (1973) expanded Teal's work. The two studies differed in that Teal emphasized energy flow in the marsh, while Nixon and Oviatt were concerned principally with energy flow in marsh creeks and embayments. Since consumption for the embayment exceeds production based on a yearly energy budget, this aquatic system must depend on input of energy in the form of organic detritus from marsh grasses. Production values of marsh grass were similar to those from New York, but markedly lower than that of southern marshes. This finding may reflect the substantial difference in climatic conditions between these geographical regions. Marked seasonal differences in energy flow patterns of New England ecosystems were observed and are graphically represented in Figure 4. The flow of energy is much more complex and values are higher during the summer than in the winter. Thus pollutants introduced at different times of the year might not only have a greater differential seasonal effect on northern marshes, but northern marshes might respond differently than those in more southern regions.

To the south, the Newport River estuarine ecosystem is being studied by the Atlantic Estuarine Fisheries Center, National Marine Fisheries Service, Beaufort, N.C. Recently this group reported on the interaction between the major plant producers and the epifaunal and infaunal invertebrates and fish populations comprising the eelgrass community, a part of the estuarine system not discussed by Teal or Nixon and Oviatt. Unlike the system studied by Nixon and Oviatt, there appears to be excess food energy for the consumers. Failure of the herbivores and detritivores to expand to the limits of their food reserves suggests that the organisms may be predator limited, fishes and shore birds being the primary predators (Thayer, Adams and LaCroix, 1975). These authors suggest that the excess plant production in the system is likely exported to the adjoining estuary, thus providing food energy, in the form of detritus, to that system. This ecosystem research program also includes detrital cycles, microbial activity studies, export of materials from grass beds, and trace metal studies.

An ecosystem study of a relatively undisturbed estuary, the North Inlet Estuary, Georgetown, S.C., was initiated by the Belle W. Baruch Institute for Marine Biology and Coastal Research, University of South Carolina, with support from the Environmental Protection Agency. Also, active studies are continuing in Georgia (Wiegert et al., 1975).

The dynamics of energy flow expressed as carbon in an estuarine-marsh ecosystem, Barataria Bay, La., was described by Day et al. (1973). This study differs from the ones described above in that it deals in greater detail with all parts of the estuarine-marsh complex. Like other marshes, energy was available to be exported to the water, but unlike the findings of Nixon and Oviatt, a net community production in the water column was reported.

In brief summary, although estuarine-marsh energy flow studies are relatively recent, some initial progress has been made in both understanding the dynamics of this fundamental phenomenon and providing information for management decisions.

Since the above studies were done on systems without regard to pollution effect, little information is available on the impact of man-introduced environmental alterations on energy flow per se in an entire estuarine-marsh ecosystem. One example is

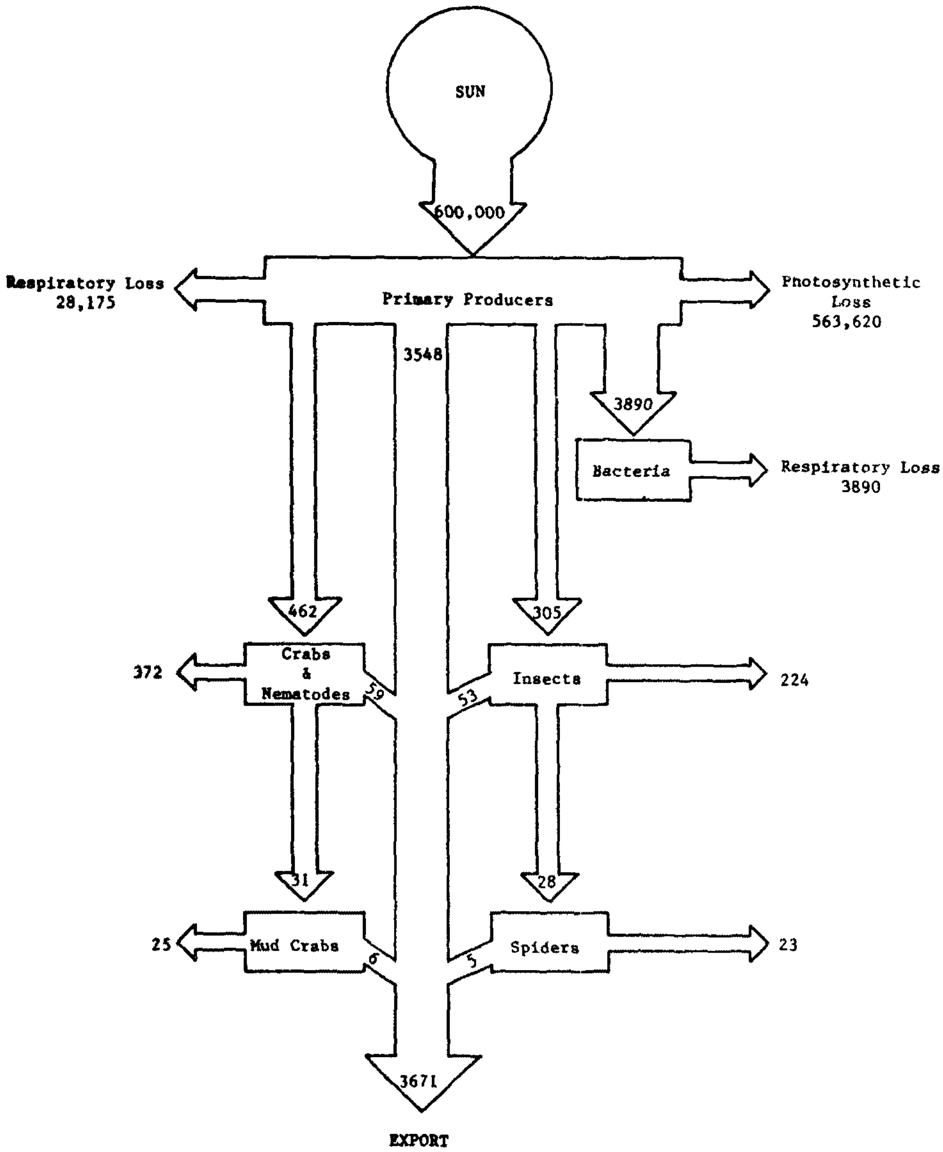


FIGURE 3.—Energy flow diagram for a Georgia salt marsh (modified from Teal, 1962).

given to emphasize how a pollutant (DDT) enters an ecosystem. Woodwell et al. (1976) analyzed DDT residues in estuarine organisms and found both an increased concentration of DDT residues as the size of the animal increased and a greater concentration in higher carnivores than in those at lower food (trophic) levels (Fig. 5). For example, the amount of total residues in plankton was 0.04 ppm while this value was 75 ppm in the ring-billed gull. The gull is at or near the end of the food chain. Although the influence of DDT on energetics was not studied by Woodwell et al., effects of pesticides on the flow of energy are suggested by studies involving single species. DDT will reduce photosynthesis in a primary producer (algae) when few cells are in culture (Wurster, 1968) and reduce the metabolism of the grass shrimp (Sansbury, 1973). These studies suggest that the estuarine energy flow could be adversely influenced by DDT. However, it is not known if the energetics of all organisms in this ecosystem are influenced in the same manner. Hence, generalizations based on a few species are dangerous and probably incorrect.

POLLUTION STUDIES AND ENERGY FLOW

Any environmental factor which influences the physiology of an organism will influence the flow of energy within an ecosystem. Estuaries inherently

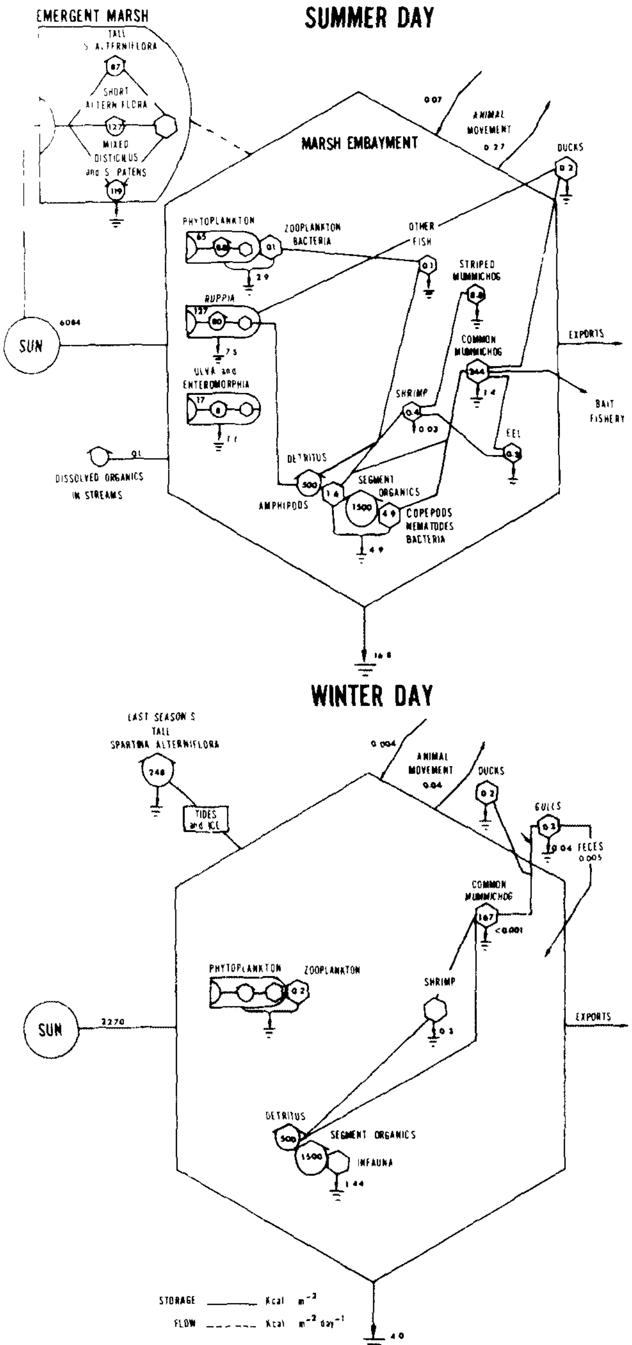


FIGURE 4.—Energy-flow diagrams for composite winter and summer days in the Bissel Cove marsh.

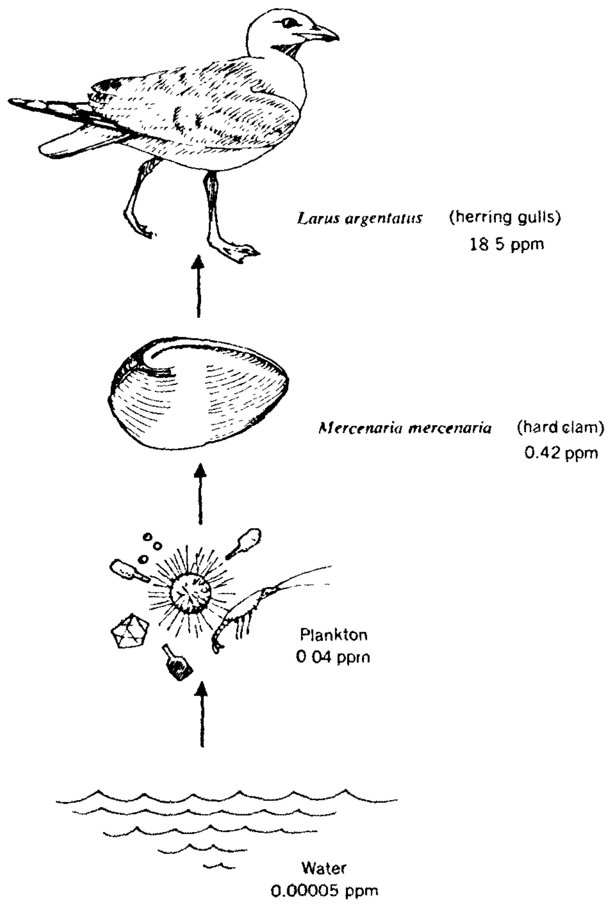


FIGURE 5.—An example of biological magnification of DDT residues (based on data from Woodwell et al., 1967).

are regions where fluctuations in natural environmental parameters occur but also they are regions where man's activities are acutely obvious, such as dredging, thermal discharges, and organic waste disposal. Ketchum (1967) has defined environmental pollution as "any substance added to the environment as a result of man's activities which has a measurable and generally detrimental effect upon the environment." In many instances, a substance has an observable detrimental effect on the biota such as when massive kills of organisms are observed; in other cases a substance might be detrimental to one species but of energetic value to a second one. Therefore, it is difficult to generalize on the influence of a substance (or a factor) on the energetics of an entire ecosystem. This portion of the report will cite the results of a few studies to illustrate how pollutants influence selected segments of the estuarine ecosystem.

Primary production is of prime significance to estuarine energetics since the primary producers are at the base of the food web. In estuaries phytoplankton are the main primary producers in the water, while vascular plants predominate in marshes. It is well known that fluctuation in natural environmental factors will influence the metabolism of phytoplankton, including the photosynthetic activity and the population density. For example, if the light intensity changes, some species will change the amount of photosynthetic enzymes in their cells while others alter the amounts of pigments (Steeman Nielsen and Jørgensen, 1968). Also, in response to salinity changes the internal osmotic concentration is higher than that of the growth medium. As a result, the range of salinity and the rate at which cell division proceeds depends upon the metabolic rates as affected by altered internal salt concentration (Guillard, 1962). In both of these examples, the energy production of phytoplankton can be altered.

Man-induced changes in estuaries can profoundly influence the phytoplankton and marine angiosperms. Dredging can increase suspended material in the water with the result that light penetration is reduced and the rate of photosynthesis is decreased (Zingmark, 1973). Chemical pollutants can also influence phytoplankton in that sublethal concentrations can inhibit metabolism. Also, since phytoplankton intensifies many substances to thousands of times their concentrations in water, plankton serve to pass pollutants to higher trophic levels when consumed by herbivores. This effect may be more ecologically deleterious than reduced photosynthesis (Walsh, 1972). Differential uptake and sensitivity to copper in species of phytoplankton has been demonstrated (Mandelli, 1969). Although all the species tested were inhibited by copper, some species concentrated copper to a greater degree than others. Copper was more toxic than zinc and mercury in phytoplankton, but the toxicity of the latter two heavy metals was increased when combined in certain compounds used as pesticides (Ware and Roan, 1970). The large plants associated with marshes or living submerged and attached in estuaries are also known to be influenced by pollutants, although specific effects are poorly known. For example, the common marsh grass, *Spartina*, concentrates DDT in its roots, and when the plant dies this toxicant is probably released as part of the detritus based food web (Woodwell et al., 1967).

Environmental problems will arise if nuclear power plants are sited on estuaries. Thermal discharges probably pose the greatest problem, but chlorine, heavy metals, and radionuclides also accompany the waste in the effluent. Phytoplankton cells respond to temperature by changing their rate of cell division (Eppley, 1972). In general, with a 10 degree increase in temperature, the cell division rate increases by a factor of two to three times providing these temperatures are within the range of temperatures favorable to growth. However, elevated temperatures may be lethal or increase productivity depending on the season of the year; growth is adversely affected during summer months but it is stimulated in the late fall and winter (Gurtz and Weiss, 1972). Phytoplankton passing through the condenser coil of a generator plant are faced with thermal stress, mechanical damage by impellers of pumps, and chlorination of the coolant water. Chlorination reduces survival and productivity of all algae, and, if the condenser water temperature exceeds 14.5°C–16°C of the incurrent water, photosynthesis is reduced (see review of Rice and Ferguson, 1975).

Radioactive substances are rapidly concentrated by the phytoplankton and the attached seaweeds and are easily passed on to herbivores. Baptist and Lewis (1969), when measuring the transfer of ^{65}Zn and and ^{51}Cr through a four-step food chain, found radionuclides readily transferred to the highest trophic level, but the levels of concentration generally declined up the food chain.

In addition to primary producers, consumer organisms are also influenced by pollutants. When young oysters, which are filter feeders, consumed zooplankton exposed to a mixture of DDT, toxophene, and parathion, they exhibited a greatly reduced growth rate and a high incidence of pathological changes (Lowe et al., 1971). Another filter feeder, the clam, *Mercenaria mercenaria*, showed abnormal metabolism when exposed to methoxychlor and malathion (Eisler and Weinstein, 1967). Fiddler crabs ate detritus containing DDT for 11 days without any overt damage. But five days later all had lost muscular coordination which for all ecological purposes is a sign of death (Odum et al., 1969). Although carnivores are also influenced by pesticides, sensitivity varies greatly with the species (Butler, 1971).

The effects of organophosphorous compounds in combination with thermal stress are just the opposite to those of the chlorinated hydrocarbons, for survival is increased with decreasing temperature. There also seems to be a wide range of relative toxicity of the two types of pesticides in marine organisms; teleosts are less resistant to chlorinated hydrocarbons than molluscs, and about equal in sensitivity to decapod crustaceans. Crustacea, however, are highly susceptible to organophosphorous compounds; molluscs relatively resistant; and teleosts are intermediate between these two groups (Eisler, 1970).

Heavy metals, such as cadmium and mercury, also influence the survival and energy budgets of estuarine animals. Studies on the fiddler crab will illustrate this point. Mercury caused the respiration rate of adult and larval stages to decrease from the normal depending on temperature and salinity. In contrast, cadmium markedly increased the metabolic rate of larvae. That animals do not respond similarly to different heavy metals is further observed in that mercury is most toxic at low temperature and low salinity while cadmium is most toxic at high temperature and low salinity (Vernberg et al., 1974).

The possibility of oil pollution is ever present. Widespread death of estuarine and marine organisms after oil spills has been well documented in the scientific literature, but the physiological effects of sublethal concentrations of the various oil derivatives are poorly known. However, one study by Anderson et al. (1974) demonstrated that the respiratory response of several estuarine species was different when exposed to several concentrations of oil-water mixtures. These findings suggest that the energy flow patterns of estuarine communities would be differentially disturbed by oil spills or chronic low level leaks.

Various field studies have been conducted involving pollution effects on estuarine communities. Some were done as an aftermath of a serious accident, such as an oil spill, while others were done before and after construction of an industrial factory or power plant. Typically, serious spills cause widespread mortality which would obviously curtail the pattern of energy flow.

Most environmental management plans do not involve consideration of ecosystem energetics. However, one example will demonstrate a preliminary attempt at how management decisions involving an estuarine and coastal ecosystem can be based on energy flow considerations.

Currently a management plan for development and channelization of the Atchafalaya Basin of Louisiana is under study. This plan involves estuaries and wetlands. Young et al. (1974) contributed to this project by using models of energy relationships on a regional and ecosystem basis to consider management alternatives. The plan with the largest energy flow values would be considered to be the greatest contributor to economic vitality.

Estimates of the existing annual energy flow patterns were made and the influence of three different management plans on energy flow was projected. These different plans were grouped as follows: 1) distribution of water and sediments widely filling the present basin and then going further by planned diversions or by accidental overflows; 2) central channelization which would shunt much of the water and sediment directly to an estuary which would result in delta formation and filling in of low wet areas to the south; and 3) a rotation plan of filling one basin, such as the Atchafalaya, until levee costs are high and then shifting to another basin for a period of time.

Their approach pointed out the need for more critical data, but based on available information, a preliminary analysis was proposed. Of the three proposed management plans for this area, the one which would distribute water more widely would be of the greatest energetic value to human society. The principal reason for this conclusion is that man's economy (based on conversion of the ecologist's energy unit to the economist's dollar unit) will be maximized when it fits itself into natural energy systems. Thus purchased fuels will add value rather than using massive expenditures of capital to counteract natural system energies.

SUMMARY

The estuarine-marsh habitat is extremely important to the environmental and economic health of the coastal region and the sea. Man, who is an integral part of this habitat, has dramatically manipulated estuaries without having an extensive scientific basis for his actions and sometimes with serious consequences.

To understand the nature of the estuarine ecosystem and to form a more rational basis for management decisions, ecologists have initiated multidisciplinary studies on the energy flow patterns, for no system can function and be biologically productive without energy. An analysis of the input, distribution, rate of transfer, and output of energy is necessary to develop sound management procedures. Based on this information alternative environmental manipulative procedures can benefit from receiving scientific input rather than relying entirely on emotional, economic and/or political considerations.

Production of food and the influence of pollutants in estuarine and marine waters is interrelated with energy flow studies. For example, an understanding of energy flow patterns is necessary if we are to be able to divert energy into maraculture activities without destroying this fragile coastal zone environment. It is also of vital concern to know the possible effects of pollutants on energy flow, since each level of energy input may be affected differently by any one pollutant.

Energy flow studies in conjunction with other investigations provide a better basis to equate a unit of ecological energy to an economic unit, such as dollars. If this is done realistically, then a clear cost-benefit analysis of a proposed environmental alteration emerges.

This paper discusses the general concepts pertaining to energy flow within an ecosystem and reviews various energy flow models of estuaries. Further, specific studies are cited to illustrate how pollutants

affect various estuarine-marsh organisms and alter energy flow patterns. Certain generalities need re-emphasizing in this summary. Pollutants represent many types of physical, chemical, and biological factors. Each pollutant may differentially influence the energetics of the myriad of plant and animal species associated with the estuary. A pollutant may significantly inhibit the metabolism of an important estuarine species thereby dramatically altering the "normal" energy flow pattern, while other species may be metabolically stimulated or unaffected. Therefore, we are unfortunately in the position of needing to examine the effects of each pollutant on numerous species. If this pollutant inhibits organisms representing a lower trophic level, the amount of energy available to the remaining organisms will be greatly curtailed, resulting in a low level of productivity.

It is conceivable that if energetic pathways were better understood, it would be possible to control the level and type of productivity by using selective pollutants to block certain pathways. It is also possible to divert energy along a different pathway leading to increased productivity of ecosystem segments that man wants to manage. This application of energy flow mechanisms could aid in aquaculture practices or hastening the ecological recovery of environmentally disturbed ecosystems.

We need to develop better predictive capabilities to assess the potential effect of any environmental additives not only on important species, but also on the complete ecosystem. Two approaches are recommended:

1) Comparative studies on energy flow patterns in disturbed and relatively undisturbed estuarine ecosystems. An intensive research program dealing with this subject has been started and should continue to be funded. The goal of this research would be to develop the predictive capability, based on studies of various estuarine types, to assist in environmental management decisions.

2) Microecosystem systems—the goal of this research approach is to develop the scientific base and technology to create small scale replicas of larger ecosystems so that the effects of manipulative activities can be studied without possibly damaging an entire estuary. This would not only preserve valuable habitats but also would provide a relatively inexpensive experimental approach to assess the possible effects of a number of environmental alternatives.

Ecosystem studies are relatively new to science and results to date suggest that they could conceivably provide valuable tools for management procedures involving estuaries. Continued support is vital to assess and perfect this potentially powerful scientific tool.

REFERENCES

Anderson, J. W., J. Neff, B. Cox, H. Tatem, and G. Hightower. 1974. The effects of oil on estuarine animals: toxicity, uptake and depuration, respiration. In: Pollution and Physiology of Marine Organisms, eds. F. J. Vernberg and W. B. Vernberg. pp. 285–310. New York: Academic Press.

Baptist, J. and C. W. Lewis. 1969. Transfer of ^{65}Zn and ^{51}Cr through an estuarine food chain. In: Symposium on Radioecology. Eds. D. J. Nelson and F. C. Evans. Oak Ridge, Tenn.

Butler, P. A. 1971. Influence of pesticides on marine ecosystems. Proc. Roy. Soc. Lond. Ser. B. 177: 321–329.

Dame, R. F. 1972. Ecological energies of growth, respiration, and assimilation in the intertidal American oyster. Marine Biology, 17: 243–250.

Day, J. W. Jr., W. G. Smith, P. Wagner, and W. Stowe. 1973. Community structure and carbon budget of a salt marsh and shallow bay estuarine system in Louisiana. Publication No. LSU-SG-72-04. Louisiana State University, Baton Rouge, La.

Eisler, R. 1970. Acute toxicities of organochlorine and organophosphorous insecticides to estuarine fish. U. S. Bur. Sports Fish Wildl. Tech. Paper, 46.

Eisler, R. and M. P. Weinstein. 1967. Changes in metal composition of the quahaug clam, *Mercenaria mercenaria*, after exposure to insecticides. Chesap. Sci. 8: 253–258.

Eppley, R. W. 1972. Temperature and phytoplankton growth in the sea. U. S. Natl. Mar. Fish. Serv. Fish. Bull., 70: 1063–1085.

Guillard, R. 1962. Salt and osmotic balance. In: Physiology and Biochemistry of Algae. ed. R. A. Lewin. pp. 529–540. New York: Academic Press.

Gurty, M. E. and C. M. Weiss. 1972. Field investigations of the response of phytoplankton to thermal stress. School of Public Health, University of North Carolina. ESE Publ. No. 321.

Hughes, R. N. 1970. An energy budget for a tidal-flat population of the bivalve *Scrobicularia plana* (DeCosta). J. Anim. Ecol., 39: 357–380.

Ketchum, B. H. 1967. Man's resources in the marine environment. In: Pollution and Marine Ecology, eds. T. A. Olson and F. J. Burgess. pp. 1–11. New York: Interscience.

Lauff, G. A. 1967. Estuaries. Am. Assoc. Adv. Sci. Publ. No. 83. Washington, D. C.

Lowe, J. I., P. D. Wilson, A. J. Rick, and A. J. Wilson, Jr. 1971. Chronic exposure of oysters to DDT, toxaphene, and parathion Proc. Natl. Shellfish Assoc. 61: 71–79.

Mandelli, E. F. 1969. The inhibitory effects of copper on marine phytoplankton. Contrib. Mar. Sci. Univ. Texas, 14: 47–57.

Nixon, S. W. and C. A. Oviatt. 1973. Ecology of a New England salt marsh. Ecol. Monogr. 43: 463–498.

Odum, E. P. 1968. Energy flow in ecosystems: A historical review. Am. Zool., 8: 11–18.

Odum, H. T. 1967. Energetics of world food production. In: The World Food Problem. A Report of the President's Science Advisory Committee. Vol. III. U. S. Gov. Printing Office, Washington, D. C.

Odum, H. T., B. J. Copeland, and E. A. McMahan. 1974. Coastal ecological systems of the United States. The Conservation Foundation. Washington, D. C.

Odum, W. E., G. M. Woodwell, and C. F. Wurster. 1969. DDT residues absorbed from organic detritus by fiddler crabs. Science, 164: 576–577.

Patten, C. B. 1971. Systems Analysis and Simulation in Ecology. New York: Academic Press.

Remane, A. and C. Schlieper. 1971. Biology of Brackish Water. John Wiley and Sons, Inc. New York, Toronto, Sydney.

Rice, T. R. and R. L. Ferguson. 1975. Response of estuarine phytoplankton to environmental conditions. In: Physiological Ecology of Estuarine Organisms, ed. F. J. Vernberg. University of South Carolina Press.

Sansbury, C. 1973. The effects of sublethal concentrations of DDT on oxygen consumption and temperature tolerance of the grass shrimp, *Palaemonetes pugio* (Say). M. S. Thesis, University of South Carolina.

Steeman Nielsen, E. and E. G. Jørgensen. 1968. The adaptation of plankton algae I. General part. Physiol. Plant., 21: 401–413.

Teal, John M. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology, 43: 614–624.

Thayer, G. W., S. M. Adams, and M. W. LaCroix. 1975. Structural and functional aspects of a recently established *Zostera marina* community. In: Recent Advances in Estuarine Research Estuarine Research Federation (in press).

Vernberg, W. B., P. J. DeCoursey, and J. O'Hara. 1974. Multiple environmental factor effects on physiology and behavior of the fiddler crab, *Uca pugilator*. In: Pollution and Physiology of Marine Organisms, eds. F. J Vernberg and W. B. Vernberg. pp. 381–426. Academic Press, New York.

Vernberg, W. B. and F. J. Vernberg. 1972. Environmental Physiology of Marine Animals. Springer-Verlag. New York, Heidelberg, and Berlin.

Walsh, Gerald E. 1972. Insecticides, herbicides and polychlorinated biphenyls in estuaries. J. Wash. Acad Sci., 62: 122–139.

Ware, G. W. and C. Roan. 1970. Interaction of pesticides with aquatic microorganisms and plankton. Residue Rev. 33: 15–45.

Watt, K. E. 1966. Systems Analysis in Ecology. Academic Press, New York.

Watt, K. E. 1968. Ecology and Resource Management: A Quantitative Approach. McGraw-Hill, Inc , New York.

Wiegert, R. G. et al. 1975. A preliminary ecosystem model of a coastal Georgia *Spartina* marsh. In: Recent Advances in Estuarine Research. Estuarine Research Federation. (in press).

Woodwell, G. W., C. F. Wurster, Jr. and P. A. Isaacson. 1967. DDT residues in an east coast estuary: a case of biological concentration of a persistent insecticide. Science, 156: 821–824.

Wurster, C. F. Jr. 1968. DDT reduces photosynthesis by marine phytoplankton. Science, 159: 1474–1475.

Young, D., H. T. Odum, J. Day, and T. Butler. 1974. Evaluation of regional models for the alternatives in management of the Atchafalaya Basin. Rept. to U. S. Dept. Interior from the Univ. of Florida. July, 1974.

Zingmark, R. G. 1973. Effects of dredging on the phytoplankton. In: Bioassay Studies, Charleston Harbor, South Carolina. The effects of dredging harbor sediments on plankton. Belle W. Baruch Institute for Marine Biology and Coastal Research, University of South Carolina.

LIVING AND NON-LIVING RESOURCES

PROBLEMS, ADVANCEMENTS, AND FACTORS CONTROLLING ESTUARINE WILDLIFE MANAGEMENT PROGRAMS

HAROLD D. IRBY
Texas A&M University
Jasper, Texas

ABSTRACT

Marshes and estuaries along our coastlines are among the most fertile and valuable land and water areas in North America. These areas provide habitats for some of our most valuable wildlife and fisheries resources, supplying livelihood, recreation, and aesthetic enjoyment for a multitude of people. Wildlife usage of high quality estuarine areas is extensive. Wildlife management is an attempt to rectify past habitat abuses and then, hopefully, to bring about a positive enhancement of the desired wildlife and their habitats. The wide variety of human activities which pollute estuarine wildlife resources is discussed along with recent progress in estuarine wildlife management programs. Finally, future trends and needs in estuarine wildlife management are discussed.

INTRODUCTION

Our estuaries, the zones of interplay between the margins of the sea and the land are environments for a remarkable assemblage of terrestrial and aquatic life. The complex of estuaries includes extensive bays, harbors, sounds, lagoons, and river mouths that are constantly flooded, and adjacent areas such as tidal flats and semi-upland marshes, salt and brackish water flats, marshes, and mangrove swamps which may be flooded only by the highest moon and storm tides. Altogether they form an ecosystem—a complex of different environments both aquatic and terrestrial.

Marshes and estuaries along our coastlines are among the most fertile and valuable land and water areas in North America. These areas provide habitats for wildlife and fisheries resources, supplying livelihood, recreation, and aesthetic enjoyment for a multitude of people. They serve as production areas and nursery grounds for shrimp, oysters, crabs and fish. They provide wintering areas for a major portion of the continental waterfowl resource, and they are extremely valuable for the production of fur animals and many species of game and nongame animals. The following discussion will be concerned primarily with wildlife other than birds. But one thought must be kept always in mind—there is a connecting webbing of interactions between all forms of wildlife occupying the same habitats.

While estuarine areas have always been important, recent years have witnessed growing public attention and deep concern in their behalf. It is a part of the expanding conservation ethic of Americans who want to retain their heritage of natural beauty, scenic values and the environmental qualities that support fish and wildlife resources. This attitude is reflected in many plans and programs for conservation action—and among these, estuaries occupy a prominent position.

WILDLIFE HABITATS IN THE ESTUARINE ZONE

Wildlife usage of high quality estuarine areas is extensive. Waterfowl and shore birds find these areas essential for nesting, resting during migration, wintering, and feeding. A wide variety of other birds make extensive use of estuaries. These include pelicans and cormorants, long-legged wading birds, eagles and ospreys, cranes and rails, gulls and terns, and some passerines. The aquatic furbearers including muskrats, minks, nutrias, beavers and otters are seldom far from wetlands. Raccoons use wetlands heavily although they may range a considerable distance from them. Other wild mammals including deer, opossums, bobcats, foxes, weasels, skunks, and many small mammals use estuarine habitats extensively but are not restricted to them. Of the large sea-going mammals, some, such as the manatee, the dolphin (porpoise), and seals enter estuaries.

None of the frogs, toads, and salamanders is truly marine, although the larvae of a few have been found in brackish pools, and adult toads and frogs have been reported in estuaries. Among the reptiles, the alligator is an important member of the estuarine zone. Along the Atlantic and gulf coasts the most typical turtle is probably the diamondback terrapin.

Of the some 130 fish and wildlife species considered by the U.S. Fish and Wildlife as rare and endangered, 10 use an estuarine habitat extensively and most would probably perish without it. These 10 species are the Florida manatee, key deer, great white heron, whooping crane, Eskimo curlew, Ipswich sparrow, dusky seaside sparrow, Cape Sable sparrow, brown pelican, and the alligator.

From the standpoint of wildlife habitats, the estuarine zone may be divided into nine types—three of which are coastal freshwater types and six, coastal saline water types. Following is a description of each of the estuarine types. Table 1 gives the types, brief description, and acreages of estuarine areas along our coasts. Table 2 lists the kinds of wildlife using estuarine habitats reported by wildlife agencies of our coastal states.

Table 1.—Description and acreage of estuarine types in the conterminous United States

Estuarine category and types	Water depth*	Total acres
Coastal fresh areas		
1. Coastal shallow fresh marshes	Up to 6 inches at high tide	2,213,000
2. Coastal deep fresh marshes	Up to 3 feet at high tide	1,631,000
3. Coastal open fresh water	Up to 10 feet; marshy border often present	197,000
Coastal saline areas		
4. Coastal salt flats	May have few inches at high tide	423,000
5. Coastal salt meadows	May have few inches at high tide	956,000
6. Irregularly flooded salt marshes	Few inches at wind tide	698,000
7. Regularly flooded salt marshes	Up to 1 foot at high tide	1,576,000
8. Sounds and bays	Up to 10 feet at high tide	1,114,000
9. Mangrove swamps	Up to 2 feet	523,000

*Refers to average conditions during growing season.

Table 2.—Use of estuarine types by game and fur animals

	Number of states reporting use in estuarine type								
	1	2	3	4	5	6	7	8	9
Small game:									
Gallinules	7	7	6	1	1	1	1	—	—
Grouse, Sage	1	1	—	—	1	—	1	1	—
Mourning dove	1	1	—	2	—	—	—	—	—
Pheasant	7	2	—	—	2	—	1	—	—
Quail, Bobwhite	4	—	—	—	1	—	—	—	—
Rails	12	11	4	5	9	8	10	—	1
Rabbit, Cottontail	9	2	—	—	—	—	—	—	—
Rabbit, Swamp	4	3	—	1	4	3	3	—	—
Snipe	10	5	—	3	4	3	4	3	—
Woodcock	5	1	—	—	—	—	—	—	—
Big game:									
Black-tailed deer	1	1	—	1	2	—	2	2	—
White-tailed deer	6	5	—	1	1	1	2	—	—
Fur animals:									
Beaver	4	4	1	—	1	—	2	1	—
Bobcat	1	1	—	—	—	—	—	—	—
Fox (Red and Gray)	10	5	—	1	8	2	7	1	—
Mink	16	13	9	—	4	4	7	3	—
Muskrat	16	16	11	1	10	5	11	3	—
Nutria	1	1	1	—	—	1	—	—	—
Opossum	4	—	—	—	—	1	—	—	—
Otter	13	12	10	—	5	—	5	1	—
Raccoon	17	12	11	2	11	6	10	5	—
Skunk	4	4	1	1	1	1	1	1	—
Weasel	2	2	—	—	—	—	—	—	—
Alligator	3	3	1	—	1	1	—	—	—

Coastal Fresh Areas

SHALLOW FRESH MARSHES

Soil always waterlogged during the growing season; may be covered at high tide with as much as 6 inches of water.

Located on the landward side of deep marshes along tidal rivers, sounds and deltas.

Vegetation of grasses, sedges, and other plants such as phragmites, giant cutgrass, big cordgrass, maidencane, jointed spikerush, threesquares, sawgrass, cattails, arrowheads, smartweeds, and arrow-arum.

Much used by feeding ducks, geese, and herons; very much by muskrats; some use by nutria, mink, raccoons, woodcock, and snipe.

DEEP FRESH MARSHES

Soil covered at average high tide with 1/2 to 3 feet of water during the growing season.

Located along tidal rivers and bays, mainly on the Atlantic and gulf coasts.

Vegetation made up of such plants as cattails, wild rice, pickerelweed, and spatterdock; pondweeds and other submerged plants, and surface mats of water hyacinth, alligatorweed, and waterlettuce prominent in openings.

Much used in fall and winter by feeding geese, ducks, sora rails, and herons; and by fish, alligators, turtles, and bullfrogs; some use by muskrats, mink, and raccoons.

OPEN FRESH WATER

Water of variable depth.

Located in tidal rivers and sounds.

Vegetation (mainly at depths under 6 feet, but scarce or absent in stained or turbid waters) of such submerged plants as sago pondweed, redheadgrass, naiads, wildcelery, coontail, watermilfoils, and muskgrasses. In many localities along the gulf, water hyacinth forms mats on the water surface.

Much used by feeding ducks and geese and other water birds; and by fish, turtles, and bullfrogs.

Coastal Saline Areas

SALT FLATS

Soil almost always waterlogged during the growing season; sites varying from those submerged only by occasional wind tides to others that are covered fairly regularly with a few inches of water at high tide.

Located on the landward side of, or as islands or basins within, salt meadows and salt marshes.

Vegetation (often sparse or patchy) mainly of glassworts, seablite, saltgrass, Gulf cordgrass, saltflatgrass, saltwort, and seaside heliotrope.

Rarely used except when flooded, then used extensively by feeding ducks, geese, and shorebirds.

SALT MEADOWS

Soil always waterlogged during the growing season; rarely covered with tidewater.

Located on the landward side of salt marshes or bordering open water.

Vegetation mainly of saltmeadow cordgrass, saltgrass, and fimbristylis; and in fresher parts, Olney three-square and saltmarsh fleabane.

Used a little by various mammals and birds, including geese.

IRREGULARLY FLOODED SALT MARSHES

Soil covered by wind tides at irregular intervals during the growing season.

Located along the shores of nearly enclosed bays, sounds, and rivers, and along open water on the eastern side of the Gulf.

Vegetation mainly of needlerush, saltmarsh bulrush, dwarf spikerush, gulf spikerush, coast waterhyssop, and dogtooth-grass; often with widgeongrass in ponds.

Used very little ordinarily; but where broken by ponds and creeks, sometimes used moderately by feeding ducks and nesting clapper rails.

REGULARLY FLOODED SALT MARSHES

Soil covered at average high tide with 1/2 foot or more of water during the growing season.

Located along the open ocean in eastern Virginia, southern South Carolina, Georgia, and eastern Louisiana, and mostly along sounds elsewhere.

Vegetation mainly of saltmarsh cordgrass. Open water in the marsh may support widgeongrass or sago pondweed.

Used very much by feeding ducks and geese, especially where vegetation-filled ponds are present; much used by nesting clapper rails and laughing gulls; also by feeding herons, mussels, snails, and fiddler crabs; some use by fish and shorebirds.

SOUNDS AND BAYS

Water of variable depth. Portions that are considered shallow enough to be diked and filled.

Located in saltwater rivers, sounds, and bays and, to some extent on the open ocean front.

Vegetation (mainly at depths less than 6 feet) of such plants as eelgrass (North Carolina northward), widgeongrass, sago pondweed, muskgrasses, shoalgrass, manateegrass, and turtlegrass.

Much used by oysters, clams, mussels, shrimp, blue crab, fish and diamondback terrapins; and by feeding ducks, geese, and some other birds.

MANGROVE SWAMPS

Soil covered at average high tide with 1/2 to 2 feet of water during the year-round growing season.

Located along the coast of the southern half of Florida, but best developed on the west coast from Cape Sable to Everglades City.

Vegetation chiefly of red mangrove with some black and white mangrove.

Used much by shellfish, fish, raccoons, and feeding water birds.

PAST AND CURRENT WILDLIFE MANAGEMENT PROBLEMS

Our estuaries have always been areas undergoing changes—sometimes rapidly and sometimes slowly and subtly. All these changes, whether occurring naturally or caused by human activities, affect estuarine wildlife habitats. Those changes which affect wildlife negatively may be termed pollutants in that they contaminate or abuse wildlife habitats. Essentially, wildlife management is an attempt to rectify past abuses of the habitats and then, hopefully, to bring about a positive enhancement of the desired wildlife and their habitats.

Most wildlife species discussed in this section occupy positions high on the food chains of estuarine life. Most pollutants which indirectly affect wildlife species by directly affecting groups of organisms lower on the food chains (plankton, shrimp, crabs, fish, et cetera) have been discussed in previous sections. Therefore, those pollutants will only be mentioned here, while problems directly associated with the welfare of wildlife and their habitats will be discussed in greater detail.

Natural Pollutants

Naturally occurring changes in estuarine areas include coastal area land subsidence, floods, droughts, fires, and hurricanes and other high-intensity storms. These changes may be good or bad from the standpoint of their effects on wildlife habitats. The timing of these events, and the plant and animal successional stages of the estuarine areas affected, largely determine whether the changes will be good, detrimental, or even disastrous.

The effects of the timing of natural events on estuarine wildlife habitats and populations are so complex that space limitations here will not permit an adequate discussion. It is usually not a single environmental factor which governs the physiological responses and population dynamics in an estuary, but a combination of numerous factors counteracting, supporting, and modifying each other's physiological effects. The effects of some natural changes are discussed in various parts of the remainder of this report.

It must be kept in mind that many changes in estuarine areas are caused by both natural and human activities taking place far from the estuaries, that is, on estuarine watersheds. The variables of size, climate, geology, and vegetation of these watersheds constitute an important, sometimes critical, array of remote estuarine factors. They determine the volume and chemical nature of fresh water, the kinds and particle-size distribution of suspended sediments, the quality and quantity of organic matter and living organisms discharged into the estuaries, and the seasonal abundance of these properties.

Pollution from Human Activities

An ever increasing range of human activities has, is, and will affect the wildlife resources of our estuarine areas. All concerned and knowledgeable citizens realize that our estuaries are areas of multiple values and multiple uses. So it is that human activities to increase certain values and uses may destroy or at least decrease other values and uses. Our history shows that wildlife values have usually decreased markedly as a result of most of our engineering and industrial activities. Until rather recently, wildlife values received little more than lip service when new activities were being planned for estuarine areas. It is encouraging to note that now many activities are required by various federal, state, and local laws to consider wildlife resources before the necessary permits are issued. It is also encouraging that many human activities that damage or destroy wildlife resources may, with proper planning and timing, work toward the betterment of our valuable estuarine wildlife habitats.

The following brief discussion shows how a variety of human activities has polluted our estuarine wildlife resources.

Dredging: Dredging is a frequent and widespread activity in the estuarine areas. It involves the cutting of new channels, the removal of accumulated sediments from existing natural or artificial channels and harbors, and the removal of material for beach nourishment or other special purposes. Dredging has also been used to create upland flood release channels and to provide marsh drainage for mosquito control purposes.

The principal ecological effects of dredging in coastal waters are:

1. Removal of the original interface between the water and the bottom, which is frequently an area of high biological activity.
2. Creation of new deepwater areas which may affect, either positively or negatively, animal and plant populations.
3. Increased upstream intrusion of salt water and the chemical, physical, and biological conditions coincident with it.
4. Release of sediments, and of dissolved or absorbed chemicals, into the water.

The effects of dredging in estuarine areas can and have been insidious. Dredging, although local as to each operation, can become general as one poorly planned operation after another changes completely the face of an estuary. Compounding the situation is the problem of alternatives. Inland there are more sites for each land use than is typical for estuaries, and choices are more abundant. In estuaries the alternatives are fewer. Even today, after years of concern, we find that estuaries have little protection from physical destruction. This physical destruction of estuarine wildlife habitats by dredging and other activities has significantly decreased our environmental heritage.

In summary, estuarine dredging always affects wildlife habitats. The ecological effects may vary from ephemeral and insignificant to permanent and extremely important.

Dredging and filling go hand-in-hand. Dredging creates a need to dispose of spoil, and filling demands areas to be dredged. These activities are carried out in a variety of forms for a variety of purposes.

Filling: Channel dredging necessarily creates spoil which must be disposed of. The three placement methods generally in use (hopper dredges, pipelines to distant sites, and spoil banks paralleling the channel) have different ecological effects.

Where hopper dredges are used to carry spoil to dumping sites, the areas affected (by increasing local turbidity, smothering bottom organisms, and decreasing depth in the dumping areas) are usually so small in proportion to the total area available, that the ecological damage may be trivial unless toxic chemicals are involved. Continued use of such spoil area may, however, change the morphology and biological value of the area.

Pipeline disposal in marsh or shallow bay areas away from the channel may replace food-producing areas or nursery areas with dry land which is of little or no use to aquatic life, however desirable it may be for human habitation or industrial sites. Marshes are a main source of food for estuarine animals, and most juvenile fishes and crustaceans of coastal waters must have shallow-water "nursery areas", preferably vegetated, in which to feed and hide from predators.

Spoil banks bordering the channel on one or both sides may have far-reaching effects on estuarine ecology. The most obvious effect is covering up any bottom plants and animals that live in the immediate vicinity of the channel. The economic loss may be considerable if valuable shellfish beds are involved. These effects are local and do not usually affect a large proportion of the estuary. Also they may be counterbalanced by beneficial effects, such as providing new areas for wildlife (where spoil banks are above tide level). However, more subtle results may seriously disrupt entire bays, especially the shallow estuaries and lagoons of the gulf coast. The depth of these bays depends on wave action and currents caused by wind. A line of spoil bands through the middle of a bay has the effect of cutting the large bay into two smaller bays, as far as wind fetch and water circulation are concerned. The end result is increased silting and shallowing of the entire bay, which increases water temperature and evaporation, and thus affects all life in the bay, for the most part adversely.

Levees and spillways: Construction of levees, especially along the lower reaches of rivers flowing to the seas, has a great influence upon the adjacent estuarine environments. The direction, period, and extent of freshwater flows are modified and changed and so are the patterns of sediment deposition along the coast.

The best example of the effects of levees in America is the Mississippi River, which has been leveed increasingly since 1717 for flood control to improve navigation. The hydraulic, geological, and engineering aspects of this development have been treated in hundreds of reports and papers, but only a few people have given attention to its vast biological impacts.

Fresh water and sediment have been shunted directly to the main mouth of the river and not spread out over a wide delta through several distributaries. As a result, Louisiana is now losing an estimated 16 square miles of coast land a year, most of it being marshland. Bays cut off from the river sediment are deepening, and becoming saltier, with vast local changes in biota.

The flood plain of the Mississippi River covers some 35,000 square miles and about half of this has been cut off from the river by levees, with great changes which in general are damaging to wetlands and wildlife. These changes and the general canalization of the river have also had various effects on the estuarine area of the lower flood plain, most of them apparently harmful to wildlife.

In any case, the whole question of the handling and control of the Mississippi River and other problem river systems must be reexamined in the light of the increasingly recognizable need for the conservation of wildlife and natural environment. Understanding the effects involved would assist in the management of riverine and estuarine environments such as the lower Sacramento and San Francisco Bay.

Municipal and industrial wastes: Many of the estuarine areas of the United States receive discharges of municipal and industrial wastes. The effects of these waste loads on the receiving watercourses depend not only on the characteristics of the waste discharge themselves but also on the nature of the receiving water bodies.

The south Atlantic and gulf coast regions of the United States are in a period of rapid industrial expansion and concomitant population growth. At present the development of these areas has not reached the magnitude of the megalopolis of the Northeast and population and industry are concentrated in generally scattered areas along these coasts. Within these areas are a wide variety of industrial operations: pulp and paper mills, oil refineries, food processing plants, chemical manufacturing plants, fertilizer plants, power generating plants, and mining operations, to name a few. Wastes from each of these operations have their own peculiar characteristics, and each can have a profound effect on the estuarine environment.

The estuaries along the south Atlantic and gulf coasts have inherent characteristics which differ from those of the north Atlantic and Pacific coasts and which play a large part in determining the effects of pollution on these waters and the means which can be used to dispose of wastes from cities and industries on their shores.

On the Pacific coast the continental shelf is very narrow, deep water and strong coastal currents come close inshore, and waste disposal practice has included the use of ocean outfalls as a common technique.

On the north Atlantic coast the estuaries generally have steep sides and good exchange of water between the estuaries and the open sea. Waste disposal practices in these areas have, in most cases, taken advantage of these good flushing characteristics and count on residual pollutants being rapidly carried away.

The estuaries of the south Atlantic and gulf coasts, on the other hand, have neither of these natural advantages. The continental shelf and shallow water extend for several tens of miles out from the coast, making ocean outfall waste disposal a very expensive proposition. The estuaries themselves are almost all associated with extensive marshlands which serve as a trap for residual pollutants and negate any good flushing characteristics the main stream of an estuary may have. These coasts also abound in the offshore bar-built estuaries that are characterized by very poor flushing properties, small tidal ranges, and shallow depths which, in these latitudes, tend to result in elevated natural temperature. Prevention of water quality degradation from waste discharges in the south Atlantic and gulf coast estuaries must, therefore, depend almost entirely on removal of pollutants at the source of waste disposal rather than dispersion and flushing of partially treated wastes.

Pesticides: An infinite number of poisons are dumped into our streams or washed in from the land and ultimately into our estuaries and the ocean. The number of chemical combinations is almost unlimited. Agricultural and industrial wastes are legion and widespread, and their numbers grow faster than do our studies to learn of their effects. Our agricultural chemicals, known as pesticides, are more appropriately listed as biocides. Many of these are highly stable and some of them are among the most poisonous substances known. When many of these get into our streams they are persistent and have caused serious loss of fish and their food chains. Some are synergistic in their effects and many are highly accumulative. There are examples of low level applications of reportedly harmless chlorinated hydrocarbon pesticides building up and concentrating in fish and wildlife more than a hundred-thousand fold.

The effects of pesticides on estuarine wildlife are primarily effects on lower-level wildlife food organisms. These are discussed in previous reports. We are only now gathering enough information on wildlife species far up the food chains, such as many fish-eating birds and mammals such as porpoises and seals, to show that relatively large amounts of pesticides are being accumulated by these species in our estuaries. Many estuarine wildlife biologists feel that pesticides are causing significant changes in estuaries that are only moderately polluted. However, the interaction of the many physical and biological factors makes the net effect unpredictable at this time.

Dams: Dams on rivers have a number of biological effects on estuarine biota. For wildlife species, the major effect is caused by the resulting change in the regime of freshwater flow into the estuary. A dam built on a river, even far upstream, prevents or delays a large portion of flood waters from reaching the estuary. This causes an increase in salt-tolerant species and a decrease in species that require low salinity either because of physiological need or because they need low salinity to protect them from their enemies (competing species, predators, or parasites). In such a river-estuary system, even reduction of the flooding that normally occurs annually or every few years may radically change the ecology of the estuary, either beneficially or harmfully. Each river-estuary system must be considered independently in relation to the effects on desired wildlife species. An evaluation of the effects of a specific dam on estuarine and marine life requires information on the physical effects, especially on salinity, turbidity, and sedimentation in the estuary.

Other: Many other human activities taking place in estuaries and their watersheds cause pollution in varying degrees. Activities such as oil exploration and drilling, clear-cutting of large forested areas on estuarine watersheds, water diversions, weed control, hurricane barriers, and the whole gamut of construction activities. Many of these activities cause only temporary and localized pollution and the affected wildlife resources recover quickly. But some, such as water diversions and hurricane barriers cause changes which are long-lasting.

RECENT PROGRESS IN ESTUARINE WILDLIFE MANAGEMENT

Wildlife management is, to a great extent, habitat management. In order to manage habitat, some form of control must be acquired—either direct ownership or some lesser form such as a long-term lease.

The Federal Wildlife Refuge System in the United States began in 1903 with the establishment of the Pelican Island Refuge in Florida by executive order of President Theodore Roosevelt to protect a colony of brown pelicans and other colonial nesting birds. Since then the Federal Wildlife Refuge System has grown to include some 45 refuges which contain significant estuarine wildlife areas. The total estuarine acreage in this system is approximately 700,000 acres.

The objective of our National Wildlife Refuge System is to preserve and manage wildlife and its associated environment for the continued enjoyment and social enrichment of the American people. The attainment of this goal requires that lands, waters, and other natural resources of the system be managed, rehabilitated, and developed for multiple uses and purposes. Basic goals of coastal and estuarine national wildlife refuges, all integrated with national objectives, are, (1) maintenance of adequate populations of migratory birds—rare, endangered, and unique species, and other wildlife through (2) manipulation and preservation of land and water resources, for (3) public use and enjoyment.

In 1937, the Congress enacted the Federal Aid in Wildlife Restoration Act (Pittman-Robertson Act), which provides financial help and has enabled many states to finance significant wildlife restoration work. Under this Act, the 11 percent federal excise tax on the manufacturers' price of sporting arms and ammunition is apportioned to state fish and game departments. A number of states have used these funds to acquire and manage estuarine areas.

With few exceptions, governments below the level of states are not purposely preserving estuarine habitats. Jamaica Bay, 12,000 acres of shallow-water marsh and small islands, is on the doorstep of metropolitan New York. It furnishes valuable habitat for many kinds of wildlife, and is operated by the New York City Parks Department. Some towns and cities along the coasts of Florida and North Carolina have considerable acreages of estuarine areas that are valuable wildlife habitats.

It does not appear feasible to put into public ownership all the estuarine areas necessary for producing and maintaining adequate wildlife populations, nor to supervise all the aesthetic, scientific, and economic uses of estuaries. Publicly owned estuarine wildlife habitats must be supplemented by areas owned by private groups, individuals, and foundations. The National Audubon Society owns or leases a number of estuarine areas. These range in size from 20-acre islands to a 27,000-acre brackish marsh. The Society tries to acquire only those areas containing rare and endangered species of plants or animals or strategic wildlife breeding areas. The Nature Conservancy is a nonprofit organization which buys natural areas, including estuaries. Entirely supported by donations, it obtains natural areas as gifts, by purchase, and by assisting with the purchase. Proving to be a valuable tool in the preservation of natural areas, the Conservancy can sometimes purchase areas quietly and hold them until a governmental agency can obtain appropriations. Private hunting clubs own and manage a number of large estuarine areas. Although most of these areas are managed for waterfowl, other estuarine wildlife also benefit. An increasing number of private owners of estuarine areas are managing their holdings with greater priority given to wildlife resources.

Once control of an estuarine wildlife area is acquired, either by purchase, lease, or other agreements, decisions governing wildlife management are necessary. The conservation agencies may decide to hold them as "estuarine banks" and manage them only when the need has been demonstrated. However, few delay initiation of wildlife management practices. Historically, and at present, the number of estuarine wildlife habitats has drastically decreased. Therefore, the need to manage them is becoming more urgent in order to maintain or expand the production of estuarine wildlife. Also, without active management, estuarine areas often cannot be maintained in the same ecological conditions as when they were acquired.

Nearly all estuarine wildlife areas are maturing and changing in character and to maintain the wildlife values, the long-term problem is to arrest development or set back vegetative succession. Management may also be necessary to restore habitats which have deteriorated through drainage, filling, or other pollutions. Management of an estuarine habitat for wildlife is aimed at increasing the production of resident species or encouraging its use by migratory species. This can be accomplished by increasing food production, making food more available, and creating a desirable ratio of open water and marsh. The objectives will determine whether an area is to be managed for maximum muskrat production, maximum waterfowl production, or some combination of these and other objectives. Management may also be needed when conflicting demands arise regarding use of estuaries: fishing, bird watching, swimming, waterfowl production or hunting, furbearer production, preservation of rare wildlife species, or other uses. Management techniques are improving and for specific objectives in specific estuarine areas, such as producing moist-soil food plants, rather detailed management information is available. However, space limitations here decree that the subject of wildlife management techniques will be treated only in general terms.

Most wildlife ecologists will agree on at least one important point—that wildlife is a product of the land. The abundance and well-being of most animal populations is an indication of the land's productivity, misuse, or both. It is necessary for the wildlife manager to know well those aspects of the environment exerting the most influence on wildlife populations. Generally, vegetation and soils are the interacting components which must be comprehended to produce the best understanding of wildlife populations.

Following is a brief discussion of wildlife management techniques used on estuarine areas. Significant forward strides have been made in recent years in gaining knowledge of the relationships of physical, chemical, and biological factors which have enabled estuarine wildlife managers to improve conditions for desired wildlife species.

Water control: Water-level control is probably the most important technique in the management of estuarine wildlife habitats. Control of water levels may be used to increase or decrease the salinity, to stimulate germination and growth of desirable moist-soil plants, to attract wildlife to an available food supply, to control undesirable plants and other organisms such as mosquitoes and wildlife diseases, to provide a permanent water supply (as in ditches and potholes) for alligators and furbearers during droughts, to enable trappers and hunters to move about the areas more easily, to clear up turbidity, to recycle nutrients, and for a variety of other purposes. Unwise manipulation of water can pose problems for wildlife. Wildlife habitat in the past was often temporarily destroyed by water drawdown; obtaining enough water for re-flooding at the proper time was difficult, and overcrowding favored the spread of disease. Fortunately, estuarine wildlife research and management have progressed to the point where such mismanagement is infrequent as managers now have broader knowledge of physical and biological characteristics of individual marshes. Bottom topography, soil characteristics, existing plant communities, current wildlife use and productivity, and seasonal water supplies, are all important factors now being considered before the decision to use drawdown is made as a habitat manipulation technique.

Dikes and levees: Many extensive estuarine areas have effective water control with simple dikes and levees which are used to hold water or to keep water off the area being managed. It is often possible to flood or drain an area by gravity with simple control structures. Thousands of acres of coastal marshes, especially in Louisiana, have natural levees and barriers, which impound adequate amounts of water in years of normal rainfall and tides, but except on limited areas, control of water levels in these marshes is almost impossible. Dikes are used to stabilize levels in marshes where water levels are drastically affected by tides and winds. Other segments of marsh are diked to provide optimum growing conditions for desirable wildlife food plants. Marshes managed in this manner often yield three to five times as many muskrats as undiked adjacent marshes.

Control structures: Most water control structures used in marshes are simple, but effective. Critical factors for effective operation of control structures are the timing of flooding and dewatering, an adequate water supply for flooding, and no flooding during dewatering.

Impoundments, although expensive, have been widely used in the southeastern United States. Also, without pumping facilities, abnormally wet or dry conditions usually result in poor wildlife food conditions, and impoundments can be built only in areas that will support a levee. Thus, other less expensive methods that have a wider application are being used to improve coastal marshes for wildlife. Two of these are weirs and earthen plugs.

A weir is a structure placed in the drainage system of a marsh and set about 6 inches below the level of the surrounding marsh. This permits the flow of tidewater in and out of the marsh, but prevents the drainage of the marsh. Weirs are particularly valuable in producing desirable aquatic vegetation in marsh ponds and lakes, and have already been used in managing over 250,000 acres of salt and brackish marshes along the south Atlantic and gulf coasts.

Earthen plugs in tidal marshes are being used for a type of management similar to that obtained by the use of weirs; however, the plugs rise several feet above the surrounding marsh level. Thus, normal tides are not permitted to enter the system and excess rainwater must run around the plug through the surrounding marsh or other depression. Most of the plugs appear to be ineffective for improving plant conditions for wildlife, but they do provide permanent water for wildlife and greatly improve access to the marsh by hunters, trappers, and fishermen.

Pumping: Pumping is used for flooding and dewatering impoundments for wildlife management. This method is usually the most expensive but is also the most reliable. Pumping may be used as a standby or supplementary method to simple inlet and outlet structures. The expenses of pumping are justified in estuarine wildlife management when valuable wildlife species and habitats are involved.

Level ditches and marsh potholes: Level ditches and marsh potholes are constructed to improve estuarine habitat for wildlife. They may be built by draglines, ditching plows and such devices as rotary tillers which have been used experimentally in some Louisiana marshes. Blasting has also been used to create ditches and potholes in extensive marshes.

The purpose of these areas is primarily to open up dense vegetation, to provide a permanent water supply and easier access to the marsh. The latter two objectives are attained easily in most areas, but usage by wildlife is not always assured. Along coastal marshes, ditches constructed with draglines are not usually productive of wildlife until after the first few years because turbidity may restrict growth of aquatic vegetation.

Burning: The marsh has undoubtedly been burned since its origin, first by natural fires caused by lightning and later by Indians as they occupied adjacent high land. As white man settled in and near the marsh he stepped up the tempo of burning to make his trapping, hunting and traveling easier and to improve grazing conditions for livestock. As the overall picture of periodic burning developed, many people noticed an improvement in the marsh, until today all phases of marsh management include periodic burning.

The major objective of marsh burning is to give some of the more valuable food plants an advantage over those that are less desirable or to remove the dense rough and provide more succulent food for wildlife. Although it sometimes backfires or goes astray this is the optimum goal of marsh burning.

Prior to 1910 along the coasts of Louisiana and Texas, intentional marsh burning was an unforgivable sin; however, by 1926 it was a fairly common practice. The reason for this was the increased interest in alligator hunting. To hunt alligators in those days it was necessary to burn off the marsh to locate the alligator holes. Unknowingly, the alligator hunter was making way for the forthcoming muskrat boom in Louisiana and Texas. Because some trappers were noticing an improvement in marsh conditions after a burn, they adopted the practice until burning was commonplace on the gulf coast by 1940.

In more recent years a number of people concerned with estuarine management have recognized that prescribed burning is another important method of managing for desirable plants. Much of the accumulation of plant growth in the northern marshes is removed by ice, spring floods, and grazing; however, in the southern marshes the long growing season produces a heavier growth, and drastic measures are needed to manage the vegetation. Hurricanes remove the vegetation from huge areas in short periods of time; when storms do not remove unwanted vegetation, fire can be an effective tool. The major objectives of burning are to give some of the more valuable food plants a competitive advantage, to remove the dense rough, to provide more succulent food plants for wildlife, and to create open water areas by burning into the marsh floor. Burning affects both wildlife and plants. Nutrients, especially potassium, calcium, phosphorus, magnesium, and chlorides, are released from vegetation and added to the soil and water. The warm temperatures of the south and the fertilization by the ash following fire stimulates new growth almost immediately, even in winter.

Burning has undesirable as well as desirable effects on marshes. An unburned marsh accumulates a very large amount of fuel; in this situation burning is dangerous. The timing of a burn is important. If a burn is made just prior to a high tide many nutrients may be lost. Heavy vegetation helps prevent erosion, thus, in coastal marshes subject to hurricanes, burning should be delayed until about October 15 when the peak of the storm season is past.

Cover burns, usually made in the fall or winter to open up dense stands of vegetation, produce an immediate change in habitat because they remove the standing vegetation, but they seldom produce a permanent change in vegetative type. Root burns, made when the marsh is dry, damage or destroy the roots of the plants and can change the composition of the vegetation. This type of burn is used to reduce or remove climax vegetation. However, it can stimulate undesirable as well as desirable plant species. To maintain the same kind of vegetation, a burn made just prior to the growing season is the most effective.

Herbicides: Large scale control of estuarine vegetation is best accomplished by water level manipulation, burning, cutting or by animals. When those methods are not feasible, and especially on smaller areas and for special purposes, herbicides are useful. Herbicides cause relatively little damage to animal organisms in the marsh when those of low toxicity to animals are used, when directions are carefully followed, and when care is taken to avoid spillage and overdosing.

Planting: On estuarine areas drained and later restored, on created areas (such as spoil islands), and on natural areas where desirable water levels have been restored, aquatic plants often return or occur naturally. Where desirable plants are absent or less desirable species are dominant, planting can be an important management tool. Plantings range from seeding cultivated grains to produce food for wildlife, to seeding exposed mud flats following drawdowns, and setting out rooted aquatics. Wildlife prefer a diversity so it is best to plan for a variety of plant species and a proper balance of open water and plants.

Planting is inadvisable where a good stand of species exist, but a paucity of natural vegetation may indicate habitat deficiences. In the coastal marshes where "cat clays" pose a problem with cultivated crops, similar problems are likely to affect plantings for wildlife. In these areas only a quick maturing plant which does not require deep drainage is suitable.

Animals: Both wild and domestic animals can control plants, but usually in different situations. Wildlife, especially when population levels are high, may exert undesirable control on the vegetation and may need to be controlled in order to maintain desirable plant communities.

When populations of muskrats and nutrias are high, their feeding activities may compete with ducks or other wildlife for food plants. At peak populations, the muskrats and nutrias make "eatouts" on some coastal marshes. Eatouts by muskrats, nutrias and geese sometimes create muck-bottomed ponds in tidal marshes and create more open water than is desirable. Eatouts by nutria normally revegetate in one growing season because these mammals feed at the surface, but an eatout by muskrats, which consume roots and all, may require as long as 10 years to revegetate. Because muskrats and nutrias are valuable furbearers, control usually involves offering ample opportunity for their legal harvest and providing trappers ready access, by impoundments and level ditches, to all sections of the marsh.

Grazing by cattle is a well-established practice in coastal marshes. Grazing is economical, usually effective, and does little damage to nesting wildlife.

High populations of fishes, especially bullheads and carp, may create conditions in a marsh that eliminate desirable aquatic vegetation. Some estuarine areas can be successfully managed for fish and wildlife at the same time, but unwanted fish must be controlled. Undesirable populations of fishes can be removed by netting or poisoning. Even when a fish population is not detrimental, the trampling of shoreline vegetation and the disturbance caused by the presence of an excessive number of fishermen may harm wildlife values.

The animal species which perhaps has had the greatest effect on estuarine habitat in the United States, although indirectly, is the salt-marsh mosquito. In attempts to control this species, people have affected the wildlife values of many thousands of acres of coastal marshlands. In the early 1930's the Civilian Conservation Corps, at the request of local communities, began to ditch marshes for mosquito control. Nearly 500,000 acres of valuable marshes from southern New England to Maryland were drained and made nearly useless for waterfowl and other wildlife.

Wildlife agencies and mosquito control agencies have now devised methods of water management that both benefit waterfowl and other wildlife while controlling mosquito populations. The eggs of floodwater mosquitoes are laid only in temporarily dewatered sites. The eggs hatch when high tides or rains reflood the eggs. By diking marshes and keeping them flooded throughout the mosquito breeding season, mosquitoes are effectively controlled, and the impoundments greatly enhance the value of tidal marshes for many species of wildlife. Construction costs for mosquito control impoundments are greater than ditching costs but the benefits are many times greater. These impoundments also provide trapping, crabbing, frogging, and firebreaks.

EVALUATION OF RECENT WILDLIFE MANAGEMENT PROGRAMS

To maintain and increase valuable estuarine wildlife resources in the face of growing pressures to convert estuarine habitats to other uses has necessitated many activities. These include land acquisition, research investigations, and intensive management programs. The objectives of these activities have been discussed previously. Thus, only results and indicated trends will be discussed below.

Wildlife habitat acquisition: National planning is lacking for estuaries, including their fish and wildlife resources. Without national planning, acquisition of valuable estuarine wildlife habitats has proceeded with only uncoordinated, spasmodic, and piecemeal efforts. Funds available nationally for acquisition of wildlife lands have been limited. Therefore, these funds have been used on a priority basis, but without national planning even the best intentions have resulted in the acquisition of less valuable areas while extremely valuable estuarine wildlife lands have been lost to other land uses. Although acquisition of less valuable wildlife lands is usually cheaper than more valuable habitats, the initial monetary savings are soon nullified by the increased costs of necessary development and management activities.

Indications are that more comprehensive planning for estuaries is in the making in order to more wisely identify, preserve and protect their fish and wildlife resources. The problem of splintered governmental responsibilities and authorities which complicate controlling use of estuarine lands held in trust for the public is now receiving much greater attention.

Wildlife research: Protecting, and even increasing, valuable estuarine wildlife resources requires research results to plan for proper management. Unfortunately, good wildlife research usually takes more time than land administrators are willing to take before initiating management practices. A large amount of good quality estuarine wildlife research has been accomplished largely through the yeoman efforts of a relatively small cadre of wildlife biologists. Unfortunately, the force of their recommendations has not always carried enough weight when management decisions have been made.

Past research on wildlife use of estuarine areas has been localized where important problems existed and where a pooling of interest, effort, and finances made an effective venture possible. The Back Bay-Currituck Sound research project is an example of this type of productive effort. However, nationally there has generally been no provision for the more general survey approach followed by more intense research on local problems according to a logical system of priorities. Ambitious, high quality, research programs have been contemplated in the past, but funding and staffing deficiences have derailed them. Encouragingly, wildlife administrators appear to be more inclined to provide the cooperation and coordination that is essential to obtain the greatest dividends from a given amount of research funds and effort.

Wildlife management: After acquiring (or establishing some control over) estuarine wildlife habitats, and after having the benefits of good research efforts, the next step is to reach wildlife resource goals by proper management. But what is proper management? This is the big question. The answer should be that level of management required to sustain optimum populations of wildlife and enable maximum enjoyment by the public. We do not know, and have hardly started to fully determine, what management is essential for the welfare of many estuarine wildlife species, or what criteria result in maximum public enjoyment. Only by improving knowledge of these requirements will better management policies be established even though many of the necessary tools and procedures are known. Although many federal, state, and privately controlled estuarine wildlife areas have accomplished much toward these goals, many instances of faulty management still remain.

Overmanagement, which wastes time, effort, and money, exists in many forms, e.g., excessive diking, pumping, farming, plant control, pothole blasting, and other practices. There are areas where most wildlife biologists concede that intensive management is not presently required by wildlife or the public, but they have been pressured into putting the land to use. At times, the explanation is offered that management activity is required to justify retention of certain lands. This type of overmanagement is deplorable. It rejects the idea of a land bank whereby the conservation agencies hold strategic parcels of land, and manage them only when the need has been demonstrated. This common fault of attempting to manage all lands under jurisdiction is costly and unnecessary.

Undermanagement of lands administered by wildlife agencies is probably less commonly encountered than overmanagement. It is less costly in money and effort, but it adds little to our knowledge. Probably the most common example of undermanagement is the lack of water drawdown even when adequate facilities are available. Apparently the fear of failure or of causing irreparable harm if stable water levels are not maintained, prevents some managers from experimenting.

Mismanagement is a product of ignorance, or lack of sufficient manpower, money, or incentive to do the job properly. Unfortunately, mismanagement is widespread.

Misdirected weed control programs can be found throughout the country. In some instances eradication programs have been directed to the control of useful wildlife foods, e.g., *Hydrochloa* or *Myrica*. Eradication programs such as the alligatorweed program often operate more on fancy than on fact. Early control of pest plants that spread rapidly and persist, e.g., Eurasian watermilfoil, water hyacinth, and water chestnut, is important, but there are examples of undue delay in action programs. The ultimate value of control is concerned not only with killing the target plant, but also with the plant communities that follow. In areas where maidencane growth succeeds alligatorweed, little has been accomplished by control.

Poorly planned plant introductions are probably not as common as they once were, when transplanting was in vogue 20 to 30 years ago. There are still a few private individuals who purchase wildlife foods and unwittingly plant them in habitats where they already occur naturally.

In summary, wildlife management on estuarine areas is far from being an exact science. A detailed, critical evaluation of all estuarine wildlife management areas would probably show that most are being well managed with the funding and manpower available. However, there are enough examples of mediocre or poor management to indicate that there is much room for improvement. The knowledge bank of estuarine wildlife management techniques is increasing, yet there are enough knowledge and communication gaps to cause many problems in trying to provide wildlife with the necessary variety and quantity of food, water, and protective cover. Lack of overall, coordinated management among all interested parties hinders the most effective management of estuarine wildlife. On the brighter side, there now appears to be meaningful effort to correct this severe problem.

FUTURE TRENDS AND NEEDS IN ESTUARINE WILDLIFE MANAGEMENT

One crucial dimension of estuarine habitat relationships must receive much more consideration if the future needs of wildlife are to be met. This is, one wetland community may contribute nutrients to another nearby, or to another distantly located. Highly productive estuaries and coastal marshes are surely the lifeline of our entire coastline and adjacent seas. Resource managers must be acutely aware of these important relationships in order to avoid misjudging the values of our dynamic estuarine communities. As we are painfully learning, energy and nutrient cycles and food webs require greater understanding.

Many of our present environmental problems result from plans executed project-by-project, without relating individual actions to an entire estuary or watershed. This case-by-case approach is the genesis of many problems (including wildlife resources) plaguing estuarine areas. Broadly integrated, rather than single purpose, planning is required for estuaries to designate where and what developments can be permitted without damaging the resource base. Estuarine landscape must be recognized as one major ecosystem with interdependent components and functions and not be subjected to insidious destructive and resource-degrading activities. With our increasing population and associated demands on resources, constructive national action is imperative.

Communication, coordination, and cooperation are the cornerstones on which science, industry, government, and citizens must build to attain a viable solution to the multi-user problems involved in equitable and effective estuarine management. Wildlife values are only a part of our total estuarine values, but they must be considered. Certainly, broad-scale estuarine planning has been discussed previously in this overall report. Thus, only the plea that our wildlife resources be justly considered will be made here along with the thought that we stand on the threshold of decision. Procrastination is no longer either profitable or possible. Our national estuarine problems must be solved with national planning and national efforts.

Following is a brief listing of some of the needs of estuarine wildlife research and management.

- Initiate a comprehensive national survey of the fish and wildlife resources of estuaries and their habitats.
- Identify and delineate those areas of special estuarine significance in need of federal, state, or local protection through land control and management, or through another vehicle such as an "estuarine authority."
- Plan a program of research and experimental management on coastal wildlife refuges and perhaps on national parks and seashores as well. The basis of this approach is that the coastal wildlife refuges offer natural bases for inventory, research, manipulation, experimental management, and rehabilitation. These refuges have land, water, marshes, fish, birds, mammals, and people with local knowledge, and a wide variety of problems associated with environmental manipulation. Coastal national parks and seashores may also offer the same opportunities.
- The entire field of habitat rehabilitation prom-

ises to yield great rewards but unfortunately has been sadly neglected. We know that thousands of acres of estuarine habitat have been damaged and destroyed and that the future promises an increase of this problem. It is time now to stop, and if possible, to reverse this destructive trend. Habitat rehabilitation certainly is one way to accomplish this goal.

• There is urgent need for an accelerated research program to give better understanding and better tools for management. Among these needs is a far better knowledge of the overall ecological relationships of total communities of organisms.

• More precise knowledge of the interrelationships of the tidal flats, marshes and periodically inundated semi-upland is needed. To what extent are our aquatic resources dependent upon these higher elevated tidal zones? To what extent does the mismanagement of these higher zones affect the permanent water areas and their productivity? To what extent does one wetland community contribute to another?

• The specific ecological requirements, degree of adaptability, life histories, food, nesting and other habits, social behavior patterns, competition, enemies, limiting population factors of abundance or population dynamics, and many other aspects of many wildlife species are known only in part. Research here surely is needed and some of it is urgent.

• Research on the economic, recreational and sporting values were urgently needed on all estuarine commercial products long before those resources were eliminated by dredging, filling and pollution. Research is now needed on how to safely restore and effectively manage the potential resources that remain. Socio-economic studies are needed to establish more firmly public values of specific and associated renewable resources. Otherwise, we cannot objectively appraise these renewable resources against other proposals for development of those areas. Too many local areas have been destroyed without thought or realization of the values being eliminated.

• Revised procedures or legislation are needed to permit adequate time to conduct wildlife studies, analyze project effects and devise protective and enhancement measures for all estuarine projects.

• With the demands for fresh water diversion, dams and more dams on all our rivers, it is apparent that less and less fresh water is going to reach the sea coast and the drainage water that does enter will likely be polluted and contain concentrations of salts and other minerals. The proposal to drain water from the Sabine down the Texas coast to the lower Rio Grande Valley is expected by most people to prevent the "loss" of fresh water into the coastal estuaries and gulf. It is obvious that to the extent that fresh water is prevented from reaching the gulf, the gulf seawater will encroach into the estuaries and accordingly change them. We need to know the critical limits to which fresh water can safely be diverted. We need to know the salt tolerance of the various organisms—commercial, sporting and food chain species in the estuaries, and we need to know what effects will result from diversion of fresh water that normally enters the various estuaries. This is an urgent research need and such studies should be generously supported.

• Human population increases will require new approaches and intensive management of species now harvested or those little used.

• Lastly, perhaps there is urgent need for studies to improve better public relations and people management as they affect our estuarine system.

Much destruction of our valuable estuarine wildlife habitats has already taken place, and many estuarine uses now being planned will destroy or damage a number of our remaining areas. Only a concerted national effort now will turn the tide. Surely we have the desire and pride to do this.

IMPACT OF ESTUARINE POLLUTION ON BIRDS

L. J. BLUS S. N. WIEMEYER J. A. KERWIN
R. C. STENDELL H. M. OHLENDORF L. F. STICKEL
U. S. Fish and Wildlife Service
Laurel, Maryland

ABSTRACT

Pollution of estuaries affects bird populations indirectly through changes in habitat and food supply. The multi-factor pollution of Chesapeake Bay has resulted in diminution of submerged aquatic plants and consequent change in food habits of the canvasback duck. Although dredge-spoil operations can improve wildlife habitat, they often result in its demise.

Pollution of estuaries also affects birds directly, through chemical toxication, which may result in outright mortality or in reproductive impairment. Lead from industrial sources and roadways enters the estuaries and is accumulated in tissues of birds. Lead pellets deposited in estuaries as a result of hunting are consumed by ducks with sufficient frequency to result in large annual die-offs from lead poisoning. Fish in certain areas, usually near industrial sources, may contain levels of mercury high enough to be hazardous to birds that consume them. Other heavy metals are present in estuarine birds, but their significance is poorly known. Oil exerts lethal or sublethal effects on birds by oiling their feathers, oiling eggs and young by contaminated parents, and by ingestion of oil-contaminated food. Organochlorine chemicals, of both agricultural and industrial origin, travel through the food chains and reach harmful levels in susceptible species of birds in certain estuarine ecosystems. Both outright mortality and reproductive impairment have occurred.

INTRODUCTION

Millions of people live in communities bordering the estuaries. They deposit their wastes in the oceans, bays, and rivers on the age-old assumption that the ocean has an infinite capacity to remove, store, and cleanse. The error of this assumption is now evident. Kinds of pollution are numerous and their sources divergent. They include agricultural pesticides, industrial wastes, sewage effluents, abnormal changes in water temperature, and soil eroded from disturbed lands. Even the hunters, concentrating on shrinking waterfowl areas, annually increase the toxic burden of lead shot in the environment. We will take examples from a few of these in relation to certain kinds of birds whose lives depend upon the estuarine ecosystem.

Pollution of estuaries affects bird populations indirectly through changes in habitat and food supply; these changes are widespread, not immediately apparent, and in practice, may not be reversible. The kinds of pollution include turbidity, sedimentation, eutrophication (enrichment by nutrients), and abnormal changes in water temperature. They also include pollution by oil and chemicals. These factors cause changes in the kinds and numbers of animals and plants in the biotic community. For example, prior to the 1950's, the canvasback duck fed primarily on parts of submerged aquatic plants in the Chesapeake Bay. Since that decade, the canvasback's diet in the bay has changed completely, until now it feeds almost entirely on small clams and occasionally on other animals that are part of the detrital food chain (Fig. 1). Similar changes in the Illinois River are believed responsible for the decline of the canvasback and other species in the area (Mills et al., 1966). Different species of waterfowl have greatly different diets, including both animals and plants.

Herons, in contrast, feed only upon animals, but these may occupy several levels of the carnivorous food chain, from aquatic insects, crustaceans, and molluscs, to fish. Pelicans and ospreys feed almost entirely upon fish, the top of the aquatic chain; and eagles eat both fish and birds (Fig. 2). Pollution-induced changes in the populations of the food organisms will inevitably change the food habits of birds and may affect populations.

Physical changes may destroy or drastically alter the estuaries. Dredge-spoil operations, for example, may have either detrimental or beneficial effects. For example, in the saline marshes of New Jersey,

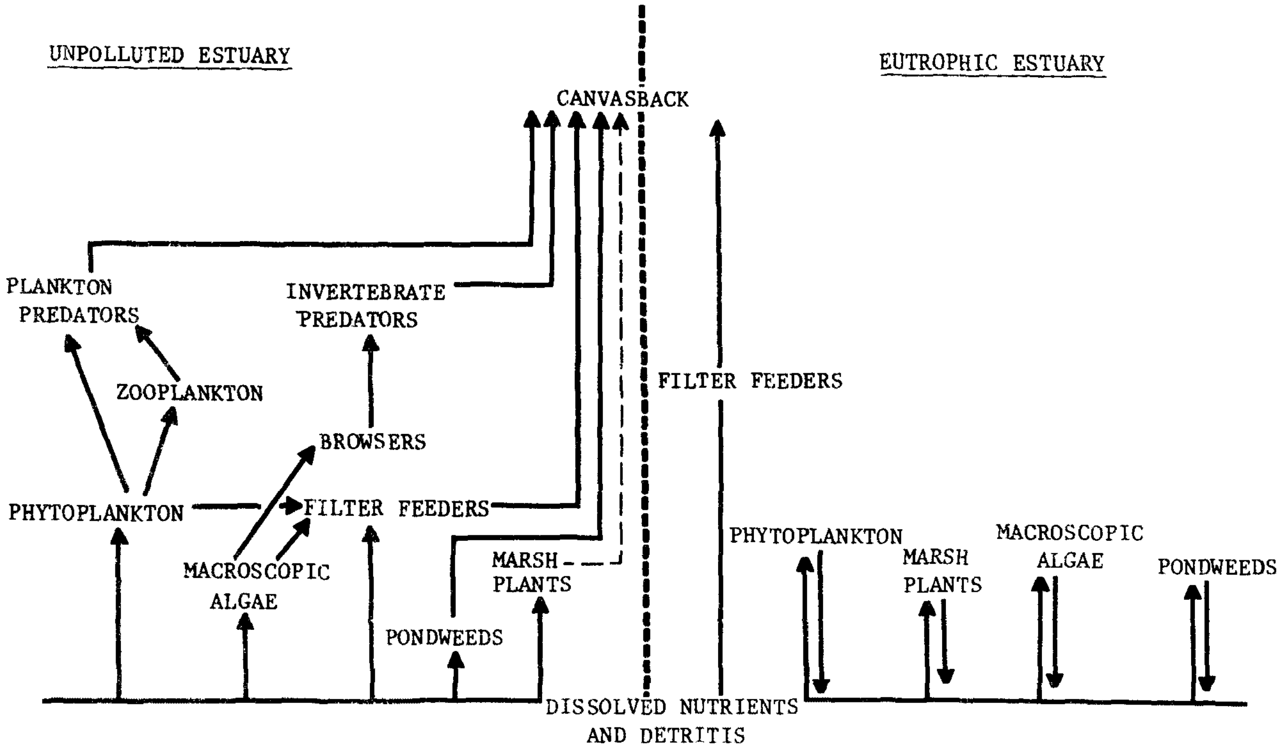


FIGURE 1.—Food chains of canvasback ducks in clean water and eutrophic estuaries. Multiple pollution of Chesapeake Bay has changed the entire biotic community. The canvasback duck has adapted by changing its diet, but the cost may be reflected in reduced wintering populations on the bay.

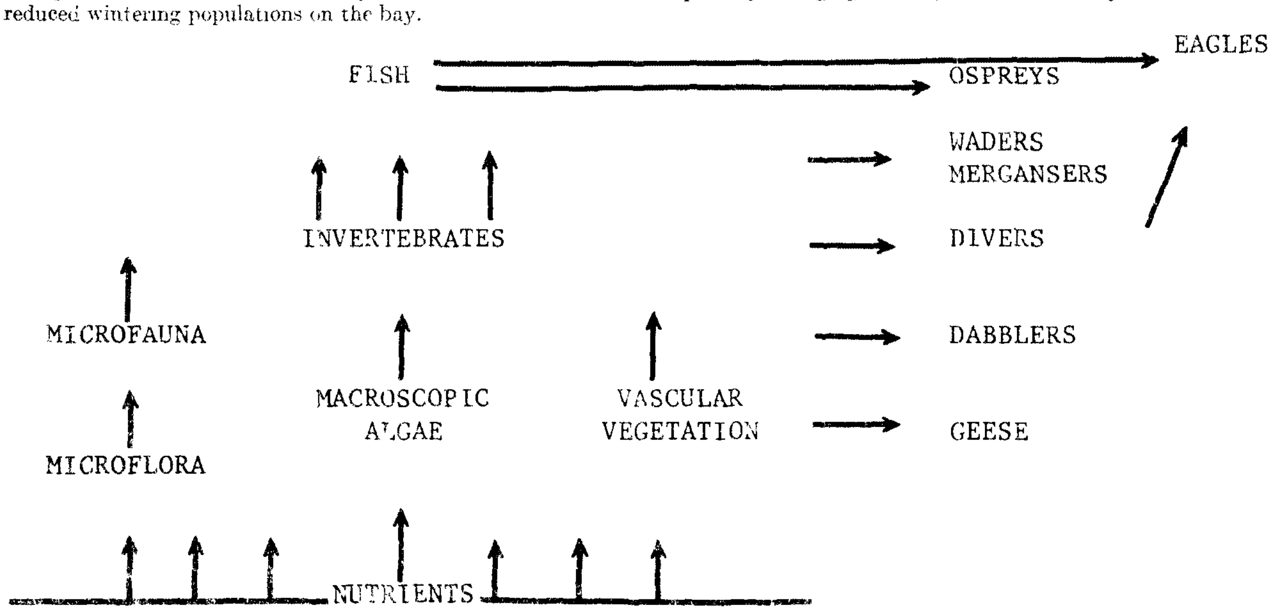


FIGURE 2.—Flow of nutrients through the estuarine food chain. This simplified diagram shows the diverse food habits of waterfowl, and the successively more restrictive requirements of wading birds, ospreys, and eagles.

valuable plant communities such as *Spartina alterniflora* may be destroyed by dredging and subsequent invasion by *Phragmites communis*, which is of only small value to wildlife populations. In contrast, spoil deposits can increase plant diversity. On the eastern shore of Maryland and Virginia, in New Jersey, and on the Outer Banks of North Carolina, dredge-spoil operations on the inland waterway have created habitat for gulls, terns, black ducks, willets, herons, ibises, and egrets. Proper management of

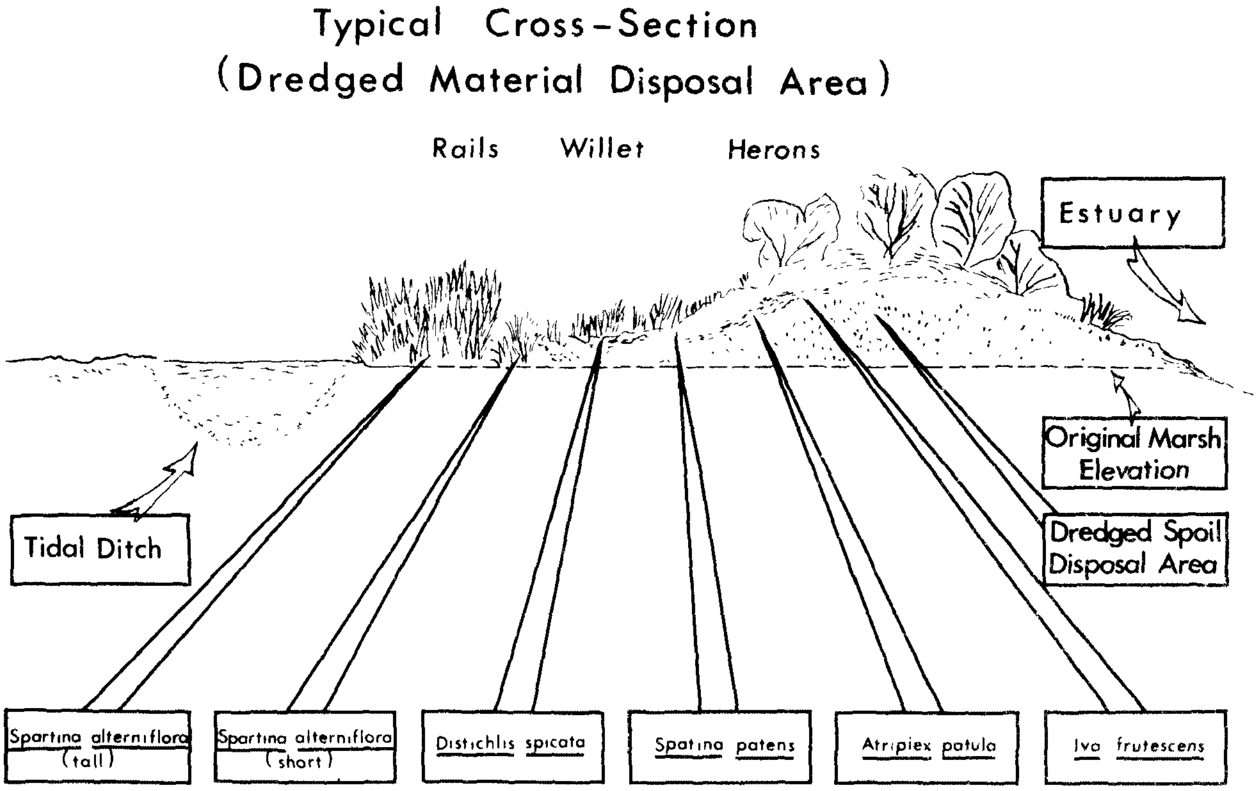


FIGURE 3.—Plant succession and nesting cover on spoil banks on the eastern shore of Virginia. Dredge-spoil operations often destroy or drastically alter estuarine communities, with seriously detrimental effects on bird populations. Proper management can ameliorate damage in some areas.

dredge spoil can be beneficial to wildlife, but development of the techniques is in its infancy (Fig. 3).

Pollution of estuaries affects birds directly through chemical toxication. High levels of chemicals may kill birds outright but lower levels may have more insidious effects, impairing both reproduction and survival. Both may be critical to survival of populations.

LEAD

Lead poisoning has been recognized as a cause of waterfowl mortality since the turn of the century. Ducks that eat lead shot experience serious physiological disturbances of the digestive, circulatory, and nervous systems, which may eventually result in death. Waterfowl mortality from this cause has been estimated as 1.5 million birds per year.

In 1972, the U.S. Fish and Wildlife Service initiated a study to examine the geographic distribution of lead levels in several species of waterfowl throughout the United States. The survey was made by examining the lead levels in the wingbones of immature ducks. Bone was selected because lead uptake by bone is rapid and loss is extremely slow. Lead levels in the bone, therefore, represent the bird's total history of exposure. Wingbones were used because statistically planned samples of wings were readily available from other studies in which wings of many species are obtained annually from hunters to assess reproductive success of the birds and to help measure the harvest. Young birds were sampled because they would be making their first southward migration and therefore would reflect the exposure of a single season. Mallards were the primary species sampled, because of their almost nationwide distribution and availability.

Lead in wingbones of immature mallards ranged from less than 0.5 ppm to greater than 100 ppm on a dry weight basis. Levels were highest in states of the Atlantic flyway, lowest in the Central flyway, and intermediate in the Mississippi and Pacific flyways (Fig. 4). Levels in black ducks from the northeastern states were similar to those in mallards. Mottled ducks from Florida, Louisiana, and Texas had the highest levels of any species from any area. It was evident that a high proportion of the waterfowl population is exposed to elevated levels of lead.

Over most of the United States, there is strong

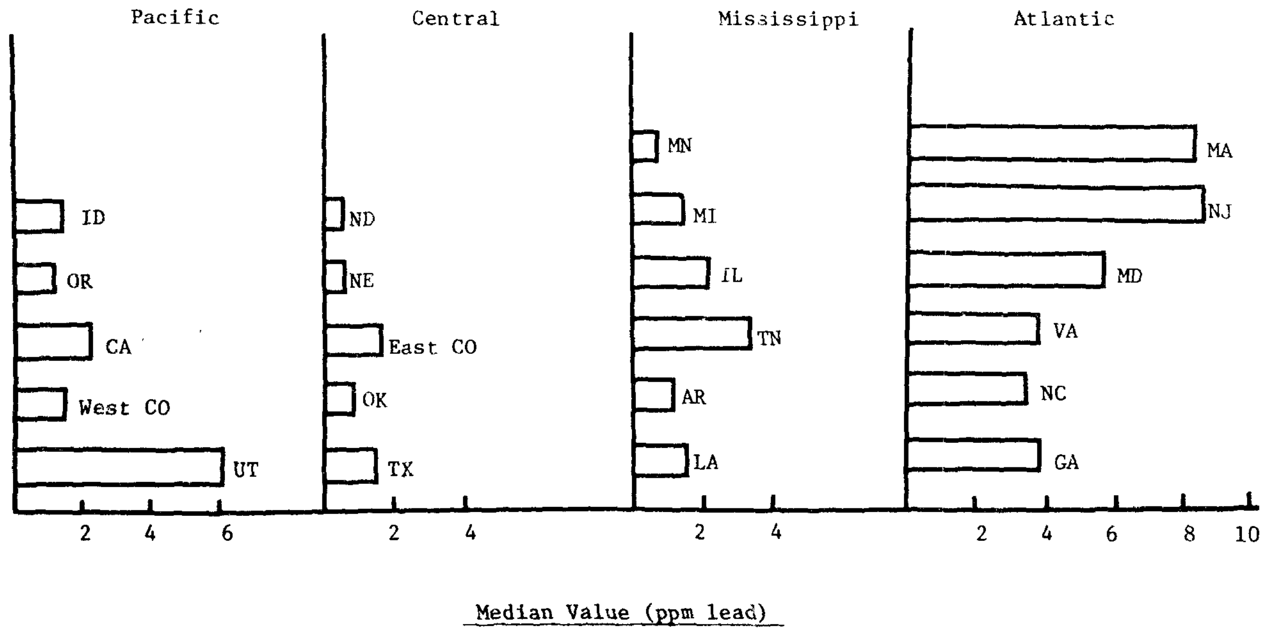


FIGURE 4.—Lead in mallard ducks. Geographic differences in lead exposure are shown by analysis of lead content of wingbones. Highest exposure is in the east, where marshlands used by waterfowl receive municipal and industrial lead as well as lead shot.

evidence that the major source of lead in ducks is ingested shotgun pellets. Each year, 2 million waterfowl hunters shoot more than 3,000 tons of lead into marshes, lakes, and estuaries. Many of these spent shot are eaten by the birds as if they were seeds or grit. The shot are ground in the gizzard, and much lead is absorbed by the body. Results of a survey of lead shot in gizzards showed a geographic distribution very similar to that of lead in wingbones (Bellrose, 1959).

However, lead from other manmade sources may account for some of the lead in the bones. This is particularly true of mallards and black ducks from northeastern coastal states, where a large percentage of the wingbone samples contained moderate to high levels of lead. In this region, hunting often is concentrated in areas that also receive lead as an industrial or municipal pollutant, and lead in the bone from the various sources is not easily separated.

OTHER HEAVY METALS

Estuaries are repositories for many other heavy metals besides lead, since these areas receive the effluent from numerous industrial areas. Heavy metals are a part of the complex of pollution that alters the energy flow and food chain composition. The effects of heavy metals on birds are not at all well understood.

Mercury is a cause for concern in some areas and has been most studied. Levels of mercury increase through the various stages of the food chain. Ducks that feed more upon animal matter (divers) have higher levels of mercury than those that feed predominantly upon vegetation (dabblers). This is shown in the distribution of mercury in samples of divers and dabblers from Wisconsin (Kleinert and DeGurse, 1972) and from Pacific flyway estuaries (Baskett, 1975). Mergansers, because of their fish-eating habits, show the highest mercury levels (Fig. 5).

The eggs of wild mergansers often contain levels of mercury that have impaired the reproduction of captive mallards and black ducks (Heinz, 1974; M. Finley and R. Stendell, personal communication), but it is not known whether the mergansers are affected, because neither field nor laboratory studies have been made.

Bald eagles, which eat both fish and birds, occasionally contain high levels of mercury (Mulhern et al., 1970; Belisle et al., 1972).

OIL

Spills of major extent may oil and kill thousands of birds and disfigure beaches. Spectacular accidents, however, constitute only a small percentage of the 5 million metric tons that is estimated to be the annual global input of oil to the oceans.

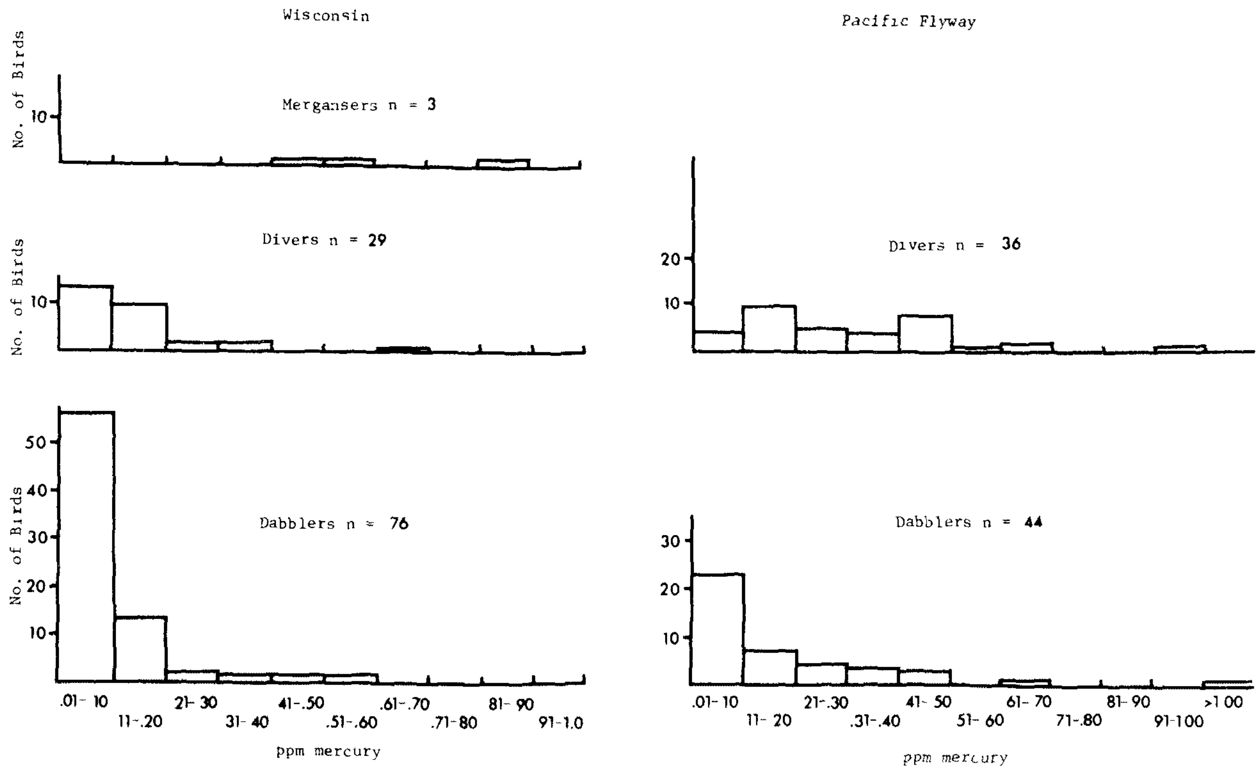


FIGURE 5.—Mercury in ducks from Wisconsin and from Pacific estuaries. Diving ducks which feed more upon animal material accumulate more mercury than do dabbling ducks which feed predominantly upon vegetation (Kleinert and DeGurse, 1972; Baskett, 1974).

Birds may be affected by oil directly, through feather-oiling, by exposure of eggs to oiled feathers, and by ingestion of oil. They may die as a result of direct exposure to oil even when the oil is essentially gone from the feathers. The damage results from the ingestion of oil during preening or during intake of food items that are coated with oil. Oil is found in tissues of birds in oil-spill areas even when feathers are not oiled (Burns and Teal, 1971). In the San Francisco spill of 1971, grebes, murres, and loons died more rapidly than other birds and the duck species appeared most hardy (Snyder et al., 1973). Various pathological conditions and signs of debilitation were present in oiled birds. Delayed feather damage also may occur (Bourne, 1974). Oil ingestion at levels obtainable from oiled plumage inhibited egg laying of mallard ducks and had other physiological effects (Hartung, 1963, 1964, 1965). A thin film of oil will prevent eggs from hatching and could be introduced by the incubating hen (Hartung, 1965; Kopischke, 1972). Ingested oil may interfere with the intestinal absorption of water by ducks that depend upon saltwater and result in death from dehydration (Crocker et al., 1974).

ORGANOCHLORINES

Manmade chemicals have become an integral part of estuarine ecosystems throughout the world. The organochlorines of agricultural and industrial origin travel through the food chains and follow the energy cycles of all living organisms. Species differ greatly in susceptibility to harm. Some species, such as fiddler crabs, are so easily killed by DDT that they may be lost from local faunas. Other species, such as snails, are less easily harmed and so serve as accumulators. Organochlorines enter the body of birds primarily through the foods they eat. Birds that eat fish and other birds generally accumulate higher amounts than do birds that eat seeds and vegetation.

Predatory and fish-eating birds that live near the estuaries and depend upon the estuarine food chain accumulate a wide variety of organochlorines in their tissues and transmit them to eggs and young. The principal chemicals—those that occur most frequently and in the greatest concentrations—include DDE, dieldrin, and PCBs (polychlorinated biphenyls). Many other kinds occur less frequently.

The effects also are various. Those of DDE are best documented, for this compound in small amounts thins eggshells and impairs reproduction of many kinds of birds, and these effects have been verified in numerous experimental and ecological studies. The relationships of DDE and other organochlorines to different species of estuarine birds can best be considered through examples.

Bald Eagles

Since 1947, eggshells of a number of species of birds of prey have thinned both in the United States and in other parts of the world (Ratcliffe, 1967; Hickey and Anderson, 1968). Bald eagle eggs from Brevard and Osceola Counties, Fla., were among those whose shells thinned significantly; the bald eagle population was declining in the area as was its reproductive success. Declines in populations and reproductive success of bald eagles nesting on the west coast of Florida had been reported earlier (Broley, 1958). Thinned eggshells are less able to support the weight of the incubating bird and are more susceptible to breakage, so that fewer eggs are hatched. The hypothesis was advanced that eggshell thinning was caused by the introduction of organochlorine insecticides, such as DDT, into the environment. This hypothesis was substantiated in later years by the results of experimental studies with several species; these studies also showed that even the unbroken thin-shelled eggs hatched poorly. American sparrow hawks (a species related to the bald eagle and osprey) that were fed diets containing DDT and dieldrin in combination, as well as DDE alone, laid eggs with shells that were significantly thinner than those of undosed sparrow hawks (Porter and Wiemeyer, 1969; Wiemeyer and Porter, 1970).

Bald eagles found dead in the field have been monitored for the presence of organochlorine insecticides since 1964, and for PCBs since 1969 (Reichel et al., 1969; Mulhern et al., 1970; Belisle et al., 1972; Cromartie et al., 1974). Their tissues contained a wide range of concentrations of many different chemicals. Some contained high amounts. The most notable finding was that 8 of 17 (47 percent) of the bald eagles from southeastern coastal states (Maryland, Virginia, South Carolina, Florida) were suspected to have died of dieldrin poisoning. The four cases from Maryland and Virginia were from tidewater areas of Chesapeake Bay (Cromartie et al., 1974). Reproductive success of bald eagles in this area has been poor (Abbott, 1973). Only 11 of 173 bald eagles (6 percent) from other areas of the United States had such high levels of dieldrin.

Table 1.—Organochlorine residues in eggs of bald eagles from estuarine areas. The high residues in eagle eggs from Maine parallel poor reproductive success in that area. (Wiemeyer et al., 1972)

Area and year	n	Residues ppm wet weight		
		DDE	Dieldrin	PCB
Alaska				
Kodiak—1969	7	1.9	0.10	2.2
Admiralty—1970	5	2.9	0.06	1.1
Florida				
Everglades—1968	6	11.0	0.21	n.a.[1]
Lee County—1969	2	18.0	1.1	12.0
Maine 1967–69, 1974	11	22.0	1.1	30.0[2]

[1] Not analyzed.
[2] Only 1969 and 1974 eggs were analyzed for PCB, therefore the sample size is 6.

Bald eagle eggs from populations near several estuarine or salt water areas have been collected for analysis of environmental pollutants (Krantz et al., 1970; Wiemeyer et al., 1972). Eggs from Kodiak Island and the Admiralty Island area of Alaska had the lowest levels of pollutants (Table 1). Those from Florida and Maine had considerably higher concentrations. The poor reproductive success in many of the eagle nests in Maine probably is the result of the high concentrations of DDE, dieldrin, and PCBs in the eggs. Reproductive success of the eagle populations in Alaska (Sprunt et al., 1973; Robards and King, 1967) and in Everglades National Park, Fla., (Sprunt et al., 1973) appears to be adequate to maintain those populations, whereas the Maine population has been declining for a number of years. Moderate eggshell thinning (about 10 percent) has occurred in each of the recent samples mentioned above, with the exception of those from the Admiralty Island area of Alaska. Eggshell thinning has also been reported for bald eagles in southern Texas (Anderson and Hickey, 1972).

Ospreys

The osprey population in estuarine areas along the coast of Connecticut, particularly at the mouth of the Connecticut River, has been one of the better studied declining populations. Seventy-one active osprey nests were present near the mouth of the river in 1960 (Ames and Mersereau, 1964), whereas only five active nests remained in 1969 (Wiemeyer et al., 1974). This population crash was accompanied by poor reproductive success. Results of studies conducted in 1968 and 1969 indicated that the most probable cause of the poor reproduction was the contamination of the birds and their eggs (Wiemeyer et al., 1974). Dieldrin, DDE, and PCBs were sus-

Table 2.—Organochlorine residues in eggs of ospreys from estuarine areas. High residues in Connecticut eggs are associated with reproductive failure and population decline. (Wiemeyer et al., 1974)

Area and year	n	Residues ppm wet weight		
		DDE	Dieldrin	PCB
Connecticut				
1964	6	9.9	0.68	13.0
1968–69	10	8.9	0.61	15.0
Massachusetts				
1972–73	7	4.6	0.17	10.0
New Jersey				
1970, 1972	8	14.0	0.20	8.8
Maryland				
Smith Island				
("fresh") 1973	10	3.5	0.06	3.0
Potomac				
("failed to hatch") 1968–69	12	3.4	0.25	2.6
("failed to hatch") 1971	8	3.2	0.24	4.6
("failed to hatch") 1972	9	3.0	0.30	6.3
("failed to hatch") 1973	13	3.2	0.15	9.9
("fresh") 1973	20	3.7	0.16	11.0
Florida				
Florida Bay 1973	10	0.90	0.02	1.5

pected of being important factors in the declines. Eggshells from this population had thinned significantly, by about 18 percent, since the 1940's. One adult osprey from Connecticut was suspected of dieldrin poisoning, and another found dead in South Carolina had levels that probably contributed to its death.

Ospreys nesting along the Potomac River in Maryland appeared to reproduce at a near-normal rate in the 1960's; these birds contained much lower residues of DDT and its metabolites, dieldrin, and PCBs in their tissues and eggs than did the Connecticut ospreys during those years (Wiemeyer, 1971; Table 2). Fish used by ospreys as food in the Potomac River area also contained much lower levels of pollutants than those in the Connecticut River area (Wiemeyer et al., 1974). Reproductive success of ospreys on the Potomac River in the early 1970's fell to about one-half to two-thirds of the success needed to maintain the population, although no decline in number of breeding pairs was observed (Wiemeyer, 1971; 1974). Eggshell thinning in the Potomac population in 1973 averaged about 15 percent. PCBs residues in the eggs increased nearly four-fold between 1968–69 and 1973. Residues of DDT and its metabolites and dieldrin in eggs from this area remained relatively unchanged during the same period.

Osprey populations also have declined in Rhode Island (Emerson and Davenport, 1963), New York (Peterson, 1969), and New Jersey (Peterson, 1969; Schmid, 1966). DDT and metabolites and PCBs were high in eggs collected in New Jersey in recent years, and eggshell thinning averaged 12 percent. A small sample of eggs collected earlier had shells that had thinned an average of 25 percent (Hickey and Anderson, 1968).

Reproductive success of ospreys nesting at Martin National Wildlife Refuge on Smith Island in Chesapeake Bay has been excellent (Rhodes, 1972). Residue levels in the eggs are generally low, with the exception of DDT and its metabolites, which were similar to the levels in the eggs from the Potomac River population. Eggshell thinning approached 20 percent in 1973 despite an apparently normal rate of reproductive success. Reproductive success remains high for a population nesting in the Florida Bay area of southern Florida (Henny and Ogden, 1970). Eggs collected there in 1973 showed no shell thinning, and concentrations of pollutants in the eggs were very low. Eggshell thinning was reported for small samples of osprey eggs collected in Florida in 1949 and 1960 (Anderson and Hickey, 1972).

Waterfowl

Organochlorine pesticides and industrial pollutants in ducks are periodically surveyed nationwide to identify trends of pollutants in time and space (Heath and Hill, 1974). Approximately 5,200 wings were involved in the survey during the 1969-70 hunting season. Pools of wings of adult mallards and black ducks from the 48 conterminous states were analyzed for DDE, DDT, DDD, dieldrin, PCBs, and mercury (Fig. 6). All except PCBs were highest in the two coastal flyways, intermediate in the Mississippi flyway, and lowest in the Central. PCBs exhibited a somewhat different geographic pattern; residues were highest in the Atlantic flyway and generally diminished westward. Black duck wings from New Jersey and New York that were analyzed individually showed that birds taken in coastal areas contained higher levels of DDE than those from inland areas. Levels of DDE in duck wings in the 1965–66 survey were similar to those in 1969–70.

Populations of some species of waterfowl appear to be declining. One example is the black duck population along the Atlantic coast that has been declining since the mid-1950's. The cause of the decline is not known, but age ratios in the harvest suggest that reproductive success is adequate. Black ducks are characteristic of a wide variety of habitats from freshwater impoundments to coastal salt marshes,

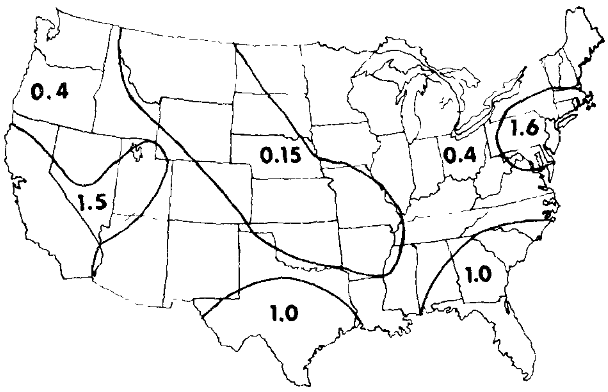


FIGURE 6.—Nationwide distribution of DDE in mallard and black ducks. Residues in wings show geographic patterns, with highest residues in the coastal flyways (Heath and Hill, 1974).

including estuarine river marshes as well as fresh, brackish, and salt estuarine bay marshes, and habitat changes seem insufficient to explain the decline.

Several studies have been made to help determine whether DDE could have adversely affected populations. In a 1971 survey of residues, black duck eggs were collected from 61 nests along the Atlantic seaboard from Maryland to Nova Scotia (Longcore and Mulhern, 1973). One egg from each nest was analyzed for organochlorine pesticides. DDE was detected in all eggs; residues ranged from a trace (<0.05 ppm) to 14.0 ppm on a wet-weight basis. DDE in eggs from Maine, New York, New Jersey, and Delaware averaged greater than 1.0 ppm. Dieldrin (up to 0.81 ppm) and PCBs (up to 6.9 ppm) were present in almost all eggs. The residues of DDE were lower than those in eggs collected from Atlantic states in 1964. The lower residues may reflect the reduced use of DDT in urban and agricultural areas in the 1960's and the discontinuance of the practice of spraying marshlands with DDT for insect control.

In an experimental study, black duck hens fed dietary doses of DDE (10 ppm dry weight) laid eggs with thinner shells than those fed untreated food (Longcore et al., 1971). A number of eggs with thinned shells were crushed or cracked during incubation; such eggs rarely hatched. Embryonic mortality and early mortality of ducklings from dosed black duck hens were significantly greater. Similar effects, although less pronounced, resulted from a dietary dosage of 3 ppm of DDE. The initial field survey in 1964 revealed that the eggs of wild black ducks contained residues comparable to those found in eggs of captive hens fed 3 ppm. The eggshell thickness of eggs collected in 1964 was significantly less than the shell thickness of eggs from the pre-DDT era. The later survey in 1971 revealed that shells were only slightly thinner than those collected before DDT use, and residues were generally lower than levels found in eggs from the 1964 survey.

An experiment to test the effects of DDE on salt-gland function suggested that this compound could be detrimental to survival of ducks in habitats of moderate or high salinity (Friend et al., 1973). Salt glands are the main route of sodium chloride excretion in marine birds. The experiment showed that sublethal levels of DDE suppressed salt gland secretion in immature mallards not previously exposed to salt. There were no adverse effects on mallards whose salt glands had been previously stimulated by low-level salt exposure. It is possible that young birds exposed to moderate levels of DDE, making their first migration from the breeding grounds to coastal estuaries where they experience their first exposure to salt, could face an inability to eliminate toxic levels of salt taken in while feeding.

Brown Pelicans

The brown pelican has shown some of the most interesting and meaningful relationships concerning the influence of pollutants on eggshell thinning, subnormal reproductive success, and population decline (Fig. 7).

This colonial species nests in estuaries from North Carolina to the Amazon River on the east coast and from southern California to Chile on the west coast. Eggshell thinning occurred in every colony of brown pelicans studied in the United States (Blus, 1970; Blus, Neely, et al., 1974; Keith et al., 1970; Blus, Belisle, et al., 1974) and in most of the colonies studied in Mexico (Keith et al., 1970; Jehl, 1973). In 1969, a catastrophic situation was found in the only colony of the California brown pelican that is located in the United States. Eggshells of these pelicans on Anacapa Island, located in the Pacific Ocean several miles off Los Angeles, were so thin that they would break soon after laying. Average eggshell thinning ranged from approximately 35 percent (Blus et al., 1971; Keith et al., 1970) to 50 percent (Risebrough et al., 1971). In 1969, residues of DDE in the egg ranged from 40 to 140 ppm (fresh wet weight) (Blus, Belisle, et al., 1974). These residues of DDE were some of the highest ever recorded in wild birds. By use of stepwise regression analysis, it was shown that DDE accounted for essentially all of the eggshell thinning in the brown pelican (Fig. 8). Even small amounts of DDE, such as those found in eggs from certain parts of Florida, were shown to induce eggshell thinning (Blus et al., 1971; Blus et al., 1972a; Blus et al.,

Figure 7.—Two downy pelicans in a nest in South Carolina. Brown pelicans are very sensitive to organochlorine pollutants, particularly DDE. Eggshell thinning and reproductive failure were associated with these agents. Reproductive success has improved as residues have declined.

1972b). In Florida, eggshell thinning in most colonies was less than 10 percent and eggshell thickness in some lightly polluted areas, such as Florida Bay, was near normal. There also was a relationship between low levels of DDE and dieldrin in the egg and hatching success (Blus, Neely, et al., 1974).

Brown pelicans are a sensitive indicator of certain forms of environmental pollution and have shown marked improvement in reproductive success within the past two years as residues have declined. For example, about 0.92 young fledged per nest in the California colony in 1974 compared to less than 0.01 in 1969 when about four young were raised in the entire colony. During the same period, residues of DDT and metabolites in the estuaries near the colony and in the pelicans decreased dramatically (D. Anderson, personal communication). Residues of organochlorine pesticides and their metabolites also have declined markedly and reproductive success has vastly improved to an essentially normal level in the South Carolina colonies.

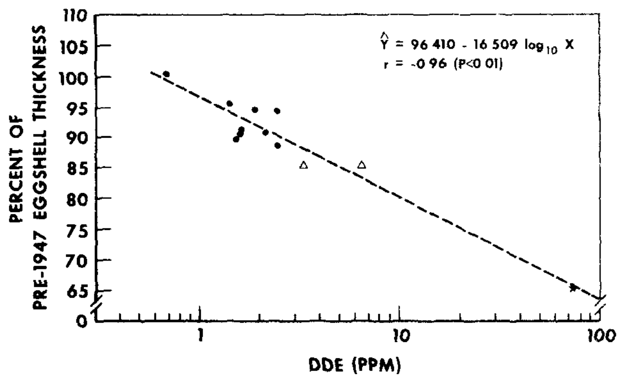


Figure 8.—Association of DDE residues in brown pelican eggs with changes in shell thickness. Data are from nine colonies in Florida (●), two colonies in South Carolina (Δ), and one colony in California (*) (Blus, Belisle, et al., 1974).

At one time, Louisiana contained more pelicans than any other state, probably in excess of 10,000 breeding pairs. They disappeared in the 1960's and did not return until reintroduced from Florida in recent years. Birds in this small colony bred successfully in 1971.

In Florida, pelicans have maintained their numbers over the past seven years, and seem to have normal reproductive success. Residues of organochlorines are generally low.

In the small North Carolina colony, reproductive success has been excellent in the past two years and the birds may be increasing in numbers.

Although there are vast improvements in reproductive success of the brown pelican in most parts of the U.S., a normal level has not yet been attained in Louisiana or California. This species is especially sensitive to certain forms of pollution, and its populations should be followed closely.

Royal Tern

Species of birds differ markedly from each other in susceptibility to organochlorines. The royal tern is an example of a relatively insensitive species. Although it lives in the same area of South Carolina as the brown pelican, it showed no evidence of eggshell thinning or lowered reproductive success. Residue levels of organochlorine pollutants in the tern eggs were similar to those in pelican eggs. The royal tern breeds for the first time when it is three or more years of age and usually lays only one egg per clutch. It is a long-lived species and its reproductive success is very good in South Carolina. Pollution effects have been suspected among other species of terns, however. Hays and Risebrough (1972) found abnormalities in several species of young terns near

Long Island, N.Y. These abnormalities seemed related to the very high load of PCBs they were carrying. Only a few dozen of the thousands of tern young seemed affected by the abnormalities. In the Netherlands, heavy pollution by certain organochlorine insecticides resulted in the virtual elimination of Sandwich terns (Koeman et al., 1967).

Estuarine Waders

The nesting colonies of herons and ibises found near the nation's estuaries are typically aggregations of several species, which vary with local habitat conditions. Greatest diversity is in the Southeast, where 10 or more of these species may nest together in a single heronry, accompanied by wood storks, double-crested cormorants, anhingas, and perhaps also brown pelicans.

Shell thickness of eggs of great blue herons, green herons, great egrets, snowy egrets, and black-crowned night herons has significantly decreased in some coastal areas since the mid-1940's (Anderson and Hickey, 1972; Faber et al., 1972; Faber and Hickey, 1973).

Reproductive success of a colony of great egrets in California declined between 1967 and 1970 (Faber et al., 1972). Successful nesting attempts decreased from 52 to 28 percent, and nests losing eggs increased from 30 to 54 percent. However, reproductive success of great blue herons in this colony did not decline during the same period. Egrets in the California colony were observed tossing broken eggs from their nests, a behavior that at least partially explains the disappearance of eggs during incubation. Grey herons in England also have been observed tossing eggs from their nests (Milstein et al., 1970; Prestt, 1970).

Thickness of the eggshells of the California egrets was 15.2 percent less than that of eggshells in museum collections (Faber et al., 1972). Thickness of great blue heron eggshells was 10.4 percent less than those collected prior to 1947.

In 1972, extensive field studies were begun of waders in the estuaries of the gulf and Atlantic coasts as well as freshwater habitats throughout the eastern United States. Both species and geographic differences in pollutant residues were apparent. Of samples analyzed thus far, great egret eggs or black-crowned night heron eggs contained the highest average amounts of DDE and PCBs at all localities where they were collected. Eggs of cattle egrets and glossy ibis generally had greater amounts of dieldrin than did the eggs of other species.

Dissimilar food preferences may be at least a partial cause of differences in organochlorine residues in different species. Great egrets and night herons feed on larger fish of different kinds than do other birds (Bent, 1922, 1926; Palmer, 1962). Night herons are particularly active at dawn and dusk, whereas the other species feed more actively during the day. Cattle egrets and glossy ibis feed more extensively on lower invertebrates. Cattle egrets feed almost altogether in terrestrial sites whereas ibises feed exclusively in mud flats. Other species feed primarily in aquatic areas, eating a variety of organisms including fish of various sizes.

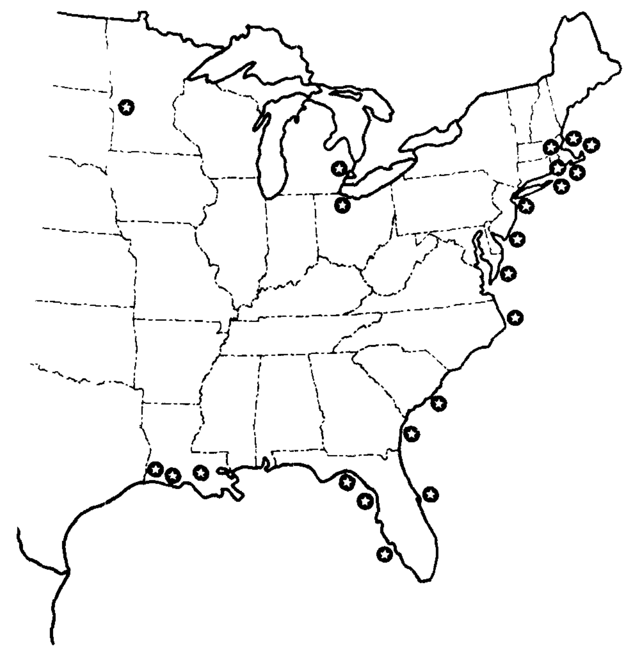


FIGURE 9.—Black-crowned night heron eggs were collected at 21 localities in estuarine and inland water areas in 1972 and 1973. Organochlorine residues are shown in Figures 10 and 11.

Differences related to geographic location proved to be greater than those related to the species. Both kinds and quantities of residues in eggs varied geographically. Distribution of residues in black-crowned night heron eggs is illustrative. Black-crowned night herons are one of the most widely located species of waders. They have declined both in Michigan and southern New England (Wallace, 1969; Hickey, 1969; Anonymous, 1971, 1973; Arbib, 1972).

Chemical residues were relatively higher in black-crowned night heron eggs from northern Atlantic estuaries (Fig. 9, 10, 11) than from gulf and southern Atlantic estuaries. On! mirex occurred more frequently and in greater amounts in the samples from the south. Residues were consistently highest in areas where the population had declined.

A black-crowned night heron egg from Long Island contained the greatest amount of DDE (61 ppm

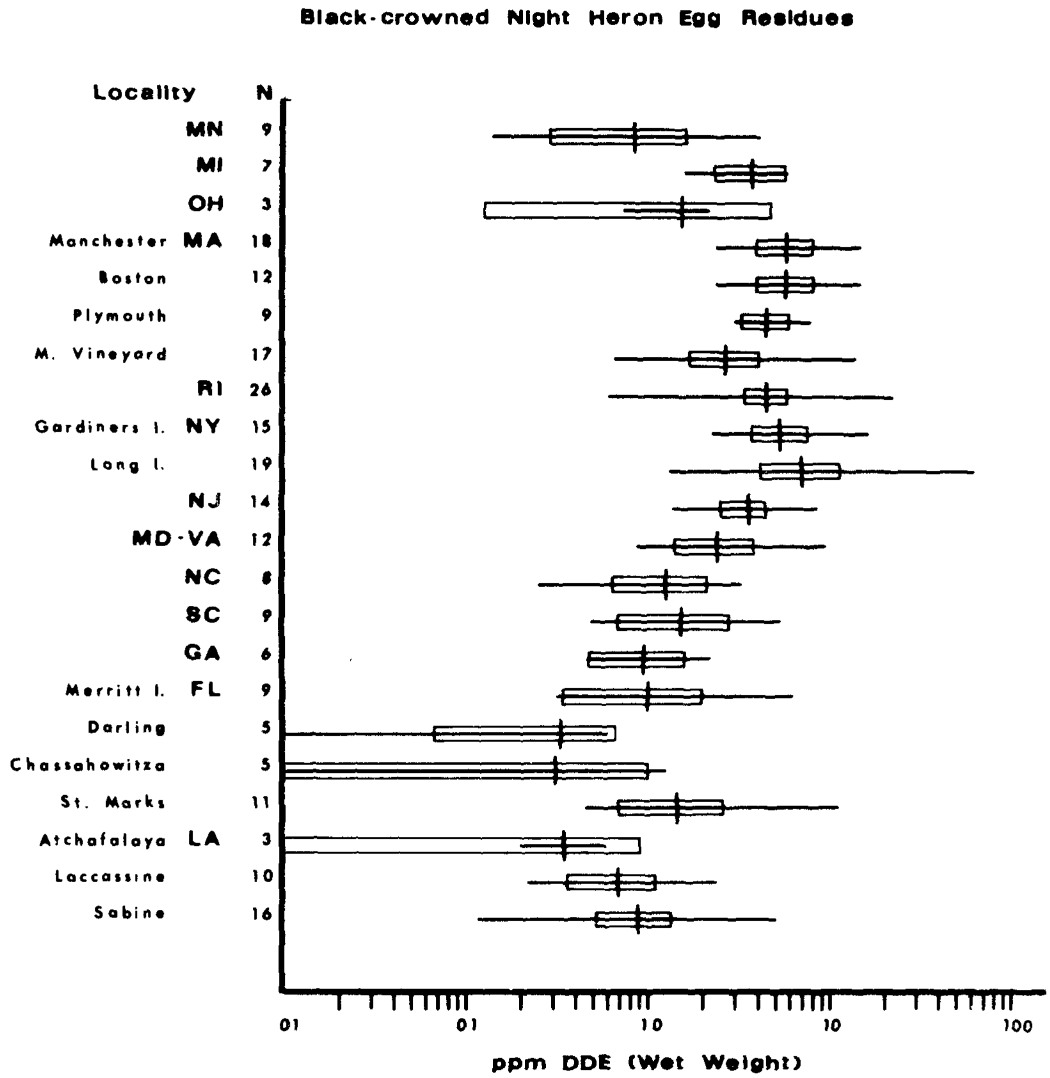


FIGURE 10.—DDE in black-crowned night heron eggs. Concentrations were highest in the northeastern estuaries. Vertical lines show the average values; enclosed bars show the limits within which 95 percent of the values are estimated to lie; horizontal lines show the complete range of values, from low to high. Residues were consistently highest in areas where populations have declined.

fresh wet weight). DDE exceeded 15 ppm only in samples from Long Island and Rhode Island. DDT concentrations generally were below 1 ppm, but measured 58 ppm in one egg from Long Island. The highest level of dieldrin in a single egg was 7.8 ppm in a sample from Plymouth Bay, Mass.; the mean for that clutch was 6.7 ppm. Dieldrin exceeded 2 ppm in samples from Martha's Vineyard, Mass., Rhode Island, and Long Island. Mirex (3.0 ppm) was highest in a sample from South Carolina; it exceeded 1 ppm in two other eggs from this locality. Hexachlorobenzene was measurable in samples from Chappaquiddick, Mass. (the maximum, 0.48 ppm), Manchester, Mass., Long Island, and western Lake Erie. The highest level of PCBs in a single egg was 102 ppm in a sample from Rhode Island, and the highest average level in a clutch was 94 ppm in samples from Boston Harbor. PCBs exceeded 25 ppm in samples from Manchester, Boston Harbor, Rhode Island, Long Island, and the Detroit River.

In six of the eight regions compared, shell thickness was significantly less in the 1972–3 samples than in samples taken before the mid 1940's. The greatest decrease has been in New Jersey (10.6 percent), Massachusetts (9.3 percent), and in New York, Rhode Island, and Connecticut combined (7.1 percent). The decline in eggshell thickness was significantly related to DDE contained in the eggs (Fig. 12).

Patterns of chemical residue distribution are diffi-

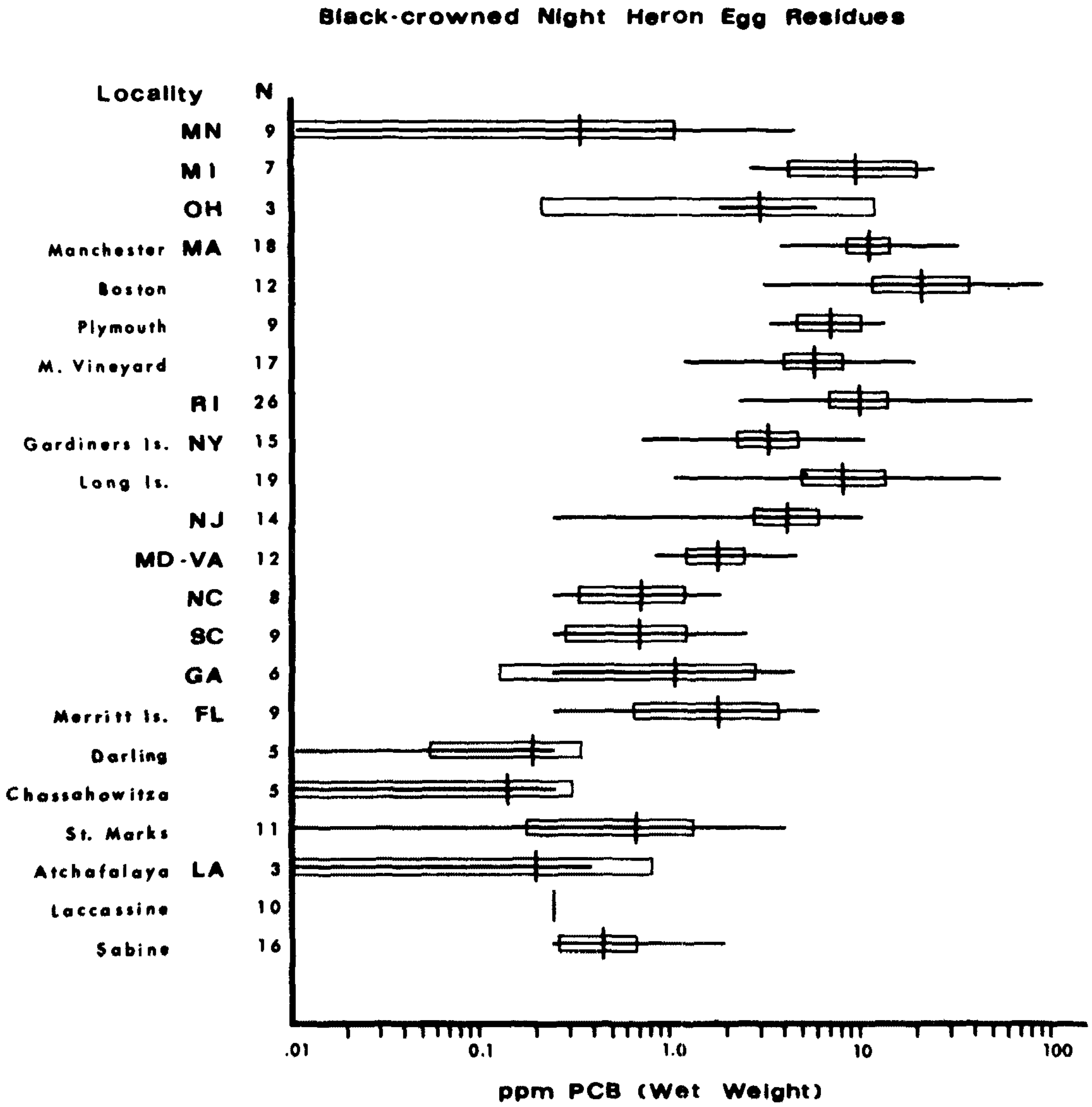


FIGURE 11.—PCBs in black-crowned night heron eggs. Concentrations were highest in the northeastern states, following the same pattern as DDE.

cult to interpret because migratory birds that nest in a particular locality may have over-wintered in dissimilar areas. Also, some herons move northward after the nesting season, prior to migrating southward. Some, however, remain along the Atlantic coast throughout the year, as far north as Maine.

It has frequently been suggested that the greatest pollution problems are in Latin America. The relationship of residues of organochlorines in eggs to wintering areas was established by examination of all available recovery records of black-crowned night herons that had been banded as nestlings in eastern North America. The records showed that fewer of the birds from the northern coast, where residues were higher, were recovered in Latin American countries, showing that the higher residues in northern birds should not be attributed to wintering in Latin America (Table 3).

CONCLUSIONS

Bird populations should increase with the reduction of estuarine pollution. Improved conditions of habitat and food supply will require reduction of both chemical and non-chemical pollution. Improved survival and reproduction will require reduction of organochlorine chemicals. Elimination of lead poi-

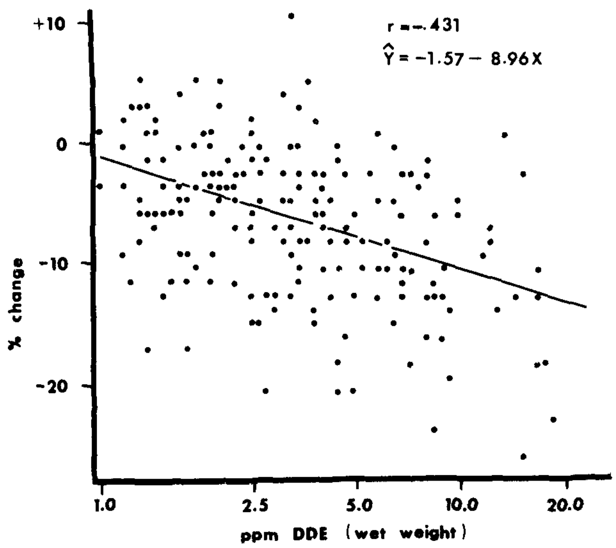


FIGURE 12.—Association of DDE residues in black-crowned night heron eggs with changes in shell thickness. Percentage decrease in shell thickness relates to eggs collected prior to DDT use.

Table 3.—*Wintering localities of black-crowned night herons that nest along Atlantic estuaries. Birds that nest in the north and have high residues in their eggs are recovered less frequently in Latin America, showing that the high residues should not be attributed to wintering in Latin America.*

Location of banding	Location of Recovery		
	U.S.—Canada	Latin America	Total
North Atlantic States[1]	147	13	160
South Atlantic States[2]	41	10[3]	51
Total	188	23	211

[1] New York to Massachusetts
[2] Florida to New Jersey
[3] Significantly greater (P = 2.29) numbers than from birds banded in northern Atlantic states.

soning of waterfowl will require the substitution of some less toxic metal, such as iron, in the manufacture of shot-gun pellets. The ecological impact of most heavy metals on estuarine birds is unknown.

REFERENCES

Abbott, J. M. 1973. Bald eagle nest survey 1973. Atl. Nat. 28(4):158–159.

Ames, P. L. and G. S. Mersereau. 1964. Some factors in the decline of the osprey in Connecticut. Auk 81(2):173–185.

Anderson, D. W. and J. J. Hickey. 1972. Eggshell changes in certain North American birds. Proc. XVth Int. Ornithol. Congr.:514–540.

Anonymous. 1971. Announcing—The blue list: An "early warning system" for birds. American Birds 25(6):948–989.

Anonymous. 1973. The blue list for 1974. American Birds 27(6):943–945.

Arbib, Robert. 1972. The blue list for 1973. American Birds 26(6):932–933.

Baskett, T. S. 1975. Mercury residues in breast muscles of wild ducks. Pestic. Monit. J. 9:67–78.

Belisle, A. A., W. L. Reichel, L. N. Locke, T. G. Lamont, B. M. Mulhern, R. M. Prouty, R. B. DeWolf, and E. Cromartie. 1972. Residue of organochlorine pesticides, polychlorinated biphenyls, and mercury, and autopsy data for bald eagles, 1969 and 1970. Pestic. Monit. J. 6(3):133–138.

Bellrose, R. C. 1959. Lead poisoning as a mortality factor in waterfowl populations. Ill. Nat. Hist. Surv. Bull. 27(3):235–288.

Bent, A. C. 1922. Life histories of North American petrels, pelicans, and their allies. United States National Museum Bulletin 121.

Bent, A. C. 1926. Life histories of North American marsh birds. United States National Museum Bulletin 135.

Blus, L. J. 1970. Measurements of brown pelican eggshells from Florida and South Carolina. BioScience 20:867–869.

Blus, L. J., A. A. Belisle, and R. M. Prouty. 1974. Relations of the brown pelican to certain environmental pollutants. Pestic. Monit. J. 7(3/4):181–194.

Blus, L. J., C. D. Gish, A. A. Belisle, and R. M. Prouty. 1972. Logarithmic relationship of DDE residues to eggshell thinning. Nature 235(5338):376–377.

Blus, L. J., C. S. Gish, A. A. Belisle, and R. M. Prouty. 1972b. Further analysis of the logarithmic relationship of DDE residues to eggshell thinning. Nature 240:164–166.

Blus, L. J., R. G. Heath, C. D. Gish, A. A. Belisle, and R. M. Prouty. 1971. Eggshell thinning in the brown pelican: Implication of DDE. BioScience 21:1213–1215.

Blus, L. J., B S. Neely, Jr., A. A. Belisle, and R. M. Prouty. 1974. Organochlorine residues in brown pelican eggs: Relation to reproductive success. Environ. Pollut. 7:81–91.

Bourne, W. R. P. 1974. Guillemots with damaged primary feathers. Mar. Pollut. Bull. 5(6):88–90.

Broley, C. L. 1958. The plight of the American bald eagle. Audubon Mag. 60(4):162–163.

Burns, Kathryn A. and John M. Teal. 1971. Hydrocarbon incorporation into the salt marsh ecosystem from the West Falmouth oil spill. National Technical Information Service, U.S. Department of Commerce, COM-73-10419. p. 1–24.

Crocker, A. D., J. Cronshaw, and W. N. Holmes. 1974. The effect of a crude oil on intestinal absorption in ducklings (*Anas platyrhynchos*). Environ. Pollut. 7(3):165–177.

Cromartie, E., W. L. Reichel, L. N. Locke, A. A. Belisle, T. E. Kaiser, T. G. Lamont, B. M. Mulhern, R. M. Prouty, and D. M. Swineford. 1974. Residues of organochlorine pesticides and polychlorinated biphenyls and autopsy data for bald eagles, 1971 and 1972. Pestic. Monit. J. In Press.

Emerson, D. and M. Davenport. 1963. Profile of the osprey. Narragansett Nat. 6(2):56–58.

Faber, R. A and J. J. Hickey. 1973. Eggshell thinning, chlorinated hydrocarbons, and mercury in inland aquatic bird eggs, 1969 and 1970. Pestic. Monit. J. 7(1):27–36.

Friend, M., M. A. Haegele, and R. Wilson. 1973. DDE: Interference with extra-renal salt excretion in the mallard. Bull. Environ. Contam. Toxicol. 9(1):49–53.

Hartung, Rolf. 1963. Ingestion of oil by waterfowl. Pap. Mich. Acad. Sci., Arts Lett. 48:49–55.

Hartung, Rolf. 1964. Some effects of oils on waterfowl. PhD thesis, University of Michigan.

Hartung, Rolf. 1965. Some effects of oiling on reproduction of ducks. J. Wildl. Manage. 29(4):872–874.

Hays, H. and R. W. Risebrough. 1972. Pollutant concentrations in abnormal young terns from Long Island Sound. Auk 89:19–35.

Heath, R. G. and S. A. Hill. 1974. Nationwide organochlorine and mercury residues in wings of adult mallards and black ducks during the 1969–70 hunting season. Pestic. Monit. J. 7(3/4):153–164.

Heinz, Gary. 1974. Effects of low dietary levels of methyl mercury on mallard reproduction. Bull. Environ. Contam. Toxicol. 11(4):386–392.

Henny, C. J. and J. C. Ogden. 1970. Estimated status of osprey populations in the United States. J. Wildl. Manage. 34(1):214–217.

Hickey, J. J., editor. 1969. Peregrine falcon populations: Their biology and decline. Univ. Wisconsin Press, Madison.

Hickey, J. J. and D. W. Anderson. 1968. Chlorinated hydrocarbons and eggshell changes in raptorial and fish-eating birds. Science 162(3850):271–273.

Jehl, J. R., Jr. 1973. Studies of a declining population of brown pelicans in northwestern Baja California. Condor 75:69–79.

Keith, J. O., L. A. Woods, Jr., and E. G. Hunt. 1970. Reproductive failure in brown pelicans on the Pacific Coast. Trans. 35th N. Am. Wildl. Nat. Resour. Conf., 56–64.

Kleinert, S. J. and P. E. DeGurse. 1972. Mercury levels in Wisconsin fish and wildlife. Wisc. Dep. Nat. Resour. Tech. Bull. 52.

Koeman, J. H., A. A. G. Oskamp, J. Veen, E. Brouwer, J. Rooth, P. Zwart, E. Van den Broek, and H. Van Genderen. 1967. Insecticides as a factor in the mortality of the Sandwich tern (*Sterna sandvicensis*). Meded. Rijksfac. Landbouwwet. Gent. 32(3/4):841–854.

Kopischke, Earl D. 1972. The effect of 2,4-D and diesel fuel on egg hatchability. J. Wildl. Manage. 36(4):1353–1356.

Krantz, W. C., B. M. Mulhern, G. E. Bagley, A. Sprunt, IV, F. J. Ligas, and W. B. Robertson, Jr 1970. Organochlorine and heavy metal residues in bald eagle eggs. Pestic. Monit. J. 4(3):136–140.

Longcore, J. R. and B. M. Mulhern. 1973. Organochlorine pesticides and polychlorinated biphenyls in black duck eggs from the United States and Canada—1971. Pestic. Monit. J. 7(1):62–66.

Longcore, J. R., F. B. Samson, and T. W. Whittendale, Jr. 1971. DDE thins eggshells and lowers reproductive success of captive black ducks. Bull. Environ. Contam. Toxicol. 6(6):485–490.

Mills, Harlow B., William C. Starrett, and Frank C. Bellrose. 1966. Man's effect on the fish and wildlife of the Illinois River. Illinois Natural History Survey Biological Notes No. 57.

Milstein, P. le S., I. Prestt, and A. A. Bell. 1970. The breeding cycle of the grey heron. Ardea 58:171–257.

Mulhern, B. M., W. L. Reichel, L. N. Locke, T. G. Lamont, A. A. Belisle, E. Cromartie, G. E. Bagley, and R. Prouty. 1970. Organochlorine residues and autopsy data from bald eagles 1966–1968. Pestic. Monit J. 4(3):141–144.

Palmer, R. S., editor. 1962. Handbook of North American birds. Yale University Press, New Haven.

Peterson, F. T. 1969. Population trends of ospreys in the northeastern United States. Pages 333–337 *in* J. J. Hickey, ed. Peregrine falcon populations: Their biology and decline. Univ. of Wisconsin Press, Madison.

Porter, R. D. and S. N. Wiemeyer. 1969. Dieldrin and DDT: Effects on sparrow hawk eggshells and reproduction. Science 165(3889):199–200.

Prestt, Ian. 1970. Organochlorine pollution of rivers and the heron (*Ardea cinerea* L.). Papers and Proceedings, IUCN Eleventh Technical Meeting, Vol. I. p. 95–101.

Ratcliffe, D. A. 1967. Decrease in eggshell weight in certain birds of prey. Nature 215(5097):208–210.

Reichel, W. L., E. Cromartie, T. G. Lamont, B. M. Mulhern, and R. M. Prouty. 1969. Pesticide residues in eagles. Pestic. Monit. J. 3(3):142–144.

Rhodes, L. I. 1972. Success of osprey nest structures at Martin National Wildlife Refuge. J. Wildl. Manage. 36(4):1296–1299.

Risebrough, R. W., F. C. Sibley, and M. N. Kirven. 1971. Reproductive failure of the brown pelican on Anacapa Island in 1969. Am. Birds 25(1):8–9.

Robards, F. C. and J. G. King. 1967. Nesting and productivity of bald eagles: Southeast Alaska—1966. U.S. Dep. Interior, BSF&W, Juneau, Alaska.

Schmid, F. C. 1966. The status of the osprey in Cape May County, New Jersey between 1939 and 1963. Chesapeake Sci. 7(4):220–223.

Snyder, S. B., J. G. Fox, and O. A. Soave. 1973. Mortalities in waterfowl following Bunker C fuel exposure. Division of Laboratory Animal Medicine, Stanford Medical Center, Processed report. xxi + 27 p.

Sprunt, A., IV, W. B. Robertson, Jr., S. Postupalsky, R. J. Hensel, C. E. Knoder, and F. J. Ligas. 1973. Comparative productivity of six bald eagle populations. Trans. N. Am. Wildl. Nat. Resour. Conf. 38:96–106.

Wallace, G. J. 1969. Endangered and declining species of Michigan birds. The Jack-Pine Warbler 47(3):70–75.

Wiemeyer, S. N. 1971. Reproductive success of Potomac River ospreys—1971. Proc. N. Am. Osprey Res. Conf. In Press.

Wiemeyer, S. N., B. M. Mulhern, F. J. Ligas, R. J. Hensel, J. E. Mathisen, F. C. Robards, and S. Postupalsky. 1972. Residues of organochlorine pesticides, polychlorinated biphenyls, and mercury in bald eagle eggs and changes in shell thickness—1969 and 1970. Pestic. Monit. J. 6(1):50–55.

Wiemeyer, S. N. and R. D. Porter. 1970. DDE thins eggshells of captive American kestrels. Nature 227(5259):737–738.

Wiemeyer, S. N., P. R. Spitzer, W. C. Krantz, T. G. Lamont, and E. Cromartie. 1974. Effects of environmental pollutants on Connecticut and Maryland ospreys. J. Wildl. Manage. In Press.

ESTUARINE LAND USE MANAGEMENT: THE RELATIONSHIP OF AESTHETIC VALUE TO ENVIRONMENTAL QUALITY

ROY MANN
Roy Mann Associates, Inc.
Cambridge, Massachusetts

ABSTRACT

Although advances in identification and management of aesthetic resources have been made possible through recent legislation and administrative guidelines dealing with the estuarine environment, new measures are needed if significant impacts on aesthetic resources and resulting effects on water quality are to be avoided. This paper recommends the adoption of expanded review responsibilities and standards on the part of federal and state agencies, and the creation of new funding elements to achieve improved estuarine aesthetic resource protection and management.

INTRODUCTION

Aesthetics has always been a hard word and difficult concept for government. Until recently, scenic or aesthetic resource protection often was more notable by its absence than by its inclusion in legislation or administrative actions dealing with critical coastal or estuarine concerns. The reasons for this are generally four-fold:

1) *unfamiliarity* on the part of agency officials and planners with the subject of aesthetics;
2) a traditional *bias* in systems-oriented planning and engineering disciplines against aesthetic considerations and values as "soft" or "subjective" areas in contrast to such "hard" and "objective" areas as economic, biological, water quality, and other factors more easily examined by empirical, systematic, and quantitative methods;
3) a *preference* on the part of protection-conscious planners and legislators to achieve aesthetic protection under the guise of supposedly more legitimate objectives as recreation, ecological protection, shore cover retention, and public safety (as in flood plain and erosion zone prohibitions).
4) a *slowness* of the courts to support government actions to protect resources on aesthetic grounds alone.

As Cerny has pointed out (1974), the bulk of case law on aesthetics has been founded on the urban experience. Little has come from litigation dealing with non-urban resources, although the latter of course has been the subject of considerable attention in terms of health, hazard, and resource utilization.

The courts have often held aesthetics to be a secondary or peripheral issue, while recognizing health and safety as primary constitutional concerns (Cerny, 1974). More recently, however, aesthetics has been recognized as an economic consideration, as in United Advertising Corporation v. Metuchen which found that "a discordant sight is as hard an economic fact as an annoying odor or sound."[1] In the noted case of Berman v. Parker the Supreme Court upheld the use of the power of eminent domain to achieve a more attractive community, stating that: "The concept of the public welfare is broad and inclusive. The values it represents are spiritual as well as physical, aesthetic as well as monetary."[2]

In the future, hopefully, the courts should be expected to increasingly support the recognition of aesthetics as a primary issue under the public welfare clause of the constitution. If this happens, government at all levels will be able to better regulate the appearance of natural and manmade resources in estuaries and their uplands. Government, however, must take the initiative in creating new legislation and administrative procedures to face the test of the courts.

Now that full and open consideration of aesthetic resources in the coastal zone has been legitimatized by the Coastal Zone Management Act of 1972, the lexicon of aesthetic resource management should soon become more familiar to officials, planners and the public. Bias against aesthetic value determinations should disappear, as criteria, standards, and

[1] 42 N.J. 1, 198 A.2d 447 (1964)
[2] 348 U.S. 26, 99 L.Ed. 27, 75 S.Ct. 98 (1954)

methods for accomplishing them come into accepted use. Aesthetic resource protection and management will surely become recognized by the courts independent of, although reinforced with, other legitimate coastal zone concerns.

It is the intent of this paper, however, to demonstrate that new approaches and measures may be needed to ensure timely and effective achievement of public aesthetic objectives in the coastal zone.

Before proceeding further, a review of several pertinent definitions will help place the discussion in proper focus. The estuarine zone, with which we are directly concerned here, is defined under Section 104(n)(4) of the Water Quality Pollution Control Act Amendments of 1972 as an "environmental system consisting of an estuary and those transition areas which are consistently influenced or affected by water from an estuary such as, but not limited to salt marshes, coastal or intertidal areas, bays, harbors. . . ." Although the terms "transition areas" and "coastal . . . areas" may be broadly interpreted as extending considerable distances into adjacent upland, it is unlikely that "estuarine zone" under the present writing of the Act can be interpreted to extend to the full view of estuary-related aesthetic resources, that is, to inland coastal zone horizons removed from consistent influence by estuarine waters.

The coastal zone, as defined under Section 304(a) of the Coastal Zone Management Act can be considered a more extensive entity, comprising coastal waters and adjacent shorelands "strongly influenced by each other and in proximity to the shorelines." The zone "extends inland from the shorelines only to the extent necessary to control shorelands, the uses of which have a direct and significant impact on coastal waters." Under this definition, virtually all coastal watersheds may be included, on the premise that runoff and water-borne pollutants and suspended materials influence coastal waters. In many instances, coastal watershed divides also effectively define the limits of aesthetic resources associated with the coastal zone, although other topographic boundaries are often needed to delineate them.

Estuarine zone aesthetic resources are features of estuaries and coastal lands which possess attention-arresting perceivable values. Intangible attributes may also be apparent and often strengthen the value of the resource. For example, common knowledge that marshes are essential to the estuarine food web and that they are endangered by man's activities adds to the aesthetic esteem in which marshes are held by the observer. Negative aesthetic factors are elements which diminish the landscape value of these resources: debris which mars a water surface, land fill encroachment which disrupts the visual integrity of a foreshore, or waterfront high-rise buildings which are architecturally styled without recognition of the inherent qualities of the estuarine zone within which they are placed.

Landscape management is a broad term which may be used to correlate four interdependent activities affecting estuarine or coastal zone aesthetic resources:

1) land use planning, including capability and area use priorities;
2) site selection for development or conservation purposes;
3) site planning of land modifications or facility development;
4) architectural and landscape design.

Each of the above four categories relates significantly to the wise management, protection, and use of the estuarine and coastal landscape.

Resource priorities are the best purposes to which land and water resources may be put under the wisest use principle. The full range of terms is employed in the Coastal Zone Management Act: preservation, protection, restoration, enhancement, utilization, and development.

One hitherto under-recognized fact is that aesthetic resources, under the definitions reviewed here, pertain to all observable manifestations of estuarine or coastal physical resources, not simply to "scenic" resources alone. The shift from scenic protection to aesthetic management implies a greater concern for the common or ordinary landscape, with which most people are in contact most of the time. Moreover, with the call for standards and criteria under both the new federal legislation and growing state legislation, emphasis is increasingly on the need for aesthetic protection, maintenance, or enhancement in all actions. Whether a physical resource is altered for conservation-education activity, for dense residential-marina development, or for large-scale facility construction, the same principle emerges: maximum maintenance or protection of appearance quality, i.e. safeguards even with development. The same principle is intended for already altered or degraded resource areas; restoration and enhancement planning is specifically called for in the CZMA, as is attention to potential, as well as existing coastal zone resources.

AESTHETIC RESOURCES AND THE FACTORS WHICH AFFECT THEM

The aesthetic resource problem in the estuarine or coastal zone is two-fold:

a) identifying and evaluating valuable aesthetic resources and deciding what may be done to maximize their preservation and wisest use,

b) identifying negative aesthetic factors and what may be done to restore the landscape-waterscape to its fullest aesthetic potential.

The Aesthetic Resource Base

Figure 1 presents a condensed analysis of four aesthetic resources of the estuarine zone, selected attributes, and managerial and institutional implications. It should be stressed that aesthetic resources can be more accurately understood as aesthetic attributes of all perceivable resources. The following selected resource descriptions will demonstrate this.

Open waters, offshore and estuarine, have important aesthetic attributes. Ocean and other offshore waters possess dramatic aesthetic value where a sea-sky horizon can be perceived without interruption. Broad estuarine waters share some aesthetic qualities with offshore waters. Natural islands falling within view may enhance the overall aesthetic, creating even greater visual drama, but artifical islands, offshore platforms, dredging and drill ships, and other point elements may diminish this view, in proportion to their randomness and proximity to shore.

Estuarine foreshores and related edges possess many unique and uncommon visual characteristics. The "sea-of-grain" qualities of broad marshes of salt-marsh cordgrass or sawgrass and the flickering of breezes across the high marsh grasses are well-known features to even distant passers-by. Visual microcosms are also of aesthetic importance to both serious and casual students of the marsh: the rushing of a tide through a narrow inlet, or the fishing of waterfowl for crustaceans, the nesting and feeding characteristics of all marsh wildlife.

Nevertheless, attitudes toward marsh aesthetics, as toward all estuarine aesthetic resources, vary considerably according to place of residence, occupation, income, recreational preferences, age, education, sympathy with the conservation ethic, and even the day of the week or season—in short, on all the socio-economic and cultural factors that help determine attitudes and preferences of people towards all environmental values. Standing opposite each other, to see it simply, are the foreshore developer and the estuary preservationist. All others may stand somewhere between these two poles.

Analysis of these individual preferences, however, will not necessarily contribute to a firmer understanding of actions needed in the estuarine or coastal zone. Aside from the difficulty experienced by researchers to date in assessing public opinion about aesthetic values, the fact that preferences vary frequently according to all these conditions makes their validity problematic as a base for public long-term land and water resource use policy.

Furthermore, in light of the new status of all aesthetics in the coastal zone, the ordinary landscape will require careful attention along with the outstanding scenic assets or issue areas. The ordinary landscape will seldom be ranked high in preference analysis, yet it is the landscape which is most frequented by people, and where many of their aesthetic and recreational interests and satisfactions are being met. With time and the greater concentration of population in the coastal zone, the ordinary landscape will become increasingly important.

Problems and Impact Factors

General Conflicts Between Natural Resource Aesthetics and Development

A careful distinction must be made between design quality and aesthetic compatability of man-made modifications of land and water resources. A modification of the terrain (e.g. a power plant, a marina, a new town) may achieve a high degree of design quality when examined independently of the surrounding environment, but may fail to achieve aesthetic compatibility with the environment in one or more ways. The development may have been sited poorly in relation to the water's edge or to scenic background—instances of visual incompatibilities. Or the development may have intruded into the last remaining unaltered reach of a coastline—an example which depicts incompatibility with visual as well as intangible aesthetic resources (the latter including the interest in wilderness or rurality and a respite from the urban environment). Aesthetic compatibility, is high, obviously, when incompatibilities are avoided, either wholly, or to the maximum degree. The term aesthetic resource protection can be said to mean the minimization or prevention of aesthetic imcompatibilities.

To a degree, therefore, aesthetic resource protection can be considered a preservationist mechanism. The Wild and Scenic Rivers Act is one example of legislation to prevent incompatible alterations to the nation's aesthetic resources. But aesthetic resource protection is not exclusively an instrument for preservation. Employed in a management sense, protection of the environment against aesthetic incompatibilites can be operative at every level of activity between preservation and intensive de-

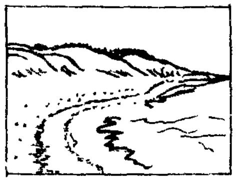
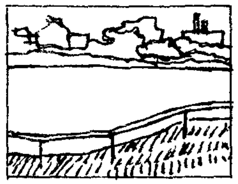
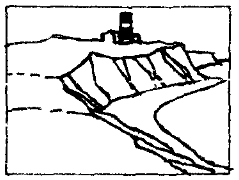
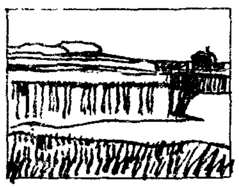
	Resource Type	(Selected) Visual Attribute(s)	(Selected) Intangible Attribute(s)	Managerial Implications	Institutional Implications
	beach	-sand qualities -forms -sweep	-molding by sea energy -primordial state, geological record	-exclusion or regulation of structures -debris, trash, dune buggy regulation -user-capacity determinations	-town exclusionary use vs. open public use (visual access) -public use of private beaches -maintenance funding
	riverbank	-landform configuration -vegetative characteristics -space/closure patterns	-order given to rural and urban land use -natural corridor provides physchological linkage to both source region and sea	-bank erosion protection -vegetative edge protection -clearance and planting management -urban area rehabilitation	-conciliation of split jurisdictions over riverbank areas -administration of public access and access acquisition
	bluff	-landform face -crest patterns -height	-impressiveness -sense of geological process -sense of hazard	-exclusion or regulation of use on or near crest and face -cautionary use of erosion protection measures	-development of legislative and administrative regulation of bluff areas
	tidal marsh	-vegetative infrastructures -seasonal change -wind imprints -tidal changes	-sense of (urban) endangerment -sense of significance in estuarine ecosystem	-prohibition of dredging, filling -regulation of permitted, compatible use	-development of legislative and administrative regulation of marsh areas

FIGURE 1.—Selected aesthetic resource and problem definitions.

velopment. In practice, aesthetic resource management has often been meshed with other environmental management considerations, from public policies and guidelines for land use and development decisions to state land use zoning (e.g. Hawaii), shoreland zoning ordinances (e.g. Wisconsin, Minnesota), shoreline appearance and design regulations (e.g. California), and strong land-use controls (e.g. Vermont, Maine).

With the above background distinctions in mind, the following conflicts should be recognized as being of prime importance in the coastal or estuarine environment.

RESIDENTIAL DEVELOPMENT

Population growth, adequate disposable incomes, increased interest in water-related recreation, and in seasonal or second-home acquisition have resulted in enormous pressures for waterfront residential development in estuarine zones of the United States. In Florida, and elsewhere, marshes and intertidal flats have been dredged and filled to create finger canal communities, resulting in severe damage to estuarine ecosystems, as well as significant aesthetic impact.

In other areas of the estuarine or coastal zone densely set seasonal homes with insufficient sideyards block views to the water and present walls of monotony. Condominium, multiple unit, and cluster development typically achieve better standards of design and improved site layout than row development or tract housing, but also elevate densities and the impression of intrusion to suburban or near-urban levels. In most cases public access to beach, bluff, or water edges is precluded or greatly diminished with a concomitant reduction in the public enjoyment or utilization of these aesthetic resources.

Bluff-top development often diminishes shoreline aesthetic value, since user desires to view water and shoreline from the bluff are frustrated, as may be the desires of users below the bluff or across the water to view natural scenic heights and skyline.

Development on sand dunes, interdunal areas, and barrier beaches seriously reduces the aesthetic value of beach and dune resources for even distant users, since one key aesthetic criterion of such systems is the magnitude of their uninterrupted "sweep" away towards the long-shore horizon. The unique geometry of windformed dunes is also lost under development. The general answers to all land and water use problems are two-fold: greater exercise of powers to prevent the siting of development in sensitive estuarine areas, and greater exercise of powers to secure appropriate siting and design within the overall site.

MARINA DEVELOPMENT

The aesthetic impacts of boating facilities in estuarine zones are complicated. On the one hand, most boats are of great aesthetic interest, since they constitute functional design responses to the challenges of moving on water. They are also generally colorful, sometimes powerful, and always part of a fascinating tradition that began with two of mankind's earliest livelihoods: fishing and navigation.

On the other hand, the congestion in large marinas, exposed repair and storage structures, and parking areas may constitute negative aesthetic factors to many people, including boaters. The preemption of marshes or of water surfaces and shorelines in small estuarine areas may also damage the aesthetic value of such areas in the view of conservation-interested users. Outboard engine noise has also been considered offensive by many. Certain recreational conflicts, such as that between power and sail users, can also be considered an aesthetic concern.

COMMERCIAL PORTS AND MINERAL EXTRACTION

Commercial navigation and ports also create mixed aesthetic impacts. Ships and dock facilities arouse the interest of most people. Yet the total image of ports and port-related industry to users in the distance may not impart a sense of high aesthetic value. Very large crude carriers (VLCC's, or "supertankers") may be impressive as a design aesthetic, but viewing them may also trigger negative intangible reactions related to anticipations of possible collisions and oil spills.

Most port areas also have large warehousing, open depot, and sprawled service and equipment storage facilities which possess little of the interest that characterizes the ships and docksides. Floating debris, polluted water, deteriorated wooden piers, blighted waterfront commercial buildings, and unattractive land uses that are unrelated to the water (e.g. scrapyards, utilities, parking lots) also are present in many port-industrial waterfronts.

Mineral extraction presents an aesthetic concern to the extent that this activity exposes structures and activities to view along non-industrial shores. The present direction of Outer Continental Shelf and shore-area oil exploration, extraction, transfer, and processing may create intense conflicts with estuarine aesthetic resources if caution is not exercised in preventing undesirable offshore or onshore patterns along scenic coasts.

URBAN CENTERS

High-rise urban development may introduce into estuarine zones and coastal areas a number of aesthetic effects other than those originating in density and land usage as such. Height, the principal visual attribute, can be perceived by the viewer as a dominance of the structure over the surrounding landscape. The higher the building, the greater the dominance, generally. Impact may be modified by such factors as proximity to (or setback from) the shoreline or other vital user locations, degree of urbanization of the surrounding landscape, elevation of the site above surrounding terrain, building mass and exterior architecture, color, texture, and reflectivity of exterior materials, and masking vegetation and landforms. In shore areas of particularly important scenic value, it is generally necessary to exclude all prominent buildings or to keep the tops of buildings close to or within the vegetational canopy if dimunition of the existing aesthetic value is to be avoided.

Adverse community reaction to planned or completed high-rise projects on coastal margins can be interpreted to be largely an expression of opposition to the anticipated dominance of the project over the landscape, as well as to the presumed preemption of public view-space by a small group of privileged users. The subordination of the Hudson River Palisades by high-rise apartment construction has prompted public reaction on both accounts. The unsuccessful 1972 San Francisco referendum bid to bring a halt to further high-rise construction is another example of strong public concern on this issue.

PUBLIC ACCESS AND RECREATIONAL SHORELINES

The fact that recreational shoreline is severely limited indicates the lack of satisfaction many coastal zone or estuarine users presumably feel as they seek out viewing or recreational access to the water. Public viewing points on coastal and estuarine shores are in short supply, while private ownership and development mask many scenic vistas and other aesthetic resources.

Public shoreline recreational facilities resolve the lack of access, but may be afflicted with congestion by numbers of people that exceed the capacity of the resource to support them. Moreover, as the Outdoor Recreation Resources Review Commission ably pointed out in 1962, the demand for beach and other shore recreation facilities is highest in proximity to urban centers, where supply is most often lowest. An indication of the intensity of the demand for coastal and estuarine access opportunities is the growth in the numbers of saltwater anglers in the U.S., up from approximately 8.3 million in 1965 to 9.5 million in 1970 and projected to as high as 29 million in the year 2000 (Deuel, 1973).

All of the above described recreational access interests also possess aesthetic implications, in terms of the visual quality of access points and appurtenant facilities, of actual or potential user congestion, or of the land usage barriers which block effective access.

UTILITIES

Power plants, because of their physical size, industrial appearance and unattractive edge qualities (e.g., high fencing, oil tanks, coal stockpiles, and equipment depots) are often aesthetically displeasing to large numbers of people. In the case of nuclear power facilities, safety questions can also be presumed to adversely affect community attitudes concerning aesthetic fitness, apart from stimulating opposition on the grounds of hazard alone. In many cases, cooling towers and their condensate plumes have been identified as negative aesthetic factors, as have been dredge and fill activities associated with site development or cooling water processes.

LAND AND AIR TRANSPORTATION

Highways, railroads, bridges, causeways, and parking facilities have major aesthetic impacts upon estuarine/coastal zones because of their size, linear encompassment or traversement of horizon or open areas, and vehicular effects (noise, motion, and exhaust fumes).

Some of these impacts may be benign, if not beneficial: a well-designed bridge span over a river mouth, for example. But many other instances are often judged detrimental, particularly where new facilities are introduced into sensitive or vital estuarine areas in a natural state.

Public transportation to shore points is an underutilized alternative which may offer important answers in the future in decreasing vehicular congestion, suburban sprawl, and related impacts in estuarine uplands.

Airports likewise have mixed aesthetic effects. Jet take-offs and general aircraft activity may be visually exciting, even spectacular to the observer. On the other hand, the airport itself may appear visually dull to the observer from an opposite shore, or on the land side of the facility. Aircraft noise and jet exhausts, airport structure visual qualities, and airport expansion on filled marshes or mudflats may also elicit strong negative visual or intangible responses.

MANAGERIAL IMPLICATIONS

The resource and impact definitions discussed above suggest a summary of related managerial issues as follows:

1) Aesthetic resources and values of estuarine and coastal zones have not been well understood or systematically evaluated by the professional or by the public as a whole.

2) Planning tools for surveying, inventorying, and evaluating estuarine/coastal aesthetic resources need to be more carefully explored and used. Direction and guidance for these are needed from federal and state agencies with responsibilities for coastal/estuarine management.

3) Aesthetic resources and values may be perceivable (visual, auditory, or olfactory) or intangible. The latter is essentially an observer response to social, cultural, economic, or physical factors which affect his or her conceptualization of the resources or values concerned.

4) Important aesthetic resources of the estuarine/coastal zone include some that are specific and unique to vital or critical areas and some that are common or ordinary within either the estuarine or upland landscapes. The intangible or psychological importance of the estuarine/coastal zone elevates both beneficial or adverse aesthetic effects to a level of significance.

5) Impacts may be effects on specific aesthetic resources (e.g. a power plant marring a scenic vista) or effects on the general estuarine resource (e.g. a power plant not marring any horizon or foreground, but objectionable on the basis of the project design's effect on the overall aesthetic value of the estuary).

6) The magnitude of an aesthetic impact and whether it can be considered negative or beneficial or both will depend largely on the degree to which the observed area is urbanized— or conversely, retained in a natural state.

7) Even within highly modified or urbanized areas, however, objects or activities which are aesthetically displeasing may still not be exempted from observer disapproval.

8) Aesthetic incompatibilities may be a) endemic, i.e., spread throughout the estuarine/coastal region, much as unregulated second-home and recreational-seasonal housing spread; b) intrusive, i.e., created by the introduction of non-"fitting" developments into local or specific resources; c) site abusive, i.e., displaying poor site planning; and d) sub-standard design, i.e., in which development is characterized by poor architectural design quality.

9) Although some aesthetic regulation has been validated by court test cases, other questions of constitutionality have not yet been resolved.

10) Permit and project review systems have not absolutely prevented development in coastal/estuarine zones. Whether the institutions responsible for administering these systems will allow large aggregate development will only be known in time and in light of political power adjustments.

Recommendations for improved estuarine zone landscape management outlined below will be addressed to the above-defined problems.

PREVIOUS AND CURRENT GOVERNMENT PROGRAMS

To date, a number of key federal and state programs have established important measures or frameworks for dealing with the estuarine and coastal landscape.

Federal Programs

The Water Resource Planning Act of 1965 provided for consideration of aesthetic factors in comprehensive water and related land resource planning. Principles and Standards issued by the Water Resources Council (1973) under the Act detailed a number of criteria for weighing aesthetic values but did not provide guidance on appearance and design of facilities in resource areas that are marked for development or on restoration and enhancement questions.

The National Environmental Policy Act of 1969 provided for the identification and consideration of aesthetic values that might be beneficially or adversely affected by actions undertaken by or under the aegis of the Federal government. The requirements for identification and evaluation of both direct and indirect effects of the proposed action, for consideration of measures that might mitigate adverse effects, and for weighing all feasible alternatives provide an incentive to project planners to exercise greater care for aesthetic values in early planning stages and a lever for adjustment under public criticism in the post-planning stages. NEPA, however, does not provide for set criteria or standards that would predetermine project site selection, planning, or design. Each project is evaluated on a case by case basis.

The Coastal Zone Management Act of 1972

expressed "a national interest in the effective management, beneficial use, protection, and development of the coastal zone." The coastal states are encouraged and assisted to define and to propose means of control over permissible land and water uses in the coastal zone and to give full consideration to aesthetic as well as other values in the development and implementation of management programs. The Office of Coastal Zone Management, in the National Oceanic and Atmospheric Administration, is expected to see that state Section 305 management plans contain unified policies, criteria, standards, methods, and processes that are adequate to deal with "land and water use decisions of more than local significance" prior to continuing CZMA grant assistance.

Under the Act, and with the guidance of OCZM, constructive and specific new actions may be anticipated on the part of the states to acquire and regulate land and water resources of aesthetic importance. Appearance and design regulations, permit procedures, comprehensive planning, and protective local and state zoning will play important roles. The CZMA, however, is permissive in nature, and will be effective in improving individual states' policies towards aesthetic resource management only to the degree that the states are willing to adopt new measures within their political and legislative systems.

The CZMA provision, under Section 306(c)(8), for adequate consideration of the "national interest" in the siting of facilities "other than local in nature" was included in the Act ostensibly to satisfy misgivings of the electric power industry. But the fortunate ambiguity of this clause should offer an opportunity for subjecting all large-scale facilities that are proposed for coastal zone locations to all the site selection, site planning, and design criteria encouraged by the Act, rather than exempting such facilities from them. Which direction will be taken will be seen only with time.

Section 306 administrative grants to the coastal states will, of course, be central to the effectiveness of the Act. It may be predicted that a large part of Section 306 funds will be used for acquisition purposes, but it can only be speculated how much will be earmarked for "restoration and enhancement" purposes. Acquisition (fee title or scenic/access easements) of presently undeveloped scenic areas is vitally necessary, but restoration and enhancement efforts are in many areas no less urgent, particularly where ill-planned development has already adversely affected aesthetic values.

Another weakness of the Act is its omission of directives to specifically consider multiple-use of resources in the coastal zone, a concern recommended by the Commission on Marine Science, Engineering and Resources (the Stratton Commission) in 1970. Because of this omission, it may be difficult to encourage large-scale facility or large private developers to provide for scenic-aesthetic or recreational access joint objectives.

The Federal Water Pollution Control Act of 1972 provides for potential beneficial aesthetic impact on estuarine waters. Many of the quality standards required by the Act (relative to color, turbidity, floating solids, debris, oil film, odor) are in essence aesthetic quality standards and are at least as great a matter of concern to the public as the Act's strictly biological and safety standards.

To secure desired water quality objectives, the Act and its 1972 Amendments provide for a number of measures designed to affect land use management, particularly under Section 208 of the Act. The level of future growth that an area can accept and land use densities may thus be adjusted, at least in theory, with consequent possible aesthetic benefits.

Under the Act, the Corps of Engineers is required to apply EPA criteria in the disposal of dredge spoil in navigable waters. Although adverse aesthetic impacts might be avoided indirectly by this requirement, there is no direct attempt to guide the Corps on aesthetic resource protection related to spoil disposal.

Section 201(f) of the Act provides for multiple use for open space and recreational purposes of lands and easements acquired for waste treatment facilities and sewers. However, the selection of flood plains or foreshores is not specifically excluded under the Act; the aesthetic impact of utility construction in such resource areas can be considerable.

The Fish and Wildlife Coordination Act of 1934, as amended, provides the basis for comment to the Corps of Engineers on project permit applications, by the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and the state in which the project is funded. The Fish and Wildlife Service issued guidelines in August 1974 to aid agency personnel in reviewing applications for Corps permits. Here too, consideration of aesthetic resource protection is indirect, at best, even though maintenance of high visual quality in marsh and estuarine environments can be considered significant to the satisfactions of angler and hunter.

The Housing and Urban Community Development Act of 1974 will provide block grants to states and communities for community and regional planning and development purposes. No specific guidelines, criteria, or standards for waterfront development, rehabilitation, restoration, or enhancement are provided. The Act, as has the Housing Act since its initial passage, thus only weakly addresses the need to distinguish development and redevelopment areas on estuarine zone and urban waterfront lands from other urban areas.

State Programs

Recent legislative and administrative actions taken by the coastal states relative to aesthetic resources and impacts are diverse and in many cases highly significant. Setback and frontage tree cover requirements are included in the shoreland zoning ordinances of Wisconsin and Minnesota. Appearance and design regulations are presently being developed by California and its six regional coastal zone conservation commissions. Washington's shoreline protection legislation provides for the development of county policies and regulations (Whatcom County Planning Commission, 1972). The state zoning of Hawaii and the strong land use control legislation of Vermont and Maine also are producing generally beneficial aesthetic impacts.

If the current programs of the coastal states were assessed, it would appear that there is a definite trend towards greater use of shoreline regulations, with an emphasis on permit and approval procedures, some emphasis on state-wide zoning, and little emphasis on acquisition.

Since all relevant federal legislation depends to one degree or another on state programs for effectuation, it may be observed that some states may meet or exceed expectations implicit in national legislation if this trend solidifies. On the other hand, permit and approval frameworks provide only partial, rather than absolute, protection to resource areas. The degree of effective area protection will depend on the degree to which permit applications are denied; even a low percentage of approvals can result in significant incremental urbanization of a presently natural area in time. The degree of effective site planning and design management, however, will be dependent on the degree to which permit approval conditions, building codes, zoning ordinances, and related tools are refined to reflect aesthetic resource protection needs, under any management system.

Both the CZMA and the anticipated national land use policy legislation, the former with regard to "areas of particular concern" and the latter with respect to "critical environmental areas," urge the states to adopt measures for the protection of unique areas, but there is no assurance that these will constitute large proportions of the estuarine/coastal zone, or that they will constitute preservation-priority areas rather than conservation-with-tolerable-development areas.

With regard to development within urban areas, little state legislation exists which provides more significant guidance on waterfront aesthetics than the minimal provisions of the Housing and Urban Community Development Act.

RECOMMENDATIONS

The character of estuarine and coastal aesthetic resources, impact factors, planning and management requirements, and shortcomings of existing legislation point to the need for improvements in the following areas of estuarine landscape management concern:

Land Use Planning/Area Use Priorities

1) A national policy and program is needed for preservation of significant estuarine and coastal landscapes that express their highest aesthetic, cultural, or historic value in their present state and are not adequately protected under existing legislation. Where states have not adopted legislation to preserve or adequately conserve significant wetlands, bluffs, islands, beaches, headlands, and other important natural aesthetic resources, the Federal government should be empowered to consider direct action to protect them.

2) The EPA should develop detailed aesthetic criteria in review of discharge effects under the Pollutant Discharge Elimination System so that it can better respond to visible water quality parameters as well as invisible parameters which indirectly affect estuarine aesthetic quality.

3) Both the federal and state levels should be assigned specific responsibilities for aesthetic review in connection with the Corps of Engineers permit program, either under new amendment to the Fish and Wildlife Coordination Act, or under new legislation.

4) New legislation is needed to express the national interest in the protection and management of aesthetic resources on a par with the national interest in other resources such as water, air, and land. The new legislation should assign primary coordinating responsibility to a single lead federal agency. Serious consideration should be given to naming the National Park Service to this post with an appropriate new congressional mandate.

5) New policies and compensatory mechanisms are needed to enable states to retain whole areas at given levels of development or at no-growth. In some parts of some states, such areas may be regional in character. Although the difficulties are severe, the

needs exist, if a diversity in coastal landscapes is to be maintained.

Site Selection

1) Legislation governing the selection of sites for large-scale facilities should be amended to require specific consideration of alternate locations situated inland of all significant estuarine landscapes, particularly those which also possess important ecological or cultural characteristics.

2) Federal legislation governing estuarine sanctuaries should be amended to provide for the acquisition or other protection of estuarine as well as related upland areas of significant aesthetic, as well as scientific and educational, value.

3) Under the CZMA, states should institute conditional permitting based on site planning and design performance standards, for designated permissible uses.

Site Planning and Design

1) Federal legislation governing housing, urban, community, and rural development should be amended to require the adoption of guidelines, criteria, and standards for development, redevelopment, and rehabilitation of areas in proximity to waterfronts. Such legislative changes would relate to inland riverine as well as to estuarine zone lands. River corridor and estuarine zone boundaries should be delineated within existing jurisdictions, urban and non-urban, to demarcate the areas within which the waterfront related provisions would apply.

2) Substantial funding for waterfront related rehabilitation, as well as for restoration and enhancement of natural or semi-developed areas within the estuarine/coastal zone should be appropriated under government programs specifically earmarked for this purpose. Funding for these needs could be aggregated with HUCDA block grants and CZMA Section 306 administrative grants, but the need for significant action in rehabilitation, restoration, and enhancement points to the desirability of independent and earmarked program elements.

3) Provision should be made for further research, consideration, and adoption of landscape assessment, site planning, and design criteria and standards for the estuarine and coastal zone. Criteria and standards for the management of aesthetic resources which are of national interest should be granted highest priority in federal, federal-state, and local programs. Further research and development of methods for inventorying and evaluating aesthetic resources should also be conducted. Federal programs should guide the states more specifically in developing appearance and design guidelines, criteria, and standards to include variable setback and height controls (varied to relate to topography, shore configuration, and other aesthetic considerations), multiple-use concepts (use of utility and other facility edges), aesthetic zone priorities (adjustment of siting and design standards in relation to the intrinsic wildness or urbanization of a given resource area), and other concerns.

Federal and state authorities with jurisdiction over the siting and design of offshore structures and artificial islands should be encouraged through legislative amendment to develop suitable appearance standards for such facilities.

REFERENCES

Cerny, J. W 1974. Scenic Analysis and Assessment. In: Critical Reviews In Environmental Control. Chemical Rubber Company.

Deuel, David G. 1973. The 1970 Salt-Water Angling Survey. U.S. Department of Commerce, National Marine Fisheries Service, Current Fishery Statistics. No. 6200.

Principles and Standards for Planning Water and Related Land Resources. Fed. Reg., Vol. 38. No. 174, Sept. 10, 1973. U.S. Water Resources Council.

Whatcom County Planning Commission. December 1972. Shoreline Inventory. Whatcom County, Wash.

Roy Mann Associates, Inc. March 1975. A Handbook on Aesthetic Resources in the Coastal Zone, Draft. National Oceanic and Atmospheric Administration.

RECREATION ACTIVITIES IN THE NATION'S ESTUARINE ZONE

ROBERT J. KALTER
Cornell University
Ithaca, New York

ABSTRACT

Determinants of recreation activity are discussed and justification for the provision of recreation services by the public sector outlined. After reviewing the availability of data and other studies pertaining to recreational use, projections of recreation demand are made for selected activities. Economic models based upon a 1972 national recreation survey serve as the basis for this effort. The implication of these forecasts for the nation's estuarine areas is evaluated and policy recommendations, based on this analysis, are provided.

INTRODUCTION

Significant portions of the nation's outdoor recreational activity are either water based or water related. The latest National Recreation Survey found that over 38 percent of total outdoor recreational hours in the summer of 1972 were spent participating in water related activities (see Table 1). As a result, recreation has become a major use of our nation's water resources.

A substantial portion of the water area available for recreation is encompassed by the estuarine zone. Moreover, the location of the zone in relation to major population centers has made it an increasingly valuable resource. Yet, 59 percent of the area, excluding Alaska, remains undeveloped and over 70 percent resides in private ownership. About 25 percent is currently used for recreation (U.S. Department of the Interior, 1973). This is one reason the nation's estuarine areas have become an important consideration for public policy. Preservation of undeveloped portions of this resource for future recreational use will require public action. The extent and mechanism for such action must be decided in the political arena.

But why public and not private action in allocating the use of a resource like our estuarine areas? A number of factors are involved. We will review only several of the principal features. First, because access to natural areas by the public is often difficult to control (at cost acceptable to a profit making enterprise), public provision and control may be required. Difficulty in extracting a price for the use of some areas like estuaries has often discouraged private sector action to develop or preserve. Second, because of the profit making motive, resource allocation by the private sector will often emphasize short term monetary returns at the expense of long run environmental or social considerations. Third, society's preferences with regard to considerations like environmental quality may not be profitable for the private sector to provide. Consequently, governments may be called upon to correct the situation.

However, when public action to correct private market failure means public provision, the self-balancing of supply and demand provided by the private market is largely lost. Price incentives are weakened and, as a result, information feedback to governmental decisionmakers is curtailed. Without information, public recreational programs may be no more responsive to social demands than the private market alternative.

As a consequence, if public intervention is to provide results which are socially more optimal than those obtained under conditions of non-intervention, public decisionmakers require an adequate information base and the appropriate utilization of that base for analytical purposes. Unfortunately, historical data relevant to the estuarine zone-recreation interface is almost nonexistent except for a few geographic areas. Consequently, any analysis of the problems and possibilities from a national viewpoint starts from a decided disadvantage. On the other hand, the literature on recreation economics has continued to develop a sound methodological framework for public policy analysis (Kalter, 1971) and the data base of national recreation statistics has continued to improve. From this background, important factors determining recreational activity, both in general and for specific areas like estuaries, can be adjudged. A discussion of these factors will be the initial task of this paper. Then, available

Table 1.—Percent of national recreation survey who participated, estimated total U.S. participation, average hours of participation, and estimated total hours of U.S. participation by water related activity in the summer quarter of 1972[1]

Activity	Percent of NRS respondents who participated	Estimated total U. S. participation (millions of act. days)
Other Swimming Outdoor (Non-Pool)	34	487.1*
Fishing	24	278.2*
Pool swimming	18	257.0*
Nature walks	17	148.9
Other boating	15	126.1
Water skiing	5	54.1
Canoeing	3	18.3
Sailing	3	32.5
Activity	**Average hours of participation**	**Estimated total hours of U. S. participation[2] (millions of activity hours)**
Other swimming outdoor (Non-Pool)	2.6	1,266.46
Fishing	4.4	1,224.08
Pool swimming	2.8	719.60
Nature walks	2.0	297.80
Other boating	2.8	353.08
Water skiing	2.6	140.66
Canoeing	2.3	42.09
Sailing	4.4	143.00
Total		4,186.77

*Statistically reliable within 10 percent.

[1] Excludes wildlife and bird photography, hunting, camping and other activities that may be water related.

[2] Total for all activities surveyed equaled 10,978.15 million activity hours.

Source. Adams, R. L., et al., Outdoor Recreation. Appendix "A", An Economic Analysis U.S. Department of the Interior, December 1973.

empirical evidence will be used in an effort to evaluate the role of the nation's estuaries as a component of recreation supply, and the impact this role has on the economy.

DETERMINANTS OF RECREATION ACTIVITY

Actual recreational activity at any time is the result of interactions between consumer demand and available facilities. The resulting activity requires the participants to make outlays for associated expenses. This cost (or price) includes items like travel and lodging, as well as user fees at the recreation site. Unlike a private market situation, however, the resulting conditions may not imply market clearing in the case of publicly provided facilities. That is, some demand may not be satisfied (at a given quality level) even though consumers are willing to undertake the necessary costs. This stems from the lack of proper market signals and government response in adjusting the supply of public facilities.

These conditions are illustrated in Figure 1. Recreation demand, DD, exhibits the normal inverse relationship between price and quantity (all other factors taken as given). When recreation facilities are publicly provided and admission fees are administratively determined, however, the average price, P, to a group of participants can remain stable during any given period of time. Since supply is also publicly provided and the quantity available during a given period depends on budget considerations, the recreation supply function can be shown as inelastic with respect to price. Thus, if public information is accurate and budget decisions are responsive, market clearing can take place. The supply function SS reflects this somewhat fortuitous circumstance. On the other hand, if government planners have inaccurately analyzed the demand for facilities at P, or if budget processes do not permit investments in facilities to point S, then a situation like that shown by the dotted line S^1S^1 will result. With an administrated price of P, a facility shortfall of S-S^1 will occur. Conversely, an over supply could develop if facility supply is developed beyond S.

Demand

Recreation demand (the functional relationship between quantity desired and socioeconomic factors) is, for the most part, influenced by the same factors influencing the purchase or use of other goods and services. Thus, an individual's demand for recreation relates to the costs (monetary or others, such as time) incurred to participate, his tastes and preferences, his socioeconomic characteristics (which may affect preferences), and the availability and cost of alternative goods, services, or uses of fixed

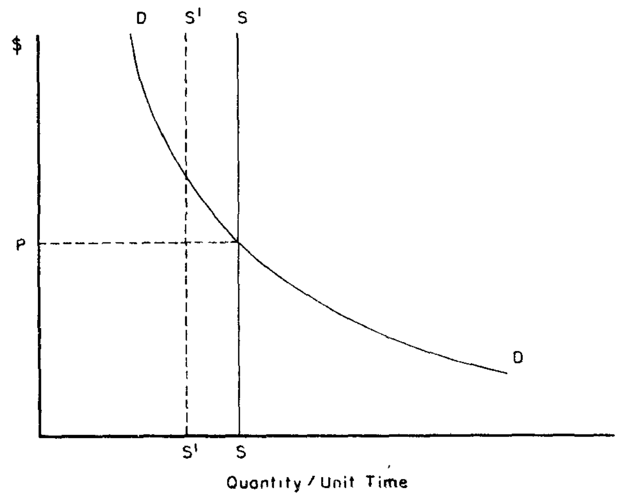


FIGURE 1.—Hypothetical recreation demand-supply relationships.

budgets (money, time and energy). Demand for a particular type of recreation or for a particular recreation facility depends on these factors as they relate to a given population and to the size of that population. In addition, quality factors will influence the shape of the demand function for specific sites and/or types of recreation.

Demand functions have been estimated, based on past experience, for individual recreation sites as well as for market areas. Functions derived with reference to specific locations have a variety of potential uses, such as developing and evaluating recreation expansion plans at the site (Clawson and Knetsch, 1966). They, however, do not usually provide adequate data for comprehensive recreation planning at the national or regional level. Account needs to be taken of overall market demand and the competition for that demand from alternative sites (Kalter and Gosse, 1969). As will be pointed out below, the question of alternatives may be critical in reviewing policy decisions relating to recreational use of estuaries.

Supply

Facility supply, or more broadly, recreation site capacity, is the balance wheel to the demand side of the recreation picture. It, however, is difficult to define in a manner consistent with normal measures of use. Whereas recreation use has traditionally been defined in terms of time (visitor days at a site or activity days of participation in a given type of recreation), capacity is basically the ability to accommodate participants. Thus, capacity can vary for a given site due to intensity of use. Moreover, since capacity cannot be stored for future use, we can only speak of instant capacities (the ability to accommodate use at a given moment in time). Thus, we often encounter the phenomena in recreation of having capacity deficiencies on weekends and holidays while maintaining extensive surplus facilities during the work week.

Of equal importance in measuring capacity are two other factors. First, the quality of a recreation experience offered by management of a given area can cause substantial variations in its capacity. For example, if one aspect of quality (crowding) is permitted to deteriorate, capacity of an area can be increased, though not necessarily at a linear rate. Although "quality" is a subjective factor determined by individual preferences, that will not be its use here. Rather, we seek to identify a set of characteristics which can be used to group sites into categories for analysis. Individuals may have different preferences among such a classification. Second, site capacity (at a given quality level) is related to the activity mix at the site. The existence and timing of complementary and competitive activities can affect the overall capacity of a site.

Thus, site capacity has been an elusive concept from a definitional point of view. From a public planning viewpoint, however, definitional problems translate to analytical problems. The need to provide a linkage between demand and supply (capacity) is basic to decisions concerning public investment in the quantity and quality of recreation-related facilities. Estimates of the value related to provision of additional capacity or of changes in the quality of existing capacity cannot be used in a benefit-cost decision framework without knowledge of the relationship between capacity provided and various levels of resource inputs.

Two techniques have been suggested and used for translating physical measures of area and facilities into economic capacity. First, physical standards have often been used by public agencies. Such standards identify the magnitude of physical areas and facilities needed to provide a recreation experience, at a given level of quality, for a given number of recreation or activity days. Because standards relate to average rather than marginal values, a preferred approach would take account of the nonlinearities involved. Thus, the traditional production function has been suggested as a second means for relating capacity to the cost of resource inputs (land, labor, and capital). Empirically estimating such functions, however, suffers from the same definitional problems raised earlier and the additional practical problem of holding quality constant for estimation purposes. Progress in quantifying supply concepts, by either method mentioned, has not progressed as rapidly as work relating to demand.

Recreational activity and quality factors

The role of quality in determining recreational activity was only referred to briefly in the previous sections. The term "quality" is a subjective and somewhat elusive factor in the economic equation. It relates to both the concepts of supply and demand. The economist normally considers separate demand relationships relevant for each level of quality of a given product or service. The physical representation of quality, then, takes place on the supply side of the equation.

The physical characteristics relating to the quality of a water-based outdoor recreation site can be natural or manmade. Surroundings, facilities, intensity of site use, and water quality, itself, all are characteristics which permit a subclassification of water-based recreation sites by quality. Each of these factors may, itself, be complex in makeup. For example, water quality is usually considered a composite of many factors (i.e., BOD (biochemical oxygen demand), nutrient levels, turbidity, et cetera). In addition, non-site quality factors can affect one's perception of the overall recreation experience.

Available studies

Studies of outdoor recreation demand relating to a given population area are relatively rare (Kalter and Gosse, 1969; Cicchetti, et al., 1969; Adams, et al., 1973). Unlike the demand for most goods and services, the demand for recreation is heavily dependent on transfer costs (costs of reaching and departing a recreation site) and is, thus, linked spatially with the site of purchase. The site has, therefore, become the natural focus for data collection and analysis. On the other hand, market or population oriented demand studies must be based on data collected from a sample of the entire relevant population, rather than those who visited certain (or even a sample of) recreational sites. Not only are such data collection efforts normally not directed at the immediate needs of a particular agency, they are expensive to carry out.

The dilemma is obvious. For most policy work at the national level, market oriented efforts are desirable. Yet they are empirically difficult and expensive. Moreover, the resulting specificity often turns out to be at a higher level of aggregation than desirable for some applications. It is precisely this problem which plagues analytical work regarding recreational demand for the nation's estuaries. Individual estuary areas may differ to the point where extrapolation from specific site oriented studies can lead to erroneous conclusions for national policy. Yet the market oriented studies which have been carried out do not permit the isolation of demand related specifically to estuarine areas nor show the trade-offs between these areas and alternative supply possibilities.

On the supply side, the data base is even thinner. Supply inventories have been conducted as part of previous national recreation surveys (ORRRC, 1962; U.S. Department of the Interior, 1973). The conceptual and definition problems discussed above, however, have made the data difficult to interpret in practice. In one instance the data has not even been compiled or released by the government (U.S. Department of the Interior, 1973). The principle involved is critical to formulating proper public policies since supply, as well as demand, data is needed if the trade-offs among alternatives are to be properly evaluated.

Because of the difficulties involved in quantifying quality factors, many analytical efforts have assumed away these issues. Since quality considerations relate to more than just the site itself, this has been an easy out. The complexity of adding elements such as road conditions and other similar factors, which also affect the quality of the entire recreation experience, clearly has argued for this course of action by early researchers.

In pioneering research, Stevens (1966) attempted to alter this approach by investigating the relationship between recreation uses and water quality. In essence, his approach assumed that a change in water quality would result in a shift of the demand relationship for a particular recreational activity using a water resource. Thus, separate demand relationships would exist for different degrees of quality in a recreation experience. Recognizing that factors other than water quality are involved in the quality issue, he, nonetheless, chose to ignore those factors as a first approximation. Using quantifiable variables as proxies for water quality, he showed a positive relationship between water quality and recreation use.

Subsequent studies have built upon this effort by the addition of other variables as measures of water quality and of environmental characteristics encountered in other aspects of the recreation experience. Each has confirmed the basic hypothesis that a relationship, which is not necessarily linear, exists between factors often felt to be proxies for recreation quality and the degree of recreation activity at a particular site (Davidson, et al., 1966; Megli and Gamble; Nathan, 1969).

Yet no clear concensus emerges as to the exact relationships involved in all cases. For example, one study indicates that threshold levels of water quality exist below which no recreation use of a given type will take place and that these threshold levels may vary for different activities (Nathan, 1969). Another study was unable to confirm such a hypothesis (Megli and Gamble). As a result of such issues, the technical literation on recreation quality has not developed to the point where it is useful in a public planning context. It has, however, provided insights into the relationships involved.

THE ECONOMIC VALUE OF OUTDOOR RECREATION

Prediction of recreation attendance, although useful, does not give an indication of the economic value derived from a particular resource or permit comparison with alternative uses of that resource. To fully evaluate the recreational use of resources, governmental decision makers need value information. To realize recreational benefits, an economic cost must be incurred for facilities and other investments. For example, water quality improvements normally require extensive capital investment programs by the public and/or private sector. To ascertain which resource use provides the greatest benefits and, thus, to determine which type of public policy is most desirable from an economic efficiency perspective, the economic value of alternative uses is required.

Measurement of the primary economic value stemming from outdoor recreational facilities or services follows naturally from the attendance prediction models discussed above. Both site oriented and market oriented demand relationships can be used for imputing monetary values to recreational activities undertaken as a result of a specific public policy action. In other words, methods have been devised for estimating the willingness of consumers to pay for participation if it were actually sold in a market place. For example, if public policy actions result in changes in water quality which in turn increase recreational uses of a particular site, estimates of the value of that change to consumers could be derived from an appropriate demand relationship and compared to the costs necessarily incurred to bring about the change. The potential value of such estimates goes without saying.

AVAILABILITY OF DATA INDICATING THE DEMAND FOR OUTDOOR RECREATION IN NATIONAL ESTUARINE ZONES

Little has changed since publication of the 1970 "National Estuary Study" which reproduced a quotation from an even earlier 1966 study by Spangler:

> The present statistics on national expenditures on ocean recreation are in such a sad state that estimates for these activities in the United States range from $50 million in 1964 according to one source to an estimated $3.86 billion in 1964 for another.
> . . . part of this 72-fold discrepency is due to the fact that statistics on expenditures for fishing, swimming, boating and related equipment do not distinguish between marine oriented activities and inland oriented activities in streams and lakes (U.S. Department of the Interior, 1970, pp. 25–26)

The "National Estuary Study" goes on to point out that secondary expenditures on outdoor recreation in estuarine zones are even more difficult to assess. Unfortunately, this state of affairs represents much of our data base regarding estuarine areas. As a result, in order to derive quantitative estimates of the amount and likely changes in outdoor recreation demand in estuarine zones, this paper is forced to depend on data which were not collected for this specific purpose. Available data will allow us to observe changes in such patterns in only a most generalized and cursory manner.

PATTERNS OF DEMAND FOR OUTDOOR RECREATION IN NATIONAL ESTUARINE ZONES, 1972–1978

As indicated above, for nationally oriented policy analysis demand functions relevant to population or market areas would be most germane. Given the availability of such estimates, a spatial allocation procedure which considers all potential recreation areas where the specific activity can take place must be used to isolate the impact on a given area (such as estuarine zones). The allocation procedures permit forecasts of recreational travel patterns, given knowledge of site capacities, travel costs, and the factors affecting consumer demand (Tadros and Kalter, 1971).

Recent analyses provide information on the demand functions for specific outdoor recreation activities in a market context. Used in conjunction with actual and forecast values of the independent variables which are assumed to cause changes in recreation demand, these functions can be used to forecast recreation use under the assumption that an adequate supply of facilities will exist. Future growth rates under alternative assumptions concerning price and other independent variables can, thus, be obtained. These rates will pertain to the actions of population groups and not to specific facilities where recreation services may be provided.

When used in conjunction with data on facility capacity and travel patterns, public decision makers have information that can be used to formulate policies which would avoid serious misallocation of limited investment capital. The result could be actions to provide additional facilities of a specific type in a given geographic area or ones which would restrict the demand focused on such areas. Cost-benefit evaluations of specific proposals would be facilititated by the data provided. Unfortunately, the necessary data and models pertaining to travel patterns and facility utilization have not been derived for activities pertinent to our nation's estuaries.

Consequently, we are forced to a second best solution. Namely, we must use information on relevant demand functions to gain insight into future growth patterns and facility needs of estuarine areas. In a study by Adams, et al. (1973), demand equations were estimated, using recent (1972) data, for 17 outdoor recreation activities. For each activity, demand relationships for three types of recreation occasions (vacations, trips, and outings) were derived. These equations were then used to estimate demand during the summer of 1972 for each of the 17 activities by the populations in 171 separate geographic areas, called BEA economic areas, which together encompass the entire area of the contiguous 48 states. The BEA economic areas are delineated by the Regional Economics Division, Bureau of Economic Analysis, United States Department of Commerce. Forecasts were then made of the demand generated by the population of each area for each activity in the summer of 1978. These forecasts were based upon projections of the 1978 value for independent variables, like population, income, age, et cetera, and the estimated demand coefficients for the activities.

Of the activities analyzed, those which are particularly relevant to a study of recreation demand in estuarine zones are "fishing," "water skiing," "other boating" (boating other than water skiing, sailing, or canoeing), "other swimming outdoors" (all outdoor swimming not taking place in swimming pools), and "nature walks." Sailing or canoeing were not studied because the estimated demand equations were not statistically significant. Unfortunately, although the Adams, et al. study does permit estimation of the demand generated by specific population groups, *it does not estimate* where these people would go to satisfy their demand (given available facilities and costs consistent with those used for the demand forecast). Thus, we cannot say how much of the demand is currently focused on estuary resources and how much utilizes alternative sites. Moreover, the optimal type and distribution of future supply locations is well beyond the scope of available data.

Despite these shortcomings, useful information can be gained by analyzing the present and future demand for outdoor recreation activities normally associated with estuarine resources. Specifically, if we assume that the existing pattern, and changes in the future pattern, of demand generated by the population groups immediately adjacent to the nation's estuaries will reflect demand for estuarine resources, it is possible to arrive at a general picture of:

1) which type of recreation services capable of being provided by estuarine resources are currently in greatest demand;

2) which specific estuarine zones currently receive the greatest demand;

3) which type of recreation services capable of being provided by estuarine resources are likely to receive the greatest growth in demand in the near future; and

4) which specific estuarine zones are likely to be the focus of the greatest increases in demand in the near future.

The remainder of the analysis presented below reflects these assumptions.

Table 2 provides a list of the 36 BEA areas which are adjacent to the estuarine zones of the contiguous United States. The area surrounding the Great Lakes was not considered to be an estuarine zone. Figure 2 is a map showing the location of each BEA area listed in Table 2. All BEA areas in Table 2 are grouped into their respective census divisions.

Table 2 shows, for each BEA area adjacent to an estuarine zone, the population in 1972, the quantity of each activity (days) demanded by the BEA area

Table 2.—Summer of 1972 and percentage increase by the summer of 1978 in the quantity of selected outdoor recreation activities demanded by populations in BEA areas adjacent to national estuarine zones

BEA area	1972 Population		Fishing	
	(Thousands)[2]	Percentage increase[2]	Activity days (Thousands)[4]	Percentage increase[3]
New England[1]				
1 Bangor, Maine	255.5	5	301 4	7
2 Portland, Maine	599.7	10	692.1	13
4 Boston, Mass.	5,182 3	10	5,954.0	12
5 Hartford, Conn.	2,435 9	11	2,804 1	14
	8,473.4		9,751.6	
Middle Atlantic[1]				
14 New York, N.Y	15,010.6	9	12,688.1	12
15 Philadelphia, Pa.	5,935.9	8	6,301.2	11
	20,946.5		18,989.3	
South Atlantic[1]				
17 Baltimore, Md.	2,169.4	9	4,904.4	11
18 Washington, D.C.	2,501.1	12	5,814.1	14
21 Richmond, Va.	822.8	10	1,852.8	12
22 Norfolk, Va	974.1	4	2,256.5	6
23 Raleigh, N.C	1,282.6	4	2,820.0	5
24 Wilmington, N.C.	380.4	3	883.2	4
30 Florence, S.C.	306.4	4	642.4	5
31 Charleston, S.C.	331.1	5	758 0	7
33 Savannah, Ga.	327 9	5	718.6	6
34 Jacksonville, Fla.	849 8	9	948.3	10
35 Orlando, Fla.	784.6	14	1,822.8	15
36 Miami, Fla	2,098 5	13	4,700.0	15
37 Tampa, Fla	1,533 3	10	3,392.7	12
38 Tallahassee, Fla.	282.0	11	629.2	13
39 Pensacola, Fla.	300 0	5	729.9	6
	14,964.0		32,872.9	
East South Central[1]				
137 Mobile, Ala.	561.1	8	1,265.7	9
	561.1		1,265.7	

BEA area	Activity days (Thousands)	Percentage increase	Activity days (Thousands)	Percentage increase
West South Central[1]				
138 New Orleans, La.	1,675.5	8	3,692.0	10
139 Lake Charles, La.	567.5	3	1,315.2	4
140 Beaumont, Tex.	318.1	10	733.1	11
141 Houston, Tex	1,895.5	13	4,499.5	14
142 San Antonio, Tex.	958.3	5	2 341.3	7
143 Corpus Christi, Tex.	390.3	3	980.2	4
144 Mc Allen, Tex.	258.2	1	638.7	2
	6,063.4		14,200.0	
Pacific[1]				
155 Seattle, Wash.	1,939 4	10	3,680 3	12
157 Portland, Ore.	1,351.6	10	2,517.8	12
158 Eugene, Ore.	437.0	5	829 9	7
164 San Diego, Cal.	1,128.7	10	2,196.4	12
165 Los Angeles, Cal.	3,654.5	13	15,690.8	15
170 Eureka, Cal.	99 3	7	186.7	8
171 San Francisco, Cal.	4,268.5	13	2,814.0	15
	17,870.0		32,915.9	
Total	68,878.4		109,995.4	

BEA area	Water Skiing: Activity days (Thousands)[4]	Water Skiing: Percentage increase[3]	Other Boating: Activity days (Thousands)[4]	Other Boating: Percentage increase[4]
New England[1]				
1 Bangor, Maine	51.0	10	153 3	12
2 Portland, Maine	125.7	17	370.9	18
4 Boston, Mass	1,381.8	20	3,433.1	20
5 Hartford, Conn.	644.6	21	1,593.9	22
	2,203.1		5,551 2	
Middle Atlantic[1]				
14 New York, N.Y.	2,938.6	27	7,298.2	24
15 Philadelphia, Pa.	1,250 8	23	3.390.2	21
	4,189.4		10,688.4	
South Atlantic[1]				
17 Baltimore, Md.	985.0	16	1,835.3	18
18 Washington, D.C.	1,366.0	20	2 483.6	23
21 Richmond, Va.	341.9	17	652.4	20
22 Norfolk, Va	418 5	10	788 8	13
23 Raleigh, N.C.	476.6	9	925 5	13
24 Wilmington, N.C	151.5	7	290 6	10
30 Florence, S.C.	98.8	9	194 9	13
31 Charleston, S C.	134.5	10	254.2	13
33 Savannah, Ga.	120 5	10	234 9	13
34 Jacksonville, Fla.	366.7	14	703 3	17
35 Orlando, Fla.	364.9	19	711.6	22
36 Miami, Fla	934.5	21	1,822.5	24
37 Tampa, Fla.	610.5	16	1,282 5	19
38 Tallahassee, Fla.	111.4	17	216.7	20
39 Pensacola, Fla.	141.3	9	267.3	12
	6,672.3		12,664.3	
East South Central[1]				
137 Mobile, Ala.	223.6	13	432.4	16
	223.6		432.4	
West South Central[1]				
138 New Orleans, La.	671.0	15	1,278 9	19
139 Lake Charles, La.	224 3	9	420 1	12
140 Beaumont, Tex.	137.7	16	263.7	19
141 Houston, Tex.	931.1	19	1,727.3	22
142 San Antonio, Tex.	462.0	11	853.3	15
143 Corpus Christi, Tex.	194 0	7	352.5	11
144 Mc Allen, Tex.	118.4	5	210.4	10
	2,738.5		5,106.2	
Pacific[1]				
155 Seattle, Wash.	985.7	10	1,616.7	19
157 Portland, Ore	636.1	8	1,101.3	16
158 Eugene, Ore.	198.5	3	349.1	11
164 San Diego, Cal	574.3	10	935.6	19
165 Los Angeles, Cal.	4,249.3	15	7,019.6	23
170 Eureka, Cal.	44.6	5	77.6	14
171 San Francisco, Cal.	2,137 5	15	3,502.7	23
	8,826.0		14,602.6	
Total	24,802.9		49,045.1	

BEA area	Other swimming: Activity days (Thousands)[4]	Other swimming: Percentage increase[3]	Nature walks: Activity days (Thousands)[4]	Nature walks: Percentage increase[3]
New England[1]				
1 Bangor, Maine	987.1	7	169.6	10
2 Portland, Maine	2,351.2	12	414.5	15
4 Boston, Mass	21,656 4	13	4,029.1	17
5 Hartford, Conn	10,057.8	15	1,848.1	18
	35 052.5		6,461.3	
Middle Atlantic[1]				
14 New York, N Y.	48,353.4	15	9,125.4	19
15 Philadelphia, Pa.	73,068.0	13	4,248.9	16
	71,421.4		13,374.3	
South Atlantic[1]				
17 Baltimore, Md.	6,234 4	13	1,460 2	16
18 Washington, D.C.	8,438.2	18	1,988 4	20
21 Richmond, Va.	1,782.0	15	489.6	17
22 Norfolk, Va	2,803.8	8	658.9	10
23 Raleigh, N C.	3,230.8	8	719 2	9
24 Wilmington, N C.	1,011.3	6	221.7	7
30 Florence, S.C.	679.6	8	147 4	9
32 Charleston, S C.	911.0	8	707 4	10
33 Savannah, Ga.	822 4	8	128.3	10
34 Jacksonville, Fla.	2,424 1	12	562.9	14
35 Orlando Fla	2,328 2	17	544 7	19
36 Miami Fla	5,967.0	19	1,458.4	21
37 Tampa, Fla.	3,957 5	14	949.2	16
38 Tallahassee, Fla.	744.3	15	167.9	17
39 Pensacola, Fla	926 5	8	212.0	10
	42,661.1		9,376.2	
East South Central[1]				
137 Mobile, Ala.	1,504 9	11	347.2	13
	1,504.9		347.2	
West South Central[1]				
138 New Orleans, La	4 489.3	13	1,047.2	15
139 Lake Charles, La	1,500.6	7	343.2	8
140 Beaumont, Tex.	899 7	14	212.0	16
141 Houston, Tex	5,961 9	17	1,410 7	19
142 San Antonio Tex.	2,987.2	9	705.2	11
143 Corpus Christi, Tex.	1,253.1	6	295 2	8
144 McAllen, Tex.	774.7	4	171 3	5
	17,866 5		4,194.8	
Pacific[1]				
155 Seattle Wash.	6,953.7	13	3,026.0	15
157 Portland, Ore.	4,647.5	12	2,045.8	14
158 Eugene, Ore.	1,469.9	7	644.5	9
164 San Diego, Cal	4,163.0	13	1,806.9	15
165 Los Angeles, Cal.	30,796 6	17	13,653.9	18
170 Eureka, Cal	326.6	9	142.6	10
171 San Francisco, Cal.	15,268.4	17	6,735.0	19
	63,625.7		28,054.7	
TOTAL	232,232.1		62,408.5	

[1] Census Division Name.
[2] Adams et al., p. 160.
[3] Ibid , p. 84.
[4] Based on unpublished data from the 1972 National Recreation Survey.

FIGURE 2.—BEA regions encompassing U.S. coastal zone.

population during the summer of 1972 on all recreation occasions, and the percentage increase in demand forecast for the 1972–1978 time period for the activities mentioned. Only activities relevant to the estuarine zone are considered. In each case, the U.S. average cost for each activity and each occasion, as calculated from the 1972 National Recreation Survey, was used in the analysis. No change in this price over time was assumed. Thus, by implication, patterns and government pricing policy were considered constant.

What is not known or shown in Table 2 is the spatial allocation of the 1972 recreation use or forecast changes in such use patterns. Since the BEA regions differ in geographic size, individuals residing in a region are located at various distances from its boundaries, and round trip distances for travel on various types of recreation occasions differ, the distribution of recreation demand stemming from a given region cannot be proportioned between it and other regions without indepth analysis. However, the 1972 National Recreation Survey data does provide some information pertinent to the issue of recreation consumption in a given BEA region which contains an estuarine zone. Table 3 indicates the distribution of recreation activity, for our selected activities, in 1972 between different types of occasions.

Table 4 shows the distribution of round trip miles for the same activities and occasions. Note that a minimum of 60 percent of all participation in the selective activities takes place on trips and outings and that at least 60 percent of this amount occurs within 400 miles of home. The figures are substantially higher for some activities. Even for vacations, 15 to 20 percent of the activity occurs within a one day round trip of the participant's

Table 3.—Percent of summer participation in selected outdoor recreation activities on vacations, trips and outings (1972)

Activity	Percent on vacations	Percent on trips	Percent on outings
Fishing	29.3	19.6	51.1
Water skiing	19.4	16.6	64.0
Other boating	35.0	29.3	35.7
Other swimming outdoors	30.9	15.8	53.3
Nature walks	40.2	22.3	37.5
Average for all activities	31.8	13.9	54.2

Source: 1972 National Recreation Survey

Table 4.—The distribution of round trip miles traveled on vacations, trips and outings by activity* (June-August, 1972)

Round trip mileage	All activities			Fishing		
	Percent vacations	Percent trips	Percent day outing	Percent vacations	Percent trips	Percent day outing
0–800	17.8	60.0	100	21.8	66.9	100
801–4000	51.9	33.4		57.2	33 0	
4001–8000+	30.8	6.7		25.4	0.0	

Round trip mileage	Water skiing			Other boating		
	Percent vacations	Percent trips	Percent day outing	Percent vacations	Percent trips	Percent day outing
0–800	21.5	85.4	100	16.6	73.6	100
801–4000	37.5	14.6		47.2	26.4	
4001–8000+	40.8	0.0		36.0	0.0	

Round trip mileage	Other swimming			Nature walks		
	Percent vacations	Percent trips	Percent day outing	Percent vacations	Percent trips	Percent day outing
0–800	19.6	68.0	100	14.0	61.4	100
801–4000	45.6	19.4		46.5	28.5	
4001–8000+	34.9	12.7		39.7	10.0	

*Outing trips for all activities never exceed 150 round trip miles regardless of activity.
Source 1972 National Recreation Survey.

home. The implication is clear. Although cross-boundary movements of recreation participants may not net to zero for a given region, demand for regional facilities tends to be concentrated in the nearby population. After taking account of cross-boundary recreation movements, the total demand for regional facilities is unlikely to vary much from the total demand forecast for the regional population.

Based on the total number of activity days demanded in all 36 BEA areas for each activity, the activity in greatest demand is "other swimming outdoors" followed in order by "fishing," "nature walks," "other boating," and "water skiing." When looking at the ranking of activities for each census division, "nature walks" and "other boating" switch positions in the ranking for the South Atlantic, East South Central, and West South Central census divisions.

Looking at the individual BEA areas adjacent to estuarine zones, Table 2 indicates the greatest amount of demand is generated by the population of the New York BEA area for "other swimming outdoors" followed in order by the same activity in the Los Angeles and Boston BEA areas. The fourth greatest number of activity days demanded is for "fishing" in the Los Angeles BEA area followed by "other swimming outdoors" in the San Francisco area and "fishing" in the New York area. In all areas, the demand for estuarine resources and facilities appears to be greatest for those resources associated with swimming and fishing.

While it is important to know what type and where estuarine resources are currently in greatest demand, this information, by itself, is not enough for formulating public policy. It is of greater importance to have information on which demands for which types of estuarine resources will be growing most rapidly in each estuarine zone in the future. The estimated percentage increases in quantity demanded shown in Table 2 indicate that the outdoor recreation activities currently in greatest demand are not necessarily those projected for the greatest future growth rate. For the United States as a whole and for the five activities under consideration in this study, "other boating" is expected to grow the fastest between 1972 and 1978 with a percentage increase of 18 percent. Following "other boating" are "water skiing" and "nature walks," each expected to grow by 15 percent, "other swimming outdoors" at 13 percent, and "fishing" at 11 percent.

A similar ranking of the percentage increases in demand for the five activities is reflected in Table 2 for the individual BEA areas. The principal difference is that "water skiing" and "nature walks" change places in the number two ranking, depending upon the census division under consideration.

Table 2 also shows that many of the BEA areas which show the greatest levels of demand are also the areas which show some of the highest projected percentage increases between 1972 and 1978. For example, the projected 27 percent increase in demand for "water skiing" in the New York BEA area is the highest for all areas listed in Table 2. The New York BEA area also has the second highest level of demand for "water skiing," surpassed only by the Los Angeles area. Likewise, the second highest of all growth rates shown in Table 2 is 24 percent for "other boating" in the New York and Miami areas. The level of "other boating" demand generated by the New York BEA area is the highest level (7,298,200 activity days) of all areas listed in Table 2. Even when a rapid rate of growth in demand is associated with lower initial levels, the growth rate may be enough, by itself, to create significant strains on the ability of the estuarine resources to absorb the increases. It appears, from Table 2, that the greatest strain on any single type of outdoor recreation resources in estuarine zones will be on "other boating" facilities in the New York, Miami, Washington, D.C., Los Angeles, and San Francisco areas. The "other boating" demands in all of these BEA areas are projected to grow by 23 percent or more.

RECOMMENDATIONS

Through Table 2, we have provided a rough indication of the facilities and resources in specific estuarine zones currently subjected to the heaviest demand, as well as those likely to face the greatest future increases in demand. Current capacity and, consequently, future facility needs cannot be identified from available data. More importantly, it is obvious that recreation sites other than those located in estuarine zones could serve as supply sources for this demand. The role of these alternative sites, for current and future policy actions, is critical to planning for the estuarine zones. Thus, only general recommendations for policy action can be given.

The principal issue involved relates to financing any additional facilities and resources and the policy implications of the financing methods. Many outdoor recreation facilities and resources are provided by the public sector at little or no charge to the facility users. In many cases this is a valid policy such as when there is no administratively feasible way to collect entrance fees or when a level of government makes a conscious decision to redistribute income by providing outdoor recreation facilities free of charge. In the former case, the failure to collect fees is justified because it would cost more to collect the fees than could be offset by the revenues from the fees. In the latter example, free provision of outdoor recreation facilities may be valid on the basis of equity, if these portions of the population who warrant free access actually make use of the facilities. When reasons such as these are not involved in the decision to provide free facilities, however, a serious distortion in the allocation of resources arises.

> Public investments, however, are often made with little attention to market prices. This is particularly true of sport fishing and boating where the public often provides hatcheries, public piers and marinas at artificially low costs to the user. This situation, in effect, may create an 'artificial demand,' with the attendant environmental pressures, and heavy use of estuarine and other resources . . . public policy must weigh not only abstract 'demands' derived from proxy data, but attempt to more fully assess net benefits and costs of public recreational investments (U.S Department of the Interior, 1970, p. 28).

One way to more fully assess net benefits and costs of public recreational investments is to charge realistic entrance or user fees for the facilities provided. The price paid by the recreationalist is a measure of his willingness to pay and the value of the recreation experience to him. When the users of a recreation facility are willing to pay a price which is great enough to cover the full cost of providing the facility, we have an indication that the benefits to society are at least equal to the costs to society of providing the facility. Assuming there is no equity (income redistribution) goal involved, if people are unwilling to pay a price which is sufficient to cover the full costs of the facility, the facility should not be provided since the costs to society will exceed the benefits.

Adams et al., (1973), provide evidence that increases in the prices of the five activities considered in this study will have a relatively small impact upon the quantity of each activity demanded by people who participate. The evidence takes the form of price elasticities of demand which are defined as the percentage change in the quantity of an activity demanded that is caused by a one percent change in the price paid for that activity. Table 5 provides the estimated price elasticities of demand for each of the five activities consumed on each of the three types of outdoor recreation occasions. For example, the price elasticity of demand for fishing on vacations is estimated to be −.24. This means that a one percent increase in the price of fishing will cause only a .24 percent decrease in the quantity of fishing demanded on vacations.

A system of full cost pricing of estuarine resources used for satisfying outdoor recreation demand for fishing, other boating, other swimming outdoors, water skiing, and nature walks can and should be employed in those estuarine zones where such a policy does not now exist. Such a policy will assure that the benefits derived will at least equal the costs of providing additional estuarine resources. Table 5 indicates this policy of rational allocation of resources can be employed with relatively little impact upon the quantities of the recreation activities demanded. This policy will be especially crucial to the survival of those estuarine zones identified above which are facing the heaviest demands and the most rapid growth of future demands.

Critics of this recommendation point out that project or investment economics are only one aspect of the possible implications which may be important politically and socially. Equity effects, for example, were referred to briefly earlier in this section. Re-

Table 5.—Estimated price elasticities of demand for selected outdoor recreation activities on vacations, trips, and outings

Recreation activity	Vacations	Trips	Outings
Fishing	−.24	−.27	*
Water skiing	−.20	−.17	−.32
Other boating	−.23	−.18	*
Other outdoor swimming	−.24	−.20	−.19
Nature walks	−.22	−.18	−.07

* Not statistically significant.
Source: Adams et al., 1970, p. 79.

gional impacts are one form of equity effect that has traditionally been important to recreation development considerations. Trade-offs may be implicit between such impacts and the pricing recommendations suggested previously. Higher entrance fees will have some effect on participation and, consequently, on regional expenditures. For example, recreation is often of interest to a region because of its export characteristics (non-residents spend money for use of the region's resources). Such expenditures may create employment opportunities for the regionally unemployed and normally result in a multiplier effect on the sales and income of other economic sectors in the region.

Direct regional income impacts can stem from two sources. First, the regional impact in terms of facility construction and maintenance must be considered. When such facilities are wholly or partially financed by non-regional funds and some of these funds are spent on inputs supplied by the region, the economy of the area is benefitted (Nathan, 1966). On the other hand, if all construction funds were raised regionally or had to be paid back by regional interests, only an internal transfer effect would occur. Second, increased expenditures in the region by recreationists who are non-residents or increased expenditures by residents through the interregional reallocation of recreation consumption patterns can beneficially affect a regional economy. Of course, both of these factors must also be offset by reimbursement considerations, taxes due directly to construction, and increased taxes required to finance additional public services in the region resulting from use of the recreation area (i.e., increased police and fire protection, et cetera).

Knowledge of direct expenditures in a region enables estimates of the multiplier or indirect impacts to be made. The more economically self-contained the area, the greater will be the multiplier value since less of the initial and subsequent round expenditures will flow to other regions. Since increased regional expenditures for recreation related goods and services can be substantial, their impact can be considered a real benefit to the region where a recreation facility is located. From the national point of view, however, both direct expenditures and their subsequent multiplier implications are normally classified as transfer effects. That is, to the extent the region is successful in attracting this type of expenditure, it will be detrimental to other areas. Moreover, regional gains must be offset by the problems created by the increased recreation activity. For example, employment in many economic sectors servicing recreation is highly seasonal, low paid and often recruited from outside the area. Requirements for government services may also increase (including off-season unemployment benefits), causing increased taxes. On balance, the regional implications of increasing recreation demand and the provision of facilities to satisfy that demand is an empirical question which must be answered for each specific region. Although net gains to one region can normally be considered as losses to other regions such distribution effects may be a conscious political decision affecting facility location. From a national perspective, however, a uniform system of public pricing with respect to federally funded facilities would not, in principle, give undue advantage to one region over another in terms of such regional impacts. In other words, a nationally imposed pricing system for use of estuarine areas would be expected to affect all regions in a uniform way. Only if a differential pricing schedule between regions was installed could a contrary result occur. Although differential pricing should not be rejected as a means for excluding peak demands for facilities, both in time and space, it is not currently a viable approach to the nation's recreational problems.

REFERENCES

Adams, R. L. et al. 1973. Outdoor Recreation: Appendix "A", An Economic Analysis, U.S. Department of the Interior. Washington.

Cicchetti, C. J. et al. 1969. The Development and Supply of Outdoor Recreation. New Brunswick, N. J.: Rutgers, The State University, Bureau of Economic Research.

Clawson, M. and J. S. Knetsch. 1966. Economics of Outdoor Recreation. Baltimore: The Johns Hopkins Press.

Davidson, P. F. et al. 1966. The social value of water recreation facilities resulting from an improvement in water quality: the Delaware Estuary. A. Kneese and S Smith, eds. Water Research, RFF. Baltimore: The Johns Hopkins Press.

Kalter, R. J. 1971. The Economics of Water-Based Outdoor Recreation: A Survey and Critique of Recent Developments. Institute for Water Resources Corps of Engineers, IWR Report 71-8. Ithaca, N. Y.

Kalter, R. J. and L. E. Gosse. 1969. Outdoor Recreation Projection for 1970–1985. Ithaca, New York: Cornell University Special Series No. 5.

Megli, L. D. and H. B. Gamble. An Analysis of the Relationship Between Stream Water Quality and Regional Income Generated by Water-Oriented Recreationists. Institute for Land and Water Resources Research Publication Number 69. University Park, Pennsylvania: Pennsylvania State University.

Nathan, Robert R. and Associates, Inc. 1969. Impact of Mine Drainage on Recreation and Stream Ecology. A Report by the Appalachian Regional Commission. Washington.

Nathan, Robert R. and Associates, Inc. 1969. Recreation as an Industry. A report prepared for the Appalachian Regional Commission.

Outdoor Recreation Resources Review Commission. 1962. National Recreation Survey. ORRRC Study Report 19. Washington: Government Printing Office.

Stevens, J. B. 1966. Recreation benefits from water pollution control. Water Resources Research. 2(2):167–182.

Tadros, M. and R. J. Kalter. 1971. A spatial allocation model for projected water-based recreation demand. Water Resources Research. 7(4).

U.S. Department of the Interior. 1973. Outdoor Recreation: A Legacy for America. Washington, D. C.

U.S. Department of the Interior, Fish and Wildlife Service. 1970. *National Estuary Study.* Washington.

THE VALUE OF ESTUARINE FISHERIES HABITATS: SOME BASIC CONSIDERATIONS IN THEIR PRESERVATION

FRANK H. BOLLMAN
Development and Resources Corporation
Sacramento, California

ABSTRACT

Comprehensive management of estuarine environments is confronted by the valuation issue—attaching relevant societal values to the degradation or improvement that accrues to fisheries and their habitats from manmade changes.

The estimation of the social and economic costs and benefits due to change in an estuary should follow a careful appraisal of the ecological effects. The backwardness of the art of assessing damage is evident in the meager and piecemeal state of knowledge of what damages have occurred and are presently accruing. Tenets of economic good sense, however, offer useful guidance. The relative scarcity of the aquatic habitat and of critical natural features in the estuary support system cannot be overlooked. Availability of substitutes and substitute sites is a basic consideration The full arsenal of economic reasoning has to be employed to provide insight to alternative courses of estuarine management.

Two broad sources of degradation of fishery habitats are foreseen as resulting from population growth and economic development. Direct pollution of nutrients and toxic materials is the first source.

The physical alterations are the second source. Three intensifications of use are identified as compounding the difficulty of maintaining fishery resources in estuaries: (1) increasing loads of municipal and industrial wastes; (2) the leakage of petroleum and petroleum products into estuaries; and (3) upstream activities affecting freshwater inflows.

Land and water use in the coastal zone is interrelated with that in the hinterland. There is an urgent need to improve environmental impact statements so that the full extent of the values is displayed for the decision makers. A major national commitment in training, research, and funding is involved in staffing state and federal agencies with the economic and biological expertise necessary for the informed management of the nation's estuaries.

INTRODUCTION, OVERVIEW AND PERSPECTIVE

The demands of society for fish and wildlife, the demands for segments of their estuarine habitat for other uses, and, last but not least, the total array of spillover effects of agricultural and industrial production on fish and wildlife and their habitats are compounding the problem of conserving their estuarine and coastal zone support system.

This was one of the principal findings of the "National Estuarine Pollution Study" and the "National Estuary Study" in appraising the status and conditions of estuarine fisheries habitats in 1970.[1] In the interim, there is little substantive and quantitative evidence to confirm that the demands for many of the different services of the estuarine zone have diminished or that their adverse impacts have lessened. While some offsetting tendencies have evolved and promise respite from the continuing erosion of estuarine habitat, the negative impact of these forces of change is still substantial and increasing as the competition for the uses of estuarine resources responds to population growth and economic development.

In contrast to the 1960's a more populous and wealthy society is now more environmentally alert and presumably better informed as to the overall values of estuaries; legislation has been enacted to permit their use for fish production among other purposes.

Nevertheless, a fundamental difficulty still confronts comprehensive management of estuarine environments—relevant values have to be attached

[1] "The National Estuarine Pollution Study" was authorized by Section 5(g) of the Clean Water Restoration Act of 1966, P.L. 89-753, approved November 3, 1966. The study was published March 25, 1970, as Senate Document No. 91-58, 91st Congress, 2nd Session. The Estuary Protection Act, P.L. 90-454, authorized the Secretary of the Interior to study estuary conditions and report to Congress. The result was the National Estuary Study, U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C., January 1970.

to the degradation or improvement which accrues to fisheries habitats from changes in the estuarine environment.

Logically, estimation of social and economic costs and benefits from ecological change in an estuary should follow a careful appraisal of the ecological effects. Is the planned change in the estuarine environment with its associated impact on the shell and fin fisheries worth it? Can benefits be increased and detrimental effects reduced by modifying this change? These questions obviously are best answered when the positive and negative impacts are identified and measured prior to assessing whether it is in society's interest to undertake the change, however small it may appear to be.

The purpose of this paper is to deal with some aspects of the complex and perplexing evaluation issue as it relates to estuarine fishery habitat. Degradation, definable in quantitative terms pertaining to fishery productivity, is also elusive. Only crude indicators are available. There are significant forces such as projected future depletion of freshwater flows in estuaries, buildup in pollutants from diffuse sources and pressures for the alteration of estuarine lands. There is, consequently, an urgent necessity to review the performance of the ameliorative measures taken to date, to make the required adjustments and, where needed, to institute new management systems and practices. This paper attempts to give an overview of the estuarine management problem as it relates to the accountability of fishery values in the short and long term, and how they might be afforded better protection by incorporating sound principles into the evaluation procedure. It does not presume to identify and assess the present status of the estuarine habitat for fish production other than in broad terms. A comprehensive treatment of the latter will demand appraisal by competent authorities in many specializations—a herculean task outside the terms of reference of the present paper.

DEGRADATION OF FISHERIES HABITATS: AN ELUSIVE AND COMPLEX PHENOMENON

The two earlier studies mentioned in the introduction complemented each other, emphasizing the paucity of reliable benchmarks for assessing the exact nature and extent of the damage to estuarine fisheries habitats. These studies pointed to the inadequacy of knowledge (including techniques and instrumentation) to diagnose principal causes affecting the health and productivity of this habitat. Prescription of remedial measures then, in 1970, could be contemplated only with great reservations and little certainty that they were least costly or most effective. There is little concrete evidence that the faculty and facility for prognosis, diagnosis and remedy have improved in the interim.

"The National Estuarine Pollution Study" found that "for the majority of the Nation's estuarine systems, there are little or no data to describe existing water quality conditions. . . ." [2] and that while the effects of physical destruction of the habitat are also easy to assess at least in terms of immediate damage caused, the more subtle related effects of organisms dependent indirectly on the habitat for food supply are more difficult, sometimes impossible, to determine. In summary, "it is not possible to say whether 38 percent of the Nation's estuarine systems are undamaged or merely present no identifiable problems at this time." [3]

The last intensive effort to inventory national estuarine conditions in the late 1960's resorted to gross indicators to typify degradation—water quality of major rivers and streams entering the estuarine area, the area of wetlands lost, the area of finfish habitat affected by water pollution, the areas of shellfish lost or closed, and the number and type of modifying structures.

It might be concluded after reveiwing more recent literature that assessment of the degradation of the total system for different estuaries and its likely effects on fishery productivity would prove to be equally difficult, for the same reasons. The interactions of basic processes are still imprecisely understood; the complexity of interactions and reactions defies the easy transfer of lessons learned in the laboratory or under actual field conditions to protect or improve fishery habitats. Usually they deal with only a few of the critical variables and a few states of nature of the total system. Advances in knowledge and the state-of-the-art in the last five years would have had to be substantial and significant to effect any improvement in the diagnosis and prognosis of the health of the estuarine habitat.

In the late 1960's, the rate of change brought about by economic activity in the estuarine zone could not be identified and work by ecologists at that time was appraised as "generally concerned with identification of system types, the development of general theory, and the measurement of system characteristics and operating phenomena. Much is known about certain elements of estuarine ecological systems, such as temperatures, salinities, abundance

[2] "The National Estuarine Pollution Study," p. 269.
[3] Ibid., p. 272.

of certain biotic communities, but the specific processes and causal relationships of complex whole systems and interacting subsystems have only recently been partially understood." [4]

A quantitative assessment of the trend in estuarine ecological system modification-degradation was not feasible; all that could be observed were three general effects and a qualitative trend.

To the three principal forms of modification brought about in estuaries as a result of man's activities—significant waste discharges, dredging and filling, and constructing physical structures on fresh water inflows or in the estuaries themselves—were attributed three generalized effects:

1. Productivity of biotic communities is generally reduced due to many factors, including reduction or over-provision of nutrients, abrupt changes in temperatures and salinities, changes in circulation patterns, and destruction of physical components of the system.
2. Specie diversity and organization are simplified.
3. Trends toward severely modified ecosystems are established.[5]

The assessment was made "that most, if not all, major estuarine areas in the continental United States are now or soon will be affected by disturbances of more than one identifiable type. These systems are characterized by heterogeneous patches of chemicals, fertilized waters, waters low in available oxygen, turbidities, acids and other conditions alien to normal life of estuarine ecosystems. The multiple stressed situation is possibly the nation's most urgent estuarine problem because the condition is a mixture and the causes several. The stress of many different kinds of wastes may be more difficult for an ecosystem to adapt to than separate types of wastes acting alone." [6]

Important estuaries such as Boston Harbor, New York Harbor, Raritan Bay, portions of Chesapeake Bay, Tampa Bay, Galveston Bay and San Francisco Bay were subject to major sources of modification which resulted in identifiable stress in more than one of the estuaries' subsystems. Twelve major sources of modification were attributed to the development of the petrochemical complex in Galveston Bay. These caused stress in seven identifiable systems. Multiple-stressed systems characterized many estuaries, and man's activities tended to increase the number of stressed systems and the degree of stress.[7]

A crude network analysis of some of the impacts and the changes brought about in an estuary as a result of a single modification—dredging—is shown in Figure 1. It illustrates the complexity of the interactions which investigators have to identify and specify in tracing the effects on an aquatic ecosystem subject to many modifications of varying intensities diurnally and seasonally.

That considerable research is needed to adequately predict the effect of erosion, siltation, and sedimentation on an aquatic ecosystem in a farm pond highlights the difficulty and the magnitude of the research effort which would allow us to predict the effects of many and simultaneous changes in an estuary.

In summary, the complexity of the estuarine systems themselves and of the responses to man's activities precluded any realistic attempt to assess national and regional trends in the estuarine environment. "At this stage of knowledge such trending based on scientifically tested information is impossible."[8]

The present status of estuarine health for fish production eludes detailed specific diagnosis; however, certain obvious symptoms can be detected. An attempt is made in Table 1 to classify selected estuaries by the degree of modification, water quality, and reported effects on fish life as evidenced in finfish kills and shellfish areas closed.

Only a partial, sometimes misleading, picture of the habitat's status is obtainable from these gross indicators. Fishery productivity measured in terms of the catch of edible species presumably is a useful indicator of the estuarine habitat. But again there is a difficulty in disentangling the effects of overfishing and other natural causes from those stemming from manmade changes in the area.

The decline of fishery productivity is not a new or recent phenomenon. An underlying condition for a century or more, in estuaries it has been especially accentuated by the social and economic changes accompanying economic growth which has been centered largely around the nation's estuaries.

And economic demands and the supply possibilities chosen by society to turn out its products and services continue to create situations in the estuarine

[4] "The National Estuarine Pollution Study," pp. 305-306. These remarks should not be construed to indicate that there is the presumption or the competency to assess the present state-of-the art.

[5] "The National Estuarine Pollution Study," p. 306.

[6] "The National Estuarine Pollution Study," p. 308.

[7] "A stress on an estuary is a process which drains available energy. Stress can be either direct as in the case of harvesting finfish or shellfish from the system, or indirect as happens when increased turbidities shade out light or when some substance such as phenol is added to the aquatic system, either causing mortality or demanding special adaptive work on the part of surviving organisms to sustain life. Energy drains on existing organisms may also occur when excesses of nutrients added to the system deplete the available oxygen necessary for respiration." Ibid., p. 305.

[8] "The National Estuarine Pollution Study," p. 308.

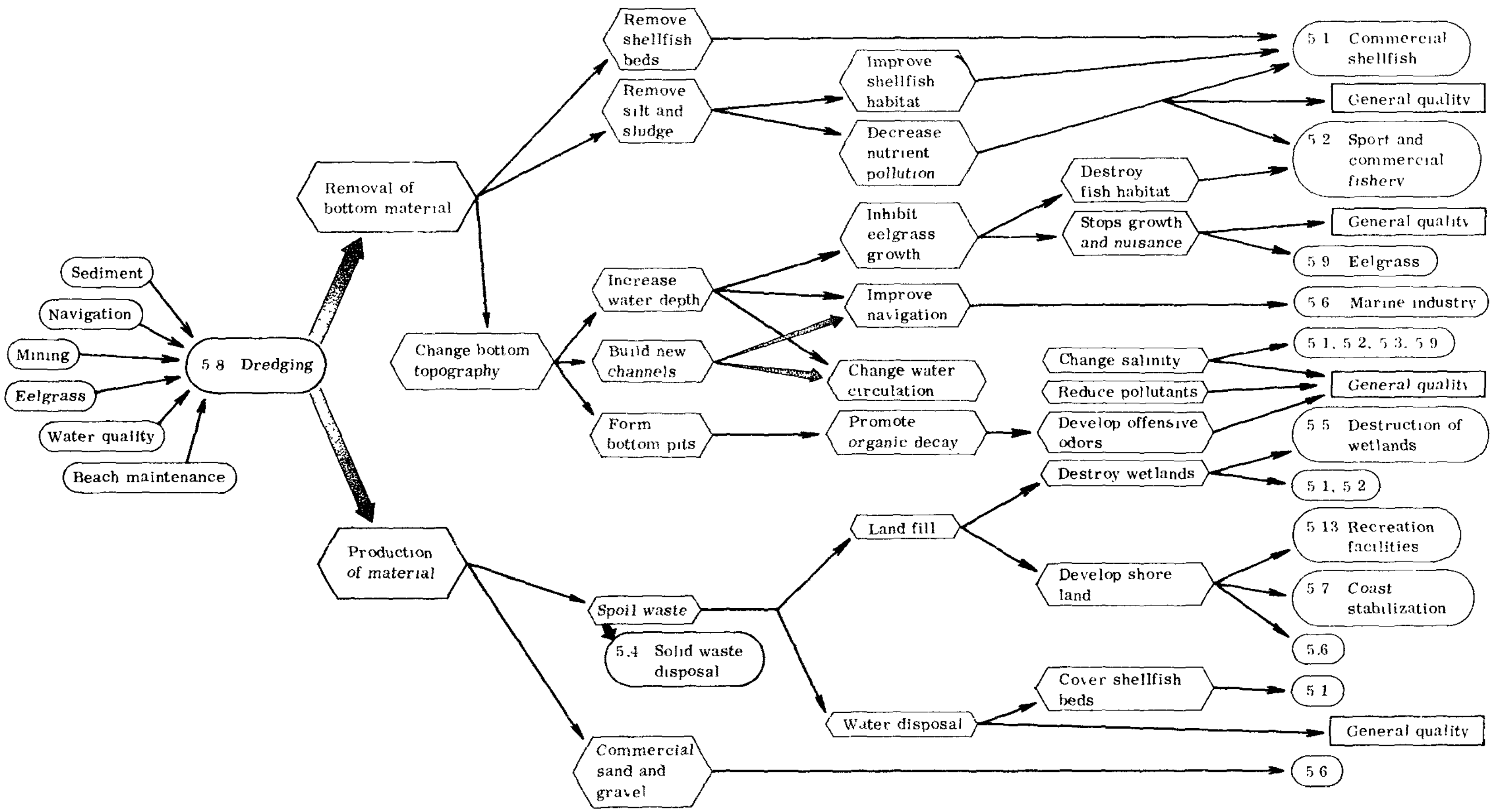


FIGURE 1.—A network analysis of dredging. Source: National Shoreline Study, Shore Management Guidelines. Department of the Army, Corps of Engineers, Washington, D.C., August 1971, p. 36. Original source: Ellis, R. H., et al, 1969. The Development of a Procedure and Knowledge Requirements for Marine Resource Problems of Nassau and Suffolk Counties. The Travellers Research Corp., Hartford, Conn.

Table 1.—Assessment of status of selected estuarine zones[1]

Biophysical region	Location	Degree of modification[2]	Water quality status	Major reported effects
North Atlantic	Penobscot Bay	Moderately Modified	Coastal industries are primarily textile, leather, and machinery. No major water quality problems.	
Middle Atlantic	Narragansett Bay	Moderately-Severely Modified	Site of major naval base and various industries A major port facility Municipal sewage and industrial waste are major pollution problems.	Prohibition of shellfish harvesting in specified areas.
Middle Atlantic	Delaware Bay	Severely-Moderately Modified	Extensive water quality problems exist resulting from the inadequate treatment of municipal waste water compounded by sewer overflows.	
Chesapeake Bay	Susquehanna River	Moderately-Severely Modified	Significant mine drainage in upper basin. Sediments are a nonpoint source pollutant in the lower basin.	
Chesapeake Bay	Potomac River	Severely Modified	A classic example of the effects of large quantities of municipal wastes on an estuary. During warm summer months dissolved oxygen levels approach zero.	Waste discharge effects are measurable for 20 miles along the river.
South Atlantic	Savannah River	Severely-Moderately Modified	The lower basin is sparsely populated. Only small quantities of municipal and industrial waste are received.	
South Atlantic	St. John's River	Moderately Modified	Large loads of domestic wastes are received. Algal and weed problems are frequent, in addition to high turbidity	Fish kills have occurred on occasion.
Gulf of Mexico	Apalachicola Bay	Moderately Modified	Limited development emphasis on commercial fishing and recreation, however, municipal wastes are a problem	Bacteriological problems have forced closure of most shellfish harvesting.
Gulf of Mexico	Mobile Bay	Severely Modified	Estuarine degradation resulting from municipal and industrial wastes, in addition to extensive physical modifications.	Highly sensitive shellfish industry threatened by increasing pollution.
Gulf of Mexico	Mississippi River	Severely Modified	Phosphorus and nitrogen sufficient for algae growth and getting worse. Phenols and hydrocarbons levels high Municipal and industrial sewage a primary factor.	Elimination of commercial fishing below St. Louis, Missouri and Baton Rouge, Louisiana.
Gulf of Mexico	Galveston Bay	Severely Modified	Concentrated industry, along with extensive channeling, dredging, and other modifications. Water quality has been significantly lowered.	Shellfish harvesting limitations have existed in many areas for the past 20 years.
Pacific Southwest	San Diego Bay	Severely Modified	Site of large naval base, extensive land fill and other modifications. Municipal wastes being cleared up.	Loss of much of the marshlands.
Pacific Southwest	San Francisco Bay	Severely Modified	Heavy concentrations of industry and population are the source of large quantities of waste. Numerous areas deficient in dissolved oxygen.	Shellfish harvesting restricted. Numerous fish kills.
Pacific Northwest	Columbia River	Moderately Modified	Supersaturation of gases from dams along river. General water quality is good, with no overall changes in past six years.	Some fish kills from supersaturation.
Pacific Northwest	Puget Sound	Moderately Modified	Water quality affected mainly by municipal and industrial wastes, as well as by agriculture and silviculture.	

[1] Sources: Environmental Protection Agency, Office of Water Planning and Standards. August 1974. National Water Quality Inventory, 1974 Report to the Congress. EPA-44019-74-001, Washington, D. C.
United States Department of the Interior, Fish and Wildlife Service. August 1970. National Estuary Study, Volume II, Washington, D. C.
National Estuarine Pollution Study. August 1970. Report to the Secretary of the Interior to the United States Congress, 91st Congress, pursuant to Public Law 89-753, The Clean Water Restoration Act of 1966, Washington, D. C.

[2] Relatively unmodified refers to an estuary approaching its natural state. Moderately and severely modified estuaries are defined as those areas undergoing limited and extensive development, respectively. None of the selected locations qualified as relatively unmodified.

and coastal zones where fisheries (and wildlife habitats) are, with few exceptions, subject to continuing encroachment and degradation. Fish and wildlife habitat in many instances become the residue of the present process—that is, what remains after all the deductions and the deleterious external effects have exacted their full measure.

That economic activities could be conducted in a way to reduce these impacts without incurring great costs underlies recent legislation to reduce the negative effects of these other production processes on the estuaries' production of finfish and shellfish.[9]

State and local governments have enacted additional legislation aimed in general at reducing the detrimental impacts of economic growth on the estuarine resource. A summary of coastal and estuarine zone legislation is given in Appendix Table 1 for the coastal states and Hawaii. The table shows that actual plans for coastal and estuarine management, with the exception of North Carolina for which a preliminary plan was prepared in 1970, are not yet in existence although legislation affording protection to coastal wetlands and tidal marshlands has been enacted in most of the states.

However, for reasons already given it is difficult to assess the efficacy of these measures since they have been in operation only a relatively short time. It takes time to repair delicate biological systems and to build up fish stocks. Besides, rehabilitation of fish stocks is subject to fishing pressures and natural changes not directly attributable to man. Little is known about the relative significance of man-caused stresses such as overfishing and naturally occurring stresses on estuarine-dependent finfish and the productivity of their habitat.

The backwardness of our skills in assessing the damage to estuarine biota can only be judged as serious when viewed against the increasing competition for the uses of most of the nation's estuaries. Failure to devise adequate monitoring and design management to conserve the fisheries resource and its habitat while equitably allocating estuarine resources to various uses, increases the likelihood that degradation by gradual attrition will be the fate of many estuaries.

Damage assessment is fundamental to the valuation issue. The value of a segment of estuarine fishery habitat may be defined as what an informed society would exchange for it in terms of the proceeds from a non-fishery use.

It has been argued that the damage to the estuarine fisheries habitat by the direct killing of commercial and sport species, by the elimination of a necessary food supply, or by damage to the reproductive capability of any link in the food chain brought about by other competing uses is difficult to establish. Damage may be, and often is, difficult to detect. This simply emphasizes that it is essential to know what fish and wildlife and habitat values are being destroyed and when their value is sufficient to buy off further encroachment or deleterious side effects of other uses.[10]

COMPETITION FOR USE AND THE VALUATION PROBLEM

Increasing competition for the use of the estuarine habitat resources is central to their present and future management concerns. The perennial challenge to management is to allocate according to value while avoiding irreversibilities.

The crux of the problem in the estuarine zone is how to allocate its resources to obtain the highest long-term net social value. The relative importance of the various demands and the benefits to be received have to be evaluated. Any manmade alteration, development, or management should account for both market and extramarket values stemming from a productive fisheries habitat as well as for those essentially market products from other uses of the estuary—cooling water, waste disposal, transportation, land fill, et cetera.

The resources involved—land, tidelands, marshes, wetlands, free flowing streams, et cetera—have alternative uses. The preservation of estuarine land and water for fish production can incur high cost in terms of the proceeds from other uses that are forfeited. Benefits that society foregoes from not using this water and land to produce power, water supply, waste disposal, industry and home real estate, in some instances, are considerable; in other situations, very few benefits are forfeited to retain healthy estuarine fishery habitat. A policy of safe minimum standard to retain fish production may require a very small insurance premium to avert what might prove to be substantial losses to society in the long run.[11]

A comprehensive evaluation of these fish production resources is consequently urgent and fundamental. Only then will society be able to see in perspective the loss-benefit balance of the many uses of estuarine resources. At this point, the neces-

[9] The criteria and guidelines society adopts for the conduct of economic and social activities as they impinge on the estuarine environment are not unalterable as major federal legislation relating directly or indirectly to the preservation of the quantity and quality of estuarine fishery habitat that has come into force since 1969 clearly testifies. The conduct of economic activity may be broadly interpreted to include the way people live, work, recreate, and are housed and transported in the estuarine zone. The following is a list of some of the more significant federal acts:

1969—National Environment Policy Act
1970—Environmental Quality Improvement Act
1972—Coastal Zone Management Act
Federal Water Pollution Control Act Amendment
Marine Mammals Protection Act
Marine Protection, Research and Sanctuaries Act
Pesticide Control Act

[10] Environmental forecasting is still in its infancy although the National Environmental Policy Act has been in force some five years. Substantial effort is now under way in "an attempt to find methodologies for forecasting the impact of man's activities on flood plains and coastal zones." The Environmental Law Institute and the International Biological Program of the National Science Foundation have focused their research efforts on these two ecosystems. *Environmental Quality, The Fifth Annual Report of the Council on Environmental Quality*, December 1974, pp. 409-410.

[11] The safe minimum standard as an objective of conservation policy is discussed by S. V. Ciriacy-Wantrup in *Research Conservation Economics*, Revised Edition, University of California Press, 1963, pp. 251-270.

sity for effective management for maximum benefits and minimum losses will become clear.

While an appropriate calculus surely should be devised, this has proved to be no easy task. The admixture of market and extramarket values makes reliable estimation difficult if not impossible.

Many of the estuarine values apply to uses such as sport fishing, boating and aesthetic enjoyment—activities for which there are no formally organized market places where monetary worth can be measured. These are extramarket values for which at best proxies may be devised.

Values established in the market place are not available for all the services provided by a productive estuarine fishery habitat; those extramarket benefits—days of sport fishing, clam bakes, et cetera—nevertheless are real, of worth to society and might be assumed to be increasing as natural estuarine areas diminish.

Values for estuarine resources are also set by the non-market system as in the legislative process which expresses choices indicating social costs and benefits not measured in marketplace terms. The acts of state legislatures to conserve estuarine marsh and wetland habitat illustrate this process of social choice.

Many of the "services" produced by an estuary are joint products—a commercial fish catch is dependent on the estuarine habitat but the estuarine zone also provides safe anchorage for the fishing fleet.

Where substantial benefits, in terms of commercial products and services, are forfeited to preserve estuarine fisheries habitat, economic reasoning is confronted by the following question: What is the optimum amount of estuary to maintain today, tomorrow and in the future for its various uses so that the stream of net social benefits from all uses of the estuary, present and potential, will be maximum?

A maximization of social welfare in the long term is the goal. Quite probably, society can afford the first yard or the first mile of estuarine tideland with much less loss in fish and wildlife than that involved in taking a subsequent segment; but to determine the point at which values foregone are greater than those gained is extremely difficult and demands a good knowledge of the working of the total ecosystem and its overall production possibilities and some informed estimates of the likely effect of changing one or another of its physical, chemical and biological characteristics.

"The National Estuarine Pollution Study" stated the valuation dilemma somewhat differently. "There are now (1970) about 5.5 million acres of important estuarine marsh and wetland habitat remaining in the estuarine zone of the United States. Perhaps each acre is not valuable by itself but the total habitat is irreplaceable."[12]

While the guiding principle to evaluation is erudite and socially sound—that net returns to society for all uses of the estuary should be the greatest attainable—there is difficulty in translating this principle into operational terms. The quantitative assessment of all the real cost created by a proposed action to alter estuarine conditions is almost unresolvable.[13]

There are, however, important practical considerations, tenets of economic good sense which can ensure that alternative courses of action do not unduly restrict future options. Useful proxies for the different pertinent measures supporting these tenets can be devised in quantitative or qualitative terms.

In deciding how much, if any, of an estuarine resource should be developed, the relative scarcity of the aquatic habitat, the numbers of flora, fauna and fish it supports, and other critical natural features must be identified. The functions that certain critical lands like wetlands serve in their natural state should be rigorously delineated and documented.[14]

The relative scarcity of the fisheries resource is an important consideration. It is demonstrable that estuarine resources provide aesthetic and unique services, in addition to the production of fin and shellfish which are increasing in economic value. Estuarine resources for fish production have appreciated in value as the demand for commercial and recreational fishing has responded to population growth and economic affluence and the diminution of estuarine habitats near large population centers.

A number of technological possibilities will moderate the impact of the other uses on fisheries habitat; water reuse and air cooling by diminishing the demands for the intake of fresh water and/or brackish water, desalting of brines and seawater, nuclear power, and improved water treatment argue a reasoned case for maintaining flexibility.

When the removal of aquatic habitat can cause irreversible consequences, there is a case for reasoned delay—time in which to demonstrate thoroughly the need for this estuary development and to acquire the knowledge that will allow its consequences to be predicted more reliably.[15] An "insur-

[12] "The National Estuarine Pollution Study," p. 289

[13] This is reimpressed if one asks what the loss to mankind is if by his actions a species of fin or shell fish is rendered extinct.

[14] The critical natural features theory was adopted in the decision of the Wisconsin Supreme Court: "The Just vs. Marinette County (4 ERC, 1941, Wisconsin, 1972) stands as an explicit judicial recognition that regulations preserving certain publicly critical features of land may be upheld without compensation despite great loss in economic development potential." See Environmental Quality, the fourth annual report of the Council on Environmental Quality, 1973, pp. 146-147.

[15] It is true that the filling of tidal marshlands, often termed irreversible, can be reversed by expenditure of large amounts of both time and money. It is virtually impossible to obtain an exact replica of the ecosystem as it was prior to disturbance. An irreversible condition for present purposes is defined as one for which the time or cost of the reversion is so high that in all likelihood it will not be undertaken.

ance premium" is paid to keep such an option open when the benefits of the development use are deferred. In some instances, these benefits may be considerable but so might the permanent loss of a critical segment of fishery habitat. These are sensitive trade-offs; the benefits should be identified and measured where possible.

Analyses ascertaining the fundamental biological relationships of the ecosystem show the relation of a part to the whole and are a necessary prerequisite to devising measures which are safeguards against irreversibility. In other words, interest centers on what happens to the whole when a part of the ecosystem is modified or converted to other than its natural use.

Investigation of the relation of the part to the whole (of the role of specific estuarine habitat such as tideland to the overall aquatic environment) presents the biologist and ecologist with a very complex problem—one which is further complicated by compartmentalized planning studies which frequently ignore or deemphasize these interrelationships.

The system's approach is violated when agencies responsible for estuarine management are requested to evaluate a development. In many instances, these agencies do not have the choice of proposing an alternative to the development they have been asked to evaluate, nor do they have the research capability and manpower to investigate and sponsor such alternatives. Appropriate tenets of evaluation are of little use in estuarine management unless they receive institutional sanction and are activated by competent technical and management staff.

The present composition of research staffing in many agencies, especially water resources and fish and game, is largely oriented to a preponderantly engineering viewpoint even to the assessment of social values. Biological, ecological, and social viewpoints should not be subservient to that of engineering, efficiency or the constructionist: a partnership is urgently required, and this will mean adequate, competent staffing in these three categories.

The type of research advocated above and the employment of sound tenets of evaluation would serve to unmask "the tyranny of small decisions" where one decision taken at a time is relatively unimportant but given time and additional decisions the system is completely altered.[16] The cumulative effects in the future of many small irreversible commitments of the remaining 5.5 million acres of estuarine marsh and wetland habitat (1970) were the special concern of the "National Estuarine Pollution Study."[17]

The relative scarcities of the fishery resource itself and the particular fishery habitat are not the only practical considerations. The availability of substitutes and substitute sites for the products to be obtained from estuarine resources is a basic consideration. Are there other opportunities including technical possibilities for the development of products which even though they make the product more costly are not so costly in terms of depleting biological resources and aesthetic qualities?

The economic reasoning in following this tenet of the evaluation credo may be illustrated from an actual case study for the San Francisco Bay. Projected dredging and retrieval of aggregate (at low operations costs) from an extensive and shallow aggregate source such as the Potato Patch Shoals, immediately outside the Golden Gate, would very likely jeopardize the support for the local supply of crabs in the bay area. In such a situation, the following questions should be answered. For what purposes is the aggregate required? Is it to be used for concrete construction or for bay fill to create additional home and factory sites to further accelerate the diminution of estuarine habitat? If the former, are there other sources of aggregate; if the latter, what is the relative scarcity of homesites in the vicinity? In other words, have all the opportunities for the projected homesites or supply centers for aggregate for construction or fill been carefully explored? What additional costs are involved in selecting alternative sites both for aggregate and for homes or factories? These costs could prove to be not so great when compared with the benefits flowing from an appreciating renewable resource.

On the other side of the ledger, what would be the economic repercussions of losing a valuable local seafood resource? The impact of losing the local crab resource is not measured solely in the loss of income to fishermen who forfeit all or part of their customary livelihood. There are the indirect or neighborhood effects which must be accounted for. Fishermen's Wharf, a traditional center for seafood, could experience a decline in expenditures by both local clientele and tourists, with further repercussions in the business sector. The costs enumerated are real and cannot be omitted in the tally of social costs occasioned by the loss of a vital part of any fish support system.

In summary, many estuaries, in providing healthy fishery habitats, are appreciating assets and some development decisions are irreversible. And although current evaluation methods do not adequately quantify all social values, even a reasonably accurate picture cannot be obtained of the social costs and benefits of maintaining or improving estuarine fish production unless economic reasoning is fully employed to provide insight to alternative courses.

[16] Kahn, A. E. 1966. The Tyranny of Small Decisions: Market Failures, Imperfections, and the Limits of Economics. Dkylos. 19 (1): 23-47.

[17] "The National Estuarine Pollution Study," p. 289.

VALUE OF COMMERCIAL FISHING: INDICATOR OF SOCIAL IMPORTANCE

While many extramarket uses of estuarine habitat remain unmeasured in strict quantitative market terms, the commercial catch can be valued in different economic terms—its value to the fishermen, to the processor, or the final price paid by consumers. In all instances, whatever value is adopted it is but one indicator, an incomplete one of the worth of estuarine fisheries habitats.

In broad terms, estuarine fisheries habitats are highly valuable and significant assets; approximately 65 percent of all commercial fish species and practically all of the sports fish species are dependent upon the estuarine zone for one or more phases of their life development.

The estuary is the ultimate source of food for some continental-shelf species and most marine predators, including tuna.[18]

The estuary is then the vital support system to a valuable renewable resource, fish, which supplies a significant portion of the edible protein consumed by man. In addition, the estuary is an important source of fish meal, a high protein feed for another important source of edible protein, poultry and swine.

Two-thirds of the total landed value of commercial fish and shellfish has been estimated as derived from estuarine-dependent species.[19] Other estimates cite the annual landed value of commercial fisheries as being 75 percent estuarine-dependent or associated fish.[20] Regionally the values vary; in the Gulf of Mexico, estuarine-dependent resources supply 90 percent of the commercial catch.[21]

The 1972 commercial catch was valued at $704 million (see Table 2). Estuarine-dependent species provided $470 million, a 57 percent increase in the landed market value of $300 million in 1965. At an interest rate of five percent, the capital investment required to return $470 million annually would be approximately $9.4 billion.[22] This provides an estimate of the importance of the estuarine fisheries habitats for the United States commercial catch.

Another measure of the economic importance of the commercial fishing industry is the income generated by its demand for basic inputs such as boats and equipment and supplies used in catching and landing fish. Sizable income would be lost to these suppliers and manufacturers if the commercial fishery were to close.

It has been estimated that the multiplier associated with commercial fish harvesting is 2.96. This means that $2.96 of economic activity (including supportive industries, expenditures on fuel, equipment, wages, et cetera) is generated from each dollar of additional income to fishermen.[23]

Estimates of future market demand, coupled with the probable scarcity of future supplies, indicate a continuation of rising values for estuarine-dependent fish. Estuaries as fishery habitats are rapidly appreciating national assets. Figure 2 illustrates the increase in future market demand, which is projected to double by the year 2000.

Further, income elasticities for different fishery products attest to increasing demands for finfish and crustaceans basically dependent upon an estuarine environment. Income elasticities of demand for fish products show the change in consumption of the product in response to a change in consumer income. Income elasticities for some important estuarine fish have been estimated as follows: lobster, 2.1; shrimp, 1.8; fresh and frozen salmon, 1.6; crab, 1.3; and groundfish (flounder being representative), 1.2.[24] Income elasticities are indicative of future consumption. For example, a 10 percent increase in per capita income would be accompanied by an 18 percent increase in the quantity of lobster consumed, a 16 percent increase in the quantity of shrimp consumed, and a 16 percent increase in the quantity

Table 2.—Fisheries: Quantity and value of catch 1930-72[1]

Year	Total	For human use	For industrial products[2]	Value (million dollars)	Average price per pound (cents)
	(million pounds)				
1930	3,224	2,478	746	109	3.4
1940	4,000	2,675	1,385	99	2.4
1950	4,901	3,307	1,594	347	7.1
1960	4,942	2,498	2,444	354	7.2
1965	4,777	2,587	2,190	446	9.3
1968	4,160	2,347	1,613	497	11.9
1969	4,337	2,321	2,016	518	12.1
1970	4,917	2,537	2,380	613	12.5
1971	4,969	2,400	2,569	643	12.9
1972	4,710	2,310	2,400	704	14 9

[1] Does not include the value of fish harvested by foreign vessels off the U.S. coast.

[2] Manufactured into meal, oil, fish solubles, homogenized condensed fish, and shell products, and used as bait and animal food

Source: U S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States 1973, 94th edition, Washington, D C., 1973, Table No. 1072, p. 635, citing U S. National Oceanic and Atmospheric Administration, Fishery Statistics of the United States, annual.

[18] Estuarine dependence is based on whether one or more phases of the species' life cycle is spent in estuaries. The estuarine dependence of important sport and commercial fish is shown in Table IV.2.1 of The National Estuarine Pollution Study.

[19] "The National Estuarine Pollution Study," p. 151.

[20] "National Estuary Study," v. 5, Appendix E, p. 16.

[21] McHugh, J. L. November 1968. "Are Estuaries Necessary?" Commerical Fisheries Review, 30 (11): 37-45.

[22] The value of tidal marshes on the east coast has been deduced as $2500 to $4000 per acre per year; when these annual social values are income capitalized at five percent interest, the estimated total social values are $50,000 to $80,000 per acre. Gosselink, J. G., E. P. Odum and R. M. Pope. 1974. The Value of the Tidal Marsh. Pub. No. LSU-SG-74-03, Center for Wetland Resources, Louisiana State University, Baton Rouge.

[23] "National Estuary Study," v. 5, Appendix E. p. 17.

[24] Ibid.

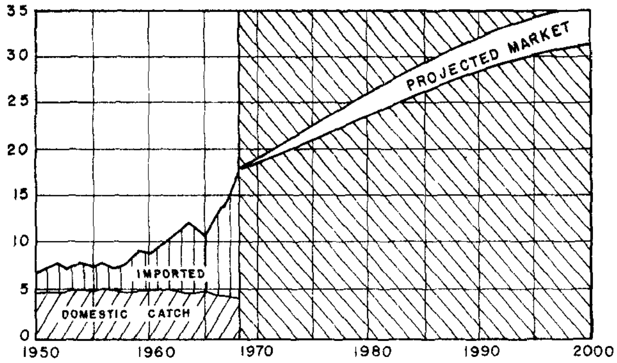


FIGURE 2.—U.S. market for fishery products. Source: U.S. Department of the Interior, Fish and Wildlife Service. March 26, 1970. National Estuary Study 5, Appendix F. Washington, D.C.: 17.

of salmon consumed. The consumption of all of the species indicated above increases more than proportionally with income rises.

IMPUTED VALUES OF SPORT FISHERIES: ANOTHER USEFUL INDICATOR

Nearly every sport fish species is dependent upon the estuarine zone for one or more phases of its life cycle.[25] It is concluded that "saltwater sport fishing is far more closely related to estuaries than commercial fisheries.[26] The estuarine zone offers a great diversity of environment and species to sport fishing. For this and other reasons, sport fishing has become an increasingly popular and economically important aspect of estuarine fisheries use.

By the year 2000 sport fishing is expected to increase by some two to two and one-half times in saltwater and the Great Lakes.[27] All indications point to sport fishing's becoming an increasingly valuable use of estuarine fisheries habitats. This value lies not only in the value of the actual fish caught, but in the social value of recreational activity, as well as in the great variety of related goods and services generated by the fishing activity. While dollars can be imputed to estuarine sport fishing activities, and a number of useful refinements have been made in the art of economic measurement, as yet the joint-products dilemma has not been resolved satisfactorily. These values, computed either by applying an administrative price for user days or by using travel-cost imputation are useful to give an order of magnitude assessment for a specific activity in a specific location but are inadequate to encompass all the joint services—values stemming from the estuarine environment as they relate to sport fishing.[28]

Not all uses of estuarine resources compete with fishery production. There is a degree of compatibility between fish production and the discharge of nutrients or heated water.

The assimilative capacities of the estuarine zone allow limited quantities of non-toxic waste to be assimilated by the system. Small quantities of waste can even be helpful to fishery productivity by supplying necessary nutrients in sufficient quantities.

The economic contribution made by the assimilative capacity of five eastern estuaries (Delaware, East, Hudson, James and Potomac) was estimated to be $5,903,000.[29] This value relates only to a miniscule part of the total chemical and biochemical processes occurring within these estuaries. The environmental services in toto performed by an estuarine zone defy meaningful calculation. The full extent of their value would become more comprehendable if it were ever necessary to replace or substitute the complete range of these services.

IMPORTANT SOCIAL AND ECONOMIC TRENDS

Changing economic and demographic patterns have exerted developmental pressures which are the most significant factors affecting the estuarine fishery habitat. Certain trends with implications for degradation of the estuarine environment are projected to continue; population will grow rapidly in coastal counties, with expansion in the urban-suburban areas, and ports and the volume of commerce will expand as these economic bases grow. Projected activities in the estuarine zone, consequently, will play a decisive and increasing role in determining the future productivity of the fishery habitat.

Two broad sources of degradation of fishery habitat are foreseen as resulting if these pressures are not suitably countered by informed management.

The first source is constituted of direct pollution of nutrients and toxic materials from municipal and industrial wastewater discharges and dumping; agricultural runoff carrying pesticides, salt, nutrients and silt; thermal heat and waste from power develop-

[25] "The National Estuarine Pollution Study," p. 115.
[26] "Economic and Social Importance of Estuaries," p. A-22.
[27] "The National Estuary Study," v. 5, Appendix E., p. 32.

[28] The annual net benefits for recreational fishing in San Francisco Bay for 1966 and 1980 were estimated to be $9 million and $15.5 million respectively. An administratively adjudged user day value varying from $.50 to $1.50 per day was applied to fishing days to impute net benefit. See Delisle, G. October 1966. Preliminary Fish and Wildlife Plan for San Francisco Bay-Estuary. Prepared for the San Francisco Bay Conservation and Development Commission: 94.

[29] Economic and Social Importance of Estuaries. April 1971. Estuarine Pollution Study Series 2, Environmental Protection Agency, David Sweet, Project Director: 55-56. The dollar value was calculated as follows. The pounds of biochemical oxygen demand (BOD) that had to be removed to achieve a one mg/l increase in minimum dissolved oxygen was estimated. The cost of removing a pound of BOD was assessed at $0.04.

ments; storm water runoff and discharges from other diffuse sources; spills and leakages of hazardous materials into coastal zone, and pollution within the estuary from dredging, channeling and other alterations. The second source can occur through the nonpollutional damage of the fishery habitat through landfills, overfishing, and even depletion of marine life by excessive collection and study. Degradation of the latter type is occurring in some parts of the tidal zone of California.

The impact of the waste in all media—water, air and solid—from point and diffuse sources varies greatly from estuary to estuary depending upon the combined concentrations that directly or indirectly find their way into a specific estuary. The geophysical structure of the estuary, the physical processes of advection and diffusion, variations in freshwater inflow and many other major physical processes which at present are only qualitatively understood determine the mixing of these various forms of wastes at the freshwater-saltwater interface and throughout the estuarine area.

The characteristics that allow an estuary to concentrate and reuse nutrients that sustain fish productivity also make the estuary a concentrator of pollution and waste.[30]

Compounding the effects of waste concentration is the vulnerability of estuarine residents. Many of the estuarine organisms are living near the limit of their range of tolerance and any further alteration, regardless of how slight it may be, has the potential of excluding an organism from the estuary.[31] Furthermore, the deposition of most of these wastes occurs offshore in the shallow areas of the estuaries, areas of highest productivity and necessary to the estuary for the production of oxygen.

Figure 3 depicts the fate and distribution of estuarine pollutants; only the elementary processes involved in what is a highly complex phenomenon are indicated.

An appraisal of the impacts of wastes on fishery productivity in different estuaries is a complicated task and cannot be attempted in this paper for reasons already given. It is possible, however, to identify those intensifications of use of the estuarine resources which are compounding and will compound the difficulty of maintaining fishery resources.

[30] Duke, T. W. and R. R. Rice. 1967. Cycling of Nutrients in Estuaries. Proceedings of Gulf and Caribbean Fisheries Institute, (19):59:67. Pomeroy, L R., R. J. Reimold, L. R. Shenton and R. D. H. Jones. 1972. Nutrient Flux in Estuaries. Nutrients and Eutrophication, edited by G. E. Likens, American Society of Limnology and Oceanography, Special Symposium 1:274-296; Schelske, C. L. and E. P. Odum. 1961. Mechanisms Maintaining High Productivity in Georgia Estuaries. Proceedings of Gulf and Caribbean Fisheries Institute, 14:75-80. (The levels of phosphorus in estuarine water have been shown to be 10 to 40 times higher than in the river-water flowing into the estuary.)

[31] Odum, William E. 1970. Insidious Alteration of the Estuarine Environment Transactions of American Fishery Society, 4: 836-845.

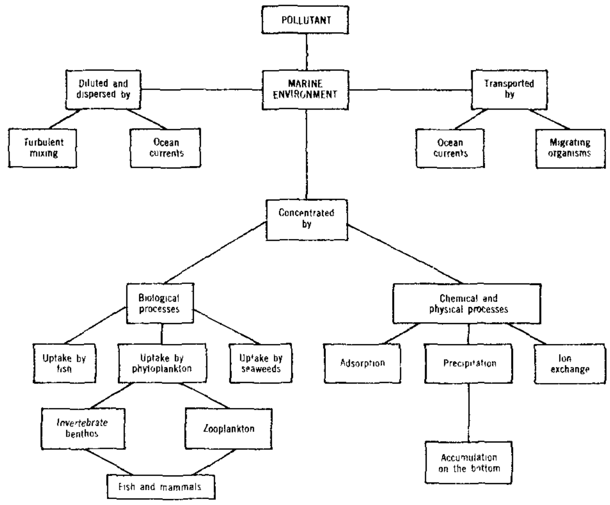


FIGURE 3.—The fate and distribution of estuarine pollutants. Under favorable conditions, the pollutants are diluted, dispersed, and transported by turbulent mixing, ocean currents, and migrating organisms. The mixing is often restricted so that high concentrations of pollutants can exist in local areas. In addition, biological, chemical, and physical processes concentrate pollutants and lead the pollution back to man. Source: *Patterns and Perspective in Environmental Science*. Report prepared for National Science Board, National Science Foundation. 1972. Figure VIII-8, p. 245.

The future aquatic environment will be greatly influenced by the success of water quality control programs not only as they relate to the estuary proper but to the freshwater streams flowing into the estuaries.

MUNICIPAL AND INDUSTRIAL WASTE DISCHARGES

Since increases in population are usually accompanied by increases in the loads of municipal and industrial wastes, discharging and dumping of these wastes, (although greatly reduced from the levels of the late 1960's) must be counted a major problem in most estuarine zones in the populous areas of the nation.

Population in the estuarine areas grew by 78 percent from 1930 to 1960 while national population grew by only 46 percent. In 1970, 33.7 percent of the United States population resided in the estuarine economic areas. The population residing in these areas as a percent of the national total is projected to grow to 34 percent by 1980, 36.9 percent by 1990, and 38.8 percent by 2000, when 107 million people out of 275 million will be living in or close to estuarine areas.

The projected populations for different estuarine

Table 3.—Estimates and projections of population in the estuarine economic region and individual area (in thousands)

Individual estuary economic areas	1950	1960	1970	1980	1990	2000
Maine coast	471.7	499.7	531.5	576.7	633.6	688.2
Massachusetts—Rhode Island coast	4,355.4	4,794.3	5,194 3	5,729.2	6,390.6	7,958.2
Connecticut coast	761.2	934.9	1,057.0	1,184.8	1,343.9	1,492.2
New York—northeast New Jersey	13,593.6	15,603.5	17,376.5	19,114.4	21,061.0	23,022.3
Philadelphia—New Jersey—Delaware	4,399.3	5,320.8	5,939.9	6,661.5	7,567.1	8,505.8
Maryland—Virginia coast	4,473 0	5,739.5	6,812.8	8,023.3	9,573.3	11,172.1
North Carolina coast	447.1	511.7	529.0	546.1	582.7	623.0
South Carolina coast	374.8	466 2	503.2	539.0	595.7	652.2
Georgia—eastern Florida coast	1,432.5	2,637.8	3,698.7	4,699.3	5,752.5	6,941.1
Southern Florida gulf coast	547.7	1,058.7	1,369.0	1,663.1	1,931.0	2,302.7
Central Florida gulf coast	98.0	126.5	134.2	150 2	171.0	198.1
Mississippi—Alabama—west Florida coast	563.0	818.5	977.0	1,135.3	1,363.3	1,603.2
Louisiana coast	1,177.8	1,535.3	1,814.7	1,974.4	2,168.6	2,930.0
Texas north gulf coast	1,324.7	1,900.8	1,206.7	2,710.4	3,304.1	4,026.1
Texas south gulf coast	441.5	563 8	635.6	704.1	792.3	878.2
Southern California coast	5,233 5	8,224.9	10,826.2	13,586.9	16,906.1	20,331.0
Central California coast	2,944.2	3,972 6	5,084.6	6,280.3	7,696.9	9,150.2
Northern California coast	78.0	122.7	151.0	188.1	230.1	273.8
Oregon coast	1,091 4	1,276.8	1,389.3	1,602.7	1,849 6	2,087.7
Washington coast	1,493 7	1,837.3	2,165.5	2,536.8	2,972.6	3,444.1
Estuarine economic region total population	45,302 1	57,946.2	68,396.9	76,606.7	92,940.0	106,900.3
Total U.S. population	151,370	179,320	203,210	225,000	252,000	275,000
Percentage of U.S. population in estuary economic areas	29.9%	32.2%	33.7%	34.0%	36 9%	38.8%

Source Office of Business Economics, Regional Economics Division, and U.S. Bureau of the Census Statistical Abstracts of the United States, 1973.

economic areas are shown in Table 3.[32] In addition, these populous coastal counties, while they contain only 15 percent of the land area, have 40 percent (1969) of the manufacturing activities within their boundaries.

Information on the effects of municipal and industrial loads and their treatment on water quality are not readily available for different estuaries, although sampling of water quality parameters in a number of estuaries is part of the ongoing effort. Overall water quality trends have been assessed for the nation, but the water quality trends as reported are insufficient indicators of the effects of changing conditions for the biological communities in estuaries.[33] They offer no high resolution of the status of water quality for fish production, but provide useful information on water quality; estuaries are natural sinks for water pollutants so that the quality of inflowing river water is of consequence to biological communities in estuaries.

In 1970, cleanup efforts to improve water quality under the federal-state program established by the 1965 Water Quality Act were appraised as only holding the line on common organic pollution. "The effects of increased treatment had been virtually cancelled by larger wasteloads. Other forms of water pollution such as phosphates and nitrate nutrients were on the rise. Fish kills, beach closings, algal growths, oily scums, and odors were still prevalent. Sporadic upgrading of municipal treatment plants were often more than offset by nearby industrial effluents. In other cases, cleanings of industry were offset by increasing municipal discharges."[34]

The 1972 amendments to the comprehensive Federal Water Pollution Control Act were designed to correct these inadequacies, and set a course for a sustained water quality improvement program.

For the period to 1977 the objective of the act, "to restore and maintain the chemical, physical and biological integrity of the nation's waters," has been interpreted as requiring standards which will protect indigenous aquatic life and permit secondary contact recreation such as boating and fishing. A quality of water which will protect aquatic life is considered adequate to ensure other uses such as public water supply, agricultural industrial use, and navigation.[35]

To achieve the 1983 interim goal of Sec. 101(a) of the act, providing for the protection and propagation of fish, shellfish, and wildlife, and for recreation in and on the water, EPA has proposed water quality criteria defining maximum limits of acceptability

[32] The estuarine zone economic region includes the coastal counties plus a few noncoastal counties included as part of estuarine zone Standard Metropolitan Statistical Areas Recent projections show U.S. population to be slightly lower than those given in Table 3. See U.S. Department of Labor, Bureau of Labor Statistics, Kutscher, Ronald. December 1973. Projections of GNP, Income Output and Employment. Monthly Labor Review, 96. 3-42.

[33] EPA National Water Quality Inventory, Report to Congress, Washington, D.C., U.S. Government Printing Office. The major waterways sampled are shown in Appendix Table 2.

[34] Environmental Quality, The Fourth Annual Report of the Council on Environmental Quality, September 1973 168. Environmental Quality, the Second Annual Report of the Council on Environmental Quality, 1971: 217-221.

[35] P. L. 92-500, Sec 101(a). See also EPA Water Quality Strategy Paper, March 15, 1974, p. 28.

for chemical and physical constituents in United States waters.[36] These criteria are based on recommendations of a National Academy of Science report and reflect current knowledge of the identifiable effects of pollutants on human health, fish and aquatic life, plants, wildlife, shorelines, and recreation; concentration and dispersal of pollutants; and the effects of pollutants on biological community diversity, productivity and stability, including factors affecting rates of eutrophication and sedimentation.[37]

The National Water Quality Inventory allows an overview of water quality trends from 1963 to 1972 for 23 waterways (a total of 35 major reaches) draining 70 percent of the Nation's land. It has furnished some evidence that nutrient levels increased. "In 84 percent of the reaches, phosphorus and phosphate (readings exceeded) reference levels associated with potential eutrophication. . . . 54 percent of the reaches showed increased phosphorus levels in 1968-72 over the previous years (1963 to 1968). Nitrate levels also increased in 74 percent of the reaches examined. . . . other pollutants with high levels were phenols that can affect fish palatability and suspended solids which interfere with some aquatic life processes."[38] The major rivers included in the water quality analysis and the results are set out in Appendix Table 2 and Appendix Tables 3 and 4, respectively.

Progress in the last five years, 1968 to 1972, is evident for oxygen demand and bacteria. The data available for heavy metals and pesticides showed that drinking water levels for cadmium, lead, mercury, iron, and manganese were exceeded by one or more samples collected over the 1968 to 1972 period in more than half the reaches examined; nine pesticides were found to exceed reference levels in more than half of the reaches.[39]

One indication of the extent and severity of water pollution at present is that to achieve the water quality target for 1977 approximately 1,600 of the 3,100 water quality reaches identified will have to go beyond 1977 technology-based effluent standards.[40]

Projections to 1985 of the state of water quality have been made in an attempt to assess the likely impact of measures taken under the Federal Water Pollution Control Act. A comparison is made of the "controlled" effluents, the levels expected to result pursuant to the standards and regulations established under current water control legislation, and

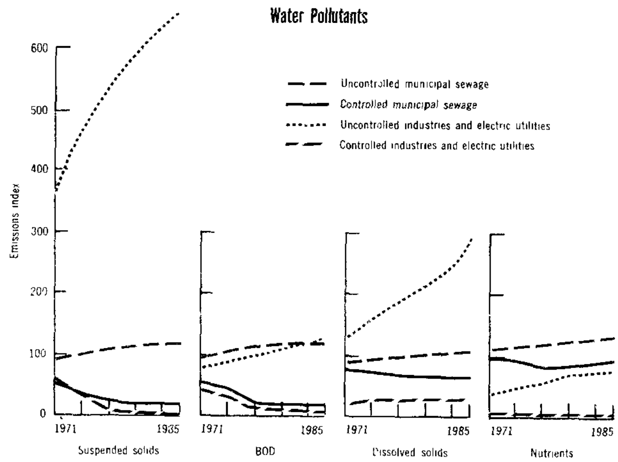


FIGURE 4.—The base case of seas: generation of pollutants, by sector. (1971 emissions = 100). Source: Council on Environmental Quality. Environmental Quality. The Fifth Annual Report: 295.

the "uncontrolled" effluents if no pollution abatement was undertaken. The result of the analytical tool SEAS, Strategic Environmental Assessment System, is shown in Figure 4.[41]

Municipal sewage treatment effluents are projected to account for virtually all of the "controlled" nutrients and 70 percent of the dissolved solids. Under the 1972 amendments to the Federal Water Pollution Control Act (PL 92-500), discharged waste loads from municipal and major industrial sources (including electrical utilities) then can be expected to decrease significantly with implementation of a responsive wastewater management program.

National projections of water quality, however reliable and illustrative, are only indirectly meaningful for specific estuaries. Projected waste loads from municipal and industrial sources for the San Francisco Bay place in better perspective the water quality management problem that will confront many "urbanized estuaries."

As in other estuarine zones, an increase in the degree of treatment and improvement in operations in recent years has kept waste loads discharged to San Francisco Bay essentially constant although population and industrial activities have steadily increased. Diffuse waste sources such as storm runoff from urban and non-urban areas, however, are projected to increase as the San Francisco Bay region continues to grow. Graphical comparisons of the waste loads for BOD, heavy metals, and nitrogen from point and diffuse sources in Figures 5, 6, and 7 point to the necessity to develop a manage-

[36] EPA, Water Quality Criteria, 1973.

[37] National Academy of Sciences, Water Quality Criteria, 1972.

[38] Results of the National Water Quality Inventory conducted by EPA are summarized in Environmental Quality, 1974, the Fifth Annual Report of the Council on Environmental Quality: 28[illegible]-288.

[39] Ibid.: 286-287.

[40] Ibid.: 112. See also EPA Water Quality Strategy Paper, March 15, 1974: 28.

[41] *Environmental Quality, Fifth Annual Report*: 297.

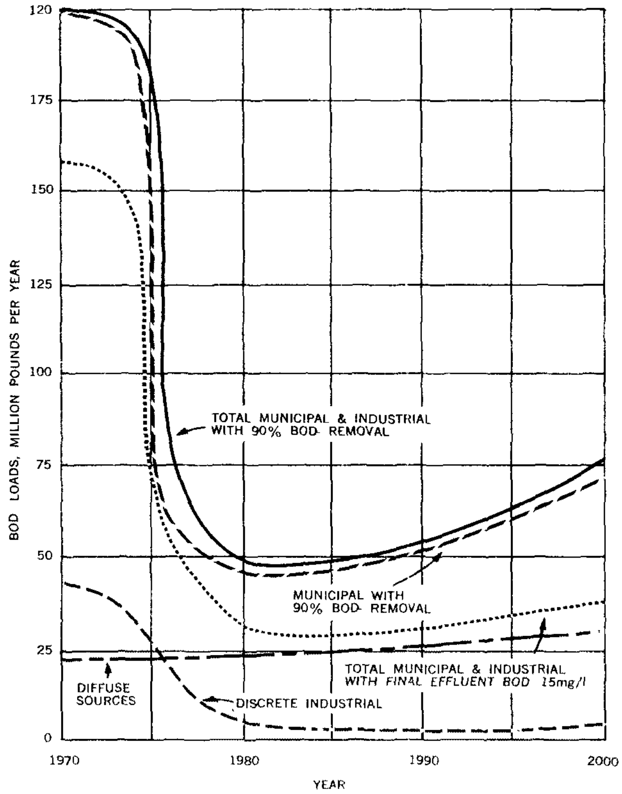


FIGURE 5.—Projected BOD loads discharged to San Francisco Bay.

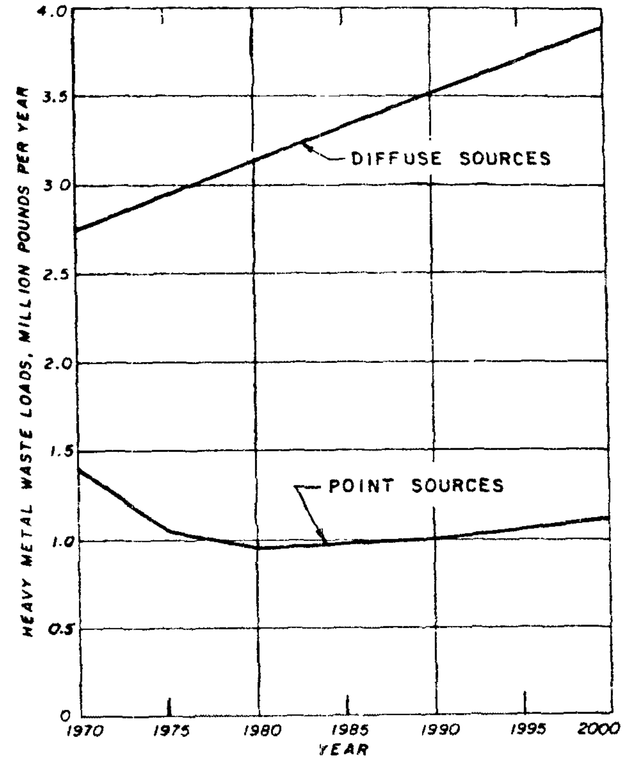


FIGURE 6.—Projected heavy metal loads discharged to San Francisco Bay.

ment system to contain discharges from diffuse as well as from point sources.[42] The projected increase in the loads of heavy metals, oil and grease, nitrogen, phosphate, and pesticides and in some estuaries polychlorinated biphenyls from diffuse sources also are sufficiently great to alert management to their implications for the retention of productive fishery habitat.[43]

The importance of runoff in degrading water quality cannot be dismissed in any plan for comprehensive water quality management in the estuarine zone. In urban estuarine areas runoff from storms can contribute a major portion of the water pollution load. In the intense discharge during storms from 94 to 99 percent of the BOD load can be contributed by runoff and bypasses.

The storm runoff from a moderate-sized city has been assessed as contributing a heavy load of metals—100,000 to 250,000 pounds of lead and 6,000 to 30,000 pounds of mercury each year.[44]

The unabated discharge in storm water of heavy metals, given the toxicity of these metals, is a cause for concern for the "urbanized estuaries." The treatment of municipal and industrial discharges alone in the future will in most instances not be sufficient to insure a productive fishery habitat, one in which the end use—edible fish—is not denied to man because of high levels of contamination from harmful and toxic substances.[45]

Storm water runoff is but one source of the toxic

[42] These figures appear as Figures 7, 8, and 9 in Development of a Water Quality Control Plan, San Francisco Bay Basin, Workshop, March 5 1974, California State Water Resources Control Board, Sacramento, California; 12. Loads of heavy metals were calculated from available data on concentration of cadmium, chromium, copper, lead, mercury, nickel, and zinc in existing municipal and industrial wastewater and in urban and non-urban storm runoff.

[43] In July 1973, EPA designated 12 chemicals used in manufacturing as toxic water pollutants, including cadmium, mercury and polychlorinated biphenyls, as well as the pesticides aldrin, dieldrin, endrin, DDT and its derivatives DDE and DDD. The pesticide compound toxaphene was also included. Other metals currently being studied for possible inclusion on the list include arsenic, selenium, chromium, lead, beryllium, and nickel.

[44] Total Urban Water Pollution Loads: The Impact of Storm Water, (PB-231/730) is available from National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia, 22151. In July 1973 EPA designated cadmium and mercury used in manufacturing as toxic water pollutants. EPA is currently developing effluent standards governing the discharge of these two heavy metals. In addition, EPA is studying arsenic, selenium, chromium, lead, zinc, beryllium, and nickel for possible inclusion on the list of toxic pollutants. See 38 Federal Register 2434 (1973), 40 CFR 129. Toxic pollutants are defined as those which "cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction) or physical deformations in such organisms or their offspring," PL 92-500, Stat. 816, 1972.

[45] The minamata disaster reimpresses the gravity of high levels of toxic forms (mercury). The effects of low-level exposure over long periods—genetic, mutagenic and tetragenicity, et cetera—are also legitimate reasons for concern.

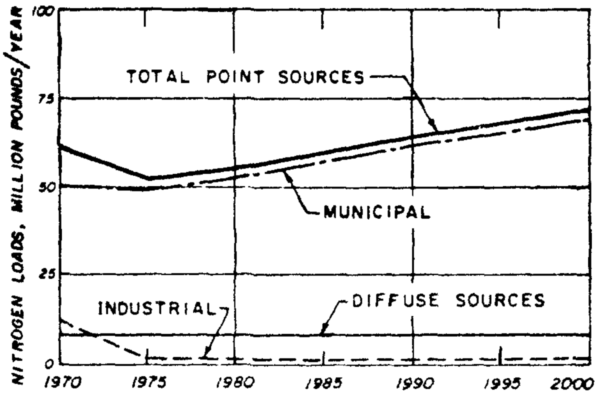


FIGURE 7.—Projected nitrogen loads discharged to San Francisco Bay.

trace element contaminants (principally heavy metals) and hazardous and toxic chemicals which are distributed by complex pathways encompassing essentially all media and their associated ecosystems. In estuaries the biological conversion to even more toxic forms, e.g., organometallics and accumulation in the aquatic ecosystems and sub-strates, underscores the importance of this pollution problem for estuaries. The potential hazard of certain trace elements is demonstrated by the concentration factor for shellfish (see Table 4).

Other sources of trace element emissions to the environment are reasonably well identified; quantitative estimates are available for air emissions from different industries and the trace element contents of wastewater from lead-zinc processing have been calculated. Sludges and solid residues (tailings) also constitute a source of trace element contaminants

Table 4.—Concentration factors for the trace elements composition of shellfish compared with the marine environment

		Encroachment factors		
		Scallop	Oyster	Mussel
Silver	Ag	2,300	18,700	330
Cadmium	Cd	2,260,000	318,000	100,000
Chromium	Cr	200,000	60,000	320,000
Copper	Cu	3,000	13,700	3,000
Iron	Fe	291,500	68,200	196,000
Manganese	Mn	55,500	4,000	13,500
Molybdenum	Mo	90	30	60
Nickel	Ni	12,000	4,000	14,000
Lead	Pb	5,300	3,300	4,000
Vanadium	V	4,500	1,500	2,500
Zinc	Zn	28,000	110,300	9,100

Source: Ketchum, B. H., editor The Water's Edge· Critical Problems of the Coastal Zone. 1972. The *MIT Press, Cambridge, Mass.*, Table 7.2: 150; based on Brooks, R. R. and M. G. Rumsby. 1965. The Biochemistry of Trace Element Uptake by New Zealand Bivalves. *Limology and Oceanography* 10:521-527.

in estuaries unless adequate storage or disposal is practiced.

There are other major sources of trace element contamination to water and land receptors in estuarine areas, notably automotive exhaust (lead), leaching from municipal landfills, and incinerator and land disposal of sewage sludge from municipal wastewater treatment.[46] Agricultural chemicals contribute to heavy metal loads as nonpoint water pollution, especially mercury, copper, zinc, cadmium, manganese, and chromium.

The setting of air and water quality standards for the various trace elements related to point and diffuse sources of contamination requires the identification of sources, forms of pollutants, pathways, and the effects of each substance on the biological communities in estuaries.

Effluent guidelines have been promulgated by EPA for some 29 industries up to June 30, 1974 (see Appendix Table 5). Nevertheless, there is urgent need for additional effluent limitation guidelines, for EPA has identified a total of about 180 industrial subcategories and 45 additional variances as requiring distinct effluent standards.

In urban storm water discharges, PCB's and pesticides have been identified as significant components.[47] Like the heavy metals, hazardous chemicals —diethyl-stilbestrol, thalidomide, DDT, polychlorinated biphenyls, vinyl chloride, pesticides, and phthalic acid esters—find their way into the estuarine environment along a variety of incredibly complex pathways from many sources.[48]

Of all chemical classes, pesticides would appear to pose the most difficult future pollution problem since sources are diffuse and spread over millions of acres in the 18 principal water regions of the nation. Pesticide use in urban areas has increased. The widespread presence and buildup of persistent pesticides in water and in fish and marine mammals are well documented. These characteristics make pesticides and other hazardous and toxic substances a major problem to resolve for the protection of the health of man as well as for estuarine biological communities.

[46] Young, D. R. et al. February 1973. Source of Trace Metals from Highly Urbanized Southern California to the Adjacent Marine Ecosystem. Proceedings of a conference on Cycling and Control of Metals, sponsored by EPA, NSF and Battelle: 21-39. On December 6, 1973, EPA promulgated regulations limiting the lead content of gasoline, allowable level of lead is reduced to an average of 1.7 grams of lead per gallon in 1975, and 0.5 grams of lead per gallon in 1979. This is the most significant and controllable source of lead exposure. 38 Federal Register 33734, (1973).

[47] Sartor, J. D., and G. B. Boyd. November 1972. Water Pollution Aspects of Street Surface Contaminants. 76-81 EPA-R2-72-081.

[48] The pesticides aldrin, dieldrin, endrin and DDT and its derivatives DDE and DDD were designated toxic water pollutants by EPA in July 1973. Sevin, chlordane, lindane, methyl parathion and parathion are currently being studied for possible inclusion in the list.

PETROLEUM LEAKAGE IN ESTUARINE ENVIRONMENTS

Natural energy demand, even if stringent conservation measures are in force, is expected to double between now and 1985. The development of new energy technologies such as coal gasification, coal liquefaction, oil, shale and tar sand processes, and nuclear reactors is likely to have effects on aquatic ecosystems in estuaries some 10 years in the future. However, the impact of the increase in thermal power stations could be expected to occur earlier while the increase in domestic offshore oil production and in oil imports can be expected to aggravate oil leakage into the coastal zone.[49]

Within the next 10 years the United States' heavy dependence on oil and gas to meet its energy demands is not likely to diminish. In 1972, oil and gas accounted for nearly 78 percent of U.S. energy consumption. Expanded total energy needs were forecast to require 28 million barrels of oil per day in 1985, nearly twice the consumption in 1970. Other forecasts before the oil embargo indicated that oil imports would likely increase to 15 to 20 million barrels per day by 1985.[50]

National steps taken to reduce dependence on foreign oil imports—federal legislation authorizing construction of the trans-Alaska pipeline, expansion of the leasing program for the outer continental shelf, and a proposal to authorize construction of deepwater ports—all have implications for increased leakage of oil and petroleum products into the coastal environment of states adjacent to offshore oil wells or that have large refineries.[51]

Approximately 60 percent of U.S. refining capacity (seven million barrels per day, 1972) is concentrated in the four coastal states of Texas, Louisiana, California, and New Jersey. Production of oil from offshore reservoirs (over 8000 offshore wells in the Gulf of Mexico alone) is expected to reach 30 to 40 percent of total oil and gas production by the early 1980's.

Accelerated imports increase the risks of potential discharges from intentional or accidental tanker spills outside or in port (estuary), while increased offshore production adds to the potential hazard of major oil spills from blowouts.[52] Coastal areas must provide the space for receiving increased quantities of oil carried by pipelines and tankers as well as additional refineries.

Annual incremental spill volumes in U.S. coastal areas have been estimated for different levels of daily oil imports. In the absence of superports and assuming continued deterioration of the U.S. energy supply posture, approximately 800,000 barrels of oil could be spilled by 1983.[53]

Petroleum leakage to the ocean and coastal zone is not confined to tanker spills or blowouts from offshore wells. There are many small chronic injections of oil and oil products into the marine environment near shore. Injections of oil and grease result from sewage discharges and storm sewers, filling station washdown operations, transportation operations, and other domestic and industrial losses, including hydrocarbons leaked from outboard motors.[54]

It has been concluded that petroleum from production, refining or transportation has penetrated the marine food chain; however, an assessment of the biological effects of petroleum from different sources on the metabolism of organisms has not been made.[55] Little is known about the long-term effects of oil in an estuarine environment. Spills and leaks of oil cause a number of adverse effects in the estuarine environment, not all of which are well understood.

Oil and components of oil can be lethal to organisms or inhibit normal feeding. The effects of oil pollution of shoreline in estuaries depend partly on the nature of the oil and partly on the means by which it reaches the shore. The coating of rocks, beaches, marshes can cause significant plant and organism mortality. The nearshore marshes and

[49] The problems of energy supply and the impacts of heat disposal from power plants in the coastal zone are discussed in Chapters 5, 7 and 8 of the Water's Edge. Critical Problems of the Coastal Zone, edited by Bostwick H Ketchum, The MIT Press, Cambridge, Massachusetts, and London, England. A major study to investigate the potential environmental effects of offshore nuclear power plants was initiated by the Council of Environmental Quality in 1973 Publication of this study is expected in early 1975.

[50] Joint Committee on Atomic Energy, 93rd Congress, 2nd Session. 1974. The Nation's Energy Dilemma.

[51] Hypothetical drilling sites and development locations for the Atlantic outer continental shelves are offshore to Massachusetts, Rhode Island, New Jersey, New York, Delaware, South Carolina, Georgia, and Florida

[52] Over 17,000 wells have now been drilled in waters off the U.S. coast. The potential impact of outer continental shelf oil development depends in part on where oil released in the ocean travels and how it weathers. The relative environmental risks of oil and gas development in the Atlantic and Gulf of Alaska outer continental shelves have been analyzed by the Council on Environmental Quality in its report to the President, on April 18, 1974, entitled, OCS Oil and Gas—An Environmental Assessment.

[53] Basic data contained in the National Petroleum Council's U.S. Energy Outlook, Report to NPC's Committee on U.S. Energy Outlook, December 1972, "Polluting Incidents in and around U.S. Waters, Calendar Year 1971," U.S. Coast Guard, Washington, D.C., 1975. Estimates were obtained by James E. Flinn and Robert S. Reimers. March 1974. Development of Predictors of Future Pollution Problems. EPA Report 600/5-74-005.

[54] An estimated 10 percent of outboard motor oil fuel mixture is unburned. Mussels exposed to water containing 50 parts per billion of these hydrocarbons showed gill damage after 24 hours of exposure, 66 percent died although they were removed after one day and placed in fresh water. Fourteen percent of oysters tested died during the test period of 10 days. Clark, R. C., Jr. and J. S. Finley. November 1974. Environmental Science and Technology, Science News 106(21): 331. Since June 1973 Switzerland has outlawed ordinary motor oil in boat engines and requires instead a special oil that is emulsifiable and biodegradable. Communication by Kohn, Henry H January 4, 1975. Science News 107 (1).3.

[55] Sanders, H L., J F. Grassle and G. R. Hampson. 1972. The West Falmouth Oil Spill! Biology (Woods Hole, Mass.: Woods Hole Oceanographic Institute), Technical report No. 72-20.

wetlands are the most biologically productive areas of the estuary and are most sensitive to oil spills.[56]

Estimates of oil persistence indicate that oil probably persists much longer in salt marshes with soft sediments (up to 10 years) than on rocky shores or coarse sediments (a few months). Oil even at low concentrations threatens fish populations; finfish and shellfish are very susceptible if oil enters spawning and nursery areas. The cleanup procedure to hasten the dissipation of visible oil by the use of dispersant and emulsifying chemicals can be more damaging to the shoreline environment than the oil.

In addition to the potential hazards from oil spills, the development of superports to handle imports and of offshore oil and gas leases whether on the outer continental shelves or in the shallow inshore coastal zone (in Louisiana over 25,000 wells are operated in this productive fishery area) require construction of major pipelines over coastal marshlands. In Louisiana, coastal marshlands and estuaries extend 20 to 40 miles inland from the Gulf of Mexico. Physical and ecological effects in these unstable marshlands include erosion, release of toxic substances from dredge spoils, turbidity, salinity, and other ecosystem changes such as barriers to nutrient flushing, to migration of estuarine organisms and to tidal flow patterns that affect aquatic life. Canal erosion and pipelaying and marsh buggy operations can destroy substantial areas of coastal marsh.[57]

UPSTREAM ACTIVITIES AFFECTING FRESHWATER INFLOWS

Trace element and toxic chemical contaminants from production processes, municipal wastewater treatment, and diffuse sources have been identified as a major problem for the retention of productive fishery habitat in urbanized estuaries. Another projected problem of national importance is the potential hazard from greater leakages of petroleum into the estuarine environment with the development of offshore oil and increased imports. A third broad category of activity which will impinge on the estuarine fishery habitat might be termed "upstream activities"—those removed from the seacoast but which importantly influence the quantity and quality of fresh water entering the estuary.

Construction of dams, diversions of river flow within a basin and from one drainage area to another, control of floods, changes in land use such as increased irrigation, and clearing and channelization of forest and bottom land have in many instances direct and significant effects on estuarine aquatic habitat.

Modification of freshwater flows by dam construction, diversion, and consumption affects the extent of saltwater intrusion, the degree of mixing of fresh and saltwater and the plankton and fish populations.[58] Reduction in freshwater flow increases salinity in former brackish water areas and can reduce the production of shrimp, oysters and other marine life.

In the Sacramento-San Joaquin estuary the changes that can be expected with modification of normal flow patterns typify the effects that can be expected in many estuaries. Losses of fish eggs and young have to be minimized when water is diverted from the estuary; moderate net flow rates have to be maintained to give positive downstream flows. Maintenance of adequate freshwater flows from the Delta into San Francisco Bay are required to maintain "suitable salinities for striped bass spawning and for *Neomysis* . . . for good survival of young striped bass . . . for salmon migrations . . . for sufficient turbidity . . . and for flushing pollutants from diffuse sources out of the estuary."[59] All these requirements should be accounted for in plans for upstream and delta water developments that would modify flows. Already outflow from the Delta is "only about half the natural level due to the combined effect of upstream depletion storage and pumped exports."[60]

Increased population, industrial and municipal usage, and the development of irrigated agriculture, especially in river basins draining arid regions, will continue to increase demand for storage and diversion. The Texas Master Plan proposes to divert most of the flow of the Sabine, Neches Nueces, Trinity, Brazos and Colorado rivers for irrigation use, while an even more ambitious scheme has been discussed—the diversion of water from the mouth of the Mississippi to the Texas High Plains.

---

[56] For effects of oil on estuarine communities see Smith, Nelson. March 21, 1972 Effects of the Oil Industry on Shore Life in Estuaries. Proceedings of the Royal Society of London, Series B. 180 (1061) 287-296 Also, IDOE 1972. Baseline Studies of Pollutants in the Marine Environment and Research Recommendations. New York IDOE Baseline Conference, May 24, 1972.

[57] McGinnis, J. T. et al. December 1972. Environmental Aspects of Gas Pipeline Operations in the Louisiana Coastal Marshes, Report to Offshore Pipeline Committee by Battelle's Columbus Laboratories St. Amant, L. S. 1971. Impacts of Oil on the Gulf Coast. Trans. 36th American Wildlife and Natural Resources Conference 206-219. St Amant, 1971. The Petroleum Industry as it Affects Marine and Estuarine Ecology. *Trans Society of Petroleum Engineers Meeting.*

[58] Pritchard, D W. 1955. Estuarine Circulation Patterns. Proceedings, American Society of Civil Engineers 81 1-11 Ketchum, B. H. 1951. The Flushing of Tidal Estuaries Sewage. Sewage and Industrial Wastes 23(2). 198-209, Ketchum, B. H. Relation *Between Circulation and Planktonic* Population in Estuaries. Ecology 35. 191-200.

[59] California Department of Fish and Game April 1973. Maintenance of Fish and Wildlife in the Sacramento-San Joaquin Estuary in Relation to Water Development.

[60] California Department of Fish and Game. June 1972. *Ecological* Studies of the Sacramento-San Joaquin Estuary: A Decennial Report, 1961-1971: 18.

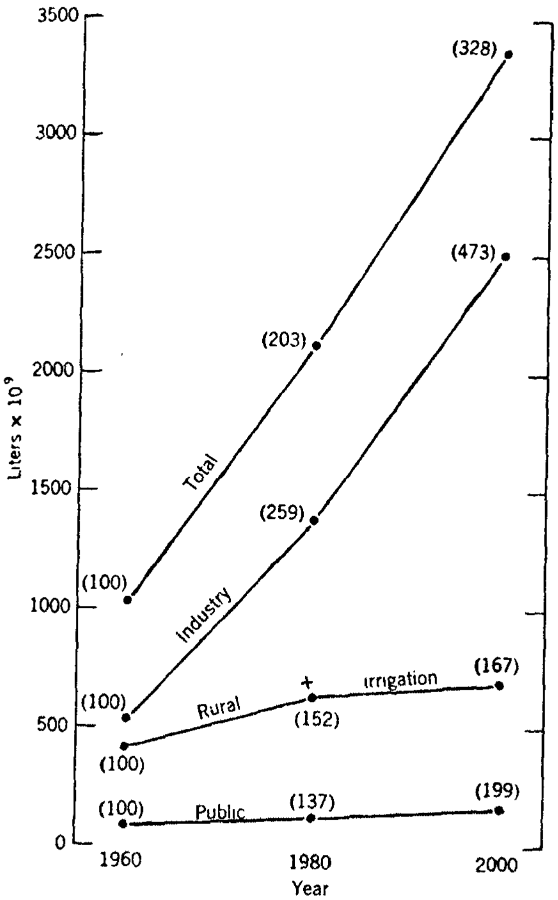


FIGURE 8.—Estimated future water withdrawal in the United States. The figures in parentheses give percentage increase over 1960 values. Source: Data of Murry, C. R. 1968. U.S. Geological Survey Circular 556; Piper, A. M. 1965. U.S. Geological Survey Water-Supply Paper 1797.

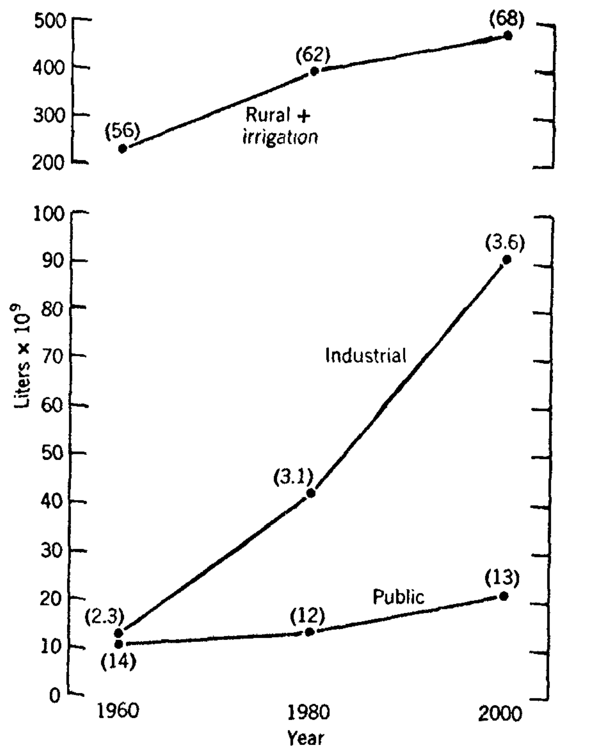


FIGURE 9.—Estimated future water consumption in the United States. Figures in parentheses give percentage of estimated withdrawal. Source: Data of Murry, C. R. 1968. U.S. Geological Survey, Circular 556; Piper, A. M. 1965. U.S. Geological Survey Water-Supply Paper 1797.

Projected future water withdrawals and consumption represent substantial increases over present-day totals (see Figures 8 and 9). Total water withdrawal in the year 2000 is estimated to amount to about 900 billion gallons per day, which compares to a runoff of 1,400 billion gallons daily. Assuming that consumption is 20 percent of total withdrawal, we will actually be losing to the atmosphere 180 billion gallons daily, a small fraction of the runoff. Recycling procedures can be developed to reduce even further the percentage of runoff required to be withdrawn. Consequently, there would appear to be enough fresh water to meet future demands. The pertinent question, however, is whether there is sufficient fresh water in different drainage areas to meet the respective demands and to maintain productive fishery habitats in downstream areas. As population pressures increase and urban activities grow in both the hinterland and coastal zone, the problems of water quality and quantity at the interface between rivers and the estuarine zone can be expected to be exacerbated.

MANAGEMENT IMPLICATIONS

Land and water use in the coastal zone is interrelated with that in the hinterland, both in actuality and policy The state land use plans should therefore incorporate plans for managing the lands along the coast in such a way as to preserve the ecological values of estuaries, other coastal waters, and marshlands to the maximum practicable degree consistent with essential uses for navigation, recreation, seafood production, power plant cooling, and other uses.

The Coastal Zone Management Act of 1972 administered by the National Oceanic and Atmospheric Administration in its first year of operation has provided assistance to all but one of 34 coastal states and territories wishing to establish resource management plans in defined coastal areas.

The management plans of the coastal zone (including estuaries) should incorporate the flexibility to be compatible with comprehensive land use planning measures as set out in the new administration bill drafted by the Secretary of the Interior.

Comprehensive plans for the use of the water and land resources of the coastal zone should be based on a careful classification of the coastal zone with respect to uses and the degree of necessary public controls over these uses. Provision should be made for public acquisition of lands and interests in lands required to preserve ecological values and provide other public benefits.

Land and water practices and programs upstream in the drainage area of an estuary importantly influence the quantity and quality of fresh water flowing into estuarine areas. Water management in the estuaries and coastal zone must be integrated with management of upstream water resources to achieve comprehensive drainage basin management. The planning of future developments and diversions upstream must recognize this crucial interrelationship and provide facilities for mitigating losses and preserving values in the estuaries and coastal zones.

Present Federal, state and local processes for making land use and development decisions as they apply to the total estuarine system, including freshwater inflows, should be made adequate to the task. Local governments cannot and should not be bypassed. On the contrary, under an effective state organization with strong regional bodies, local governments should perform an indispensable role in coastal zone management.[61]

There is urgent need to improve environmental impact statements required by Section 102(c) of the National Environmental Policy Act of 1970 (NEPA) for all the changes and activities affecting estuarine areas. Improvement of impact assessment procedures and analyses is required at all levels of federal, state and local governments. This will require a major commitment of resources to attain levels of competency and ensure that the evaluations are thorough.

An early improvement in making the content of environmental impact evaluation more relevant could be brought about by re-establishing a coordination arrangement between the Water Resources Council and the Interagency Committee on Marine Resources of the Federal Council for Science and Technology, which is now responsible for the policy coordination aspect of the National Marine Sciences Program. This would assure that research programs are designed to furnish the information for proper integration of water resources planning and estuarine and coastal zone management.

Estuarine research programs of Federal and state agencies should be strengthened to provide a better basis for the establishment of water quality standards for estuarine and coastal waters.

While programs of research have been initiated on problems related to estuarine and coastal zone management, they need to be accelerated and broadened to provide information so that effective means can be taken to monitor and predict the impact of upstream development and waste disposal on coastal zone waters and the oceans. Additional knowledge is needed to protect, enhance, and develop the coastal zone environment, particularly estuaries.

High priority should be given and the necessary support found for research on the determination of water quality requirements for various water uses and for the criteria which serve as the basis for water quality standards.

Additional investigations are needed to determine the effects of waste disposal in estuarine waters and to determine the extent of pollution so that measures to cope with problems can be devised. These programs might be merged with and supplement the ongoing and emerging programs of research now under the auspices of the National Oceanic and Atmospheric Administration—Marine Ecosystem Analysis (MES) and Marine Monitoring Assessing and Prediction (MARMAP).

[61] The principles drawn up by the California Advisory Commission on Marine and Coastal Resources propose a structure and function for coastal zone management organization which includes state, regional and local contributions as essential components. These principles are stated in Appendix B.

REFERENCES

California Department of Fish and Game. April 1973. Maintenance of Fish and Wildlife in the Sacramento-San Joaquin Estuary in Relation to Water Development. Sacramento, Calif.

California Department of Fish and Game. June 1972. Ecological Studies of the Sacramento-San Joaquin Estuary: A Decennial Report. 1961–1971. Sacramento, Calif.

California State Water Resources Control Board. March 5 1974. Development of a Water Quality Control Plan, San Francisco Bay Basin. Proceedings of a Workshop. Sacramento, Calif

Ciracy-Wantrup, S. V. 1963. Resource Conservation Economics and Policies. Revised Edition. Berkeley: University of California Press.

Clark, R. C. Jr., and J. S Finley. November 23, 1974. Environmental Science and Technology. Science 106.

Council on Environmental Quality. 1974. Environmental Quality. Fifth Annual Report. Washington, D. C.

Council on Environmental Quality. 1973. Environmental Quality. Fourth Annual Report. Washington, D. C.

Council on Environmental Quality. 1971. Environmental Quality. Second Annual Report. Washington, D. C.

Council on Environmental Quality. April 18, 1974. OCS Oil and Gas—An Environmental Assessment. Report to the President.

Delise, G. October, 1966. Preliminary Fish and Wildlife Plan for San Francisco Bay-Estuary. Prepared for the San Francisco Bay Conservation and Development Commission.

Duke, T. W., and T. R. Rice. 1967. Cycling of Nutrients in Estuaries. Proceedings of Gulf and Caribbean Fisheries Institute 19:59.

Flinn, James E., and Robert S. Reimers. March 1974. Development of Predictors of Future Pollution Problems. EPA Report 600/5-74-005.

Gosselink, J. G., E. P. Odum, and R. M. Pope. 1974. The Value of the Tidal Marsh. Publication No. LSU-SG-74-03. Center for Wetland Resources. Baton Rouge: Louisiana State University.

IDOE. March 24–26, 1972. Baseline Studies of Pollutants in the Marine Environment and Research Recommendations. IDOE Baseline Conference, New York.

Kahn, A. E. 1966. The Tyranny of Small Decisions: Market Failures, Imperfections, and the Limits of Economics. Dykos 19(1).

Ketchum, Bostwick H. 1972. The Water's Edge: Critical Problems of the Coastal Zone. Cambridge, Massachusetts: The MIT Press.

Ketchum, B. H. 1954. Relation Between Circulation and Planktonic Population in Estuaries. Ecology 35.

Ketchum, B. H. 1951. The Flushing of Tidal Estuaries. Sewage Industry Wastes. 23(2).

Kohn, Henry H. January 4, 1975. Letter to the Editor. Science News 107.

Kutscher, Ronald. December 1973. Projections of GNP, Income, Output, and Employment. Monthly Labor Review 96:3–42.

McGinnis, J. T., et al. December 1972. Environmental Aspects of Gas Pipeline Operations in the Louisiana Coastal Marshes. Report to Offshore Pipeline Committee by Battelle's Columbus Laboratories.

McHugh, J. L. November 1968. Are Estuaries Necessary? Commercial Fisheries Review 30(11).

Murray, C. R. 1968. U.S. Geological Survey Circular 556.

National Academy of Sciences 1972. Water Quality Criteria. Washington, D. C.

National Petroleum Council. December 1972. U.S. Energy Outlook. Report to NPC Committee on U.S. Energy Outlook.

National Science Foundation. 1972. Patterns and Perspectives in Environmental Science. Report prepared for National Science Board.

Odum, William E. 1970. Insidious Alteration of the Estuarine Environment. Transactions of the American Fisheries Society 4.

Piper, A. M. 1965. U.S. Geological Survey Water-Supply Paper 1797.

Pomeroy, L. R., R. J. Reinold, L. R. Shenton, and R. D. Jones. 1972. Nutrient Flux in Estuaries. Nutrients and Eutrophication Edited by G. E. Likens. American Society of Limnology and Oceanography. Special Symposium 1.

Pritchard, D. W. 1955. Estuarine Circulation Patterns. Proceedings American Society of Civil Engineers 81.

St. Amant, L. S. 1971. The Petroleum Industry as it Affects Marine and Estuarine Ecology. Transactions of the Society of Petroleum Engineers.

St. Amant, L. S. 1971. Impacts of Oil on the Gulf Coast. Transactions 36th American Wildlife and Natural Resources Conference.

Sanders, H L., J. F. Grassle, and G. R. Hampson. 1972. The West Fallmouth Oil Spill! Woods Hole, Massachusetts: Woods Hole Oceanographic Institute Technical Report No. 72-20

Sartor, J. D , and G. B. Boyd. November 1972. Water Pollution Aspects of Street Surface Contaminants. 76-81 EPA-R2-72-081.

Smith, Nelson. March 21, 1972. Effects of the Oil Industry on Shore Life in Estuaries. Proceedings of the Royal Society of London. Series B 180 (1061).

U.S. Coast Guard. 1975. Polluting Incidents In and Around U.S. Waters, Calendar Year 1971. Washington, D. C.

U.S. Congress. Joint Committee on Atomic Energy. 93rd Congress, 2nd Session. 1974. The Nation's Energy Dilemma. Washington, D. C.

U.S. Department of Commerce. National Technical Information Service. Total Urban Water Pollution Loads. PB-231/730. Springfield, Va.

U.S. Department of Commerce. Bureau of the Census. 1973. Statistical Abstract of the United States: 1973. 94th edition. Washington, D. C.

U.S. Department of the Army. Corps of Engineers. August 1971. National Shoreline Study, Shore Management Guidelines. Washington, D. C.

U.S. Department of the Interior. August 1970. National Estuarine Pollution Study. Report of the Secretary of the Interior to the U.S. 91st Congress Pursuant to Public Law 89-753. The Clean Water Restoration Act of 1966. Washington, D. C.

U.S. Department of the Interior. Fish and Wildlife Service. August 1970 National Estuary Study. Washington, D.C.

U.S. Environmental Protection Agency. April 1971. The Economic and Social Importance of Estuaries. Estuarine Pollution Study Series 2. Washington, D. C.

U.S. Environmental Protection Agency. April 1973. Guidelines for Developing or Revising Water Quality Standards. Water Quality Division. Washington, D. C.

U.S. Environmental Protection Agency. Office of Water Planning and Standards. August 1974. National Water Quality Inventory, 1974. Report to the Congress. EPA-44019-74-001. Washington, D. C.

U.S. Environmental Protection Agency. 1973. Water Quality Criteria. Washington, D. C.

U.S. Environmental Protection Agency. March 1974. Water Quality Strategy Paper. Washington, D. C.

Young, D. R., et al. 1973. Source of Trace Metals from Highly Urbanized Southern California to the Adjacent Marine Ecosystem. Proceedings of a Conference on Cycling and Control of Metals.

APPENDIX A

TABLES

Appendix Table 1.—A summary of legislation relating to coastal and estuarine zones

Zone	Comprehensive coastal zone planning legislation	Wetlands	Industries and power plant siting	Shoreline—recreation
Alabama	None at present—in the planning stage.	U.S. Army Corps of Engineers projects deemed harmful are refused.	Alabama Water Improvement Commission regulates the location of industries and domestic pollution sources.	
Alaska	None at present—in the study stage.			
California	Coastal Zone Conservation Act (1972)—to develop plans and control development Permits required for any development in the coastal zone. The California Comprehensive Ocean Area Plan was completed in 1972.		A power plant siting bill was passed in 1974.	
Connecticut	$3.5 million study of Long Island Sound to develop a comprehensive plan for this area.	Wetlands Protection Act—1969 —Inventory of all wetlands. —No dredging or construction on designated wetlands without a permit.		
Delaware	Delaware Coastal Zone Act (1971)—to control the location, type, and extent of industrial development in coastal areas, prohibition of new heavy industries.	Delaware Wetlands Act (1973)—permits required for virtually all activity in the wetlands.	The state has banned heavy industry within two miles of the coast, with permits required for other uses.	An assessment of present and future demands on coastal zone.
Florida	Environmental Land and Water Management Act (1972): land development regulations for "area of critical state concern."			Land Conservation Act (1972)—to finance the cost of recreation lands.
Georgia		Coastal Marshlands Protection Act (1970)· "No person may remove, fill, dredge, drain, or otherwise alter any marshlands within the estuarine areas without first obtaining a permit...."		
Hawaii	Legislation requiring a coastal plan passed in 1973.			Shoreline Setback Areas (1971). Construction within 20 to 40 feet from edge of vegetation growth is prohibited without a special permit.
Louisiana	No coastal zone plan.			
Maine	"Coastal Development Plan" being prepared.	Wetlands Preservation Act (1967)—State Wetlands Control Board can impose any conditions regarding dredging, filling, etc., on coast if they feel it is in public's interest.	Legislation to limit heavy industry on coast is now pending.	
Maryland	Still being developed. A critical areas bill (S.B. 500) was enacted.	Wetlands Act (1970, amendment) no dredging or filling without a permit		Shore Erosion Control Act (1970 as amended)—provides loans for shore erosion protection devices.

Zone	Comprehensive coastal zone planning legislation	Wetlands	Industries and power plant siting	Shoreline—recreation
Massachusetts	A commission has been created to develop a comprehensive plan for estuarine area management.		Power plant siting law was recently enacted.	
Mississippi	Coastal zone management plan in review stage.	Coastal Wetlands Protection Act (1973)—designates the Marine Resources Council as the regulatory agency for activities on wetlands.		
New Hampshire	No plan at present.	Wetlands Act (1967)—controls dredging and filling of tidal areas. Dredge and Fill Act (1971) promulgates rules and regulations for dredging in tidal areas.	Power Plant Siting (1971)—sites must be approved by PUC and not environmentally detrimental.	
New Jersey	Plan being formulated. Some coastal zone land uses regulated by 1973 law.	Wetlands Act (1970) permit required for any dredging, filling, polluting, building, or otherwise altering wetlands—wetlands being mapped.		
New York	Plan being formulated. Coastal zone authority influences land use.	New York Wetlands Act (1971)—moratorium on wetland alterations.	Power plant siting law.	Multi-year study begun in 1971 inventorying Long Island Sound resources.
North Carolina	Coastal Areas Management Act (1974)—also a preliminary, comprehensive plan prepared December 1972. Land Policy Act (1974).	Wetlands Protection Act (1971)—authorizes the adoption of rules to protect marshes and contiguous lands. Dredge and Fill Act (1971)—makes permits required.		
Oregon	Coastal Zone Management Plan Act (1971) provides for a comprehensive plan to be submitted to State Legislature by 1975.		State has a power plant siting law.	Oregon Land Use Law (1973) regulating land uses. Beach Access Act (1967)—citizen's right to unrestricted beach use up to vegetation line.
Puerto Rico			As required under Federal Water Pollution Control Act, no new municipal or industrial discharges without special authorization.	
Rhode Island	Comprehensive plan being developed. Some coastal zone activities regulated by state permit system.	Coastal Wetlands Act (1965), land use restrictions in such areas. Intertidal Salt Marsh Act (1965)—permits needed to fill, dredge, etc.		Coastal Management Council Act (1971) to administer management program for coastal areas.
South Carolina	No plan at present.			No major legislation but increased study and survey of coastal areas.
Texas	Coastal Public Lands Management Act (1976) provides for the comprehensive management of state-owned coastal lands, and establishes permit system for construction on coastal islands and submerged lands. The Texas Council on Marine Related Affairs was created in 1971, to study and plan for marine resources.			Public ownership of state beaches up to vegetation line.
Virginia	Plan being developed.	Wetlands Act (1972)—a permit system for wetlands regulation.		A coastal zone management program is being undertaken.
Washington	Shoreline Management Act (1971)—sets responsibilities of state and local areas for permit system, and inventories.	Marshes, bogs, swamps, floodways, and river deltas are regulated under the Shoreline Management Act.	Thermal Power Plant Siting Act (1970)—environmental and biological considerations will be main guidelines in location of sites.	

Appendix Table 2.—Major U.S. waterways

10 longest rivers (miles)	10 rivers with highest flows (cubic feet per second)	Waters of 10 largest urban areas
Missouri (2,564)	Mississippi (620,000)[1,2]	Hudson River—New York Harbor
Mississippi (2,348)	Ohio (255,000)[1]	Los Angeles Harbor
Rio Grande (1,885)	Columbia (235,000)[1]	Lake Michigan and other waters of Chicago area
Yukon (1,875)	Missouri (70,000)[1]	Delaware River (Philadelphia)
Arkansas (1,450)	Tennessee (63,700)	Detroit River and Detroit area tributaries
Colorado (1,450)	Alabama-Coosa (59,000)	San Francisco Bay and Sacramento River
Columbia—Snake (1,324)	Red (57,300)[1,3]	Potomac River (Washington, D. C.)
Ohio (1,306)	Arkansas (45,200)[1]	Boston Harbor
Red (1,222)	Susquehanna (35,800)	Ohio River (Pittsburgh)[1]
Brazos (1,210)	Willamette (30,700)	Mississippi and Missouri Rivers (St. Louis)[1]

[1] Contained in first (or second) columns.
[2] Includes Atchafalaya River (about 25 percent of flow).
[3] Includes flow of Ouachita River.
Source: Environmental Protection Agency. 1974. National Water Quality Inventory Report to Congress. Table I-1.

Appendix Table 3.—Major waterways: Water quality trends 1963-72[1].

Parameter	Number of reaches analyzed	Percent of reaches improved[2]
Suspended solids	28	82
Turbidity	29	79
Fecal coliforms (membrane filter)	9	78
Ammonia	25	76
BOD_5	31	74
Total coliforms (membrane filter delayed)	23	70
COD	20	70
Temperature	33	67
Total coliforms (most probable number)	9	67
Dissolved solids (105° C)	28	64
Chlorides	34	62
Dissolved oxygen	31	61[3]
Dissolved solids (180° C)	23	61
Odor	5	60
pH	34	59[4]
Total coliforms (membrane filter immediate)	12	58
Phenols	12	58
Dissolved phosphate	18	56
Sulfates	33	55
Organic nitrogen	11	55
Total phosphate	16	44
Alkalinity	32	41[3]
Nitrite	5	40
Nitrite plus nitrate	27	37
Color	30	33
Nitrate (as NO_3)	19	26
Nitrate (as N)	17	24
Total phosphorus	28	18

[1] Based on median values at each reach. Reaches included only if they contain one or more stations with at least seven samples each. Parameters included only if five or more reaches were measured.
[2] Except where noted, "improved" means that 1968–72 median concentrations are lower than 1963–67 median concentrations at mean station.
[3] "Improved" means higher concentration.
"Improved" means pH becomes higher (less acid).
Source: Council of Environmental Quality. Fifth Annual Report. Table 20, p. 285.

Appendix Table 4.—Major waterways: Reference level violations, 1963 to 1972

Parameter	Reference level and source[1]	Percent of reaches exceeding reference levels		
		1963–67	1968–72	Change
Suspended solids	80 mg/l-aquatic life	26	14	−12
Turbidity	50 JTU-aquatic life	28	28	0
Temperature	90° F-aquatic life	0	0	0
Color	75 platinum-cobalt units-water supply	0	0	0
Ammonia	0.89 mg/l-aquatic life	16	6	−10
Nitrate (as N)	0.9 mg/l-nutrient	12	24	+12
Nitrite plus nitrate	0.9 mg/l-nutrient	18	26	+8
Total phosphorus	0.1 mg/l-nutrient	34	57	+23
Total phosphate	*0.3 mg/l-nutrient*	30	41	+11
Dissolved phosphate	0.3 mg/l-nutrient	11	22	+11
Dissolved solids (105° C)	500 mg/l-water supply	25	18	−7
Dissolved solids (180° C)	500 mg/l-water supply	28	12	−16
Chlorides	250 mg/l-water supply	12	9	−3
Sulfates	250 mg/l-water supply	12	12	0
pH	6.0–9.0-aquatic life	0	0	0
Dissolved oxygen	4.0 mg/l-aquatic life	0	0	0
Total coliforms (MFD)[2]	10,000/100 ml-recreation	24	13	−11
Total coliforms (MFI)[2]	10,000/100 ml-recreation	50	30	−20
Total coliforms (MPN)[2]	10,000/100 ml-recreation	23	20	−3
Fecal coliforms (MPN)[2]	2,000/100 ml-recreation	45	21	−24
Fecal coliforms (MPN)[2]	2,000/100 ml-recreation	17	43	+26
Phenols	0.001 mg/l-water supply	86	71	−15

[1] With the exceptions that follow, reference level designations are from "Guidelines for Developing or Revising Water Quality Standards," EPA Water Planning Division, April 1973, for ammonia, chlorides, sulfates, and phenols, "Criteria for Water Quality," EPA, 1973 (Section 304(a)(1) guidelines), and for nitrate (as N), "Biological Associated Problems in Freshwater Environments," FWPCA, 1966, pp. 132–133.
[2] Membrane filter delayed, membrane filter immediate, most probable number.
Source: Environmental Quality Fifth Annual Report, Council on Environmental Quality.

Appendix Table 5.—Published effluent guidelines for industries as of June 30, 1974

Industry	Proposed	Final (effective date)
Fiberglass	8/22/73	1/22/74
Beet sugar	8/22/73	1/31/74
Cement	7/7/73	1/20/74
Feedlots	9/7/73	2/14/74
Phosphates	9/7/73	2/20/74
Flat glass	10/17/73	2/14/74
Rubber	10/11/73	2/21/74
Ferroalloys	10/18/73	2/22/74
Electroplating	10/5/73	3/8/74
Asbestos	10/30/73	2/26/74
Inorganics	10/11/73	3/12/74
Meats	10/29/73	2/28/74
Plastics and synthetics	10/11/73	4/5/74
Nonferrous metals	11/30/73	4/8/74
Cane sugar	12/7/73	3/20/74
Fruit and vegetables	11/9/73	3/21/74
Grain mills	12/4/73	3/20/74
Soaps and detergents	12/26/73	2/12/74
Fertilizer	4/8/74	7/2/74
Petroleum	12/14/73	5/9/74
Dairy	12/20/73	5/28/74
Leather	12/7/73	4/9/74
Pulp and paper	1/15/74	5/29/74
Organics	12/17/73	4/25/74
Builders paper	1/14/74	5/9/74
Seafood	2/6/74	6/26/74
Timber	1/3/74	4/18/74
Iron and steel	2/19/74	6/28/74
Textiles	2/5/74	7/5/74
Steam and electric power	3/4/74	Not yet published

Source. Environmental Quality. The Fifth Annual Report of the Council on Environmental Quality. 1974. Table 8, page 141.

APPENDIX B

Principles for Coastal Zone Management

Drawn up by

California Advisory Commission on Marine and Coastal Resources

1. Findings and Declarations

a. Legislative findings should be brief and directed toward the positive aspects of the regulatory scheme.

2. State Coastal Zone Management

a. The state should provide leadership in assisting local governments in the planning and management of the coastal zone.

b. Coastal zone management legislation should designate a single state organization to provide leadership in the planning and management of the coastal zone.

c. The state organization to be selected to administer the plan of regulation should be directed by a board consisting of persons qualified and experienced in the development, conservation or use of marine and coastal resources (e.g., concerned with environmental quality, conservation and recreation, living marine resources, land use planning and coastal development, and economics and law of natural resources) and persons not required to have specialized knowledge.

d. The state organization should be required to establish continuing liaison and coordinate its activities with all other major state and private agencies directly interested in the administration of the coastal zone.

e. The state organization should be empowered to require periodic review and updating of all local and regional plans.

f. The state organization should be designated as the state coastal zone authority for all purposes stated in any federal coastal zone management legislation and be given the authority to administer any statewide program of research and planning pertaining thereto.

g. The state organization should be a clearinghouse for planning information pertaining to the development and conservation of the marine and coastal resources of the state.

h. The technical advisory committee should consist of the California Advisory Commission on Marine and Coastal Resources ("CMC").

i. The advisory committee should be given the responsibility to advise the state organization either when requested by it or when deemed appropriate by the committee.

2. Regional Coastal Zone Management

a. Coordination of this planning and management function will require regional entities, encompassing aggregations of several local governments.

b. Regional boards should be designated to supervise the implementation of the program.

c. Regional areas should be designated following county lines and be functionally related to resource planning.

d The governing boards for the designated areas should consist of persons qualified and experienced in the development, conservation or use of marine and coastal resources (e.g., concerned with municipal government, county government, water use, environmental quality, recreation and conservation, land use and land use planning, living marine resources, and economics and law of natural resources).

4. Local Government Coastal Zone Management

a. The planning and management of the coastal zone is primarily the responsibility of local government.

b. Planning and management of the coastal zone located within the boundaries of units of local government are and should remain primarily the responsibility of units of local government in accordance with state criteria

c. Local governments should coordinate their planning and management within overall state policy and should administer the coastal zone under the state's certification.

5. Permit Area Boundary

a. The state organization selected should have legally precise and ascertainable boundaries.

b. Any administrative discretion to expand the coastal zone should be of short duration.

c. The practicability of the plan of regulation should be considered in determining the extent of the defined coastal zone, it being more desirable to have a coastal zone with numerous exceptions based upon unquantified considerations.

6. Coastal Zone Policy and Criteria

a. The state organization selected should formulate and adopt state policy for coastal resources conservation and development.

b. Criteria for certification of local plans and programs should be established and administered by the state.

c To the extent practicable, principles underlying criteria to be applied by any new state coastal zone management should be established prior to or concurrently with the implementation of the regulatory aspects of that system.

d. The criteria to be developed should include components for all lawful uses of the coastal zone and none should be generically prohibited.

e. The criteria to be developed should facilitate an optimum combination of all lawful uses in the coastal zone by a consideration of all private and public benefits and costs resulting from them.

f. Special consideration in forming criteria should be given to uses which cause irreversibility in potentially permanent flow (e.g., renewable) resources.

g. The staff of the state organization selected should be given the responsibility of preparing recommended planning criteria.

h. A technical advisory committee should have the responsibility to review and comment upon recommended planning criteria.

7. Coastal Zone Plan Development

a. The state organization selected should ultimately incorporate the Comprehensive Ocean Area Plan ("COAP") into the state plan.

b. The state organization selected should integrate regional plans developed by the regional boards into the state program.

c. Regional boards should be required to prepare regional plans incorporating coastal elements developed by units of local government to the extent that the same are consistent with the criteria developed by the state organization.

d. Regional planning entities should provide a comprehensive format for coordinated planning and management in accordance with state policy objectives.

e. Primary responsibility for management of marine living resources should not be affected by coastal zone management legislation.

f. The state organization should certify conformance of regional plans to state policy.

8. Land Use Permit System

a. Units of local government should be required to give notice to the regional boards of permits granted for regulated uses of the coastal zone with supporting data for the decision made, and the regional boards should have the power to review the same within a designated period of time (e.g., 30-60 days) to determine whether the decision meets with the relevant criteria. If a regional board does not give notice of nonconformance with such criteria within such period, the permit shall be effective.

b. Regional boards should have the power to issue orders to units of local government or their permittees to rescind permits issued for uses not conforming to relevant criteria.

c. Regional boards should have the power to obtain injunctions and other appropriate legal relief.

d. Where the matter is of regional concern, regional boards should also have the power to hear appeals from denials of permits by units of local government and to confirm or rescind such action.

e. The state organization should upon petition of an aggrieved person, public agency, unit of local government or its own motion review any action or failure to act by a regional board with respect to any requested use of the coastal zone considered not in accordance with state criteria.

f. State agencies should be required to give notice to the appropriate regional board of regulated uses of the coastal zone proposed to be made by them and of permits proposed to be granted for such uses with supporting data for the decision made with respect thereto. The appropriate regional board should have the power to review the decision within the designated period of time (30–60 days) to determine whether the same meets with the relevant criteria of the regional plan. If the appropriate regional board does not give notice of nonconformance with such criteria within such period, the proposed use shall be deemed approved.

9. Economics and Financing

a. The legislation should provide funding for all affected governmental agencies at all levels to enable them to perform assigned responsibilities in an adequate and timely fashion.

b. The state organization should be structured so as to take maximum advantage of existing organization, personnel and equipment.

c. The state organization selected should allocate to the regional boards from funds appropriated to it such monies as may be necessary for their professional staffing and other administrative expenses.

d. The legislation should recognize private property rights in the coastal zone and require payment of fair compensation in the event that any taking is effected thereunder.

e. The legislation should give appropriate recognition to the effect of the plan of regulation of units of local government and should provide a means for equalizing benefits as well as costs incurred in environmental maintenance or sustaining low density uses.

THE EXTRACTIVE INDUSTRIES IN THE COASTAL ZONE OF THE CONTINENTAL UNITED STATES

STANLEY R. RIGGS
East Carolina University
Greenville, North Carolina

ABSTRACT

The extractive industries in the coastal zone consider all known mineral sources excluding petroleum, that presently occur or may occur in the future within the estuaries, the nearshore continental shelf waters, and the adjacent land areas within continental United States exclusive of the Great Lakes. This includes all activities in the recovery of natural materials from the sediments and rocks of the earth's crust and from the water column and the preparation and treatment of these natural materials in order to make them suitable for use.

Mineral extraction, excluding petroleum, is presently nonexistent in most estuaries and very limited both in commodities and quantities in the few estuaries where extraction is taking place. Any consideration of estuarine and offshore mining must deal with the potential. To develop an adequate inventory of the resource potential of the United States coastal areas will necessitate a massive and coordinated detailed study of the surface and subsurface geology. Most extractive industries, whether in, adjacent to, or distantly remote from an estuarine system will have some impact upon the pollution of the coastal zone; however, no two extractive industries will have similar effects or degrees of pollution impact upon the estuarine system.

A basic knowledge of the mineral reserves and the general economic value to man is essential prior to the development of any land and water use management plans involving the continued development of our coastal zone. Economics of a given mineral resource may change dramatically in response to new technological advances, discoveries of new ore deposits, or as industrial and social demands change through time. Such changes can have drastic effects upon the same management programs which define land and water uses. The resulting dilemma becomes of paramount importance: the need to protect a delicately balanced estuarine system, upon which man is dependent, and at the same time dramatically increase its use and modification for materials which man is also dependent upon.

INTRODUCTION

This report on the extractive industries in the coastal zone considers all known mineral resources excluding petroleum, that presently occur or may occur in the future within the estuaries, the nearshore continental shelf waters, and the adjacent land areas within continental United States exclusive of the Great Lakes. Also, it does not directly consider the consequences of dredging, particularly as related to channel and harbor dredging and maintenance.

The estuarine zone or coastal zone, as used in this report, refers to the geographic region including the coastal counties between the landward limit of tidal influence and the three-mile limit to seaward ("National *Estuarine* Pollution Study," 1970, p. 5).

> The estuarine zone is an ecosystem. That is, it is an environment of land, water, and air inhabited by plants and animals that have specific relationships to each other. This particular ecosystem is the interface between land and water and one of its key components is human society (p. 8).

In order to evaluate the mineral resource potential of the coastal zone, one must first establish what the mineral resources are. Any naturally occurring material, whether it be an individual mineral, an aggregate of minerals combined into unconsolidated sediments or consolidated rocks, or a natural material in the form of liquid or gas is a mineral resource if its physical or chemical characteristics make it a desirable ingredient in man's technological society. Since almost all natural materials may be usable resources in some form and at some time or other, whether it be for general land fill, beach replenishment, construction materials, or as a source of some metal or fuel, all of the materials bounding and occurring within the coastal zone become potential resources.

The extractive industries include all forms of recovery of natural materials from the sediments and rocks of the earth's crust and from the water column comprising the oceans and estuaries. More specifically these include (1) breaking of the surface soil in order to extract natural materials; (2) all activities or processes involved in the extraction of natural materials from their original location; and (3) any preparation and treatment of these natural materials in order to make them suitable for use. This broad array of activities associated with the mineral extraction industries range from the exploration and mining activities, to the processing and treatment plants, to the complex transportation systems involving pipelines, channels and harbors. The potential conflict with other coastal uses and the potential impact of these activities upon the delicate balances of the fragile and limited estuarine zone have given birth to a dilemma that is slowly growing to prohibitive proportions.

Various geologists have projected that the major mineral reserves in the United States, which are presently derived from land, will be exhausted by the year 2000 (Moore, 1972). If this is the case, then where are the future resources to come from?—the coastal areas and the continental shelves! Since the shelves are geologically nothing more than submerged portions of the continent, McKelvey (1968) believes that it is logical to assume that the mineral potential should be roughly comparable to that which has already been found on land. Partly for these reasons, Moore (1972) projects a truly large-scale undersea mining industry by 1980 with complete dependence upon this source by the year 2000. The fact that the United States Department of the Interior has recently issued a "Draft Environmental Impact Statement" in connection with undersea mining, as well as a set of proposed regulations for the actual leasing and mining of undersea hard rock minerals, underscores the anticipation of the increased development of these presently poorly known resources.

However, the total present world production of minerals from the sediments and rocks comprising the sea floor of the continental margins, excluding oil and gas, is only about $470 million annually or 2 percent of the on-land production of these minerals. Another $415 million worth of minerals are presently extracted from seawater making the present value of all extractive resources from the marine environment a minor part of the total mineral production (Rigg, 1975). However, to date only a very small percentage of the coastal and shelf environments have even been explored for anything other than possibly petroleum. If the major thrust for future mineral resources is on the continental shelf, then the coastal zone will play an ever increasing role in the extractive industries. This role will include some mining itself, but probably of greater significance will be the critical role the estuaries will play [illegible] transportation system and processing plants necessary for the offshore extractive industries.

At the present time, it is nearly impossible to describe accurately or completely the location and size of existing extractive industries in the coastal zone, to say nothing about the mineral reserves. In fact, the mineral resource potential of the estuaries and continental shelves, with few exceptions are at best only superficially known. The reasons for this are: (1) the geologic and mining agencies that monitor these industries do not differentiate the extractive operations that are related to the coastal zone from any other region; (2) for competitive reasons, the same agencies generally are not able to relate production statistics and rarely do they have access to good reserve information if it is even known; and (3) detailed geologic investigation, exploration, and research in the coastal zone is extremely expensive, technologically difficult, and generally a relatively "new" science.

Recent inquiries by the author, to the geological surveys of the coastal states, underscored both the lack of knowledge of the resources and the meager effort to monitor any existing mineral extraction within or adjacent to the estuaries or the offshore areas. In fact, much of the existing published data, such as Table IV.2.8 entitled "Major Exploitation of Coastal Mineral Resources" in the "National Estuarine Pollution Study" (p. 124, 1970), is extremely misleading. The table states that in 1967 there were 1,479 coastal operations in the United States exploiting $373,192,000 worth of minerals including 168 metal operations, but excluding all petroleum and other mineral fuels. These numbers are only correct if one includes all of the inland coastal plain areas. A study of the case histories of specific estuarine zones within the same publication, as well as in "The Economic and Social Importance of Estuaries" (Environmental Protection Agency, 1971) and the "National Estuarine Pollution Study" (United States Department of the Interior, 1970), suggest that mineral extraction is actually nonexistent in most estuaries and very limited both in commodities and quantities in the few estuaries where extraction is taking place. To adequately know and inventory the resource potential of the United States coastal areas will necessitate a massive and coordinated detailed study of the surface and subsurface geology—a mammoth undertaking. Only slow, isolated, and individual progress is presently being made in this direction.

Consideration of estuarine and offshore mining must deal with the potential since the present mineral production from below the sea is limited to only a few commodities, the major one being petroleum. However, [illegible] present [illegible] technological restraints, which are the major limiting factors of mining the sea floor, are rapidly being overcome by the current efforts within the rapidly changing offshore petroleum exploration and development. These include: (a) a rapid annual increase in the number of holes drilled: (b) an expansion into deeper waters further from shore; (c) a complementary increase in the size and capabilities of the offshore drilling rigs; and (d) an increasing sophistication of underwater operating facilities and pipeline systems. As the petroleum industry continues to expand its exploration and operations into the coastal and offshore areas, there will be an increase in the discovery and recovery of associated minerals that can be recovered by pumping and solution mining. Such minerals as sulfur and potash occur in salt domes, which are major petroleum reservoirs. The sophisticated technology necessary for the exploration and mining of other types of mineral deposits from the sea floor will quickly follow.

The United States' economy needs over 4 billion tons of raw mineral supplies to produce $175 billion worth of domestically produced energy and processed materials of mineral origin annually; the demand still far exceeds the domestic production of both raw materials and processed minerals (Morgan, 1974). The Secretary of the Interior issued in mid-1973 his "Second Annual Report Under the Mining and Minerals Policy Act of 1970," in which he stated that the "development of domestic mineral resources is not keeping pace with domestic demand," for nine major reasons (Morgan, 1974):

1. Mineral imports have an unfavorable impact upon the United States' balance of trade and upon the United States' balance of payments;

2. Expropriations, confiscations, and forced modifications of agreements have severely modified the flow to the United States of some foreign mineral materials produced by United States firms operating abroad, and have made other materials more costly;

3. United States industry is encountering greater competition from foreign nations and supranational groups in developing new foreign mineral supplies and in assuring the long-term flow of minerals to the United States;

4. Development of the United States transportation net is not keeping pace with demand, thus seriously affecting the energy and minerals industries;

5. Removal of billions of tons of minerals annually from the earth contributes to a variety of disturbances,

6. The United States mining, minerals, metal, and mineral reclamation industries are encountering increasing difficulty in financing needed expansion of capacity and the introduction of new improved technology,

7. Management of the resources of the public lands, including the continental shelves, must be improved;

8. The factual basis for the formulation and implementation of environmental regulations must be improved, so that man and nature are properly protected with minimum dislocation of important economic activities; and

9. The United States Government information base for the conduct of its mineral responsibilities is grossly inadequate.

Morgan also points out that the world economy has grown faster recently than the United States' economy has; this has resulted in increased competition for needed raw materials. Likewise, it is becoming increasingly difficult to sell manufactured articles in world markets to pay for imported raw materials. Thus, the United States is faced with an ever-increasing need for self sufficiency in mineral resources.

Most extractive industries, whether in, adjacent to, or distantly remote from an estuarine system will have some impact upon the pollution of the coastal zone. Since most of the drainage systems from the land ultimately end in the estuaries, the drainage network funnels a great variety of contaminants into the coastal system. These contaminants are derived from a multitude of sources including the extractive industries, agriculture, urban, and industrial wastes. Consequently, coal becomes part of the sediment load entering the Potomac River, dissolved phosphorus enriches the waters of the Pamlico River in North Carolina, and dissolved metals reach San Francisco Bay from the mines in the Sierras.

On the other hand, no two extractive industries will have similar effects or degrees of impact. For example, a sand and gravel quarry adjacent to an estuary can be completely sealed so that no sediment reaches the estuarine waters, while a mercury mine many miles from the estuarine zone may contribute minute but lethal concentrations of dissolved mercury to the bottom muds. Unless the extractive industry is directly within the estuary, the processing plants and allied industries utilizing the recovered commodity will often have a greater potential or actual long-term pollution effect upon the estuarine system than the mechanical or the chemical extraction in an adjacent land or offshore area will have

The economic value and demand for a given commodity is determined by (a) the specific qualities of that material which in turn determines the technological uses; (b) the availability and concentration of the material; (c) by the cost of recovering and processing the commodity; (d) transportation of the ore for processing as well as the distance to markets; and (e) time delays resulting from possible restraining orders, hearings, and court litigations. Knowledge of these parameters is essential prior to the development of any land and water use management plans involving the continued development of our coastal zone. However, the economics of a given mineral resource may change dramatically in response to new technological advances, discoveries of new ore deposits, or as industrial and social demands change through time. Such changes can have drastic effects upon the same management programs which define land and water uses.

As we begin to go to the sea for more of our mineral resources to offset dwindling onshore supplies, spiraling prices, and satisfy the increasing need for national independence, new pressures will develop. These new pressures, when combined with the existing pressures of growing technology and population, can only have significant increased pollution impact upon an already environmentally overstressed coastal system. According to the "National Estuarine Pollution Study" (1970, p. 20), the coastal counties of the United States contain 15 percent of the land area; however, they carry 33 percent of the population and 40 percent of all manufacturing plants in the United States—and they continue to grow. Thus, man's dilemma continues to grow—the need to protect a delicately balanced natural system, upon which man is dependent, and at the same time dramatically increase its use for materials on which man also depends.

Before discussing the specific extractive industries in the estuarine zone, the interrelationship of man and mineral resources should be put into proper perspective. This interrelationship is summarized by T.S. Lovering (1969, p. 110):

> Whether a particular type and grade of mineral concentrate at a particular location in the earth's crust is or can become an ore (a deposit that can be worked at a profit), moreover, depends on a variety of economic factors, including mining, transportation, and extractive technology. The total volume of workable mineral deposits is an insignificant fraction of 1% of the earth's crust, and each deposit represents some geological accident in the remote past. Deposits must be mined where they occur—often far from centers of consumption. Each deposit also has its limits, if worked long enough it must sooner or later be exhausted. No second crop will materialize. Rich mineral deposits are a nation's most valuable but ephemeral material possession—its quick assets. Continued extraction of ore, moreover, leads, eventually, to increasing costs as the material mined comes from greater and greater depths or as grade decreases, although improved technology and economics of scale sometimes allow deposits to be worked, temporarily at decreased costs. Yet industry requires increasing tonnage and variety of mineral raw materials; and although many substances now deemed essential have understudies that can play their parts adequately, technology has found no satisfactory substitutes for others.

Table 1.—Categories of extractive resources and their development potential within the coastal zone

Resource category	Extractive resources	Resource potential		
		Past or current production	Near future	Long range
Surface deposits				
Unconsolidated to partially consolidated sediment	Total sediments	***	***	***
	Shell gravels	**	**	**
	Quartz and rock gravels	*	**	***
	Light mineral sands	*	*	*
	Heavy mineral sands	**	**	**
	Salt	*	*	*
	Clay minerals	*	*	*
	Phosphate	*	**	***
	Peat	*	*	*
Consolidated Rock	Rock aggregate	NP	*	**
	Limestone	NP	*	*
Subsurface deposits				
Pumpable materials				
Gas and fluids	*Oil*	***	***	***
	Natural gas	***	***	***
	LPG	***	***	***
	Geothermal energy		*	**
Soluble solids	Sulfur	**	***	***
	Potash	*	**	***
	Salt	*	**	**
Slurry solids	Phosphate	NP	***	***
	Glauconite	NP	*	*
	Sand	NP	*	**
Partially consolidated to *consolidated rocks*	*Phosphate*	NP	**	***
	Fuels (coal, uranium, etc)	NP	**	***
	Metals (gold, silver, copper)	NP	**	***
Aqueous deposits				
	Chlorides	**	*	*
	Magnesium	***	***	***
	Bromine	***	*	*
	Fresh water	*	***	***
	Other materials	NP	*	**

KEY: NP—No known production
*—Minor source or potential
**—Moderate source or potential
***—Major source or potential

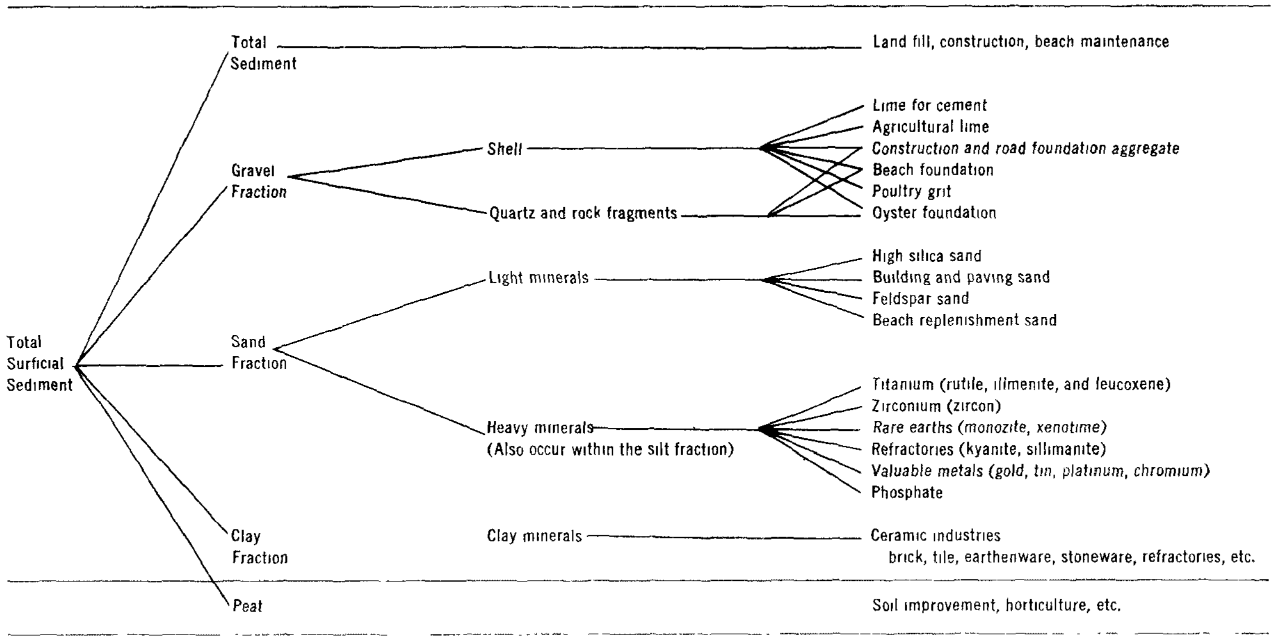
THE EXTRACTIVE INDUSTRIES AND THEIR POLLUTION IMPACT UPON THE COASTAL ZONE

The extractive industries that occur either within the estuaries, on the nearshore continental shelf, or adjacent land areas can be placed into three general categories: the surface, subsurface, and aqueous deposits (Table 1). Each category of deposit has its own type of materials and problems associated with recovery and consequently, will be considered separately.

Surface Deposits

The natural materials occurring within or constituting the surficial deposits of the estuarine zone are not only extremely varied in composition, but also in their potential use (Table 2.). In general, the

Table 2.—Utilization of surficial sediment deposits



materials in this category are unconsolidated or poorly consolidated sediment which are capable of being dredged directly without the problems of removing overburden sediments or breaking up consolidated materials. These materials are generally only renewable over extended periods of time. Under local high energy conditions, and if there is an adequate source and supply, some sediment deposits can be rapidly renewed; examples of such deposits are sands and gravels associated with inlets, near shore shoals and capes, and river mouths.

For the most part the deposits considered here are low value commodities (the exceptions being some of the heavy minerals, Table 2.) that require very modest, if any, benefaction or preparation prior to use. Also, because of this low unit value, the commodities have limited and often local markets that are dictated by the very high transportation costs. Consequently, most operations are very small scale, low budget, and temporary depending on the highly variable local markets and economies.

The surface deposits represent the most widely exploited group of mineral resources within the coastal waters today, with the major exception of petroleum. The present and future importance of these surface resources and the resulting pollution potential to our estuarine system, will be considered in more detail. The surficial deposits include the following commodities: sand and gravel, heavy and light minerals, shells, clay, peat, and total sediment for land fill.

SAND AND GRAVEL

The rising demand for sand and gravel is reflected in the total United States consumption which has accelerated from 500 million tons in 1954 to 980 million tons by 1970, with a projection of 1,670 million tons by 1985 and 2,530 million tons annually by 2000 (Grant, 1973). The rate of consumption of sand and gravel during 1970 amounted to 5 tons per capita, which is greater than all other mineral commodities except water (McKelvey, 1968). Most of this sand and gravel comes from the land, even so, sand and gravel probably represent the most important commodities recovered from the coastal zone in terms of both volume and value. However, since no records are kept of production in the estuarine zone, the commonly quoted values are highly suspect. Nevertheless, the explosive urban and industrial growth in the coastal areas, which demand an ever-increasing amount of construction aggregate, is rapidly depleting the known land supplies in nearby areas or is burying them in their urban sprawl. Since most of the cost of these essential low unit-value commodities is in transportation, a proximal location to the market is essential. However, since such large reserves and acreages are necessary, faced with strong urban zoning restrictions, resource development near the markets in metropolitan areas becomes essentially prohibitive. Thus, as transportation costs rise and as land supplies dwindle, the extensive and high quality deposits of submarine sand

and gravel occurring in the coastal zone become increasingly more attractive. England has already been forced to the sea to supply over 13 percent of the required aggregate, utilizing 75 ocean-going dredges representing 32 companies (Hess, 1971).

Manheim (1972) estimated that 400 billion tons of sand grading 75 percent or more are present in the upper three meters covering 20,000 square miles of the continental shelf off the northeast United States coast. Pings and Paist (1970) have estimated that sand deposits cover about 50,000 square miles of the Atlantic shelf and areas about half as large on both the gulf and Pacific shelves Extensive gravel deposits have been outlined north of Barmount Bay off the New Jersey coast (Schlee, 1968), within Massachusetts Bay, the Gulf of Maine, and on the Florida shelf (Rigg, 1974). Pings and Paist (1970) believe that the offshore sand and gravel industry is still in its infancy and will grow and develop extremely rapidly due to the abundance of suitable deposits in shallow water near markets and the relative ease with which materials can be recovered, classified, and transported by barge. This will be particularly true in the Boston to Norfolk megalopolis. Detailed studies are already underway in the coastal and offshore areas of most other coastal states to define the potential of these resources with the U.S. Army Corps of Engineers doing much of this work through the Coastal Engineering Research Center.

In addition to the massive needs of aggregate for the construction industries, another important use is emerging for the submarine sands and gravels. During 1973, millions of cubic yards of sand were pumped from Cape Hatteras, N.C., to the nearby beaches by the National Park Service. This major effort to replenish 2.2 miles of lost beach with sand is only temporary since shoreline recession in this area has averaged 9 meters per year for the past 100 years (Dolan, et al, 1973). This is becoming an ever increasing problem around the entire country as the rate of shoreline development spirals. The Corps of Engineers estimates that about 7 percent of the United States shorelines are experiencing critical coastal erosion while an additional 36 percent are experiencing slight to moderate erosion (1971). Where is the sand going to come from if the beaches are to continue to be replenished, particularly when the sand has to be of a certain grain size which is in equilibrium with that particular energy regime? This resource problem is a little more difficult than locating construction aggregate.

HEAVY AND LIGHT MINERALS

Many of the sand resources of the coastal area contain varying concentrations of heavy and light minerals that have significant economic value. The heavy minerals (minerals with high specific gravities) include the titanium and refractory minerals, zircon, monazite, and the less common minerals such as gold, tin, platinum, chromium, and diamonds (Table 2.). These minerals occur concentrated in placer deposits in drowned river channel deposits, modern beaches, and old beaches on both the adjacent coastal plain and continental shelf that were formed during fluctuations in the sea level. These minerals are commonly mined from similar types of deposits on the land, but rarely have they been successfully mined in the offshore zone. In spite of the lack of past economic development of these coastal deposits within the United States, heavy minerals are extremely popular and have been and are presently being extensively studied in the marine sediments in most coastal states. Many of these studies have been in connection with the heavy metals program of the United States Geological Survey, which was initiated in 1966 to stimulate domestic production of a small group of critical metals including gold. Some of these metals, such as gold, tin, platinum, and chromium, will probably be dredged from the United States sea floor in the near future simply because they are in considerably short supply. The Pacific shelf has known deposits of gold off California and Oregon, chromium off Oregon, and gold, tin, and platinum off the Alaskan coast.

The light minerals (minerals with average or less than average specific gravities) include pure quartz or high silica sand or feldspar-rich sands which can be used as a source of potash (Table 2.). Both of these commodities are of considerably less value than the heavy metals, and are very abundant on land; consequently, the potential of these commodities being economically extracted from the sands in the marine environment probably lies sometime in the future yet.

SHELL

Shell aggregate is commonly dredged from shallow estuarine waters and adjacent land areas in several portions of the United States coastal zone. The shell, mostly from old oyster reefs, is primarily used for aggregate in road building and concrete, the manufacture of Portland cement and lime, and in small amounts, for miscellaneous markets such as poultry grit and cultch material for modern oystering. Generally, the total land resources of calcite ($CaCO_3$) in the United States are presently adequate. However, in local metropolitan regions, this resource is often unavailable or lacking; then transportation and land values again become the controlling factors and the estuarine shell deposits become an alternate supply.

The largest production of shell comes from the gulf coast states including Texas, Louisiana, Mississippi, and Alabama with lesser amounts produced in Florida and California. Some minor production has come from the mid-Atlantic states of Virginia, Maryland, and New Jersey. The State of North Carolina is presently carrying out a shell survey within some estuaries. Extensive shallow Pleistocene oyster reefs and marine shell beds underlie the estuaries and the mainland areas adjacent to the estuaries in northeastern North Carolina (Riggs and O'Connor, 1972). Since extensive limestone deposits outcrop along most of the North Carolina coast, the muddy shell deposits are only locally mined for landfill purposes. Most of the central and south Atlantic coastal states have a similar geologic setting with abundant limestone just inland from the coast. Consequently, the need for and the probability of developing the estuarine shell resources in these areas is minimal. The north Atlantic states have only minor shell deposits due to the occurrence of extensive glacial sand and gravel deposits throughout the coastal zone.

In contrast to the Atlantic coastal plain, the Texas coastal zone has limited limestone, gravel, and crushed stone reserves to supply the needs for constructional aggregate, cement, and the large chemical industrial complexes. These massive needs are supplied largely by the extensive shell dredging industry in the shallow Trinity, Galveston, and San Antonio Bays, about 75 percent of current production coming from the latter. The shell occurs as distinct reefs either at the bay bottom, which support living oysters, or buried at varying depths within the bay muds. Shell production began in the late 1800's and continued slowly until the 1950's, reaching peak levels during the last 15 years (Fisher, et al, 1973). In 1971, production began to fall off considerably, due to both rapidly diminishing reserves and increasing environmental pressures.

CLAY

Clay is another low unit cost commodity critical to the construction industries and therefore is related to the metropolitan markets; thus, transportation costs and land values are again the critical parameters. Clay is primarily used in the ceramic industries for building bricks, refractories, tiles, et cetera. Since clay deposits are extremely common and widespread on the land there is little need to develop submarine clays. Nevertheless, clay is a major sediment type which is being deposited in the modern estuaries, as well as occurring in the older Pleistocene sediments. Riggs and O'Connor (1974) have described extensive clay wedges in the estuaries of northeastern North Carolina. The proximity of these clay deposits to the Norfolk metropolitan area which is a great distance from the nearest brick factories has provided some potential economic value to an otherwise noneconomic sediment. Similar Pleistocene clay deposits in the Myrtle Beach, S.C., area are presently being exploited as raw material for brick.

PEAT

Extensive peat deposits commonly occur in the protected estuarine intertidal salt marshes and freshwater swamps. These low energy transitional zones from water to land represent areas of rich organic growth which produce the thick peat accumulation of partially decomposed organic matter. This peat is used in horticulture for soil improvement; however, this market is both local and somewhat limited. Consequently, most peat extractive industries are very small operations.

TOTAL SEDIMENT

Probably the most common form of extractive industry in the estuaries is the dredging of sediment for adjacent land fill and shoreline modification purposes, in which case the sediment itself has a low unit value. This whole category seems to be a very gray zone that nobody claims, acknowledges, or considers as a legitimate part of the minerals industries within any of the coastal states. This total sediment dredging includes everything from landfill itself to beach replenishment, ditching for mosquito control, drainage of marshes for agriculture and logging, stream channelization, harbor development, and finally, into channel dredging and maintenance. This extractive industry represents by far the greatest volume of material extracted directly from the estuaries. As a result, it probably has a far greater pollution impact upon the estuaries than all other forms of mineral extraction.

POLLUTION EFFECTS

The pollution effects resulting from the extraction of the surface sediments by mine dredging are no different than those from conventional channel and harbor dredging. In fact, the latter probably represents by far the single most important form of "estuarine mining" that takes place in our coastal waters. The subject of channel dredging is being treated in considerable depth independently within the study of estuarine pollution. In general, the pollution effects of the extraction of mineral resources from the surface sediments within the coastal zone can be summarized as follows:

1. Since there is often very little processing other than washing and sizing, surface sediment operations are less likely to contribute chemical pollution to the coastal system. Likewise, they generally contribute minimal amount of dissolved metals and substances to the coastal waters.
2. Extraction operations of surface sediments on the land areas adjacent to the estuaries can generally be carried out in shallow closed systems so that little deleterious sediment escapes into the coastal waters and there is minimal impact upon the groundwater system of the region.
3. On the other hand, the extraction operations within the estuarine waters can produce vast amounts of sediment pollution and have a dramatic impact on the physical-chemical character of the estuaries. More specifically, these include the following:

    a. Large amounts of sediment will be suspended producing increased water turbidity. This tends to decrease organic productivity by affecting light penetration and the resulting photosynthesis. More importantly however, these increased suspended sediments can drastically change the bottom sediment patterns and the resulting benthic floral and faunal populations. In a study by Riggs and O'Connor (1974) in the nearshore area off Pinellas County, Fla., the effects of the high amount of organic rich suspended sediments derived from landfill dredging in Boca Ciega Bay had a drastic effect upon the nearshore environments around John's Pass. The suspended sediments in the murky estuarine waters are pulled out of suspension primarily by "filter-feeding benthic organisms (mostly polychaetes) and excreted as fecal pellets which then accumulate in extensive ephemeral deposits." The resulting pelletal muddy sand populated by polychaetes is rapidly displacing the "more desirable" populations including the beautiful and extensive "sponge gardens" and associated invertebrate and fish populations which occur throughout this nearshore area.
    b. The removal of materials from the estuarine bottoms and the disposal of spoils produces great modifications of the bottom topography. Such changes have dramatic effects upon the remainder of the estuarine system which include circulation and the resulting water chemistry (salinity, dissolved oxygen, et cetera.) The deepening of the water and the steepening of slopes will also increase wave-induced erosion of the adjacent estuarine shorelines.
    c. In addition, these extraction processes produce temporary disruption of the productive habitat and oftentimes a permanent change in the type of habitat. For example, generally a greater area will have deeper water and steeper slopes after the dredging than existed prior to dredging, thereby producing a net loss of the more productive shallower water environments. This would result in major changes to the biological population inhabiting the area as well as a loss of the shallow breeding grounds.

4. Most extraction operations of the surface sediments on the continental shelves could probably be carried out with a smaller immediate and less far-reaching pollution impact upon the estuaries than direct estuarine mining itself. However, since there are so many variables such as geographic location, character of the sediment, local current system and energy levels, et cetera, each specific circumstance must be considered independently. For example, a recent effort to extract gravels from the shelf in Massachusetts Bay was temporarily halted because of the sediment dispersal patterns from the dredge site (Nelson, 1974).

In summary, the extraction of surficial deposits in the estuarine zone has extremely variable effects upon the estuarine system. Exploitation of land deposits adjacent to the estuaries should be allowed to fully develop to supply the local needs, however, only with strong controls for handling and discharging surface waters, effluent control, and reclamation. Exploitation of the vast potential resource wealth in the offshore area should be encouraged, but again, only with strong controls which allow each deposit or operation to be evaluated independently. On the other hand, extraction of the surface deposits within the estuary itself should not be allowed. The resources in the surficial deposits are usually stimulated by local economic development and are absorbed into the local urban development and do not spawn significant new industrial and

Table 3.—Relationship of type of mineral resource to the general resource value and cost of production within the coastal zone

Resource category	Examples	Mining method	Present status	Value	Cost
Surface Deposits				General increase in value of the resources available for exploitation ↓	General increase in cost of exploration and exploitation ↓
Unconsolidated to partially consolidated sediment	Sand, gravel, shell, etc.	Dredge	Abundant Production		
Consolidated rock	Crushed rock and limestone	Explosives and dredge	No Production (only for channel dredging, pipelines, etc.)		
Subsurface Deposits					
Pumpable materials					
Gases and fluids	Oil, gas, LPG	Drill hole (pumping)	Very Abundant Production		
Soluble solids	Sulfur, potash	Drill hole (solution mining)	Abundant Production		
Unconsolidated sediment	Phosphate	Dredge (island damming and open pit)	No Production (technology being developed)		
	Phosphate	Drill hole (slurry mining)	Moderate Production		
Consolidated sedimentary and crystalline rocks	Coal, iron, oil shales, metals (gold, silver, copper, etc.)	Hard rock underground mining methods	No Production (technology available for working from adjacent land areas or artificial islands)		

economic development. Also, most often these commodities can be replaced with other low unit cost alternative materials, including natural, manmade, and waste products. The short-term gains of low unit value materials cannot justify the increased pollution and modification problems in an already highly stressed system which plays such an important role in the productivity of the oceans.

Subsurface Deposits

The extraction of natural materials from the subsurface is a much more expensive operation which requires more sophisticated technology and equipment than the extraction of surficial materials. Consequently, the types of materials that can be recovered from the subsurface are the glamor commodities which include the fuels, the metals, and the higher unit cost non-metallic resources (Table 3.). The deeper in the ground or the further to sea one has to go to recover these commodities, the higher the cost and the more "glamorous" the material has to be. Also, the technical problems and the cost of recovery increases dramatically as we move from the materials that can be pumped to the surface, to unconsolidated sediments, to consolidated rock (Table 3.). These three categories represent a logical approach to discussing the extraction of specific materials and their resulting pollution potential upon the coastal system.

PUMPABLE MATERIALS

Quantitatively, the most important materials in this category are natural gas, oil, LPG, ground water, and geothermal energy. Because of the extreme importance and size of the extractive industries associated with these commodities, they will be considered separately in another report.

The other natural materials included here are the soluble solids which include sulfur, salt (NaCl), and the various potash minerals. All three of these materials are associated with evaporite deposits and the resulting salt domes, which are in themselves a very important reservoir trap for petroleum. Since salt domes commonly occur in the coastal zone and on the continental shelves, and because of the rapid increased exploration and development of offshore petroleum, the future increased extraction of these commodities in coastal areas is pretty much assured.

Presently, sulfur is the only soluble solid being produced from the coastal zone in the United States; however, salt and potash are being produced by solution mining from inland Canada. The presently known deposits of sulfur occur in the Texas and Louisiana estuarine zone, with present production coming from only one offshore area in Louisiana. The extraction of sulfur is from many wells located on fixed, above-water platforms. Utilizing the Frasch method of solution mining, the sulfur is then pumped through heated pipelines to processing plants on land.

The pollution problems associated with solution mining in the coastal zone can be summarized as follows:

a. The problems of leaks, breaks, and effluent (hot water, brines, drilling mud, et cetera) associated with solution mining and pipeline operation;

b. The problems resulting from the operation and maintenance of the big equipment associated with drilling, pumping, and transportation;

c. The most important problem, particularly with petroleum, of the allied industries which are established in nearby coastal waters.

UNCONSOLIDATED TO PARTIALLY CONSOLIDATED SEDIMENTS

This category would include any mineral resource that occurs in the subsurface in soft or unconsolidated sediments that are diggable. The major resources that presently fit into this category are phosphate and possibly coal and oil shale. Coal is mined from below coastal waters in many places around the world; however, in the United States the underwater coal potential does not appear to be very great and oil shale is probably down the road some. On the other hand, both the Atlantic and Pacific coastal waters have vast phosphate reserves which occur primarily in the subsurface with only small surface concentrations.

The outer coastal plans, estuaries, and nearshore shelf areas of North Carolina, South Carolina, Georgia, Florida, and California have tremendously large and extensive beds of phosphorite sediments that occur under from 10 to several hundreds of feet of overburden sediments. In Beaufort County, N.C., the Pungo River Formation is presently being strip-mined directly on the banks of the Pamlico River estuary. Three million tons of phosphate have been produced annually for the past eight years from a 50 foot bed below 90 feet of overburden. The operating company is presently doubling its plant capacity while another company has just recently announced its plans for opening a new mine next year. The projection for the new mine is to produce 4 to 5 million tons a year by 1977. The operating company controls 30,000 acres which contain over 2 billion tons of phosphate reserves. Of this, 10,000 acres occur on a state mining lease below the Pamlico River estuary. In fact, this very rich phosphate bed underlies not only several large counties in eastern North Carolina, but hundreds of square miles of the Pamlico Sound and Neuse and Pamlico River estuaries. The existing phosphate mining operation has had a very small direct impact upon the adjacent estuaries. Hobbie, et al (1972) reported that the addition of phosphorus in the estuary resulting from the adjacent phosphate mine was irregular, but small, producing only slightly higher concentrations than normal. The periods of high photosynthesis within the estuary are a direct function of nitrate fluctuations coming from upstream and not the phosphorus. There have also been only very minor effects upon the major fresh water aquifer directly beneath the phosphate bed, due to the need for heavy pumping to dewater the large open-pit mine.

Similar extensive subsurface deposits of phosphorite occur in the coastal areas extending from Charleston, S.C., to south of Savannah, Ga. An attempt by a major mining company in 1966 to mine part of the 7 billion tons of phosphate reserves occurring under the coastal marshlands and estuaries of Chatham County, just east of Savannah lead to a major study by the University of Georgia System (1968). This report studied the geology and economic potential of the deposit, as well as the effects of mining upon the ground-water system. Even though the report was generally favorable, mining was completely blocked by the environmental aspects of the potential open-pit dredge mining. Furlow (1972, p. 226) said that:

> . . . public opinion, aroused by conservation groups two years ago, is still so adamantly opposed to mining marshland and disrupting ecological chains that I can foresee no time in the future when marshland mining will be allowed. These conservation groups have only to point to phosphate mining areas in Florida as prime examples of what would happen to the Savannah area.

Drill hole information from the Georgia Department of Mines, Mining, and Geology suggests that the Chatham County deposit extends offshore at least 10 miles and possibly as much as 20 miles with small overburdens, high grades, and large tonnages. Furlow (1972, p. 228) concludes that the:

> . . . future of phosphate mining in Georgia lies entirely in the offshore area rather than in the marshlands. Offshore dredge mining, while more difficult and expensive than onshore mining, can be accomplished with present or presently developing technology. Last, but certainly not least of mining considerations, conservation and ecologically-oriented groups would have far less objection to offshore mining than they would to mining in the unspoiled marshes of Chatham County.

The California Continental Shelf also has extensive deposits of phosphate sediments. In fact, these deposits were planned for development in 1961; the United States Geological Survey subsequently sold its first and only hard mineral lease on the continental shelf in April 1974 (Rigg, 1974). However, this sale involving six tracts and totalling 30,000 acres, was subsequently cancelled by the United States Geological Survey when it was learned that there was a World War II munitions dump on the lease site.

The exploitation of the unconsolidated sediments from the subsurface generally represents tremendous earth moving operations utilizing open-pit strip mining techniques with massive equipment. Vast acreages are involved in both recovering the extensive beds of reserves and treating and disposing of the waste materials. It has been demonstrated in North Carolina that such operations can safely take place on the lands adjacent to the estuaries with only very minimal pollution and direct environmental impact upon the estuaries. However, similar mining operations in central Florida, 20 to 50 miles inland from the coastal zone, have been extremely damaging to the estuaries; upon occasion the wall of a slimes pond will fail, sending millions of tons of mud downstream.

Similar types of mining operations are technically feasible within the estuarine waters; the shallow waters can be filled, or even diked and drained allowing for either open-pit dry mining or underwater dredge mining. However, due to the extremely large land requirements, the vast amounts of earth movement, and the problems of the resulting waste materials, there is a tremendous permanent modification of the estuarine environment and system. Also, a great potential exists for massive estuarine damage resulting from broken dikes during major storms and storm tides.

Offshore mining of these deep phosphate reserves is technologically and economically questionable at the present time. The two greatest factors are probably the high energy levels of the Atlantic and the economic factors of ore dilution with dredge mining. With respect to the potential effect upon the adjacent estuarine systems, each situation would have to be individually evaluated as with offshore surface mining.

The technology which would allow surface mining of phosphates utilizing a subsurface pumping method is actively being tested on the deep phosphate deposits in North Carolina. If this pumping procedure can be adequately developed, it could provide a satisfactory alternative to open-pit mining for recovering the vast estuarine and offshore phosphate deposits with minimal estuarine damage.

CONSOLIDATED ROCK

Because of the high cost of hardrock mining in the subsurface, the only potential mineral resources that can be economically considered in this category are the glamor metals (gold, silver, copper, lead, zinc, et cetera) and the fuels such as coal and radioactive minerals. Extensions of underground mines from adjacent land areas have been producing about 30 million tons of coal per year from under the sea in eight different countries for a long time (McKelvey, 1974). The fact that there are at present no such undersea mines in the United States does not indicate the potential. Since the continental shelves are merely the submerged portion of the continents, they can be expected to contain similar mineral resources as the continents. For example, a copper and zinc deposit below the tide flats of Penobscot Bay in Maine was originally mined from three underground shafts (Smith, 1972). More recently, a 90-acre salt marsh was dammed and drained for a short-lived open-pit operation. The environmental pollution problems included salt water encroachment into the fresh water aquifer, silting and water turbidity, and heavy metal contamination in the estuary.

Technology presently exists for mining below the estuary from shafts on the mainland or from man-made islands within the estuary. The technology already exists for using a lock tube seated in a shaft cored by a big-hole drill supplying vertical hole entry with an open air underground mine. This would allow for the use of the same mining techniques as used on land (McKelvey, 1968). To date, this technology has not been put into operation in the nearshore ocean environments. This, however, is not too far in the future. Moore (1972) believes that the technology will exist and the need will be great enough to support large-scale mining of noble and base metals from the shelf by 1980 with almost total dependence upon this source by the year 2000. A pretty firm basis has already been well established for such a prediction—the present transition of the major petroleum reserves to the coastal and offshore shelf environments. Another important factor that is involved here is that at present only a very small percentage of the coastal and inshore shelf has been explored for anything other than petroleum.

The potential impact upon the estuaries of subsurface hard rock mining on land is extremely variable and is only partially dependent upon its proximity to the estuary. Regardless of its location, resulting heavy metal contamination of the estuarine waters and bottom muds is common. On the other hand, those operations which are in close proximity to the estuarine system could also have a more direct impact upon both the groundwater and estuarine waters.

POLLUTION EFFECTS

The potential pollution impact resulting from subsurface mining within the estuary and nearshore environments is probably not as great as surface mining in the same areas would be. This type of extractive operation would cover smaller areas, move smaller volumes of material, and would not be directly connected with the water column, which means that it generally would be a cleaner operation. The major impact would be associated with the barge transportation of the ore and the necessary processing plants located on the nearby coastal area. The potential chemical and sediment pollution resulting from hardrock-metal benefication plants and smelters is generally very great.

Aqueous Deposits

Most of the elements known on the earth's surface can be found in seawater. These various chemical constituents comprise an impressive 165 million tons of dissolved solids per cubic mile of sea water in the world's oceans. This amounts to a total mineral reserve of 50×10^{15} tons for the 330 million cubic miles of sea water, thus forming the largest continuous ore body available to man (Shigley, 1968). However, the concentration of most of the elements is so low that only very few are presently and probably will be economically exploitable in the near future. Four groups of commodities are presently being extracted, or recently have been extracted, from sea water in the United States; these include the chlorides (including common salt), the magnesium compounds and magnesium metal, bromine, and water. In addition to these, the ocean waters may some day yield the most important source of energy for the long-term solution to the ever-increasing energy needs—deuterium. Deuterium is a heavy isotope of hydrogen useable in the process of fusion; the ocean waters contain 25 trillion tons of deuterium (McKelvey, 1974)—so much that only 1 percent would supply about 500,000 times the world's initial supply of fossil fuels; the total could supply the world's energy needs for 120 million years at 40 times the 1968 level. (Holdren and Herrera, 1971.) It also appears that deuterium can be extracted from sea water without any ill effects upon the water and biological system.

Technological processes have been developed for recovering all of the major elements and many of the minor elements dissolved in sea water. However, only four groups of materials are presently being economically extracted on a large scale. A brief discussion of each of these groups follows.

Sodium and Calcium Chlorides

These two commodities are presently being produced by solar evaporation behind extensive diked flats in the estuaries of San Francisco Bay, Calif. Recently, salt was also produced in similar evaporation flats in Newport and San Diego Bays, Calif. However, due to the extensive acreages of estuarine flats necessary for this operation and the extreme urban pressure for development, the latter two have closed. It is not likely that future fields will be opened since salt is readily available from brines, rock-salt mines, and as byproducts of potash mining. The environmental pollution resulting from the salt operations is very poorly known and is generally thought to be minimal. This is pointed out by the recent establishment of a National Wildlife Refuge in San Francisco Bay which includes 12, 243 acres of salt company lands, most of which is used for salt production. The company has been assured, however, that continued salt production is considered compatible with the Refuge (Davis and Evans, 1973). However, the diking of the estuarine flats, along with the resulting bitterns from the salt operations, definitely does modify the geometry, chemistry, and the biota of the coastal environment.

Magnesium Compounds and Metal

Many of the various compounds of magnesium produced in the United States are derived from sea water in eight coastal plants operating in six states (Table 4.). The remainder of the magnesium is produced from well brines and magnesium minerals. The process involves adding the sea water to lime solutions, forming a magnesium hydroxide precipitate. The lime is generally derived from oyster shells which are dredged from the estuaries. Magnesium metal is also produced from sea water at the Dow Chemical Company plant in Freeport, Tex. In 1972, they produced 120,000 short tons of metal utilizing chemical and electrochemical processes. The production of the magnesium compounds itself produces very minor estuarine pollution; however, since the production of the metal is a chemical process, it has a greater potential chemical impact upon the estuarine system.

Table 4.—Domestic producers of magnesium compounds from sea water in 1972 (from Minerals Yearbook for 1972, United States Department of the Interior, Bureau of Mines, v. 1, p. 748)

Company	Location	Capacity (short tons MgO equiv.)
Basic Magnesia, Inc.	Port St. Joe, Fla.	100,000
Barcrott Company	Lewes, Dela.	5,000
Chorchem, Inc.	Pascagoula, Miss.	40,000
Dow Chemical Company	*Freeport, Texas*	*250,000*
FMC Corp.	Chula Vista, Calif.	5,000
Kiser Aluminum & Chem. Corp.	Moss Landing, Calif.	150,000
Merck & Company, Inc.	S. San Francisco, Calif.	5,000
Northwest Magnesite Company	Cape May, N. J.	100,000
		655,000

BROMINE

This element was economically produced from seawater in combination with other extraction processes. For example, in 1967 the Dow Chemical plant in Freeport, Tex., produced large amounts of bromine as a byproduct of magnesium extraction. Also, the solar salt pans at Newark, Calif., produced bromine as a byproduct of the evaporite bitterns. These extraction operations required chemical plants located directly at the water's edge and, therefore, produced minor amounts of chemical pollution. However, by 1971, all of the bromine produced in the United States was from well brines in Arkansas and Michigan and lake brines in California (United States Department of the Interior, 1973).

WATER

The desalinization of seawater to produce usable fresh water is an old idea that is becoming increasingly important in the world today and locally it is even becoming an economic extractive industry. In 1966, there were 153 seawater desalinization plants in the world with daily capacities greater than 24,000 gallon per day (Shigley, 1968). He believes that: . . . "the rate of growth of desalinization has been about 30 percent per year for the past 10 years; it is now predicted that the installed capacity will be about one billion gallons per day by 1978."

Since 1958, when the United States Office of Saline Waters authorized the construction of five pilot plants to test different desalinization processes, three coastal based plants have been desalinizing seawater. These plants are located at Wrightsville Beach, N.C., Freeport, Tex., and San Diego, Calif. Today the costs of water production in these specific plants averages between 75 cents to $1 per 1,000 gallons as compared to the average freshwater costs of 30 to 35 cents per 1,000 gallons for industrial and municipal use and about 5 cents per 1,000 gallons for agricultural uses (Cargo and Mallory, 1974). Since the effluents of desalinization are more valuable as a source of minerals than the average seawater, the development of the necessary technology could play an important role in changing the economics of the entire extractive industries from ocean water, including fresh water. Indeed, due to increasing demands for limited ground water plus the rapidly increasing pollution of our water resources, these plants will become more important and abundant in the near future.

Several critical areas in the United States where desalinization could become economic very soon are portions of South Florida, the Outer Banks of North Carolina, South Texas, and Southern California. Consequently, the estuarine impact of this extractive process will only increase with time in the United States. The impact resulting from the effluents derived from desalinization is local and relatively small as compared to other extractive industries. The effluents are about equal in volume to the amount of fresh water produced, and they have about twice the concentration of the original seawater (Shigley, 1968). Of far greater impact is the associated urban, industrial, and agricultural development that would follow, particularly in the areas that presently are deficient in fresh water resources.

POLLUTION EFFECTS

The environmental impact of those industries extracting from aqueous deposits upon the associated estuarine systems appears to be less than some of the other extractive industries. Since these are land based operations, the physical intrusion is limited to the adjacent shoreline area. However, all of the extractive industries described in this section produce brines with increased heavy metal contents, often heat, and in some cases chemical effluent. Discharge of these effluents, unless properly monitored and controlled, could produce significant local estuarine pollution. Probably the greatest impact that this group of extractive industries has upon the estuarine system is indirect, resulting from the stimulation of and interdependence upon numerous other industrial, commercial, and residential activities. Shigley (1968), pointed out that the combination of raw materials and location at Freeport, Tex., has stimulated the development of a large chemical manufacturing complex, of which seawater processing activities are only a part. Because the seawater processing activities share raw material overhead, and research with over a 100 other products in such an industrial confine, what would otherwise be either a marginal or uneconomic operation, can become economic and viable.

CONCLUSIONS

The relationship between mineral resource utilization and the coastal system is presently and will continue to produce an ever-increasing dilemma with respect to estuarine pollution. This basic dilemma can be summarized with the following conclusions:

1. Our growing technological society is totally dependent upon a myriad of basic mineral resources which are the raw materials for the technical machine. The value of, and demand for any of these basic

resources is dictated by the industrial technology and economic considerations at any given time, both of which are highly changeable and volatile controls.

2. Extraction of minerals has to take place where the minerals occur; the location of resources cannot be legislated or decreed. Since the coastal zone does contain a myriad of potential resource commodities necessary for our technological society and since these commodities do have an economic value, society demands exploitation.

3. Even though there is considerable mineral resource potential within the coastal zone, there is a dramatic lack of information pertaining to the occurrence, distribution, and concentration of specific materials. This is absolutely essential information which is prerequisite to any form of coastal zone management.

4. The potential environmental and pollution problems associated with resource extraction, preparation, and transportation, which are prerequisite to their use, are often exceedingly great. The processes of extraction of these resources are often messy operations that are capable of physically, chemically, and biologically disrupting and/or modifying the fragile coastal and estuarine system. The resulting effects may be either direct or indirect, local or broad scale, temporary or permanent, and of varying degrees of severity, all depending upon the commodity itself and the methods of extraction and processing. In addition, a myriad of satellite industries develop in the coastal zone in response to a given extractive industry; often these industries have a greater potential cumulative impact upon estuarine pollution than the extractive industry itself. Some extractive and satellite industries are not compatible with other legitimate uses of the estuarine system.

5. Some resource materials have alternate sources from which the necessary raw materials can be supplied and many have substitute materials that can be made available or developed. This is particularly true of the low unit cost aggregate materials. Other materials, however, do not have alternate sources or substitutes. Consequently, attitudes towards and necessity for the recovery of the mineral resources within the estuaries and offshore areas vary between the two opposite extremes of complete abstinence to complete development.

6. The estuarine system of the United States occupies a very narrow transitional zone between the land area and the continental shelf; the total extent of this system represents an extremely small but manifestly important percentage of the United States. The estuaries, for the most part, are the terminal mixing basins of the freshwater drainage systems with the ocean's waters. Therefore, they receive the cumulative residue, waste, pollution and sediment resulting from all man's and nature's activities within each drainage system, subsequently funneled into the estuaries.

7. Socially, industrially, and demographically, the United States has evolved, in a manner that appears to be continuing, with disproportionate concentrations within the coastal zones. This continual encroachment and the mounting intensity of development and use of the estuarine zone has produced a highly stressed system which is resulting in major and potentially devastating changes within this fragile and important transitional area.

If one can accept these statements as valid, then there is no alternative but to establish a moratorium on all estuarine activities that will continue to add stress to an environment that represents such a vital part of the earth system and which presently sits in a very precarious balance. The extractive industries, to a large extent, fall into this situation. Development of the mineral resources on the adjacent lands and the offshore continental shelf areas should be encouraged with the proper setback lines from the shore, environmental controls, and a viable monitoring system. However, the question of mineral extraction from within the estuaries themselves should be seriously reevaluated. The age old question of which is the most valuable to man, provokes the honored response—the old "trade-off" game. But as man's needs grow, the "trade-offs" grow and pretty soon we're "trading off the trade-off." Man can no longer afford this sort of approach to the continued development of some small part of the system which in its totality is a critical resource that has well defined limits. The need is to start evaluating the natural systems, upon which man is so dependent, from a long-term basis of interdependence and not the immediate short-term dollar value. Multiple use and estuarine management are fine concepts that satisfy quarreling factions, but all too often they amount to little more than a sophisticated land grab—like the old miners staking their claims. One must approach the continued use and development of the estuaries as a single complex interacting ecosystem which has finite limits—these limits must be defined now.

RECOMMENDATIONS

In order to meet the objective of the overall study considering the status of pollution in the nation's estuarine zone with respect to the mineral extraction processes, I propose the following recommendations:

1. Establish a moratorium on any further development of the extractive industries within the estuaries until the proper background resource information can be obtained to set up a viable management program. After a national resource priority base has been developed, establish stringent sets of procedures that define what resources can be extracted from the estuarine system, where, and by what methods.

2. An extensive and exhaustive study should be initiated by Congress and placed under the direction of the U.S. Geological Survey, to map the geology and inventory the mineral resource potential of the United States coastal zone in a similar fashion to the extensive U.S. Geological Survey-Woods Hole Atlantic Continental Shelf study or the U.S. Geological Survey heavy metals study. Such environmental and geologic mapping is an absolutely essential first step for any resource management program which will consider the multiple use by conflicting interests. One cannot plan the destiny of a system without an intimate knowledge of the composition and processes operating within the system. Use evaluations and trade-offs cannot be made until the total resource potential is known.

3. A mechanism should be set up within the geological surveys in the coastal states under the direction of the U.S. Bureau of Mines to monitor the extractive industries within the coastal zone of their state. This monitoring system should include: (a) the volume and values of annual production and the reserve situation of each specific mineral commodity; (b) the extraction methods and disruptive effects of each specific mining operation upon the estuarine system; and (c) the processing and transportation methods of each mining operation and its actual and potential disruptive impact upon the estuarine system.

4. Establish rigid stress limits to stabilize the disproportionate growth and development of the estuarine systems throughout the United States. This should include delineation of the type as well as the amount of growth and development.

REFERENCES

Cargo, D. N., and B. F. Mallory. 1974. Man and his geologic environment: Reading, Mass., Addison-Wesley.

Davis, F. F., and J. R. Evans. 1973. Mining activity in California: Calif. Geology, v. 26, no. 12, p. 291–305.

Dolan, R., P. J. Godfrey, and W. E. Odum. 1973. Man's impact on the barrier islands of North Carolina: Am. Scientist, v. 61, no. 2. p. 152–162.

Environmental Protection Agency. 1971. The economic and social importance of estuaries: prepared for EPA by Battelle Memorial Institute, U.S. Government Printing Off., Washington, D.C.

Fisher, W. L., L. F. Brown, J. H. McGowen, and C. G. Groat. 1973. Environmental geologic atlas of the Texas coastal zone: Univ. of Texas, Austin, Texas, Bureau of Econ. Geol., 7 v.

Furlow, J. W. 1972. Georgia phosphate stratigraphy and economic geology of the Chatham County deposit in geology of phosphate, dolomite, limestone, and clay deposits, H. S. Puri, ed.: Florida Dept. Natural Res., Tallahassee, Florida, Bur. of Geology Sp. Pub. no. 17, p. 227–228.

Grant, M. J. 1973. Rhode Island's ocean sands: management guidelines for sand and gravel extraction in state waters: Univ. of Rhode Island, Kingston, R. I., Sea Grant Prog., Marine Tech. Rept. no. 10.

Hess, H. D. 1971. Marine sand and gravel mining industry of the United Kingdom: National Oceanic and Atmos. Ad., Tech. Rept. ERL 213-MMTCI.

Hobbie, J. E., B. J. Copeland, and W. G. Harrison. 1972. Nutrients in the Pamlico River estuary, North Carolina, 1969–1971: Water Resources Research Institute, Univ. of North Carolina, Raleigh, N.C., Rept. no. 76

Holdren, J. and P. Herrera. 1971. Energy: San Francisco, Calif., Sierra Club.

Lovering, T. S. 1969. Mineral resources from the land in Resources and Man: National Acad. of Sciences, W. H. Freeman and Co., p. 109–134.

McKelvey, V. E. 1974. Ocean developments in the United States: Ocean Industry, v. 9, no. 4, p. 208–211.

—— 1968. Minerals in the sea: Ocean Industry, v. 3, no. 9, p. 37–43.

Moore, J. R. 1972. Exploitation of ocean mineral resources—perspectives and predictions: Proc. Royal Soc. Edinburgh, v. 72, p. 193–206; Sea Grant Reprint, WIS-SG-73-333.

Morgan, J. D. 1974. The current status of the United States mining industry and the need for both increased production and increased productivity: Conf. on Productivity in Mining, Univ. of Missouri, Rolla, Mo.

Nelsen, T. A. 1974. The New England offshore mining experimental study (NOMES): Geol. Soc America, Abstr. with Programs, p. 887.

Pings, W. B., and D. A. Paist. 1970. Minerals from the oceans—Part I: Mineral Industries Bull., Colorado School of Mines, Golden, Co., v. 13, no. 2, p. 1–18.

Rigg, J. B. 1974. Minerals from the sea: Ocean Industry, v. 9, no. 4, p. 213–219.

Riggs, S. R., and M. P. O'Connor. 1974. Relict sediment deposits in a major transgressive coastal system: East Carolina Univ., Greenville, N.C., Sea Grant Pub., UNC-SG-74-04.

Schlee, J. 1968. Sand and gravel on the continental shelf off the northeastern United States: U.S. Geol. Survey Circ. 602.

Shigley, C. M. 1968. Seawater as raw material: Ocean Industry, v. 3, no. 11, p. 43–46.

Smith, P. A. 1972. Underwater mining—insight into current United States thinking: University of Wisconsin, Madison, Wisc., Sea Grant Pub. no. WIS-SG-72-330.

U.S. Army Corps of Engineers. 1971. National shoreline study including the report on the national shoreline study, nine regional inventory reports, shore protection guidelines, and shore management guidelines: Washington, D.C., U.S. Government Printing Office.

U.S. Dept. of the Interior. 1973. Minerals yearbook for 1972: Bureau of Mines, v. 1.

—— 1970a. The national estuarine pollution study: U.S. Senate Document no. 91-58, 91st Congress, 2nd Session, Washington, D.C.

—— 1970b. National estuarine study: Fish and Wildlife Serv., U.S. Government Printing Office, Washington, D.C., 7v.

University System of Georgia. 1968. A report on proposed leasing of state owned lands for phosphate mining in Chatham County, Georgia: Advisory Committee on Mineral Leasing, Athens, Ga.

FISHERIES

STATUS OF ESTUARINE ECOSYSTEMS IN RELATION TO SPORTFISH RESOURCES

JOHN CLARK
Conservation Foundation
Washington, D.C.

ABSTRACT

Increasing numbers of anglers—ten million at this time—fish along the coastal shores, an estimated 57 percent of them in the estuaries. Factors affecting the ecosystem are discussed. Recommendations are made to meet management needs, on the federal, state, and local levels.

INTRODUCTION

Ten million American anglers fish in coastal waters; they catch nearly one and a half billion pounds of fish each year. This massive recreational activity is supported by fish resources that are dependent on the continued health of estuarine and coastal ecosystems.

The number of people fishing in coastal areas has increased 50 percent since 1960, while the average yearly catch per angler has declined somewhat. The causes for the decline in catch—an indicator of fish population size—have not been determined with acceptable scientific validity and because of the environmental complexities of coastal ecosystems they may never be. In the following account we have had to work with skimpy circumstantial evidence to explore the causes and effects.

All in all, marine fish resources appear to be in surprisingly good shape. Atlantic stocks are improving after a period of general depletion during the 1960's. This may in part reflect the results of the recent national effort to clean up our waters and protect the environment. Further gains will depend upon how well fish harvest management and ecosystem protection can be combined into effective federal, state and local programs and how well societal goals for use of the resources can be defined and implemented.

THE COASTAL SPORT FISHERY

The ten million coastal anglers spread their efforts rather evenly along the U.S. shoreline, as shown for 1970 in Table 1, the latest year of record (from the National Marine Fisheries Service).[1] While there is reason to believe that the catches may be somewhat over-estimated by the inherent biases in the angler interview-recall system used, they can be assumed to give a reliable indication of the distribution of catches.

Anglers fish in both estuaries (tidal rivers, bays, lagoons, sounds) and oceans (surf and offshore waters), with 57 percent of the fish taken in estuaries. They spend about $100 each on fishing gear and other expenses per year.[2]

Coastal angling is a widespread attraction. Half the anglers have family incomes of less than $10,000 (1970 data).[2] Twenty-two percent are women. Most come from rural areas, towns, and suburbs rather than from large cities.

National surveys in 1960, 1965, and 1970, show that coastal fishing has increased by 50 percent in the span of one decade.[1,2] As the number of anglers increased from 6.2 to 9.4 million, the yearly average catch dropped from 102 fish to 87 fish per year per angler. This reduction is most likely a consequence of reduced carrying capacity of fishing waters, a possible natural reduction of fish stocks, or more fishing pressure on the stocks than can be accommodated at the same high catch rate.

The national sport-fishing surveys are not adequate to provide a statistical basis for examining trends in abundance because they are done so infrequently (5-year intervals) and because they contain inherent biases typical of poll (interview-recall) systems of data collection. A somewhat more sensitive indicator of abundance trends is the commercial catch which is recorded by the National Marine Fisheries Service through collection and tabulation of dealers' records. Example trends shown by commercial catch records are depicted in Table 2 for

Table 1.—Estimated number of anglers and catch for 1970[1]

Region	Number of anglers	Catch (millions of fish)	
		Ocean	Estuary
North Atlantic	1,700,000	35.3	81.7
Middle Atlantic	1,800,000	69.5	98.7
South Atlantic	1,800,000	112.2	72.0
Eastern Gulf of Mexico	1,500,000	42.4	146.6
Western Gulf of Mexico	900,000	47.2	50.5
South Pacific	900,000	34.7	2.5
North Pacific	1,300,000	8.3	15.8

four of the major Atlantic and Gulf of Mexico sport fish species.

The pattern is different for the various species, reflecting differences in biological, environmental and economic factors that affect their populations and their fisheries. Common to all, however, is a low point in catch in the late 60's, centering in 1967, followed by an upward swing into the 1970's, a trend not discernible in the 5-year national surveys of sport fishing catches (Table 3).

It is quite possible that the upswing of the latter 60's is partially due to a general lessening of pollution impacts and an improvement in water quality in coastal areas. For example, Edwin Joseph suggests that the increase in sea trouts may have been caused by decreasing agricultural use of DDT.[3] After World War II, DDT use rapidly increased in shorelands draining into estuaries where the spawning and nursery areas of the sea trouts are located. Lethal doses of DDT lodge in the yolk oil of many species causing death to embryos. Then after the middle 60's DDT use began to drop off. As it did, breeding likely was restored to normal. Reduction of other chemical and industrial pollution is undoubtedly a factor in recent fisheries improvement.

Table 2.—The total commercial catches of certain estuarine dependent species groups for the Atlantic and Gulf States combined. (Source: National Marine Fisheries Service; 1972 statistics are preliminary)

Year	Millions of Pounds			
	Bluefish	Croaker	Flounder	Sea trouts
1955	4.2	47.3	63.4	16.4
1956	4.1	56.8	65.1	15.5
1957	4.8	19.0	69.3	14.1
1958	3.3	24.7	77.3	12.8
1959	3.8	11.9	75.0	10.6
1960	3.5	6.9	79.4	9.9
1961	3.7	5.2	85.5	10.2
1962	5.9	3.3	104.5	10.0
1963	5.9	2.7	125.5	9.3
1964	4.6	2.5	129.0	10.1
1965	5.0	3.5	133.7	11.9
1966	5.5	3.4	127.7	10.7
1967	4.3	2.5	112.5	9.5
1968	5.4	4.7	114.0	12.0
1969	6.0	6.7	115.0	11.4
1970	7.2	8.4	123.0	14.9
1971	5.6	10.6	125.0	18.7
1972	6.3	16.6	128.0	21.0

Table 3.—The estimated total U.S. angler catch of certain estuarine dependent species groups for Atlantic and Gulf States combined.[1] Catch in millions of fish

Year	Bluefish	Croaker	Flounder	Sea trouts
1960	23.8	46.0	50.6	83.8
1965	31.0	51.0	54.6	89.4
1970	36.0	66.0	57.4	107.0

Although these improvements are encouraging, many threats remain; vigilance is necessary, and a much higher potential is realizable. This potential is particularly high for reducing damage from effects such as urban drainage and physical destruction of estuarine systems, effects that do not originate with point source pollution (pipe discharges). To correct these, there usually must be control of land uses in the watersheds and along estuarine shores coupled, of course, with the control of point discharges. Such combined land and water ecosystem management programs are necessary to maintain the vitality of estuarine fish populations.[4]

THE ESTUARINE ECOSYSTEM

An estuary is a constricted coastal water body that connects to the sea and has a measurable quantity of salt in its waters. For management purposes, the following rule of thumb, which is based upon the degree of confinement, may be used to distinguish between estuarine and open coastal areas: An estuary is a waterbody that has a basin circumference in excess of three times the width of its outlet to the sea.[4]

The exceptional natural value of the estuarine ecosystem comes from a beneficial combination of physical properties that separately or in combination perform such functions as those listed below[4]:

1. *Confinement*: Provides shelter which protects the estuary from wave action, which allows plants to root, clams to set, and fragile small animals to exist; and permits retention and concentration of suspended life and nutrients.
2. *Shallowness*: Allows light to penetrate to plants on the bottom; fosters growth of marsh plants and tideflat biota; encourages water mixing; and discourages large oceanic predators which avoid shallow waters.
3. *Salinity*: Freshwater dilution deters ocean predators and encourages estuarine forms; precipitates sediments; and provides buoyancy and physiologically beneficial salt concentrations. Freshwater flow

over saltier, bottom water typically induces beneficial stratified flow.

4. *Circulation*: Tidal and wind forces plus stratified flow set up a beneficial system of transport for suspended life, enhance flushing, and retain organisms in favorable habitats.

5. *Tide*: Tidal energy is a major driving force of circulation; tidal flow transports nutrients and suspended life, dilutes and flushes wastes; tidal rhythm acts as a regulator of feeding, breeding, and other functions.

6. *Nutrient storage*: Trapping mechanisms store large amounts of nutrient within estuary; marsh and grass beds store nutrients for slow release as detritus; richness induces high accumulation of available nutrients in animal tissue.

About two thirds of the Atlantic and Gulf of Mexico species of coastal sport fish depend upon the special life giving properties of the estuaries for sanctuaries, or nursery areas for their young. Fewer Pacific than Atlantic species are critically dependent upon estuaries.[4]

The estuarine dependent species include those that spawn in the ocean, along the beaches, in the inlets, within estuaries, and up the tidal rivers. The young of all these converge in the estuaries for food, refuge, and suitable water. Most estuarine dependent fishes are ocean or coastal migrants who spend only part of their lives in the shallow estuaries. But this one period may be the most crucial part of the survival of the species. Three major categories of estuarine dependency are shown below with examples for each species:[5]

Adults found mostly in the estuaries, some only seasonally.	*Adults found partially in the estuaries, some only seasonally.*	*Adults found mostly along the open coast.*
Flounder (winter flounder)	*Striped bass (rockfish)	Bluefish
Spotted trout	Fluke (summer flounder)	Tautog (blackfish)
Tarpon	Porgy (scup)	King whiting (kingfish)
Croaker (hardhead)	Red drum (redfish or channel bass)	*Alewife (river herring)
Snook (lafayette)	Black drum	*Shad
*White perch	Mullet	Atlantic mackerel
		Menhaden (bunker, pogy)

* Anadromous species: Living as adults in salt or brackish water but spawning in fresh or nearly fresh water.

Estuaries and their adjacent shorelands are easily accessible for urban or industrial development. Use pressures are heavy in urban areas adjacent to estuaries and the pollution potential is high. The confinement and shallowness of estuarine water basins allow pollutants to pervade their waters, particularly those that have poor flushing characteristics.

There is irony in all this. The most urbanized estuaries which often suffer the highest environmental stress are at the same time potentially subject to the highest sport fishing demand because of the human populations concentrated there. Therefore, the very water bodies that should carry the greatest sport fish resources may actually carry the least.

Because of the variety of man-caused disturbances that affect estuarine waters and because of year to year natural changes in the environment that affect species, it is nearly impossible to establish any scientifically valid correlation between the type of pollutant, or other disturbance, and the status of any fish population. There does not exist in the scientific literature one scientifically convincing cause and effect relation between a single disturbance and a single effect. Therefore, one must look broadly at complete ecosystems in all their complexity and try to judge the multiple effects of multiple disturbances upon carrying capacity limiting factors.

CARRYING CAPACITY LIMITING FACTORS

The potential fish yield of any estuarine water body is governed by its carrying capacity for the species it supports. Carrying capacity in the strict scientific sense is the number of a particular species that can be supported per acre, or other measure of size. However, we use it here in a more general sense as the amount of life that a habitat can support.

Exactly what makes good fishing waters has always been a bit of a mystery. However, science has unraveled enough of the mystery to understand what environmental disturbances degrade good fishing waters and generally how they do it. Each type of disturbance reduces carrying capacity in a specific way and a combination of them causes a combination of carrying capacity reductions.

The National Pollutant Discharge Elimination System (NPDES) and related provisions of the 1972 Water Act should provide adequate control of disturbances arising from point sources of pollution (pipe discharges) including industrial and municipal wastes by the mid-1980's. This alone should considerably improve the carrying capacity of estuaries for fish. But controlling point sources is only part and perhaps the easiest part of the much larger job of restoring the carrying capacity of the nation's estuaries. Controlling non-point pollution may present a far greater challenge. For example, a primary source of non-point pollution discharge to estuaries is urban runoff—water from city streets, industry sites, parking lots, and other developed areas—which often carries massive loads of pollutants into estuaries. The following amounts might be expected from a typical city of 100,000 population following a one-hour storm (in lb./hr.):[6]

	Street surface runoff	*Raw sanitary sewage*	*Secondary plant effluent*
Suspended solids	560,000	1,300	130
BOD_5	5,600	1,100	110
COD	13,000	1,200	120
Nitrogen (Kjeldahl)	800	210	20
Phosphates	440	50	2 5

Erosion from disturbed land surface often produces massive amounts of sediment that may be transported to estuaries, as shown by the following estimates.[7]

Activity	*Sediment Produced (tons/sq.mi./yr.)*
Construction	48,000
Cropland	4,800
Grassland	240
Forest	24
Disturbed Forest (not clear-cut)	24,000
Active Surface Mines	24,000
Abandoned Mines	2,400

This erosion may also bring excessive nutrients, toxic matter, and bacteria down to the estuaries to reduce carrying capacity for sport fish populations.

In the following sections we first describe each major natural factor that limits the total carrying capacity of an estuarine fish habitat. Second, we discuss the point and non-point pollutional disturbances that lower carrying capacity. And third, we relate the disturbances to specific human activities.

Oxygen

Of the various gases that are found dissolved in coastal waters, oxygen is of the most obvious importance to fish and other animal life. They need ample oxygen to survive and even more to grow and function well—the federal water standard is a minimum of 4.0 ppm (parts of oxygen per each million of water).

When sewage and other wastes with high BOD (biochemical oxygen demand) pollute coastal waters, bacteria multiply to enormous abundance and deplete the water of oxygen faster than it can be replaced by either plants or the atmosphere. Fish may be killed by a sudden oxygen drop but more often the problem is a persistent and pervasive lack of oxygen which reduces carrying capacity and repulses fish. For example, low oxygen from industrial and municipal wastes has eliminated striped bass spawning in the Delaware River and oxygen depletion from papermill waste disrupted salmon runs in Bellingham Bay, Wash. Oxygen levels are depressed to low levels in Florida canals built for seaside housing developments where fine sediments accumulate and water becomes stagnant—a half pound of organic wastes per day (e.g., grass clippings) is enough to contaminate a 100-foot length of canal, reducing oxygen from an acceptable 4.5 to an unacceptable 3.8 ppm.[9] In August 1971, all bottom fish deserted the western part of Long Island Sound around Glen Cove because of oxygen depletion caused by pollution.[10]

Temperature

Temperature controls life in the coastal ecosystem. Migration, spawning, feeding efficiency, swimming speed, embryological development, and basic metabolic rates of fish are controlled in large part by temperature. Temperature increase, such as that caused by power plant effluents may disrupt these basic life processes. (Power plants also suck fish in with cooling water and kill them in the pumps and pipes.) Where multiple power plants are placed on an estuary, temperatures can increase to damaging levels over extensive areas, such as the striped bass breeding grounds shown in Figure 1 or the vital grass bed nursery area shown in Figure 2 where 91 percent of the grasses were killed.

Fresh Water Inflow

The volume of fresh water supply not only governs the salinity of estuaries, but also controls circulation patterns (circulation strongly influences the abundance and the pattern of distribution of fish and other life in the estuary).

Some fish require different salinities at different phases of their life cycle such as those provided by runoff, summer drought, et cetera. Alterations affecting freshwater inflow may upset the natural salinity regime, upsetting habitat conditions to which the fish are naturally adapted and lowering carrying capacity. Salinity throughout the coastal ecosystem fluctuates primarily with the amount of dilution by freshwater inflow and the extent of evapotranspiration. The inner ends of estuaries may become so salty in summer when fresh inflow water is diverted for other uses that the water becomes

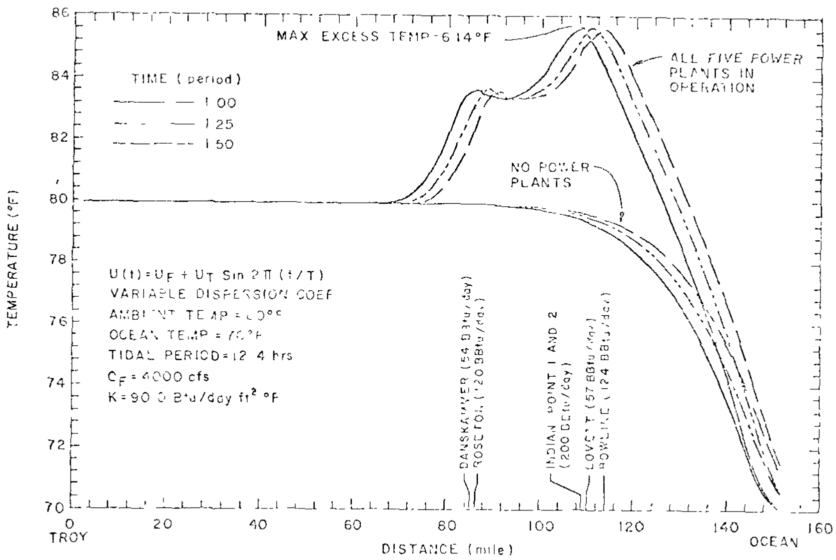


FIGURE 1.—Temperature of the Hudson from Troy, N.Y., to the ocean at three tidal times with five power plants in full operation.[11]

virtually uninhabitable for sport fish—for example, Tomales Bay, Calif. (39 ppt salinity),[13] and Rookery Bay, Fla., (to 40 ppt).[14]

Sedimentation

Also related to the volume of runoff inflow is the amount of sediment carried down into the estuary. Uncontrolled development in estuarine watersheds creates adverse effects by reducing the capability of the land to filter and hold back storm water runoff and to cleanse it of sediments as well as nutrients and a wide variety of other contaminants from the land surface. Therefore it is a fundamental goal of estuarine resource management to protect water bodies against excess loading of polluting materials by achieving control of damaging activities in the watershed.[4]

Accumulation of sediment on the bottom of an estuary results in shoaling of the basin and the creation of a soft, shifting, and basically unsuitable habitat for bottom life. These sediments also trap pollutants that are harmful to water quality when resuspended by wind, currents, or boat traffic. Virtual elimination of bottom life—as has now happened in the New York Harbor estuary—seriously degrades the ecosystem and dismantles the food chain of fishes.

An example of gross pollution from agricultural drainage and clearing is the estuarine system of Back Bay, Va., and Currituck Sound, N.C., which was loaded with silt which killed bottom vegetation, created high turbidity, and lowered the carrying capacity.[15] Sedimented and degraded estuaries with reduced carrying capacity for sport fishing are found along all sections of the U.S. coastline.

Corrective measures require control of: (1) erosion from land clearing and site preparation in the water-

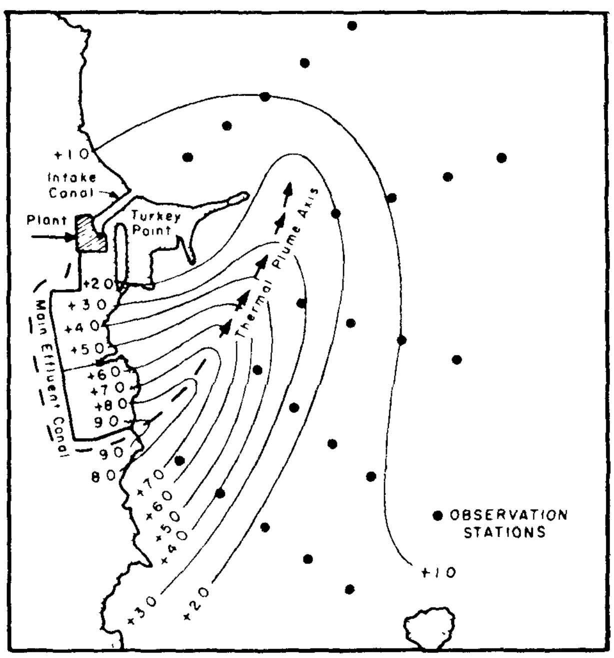


FIGURE 2.—Profiles of isotherms above ambient (°T) in Biscayne Bay during summer—the Turkey Point plant was subsequently fitted with an alternate cooling system.[12]

shed; (2) dredging activity in estuarine basins; (3) municipal and domestic pollution which creates organic sediments; and (4) boat traffic (which resuspends sediments).

Water Circulation

The circulation of water through an estuary is a key factor in carrying capacity. It transports nutrients, propels plankton, spreads "seed" stages, (planktonic larvae of fish and shellfish), cleanses the system of pollutants, controls salinity, shifts sediments, mixes water, and performs other useful work. The fish populations and the entire dynamic balance of an estuary revolve around and are strongly dependent upon circulation. Channel dredging and filling alter the flow patterns of estuaries as does the construction of bridges, causeways and piers which impede circulation.

Light

Sunlight is the basic force driving the ecosystem. It is the fundamental source of energy for plants which in turn supply the basic food chain which supports all fish. Sunlight must be able to penetrate the water so as to foster growth of the plants.

Estuarine waters are normally more cloudy (turbid) than ocean waters, being more laden with silt and richer in nutrients and phytoplankton. Excess turbidity reduces penetration of sunlight into water and thus depresses plant growth. This may be caused by excavation in water basins, by the discharge of eroded soil with runoff, by nutrients in the runoff or by sewage or industrial waste discharges which stimulate the growth of algae and lead to clouding of the water.

Nutrients

In addition to light, nutrients must be present to support the food chain. The amount of nitrate dissolved in the water is generally believed to be the primary nutrient control on abundance of estuarine plants. Nutrients continuously trickle out of the estuarine system and must be replaced by minerals in the inflow of land runoff. This supply should not be diminished.

Conversely, the ecosystem may be unbalanced by an excessive and unnatural supply of nutrient chemicals from septic tank leaching, discharge of sewage effluent, industrial organic wastes, contaminated land runoff water, and so forth. The result is overfertilization (eutrophication) which involves rapid "blooms" of phytoplankton followed by mass death and decay, clouding the water, fouling estuarine bottoms and depleting oxygen.

While sewage has been the usual suspect for overfertilization of natural waters, the potential damage by fertilizer runoff has increased dramatically—the amount of nitrogen used in agriculture in the United States increased fourteenfold in 25 years.[16] Fertilizer runoff can jeopardize the carrying capacity of estuarine systems, particularly poorly flushed ones.[4]

Water Suitability

Protection of water quality for fish life involves more than just avoiding lethal concentrations of pollutants—the water must be suitable beyond bare survival. There are definite limits below which animals desert an area or survive in very reduced abundance. Sensitive oceanic migratory fishes may be particularly affected by water suitability and abandon coastal areas with bad water. The result may be failure of a fishing area and decrease of the overall carrying capacity for the excluded species.

A variety of substances from industrial discharges or sewage effluent—heavy metals, oil, organic substances—are repelling to fish; for example, salmon avoid water with copper in very small amounts (0.0024 mg/l)[17] such as comes from fertilizer runoff.[14] Such repellents are probably responsible for the general avoidance or apparent virtual abandonment by oceanic sportfish species of many estuarine and nearshore ocean waters such as Boston Harbor, the Savannah River, and the Hudson Estuary. Elimination of all significant discharge of pollutants would restore the abundance of fishes in many of these areas.

Toxic Substances

It is not possible to determine the amount of damage done to sport fishing resources by the discharge of toxic chemicals into estuaries, but the damage appears to have been extensive; e.g., the severe reduction of the sea trout previously discussed. In another circumstantial example, the virtual disappearance of the California sardine (an important forage for pelagic game fish) is correlated with increasing DDT use after World War II (Figure 3).[18] DDT use is banned in California but a 50-square mile area off the Los Angeles sewer plant discharge (Palos Verdes area) has a persisting deposit of about 200 tons of DDT in the surface sediments on the bottom of the continental shelf.[19]

The same area has also received toxic metals from

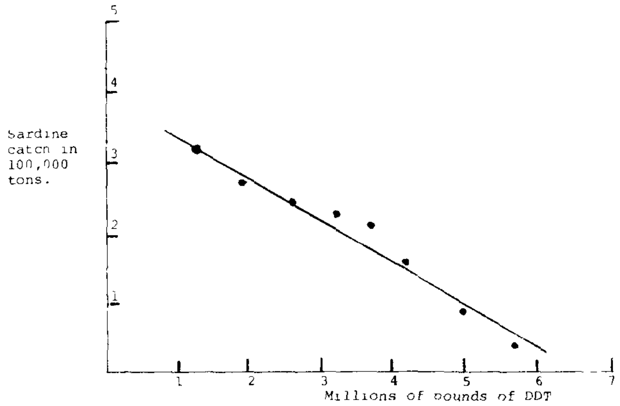


FIGURE 3.—The decline of the Pacific sardine from the mid-40's to the early 50's and the amount of DDT used in California in the same period.[18]

the discharge. leading to fish diseases[19] and widespread reproductive failure of marine species of the area. But now there are signs of a comeback as young stages of species missing for decades are reappearing in the area indicating a water quality improvement.[20] Because of the ocean outfall, water quality of the harbors is better in certain respects than that of the ocean, a reversal of the usual situation.

The NPDES program of EPA has an important role to play in eliminating the discharge of toxic substances to estuarine and coastal waters. The potential benefits are supported by encouraging results of pollution abatement efforts to date.

Severe disease (fin rot) of estuarine and coastal fishes is caused by municipal waste discharge. In the New York harbor area 22 species were affected by fin rot, including both pelagic fishes (e.g., bluefish, striped bass) and bottom fishes (e.g., flounder, hake).[20] In the Los Angeles area about 50 percent of sole, rockfish, croaker, and other bottom fish sampled were affected.[19]

Vital Habitat Area

Vital habitat areas are particularly critical elements of the ecosystem whose protection is essential to prevent degradation of the system, including depletion of fish. In the profile of the shorescape, wetlands are the areas above the mean high tide mark and below the yearly high storm mark. Wetlands, vegetated with a combination of salt-tolerant, wet-soil, plants—grasses and rushes—often grade into some combination of fresh water marsh plants at the upland edge. Vegetated tidelands are the swamps and marshes from mean high tide down to the low water mark.

Wetlands and tidelands vegetation converts nutrients in land runoff and estuarine waters to basic food for aquatic life, a sort of floating humus of small particles (detritus). It also removes excess nutrient, sediment, and other dissolved and suspended matter. The marsh and swamp areas provide critical habitats for many species as well as stabilize shorelines, prevent erosion, and buffer the force of storms and floods

If the wetlands-tidelands vegetation is eliminated, carrying capacity of the ecosystem for fish is reduced—about 50 percent in a typical case.[22] Reduction of freshwater inflow to tidelands or canalizing or bulk-heading tidelands may also significantly reduce estuarine fish resources. Therefore, fishery management programs should require that wetlands be protected from obliteration, alteration, or degradation by pollution and by drainage or dredge-and-fill projects which reduce the area of the wetland or disrupt the natural water flow patterns—as is addressed under Section 404 of the 1972 Federal Water Act Amendments.

Submerged grass beds convert and provide detrital nutrient to the system, add oxygen (during daylight), and stabilize bottom sediments. They usually attract an abundance and diversity of life and are nursery areas for young fishes and crustaceans. Grass beds are vulnerable to turbidity, which screens out light and prevents growth of the grass, and to fine sediments (mud) which create unstable bottom conditions wherein the grasses often cannot anchor. Heated power plant effluent (along with induced turbidity) may destroy local grass beds; for example, in the Patuxent River, Md., and Southern Biscayne Bay, Fla.[12] Boat traffic over grass flats may compound the problem by stirring up sediments and ripping out plants.[4]

MANAGEMENT NEEDS

Fishing success depends upon the abundance of fish which in turn depends upon the current carrying capacity of the aquatic ecosystem. Carrying capacity itself is governed by specific limiting factors. These limits in turn are depressed by adverse ecologic impacts from development and human occupancy. Therefore, coastal sport fisheries management should incorporate ecosystem management aimed at optimizing carrying capacity.[14]

Secondly, it should be directed toward optimizing the social benefits from the resource. This requires that goals and policies for management be based upon a realistic evaluation of social, economic, and ecologic factors.

It is customary for states to regulate coastal fisheries. Stronger roles for both federal and local governments should be considered if successful integrated programs of fisheries management are to be implemented. Local governments sometimes regulate shellfish and less often, a herring run or other special situation. But local government plays an important role in controlling access to fishing, via roads, parking lots, beaches, piers, boat ramps.

The states have the leading role partly because fish migrate between local fishing areas. A species may spawn in one area, feed in another, and winter somewhere else again, making it impossible for any local government to act effectively. In addition, the water moves from one locality to another bringing one town's wastes to another's shores. Therefore, the states are better equipped to deal with management of fisheries.

There is clearly a Federal role for management of coastal migratory fish and for protection of interstate environments. No state can do the whole job alone because both fish and water move from state to state. For the most part interstate commissions have proved ineffective in coordinating fishery management of the states into successfully integrated programs.

Typical state fisheries management programs have dealt only marginally with the coastal environment. Fish regulations are usually aimed at allocating fish to fishermen by limiting the type of gear, size of fish, time of year, number of fish taken per day, and so forth. This passive portioning out of the catch is usually done without any attempt to scientifically optimize the yield from the ecosystems involved.

In state management the target usually is a single species. Rules are laid down for the species without regard for other species that share the ecosystem—species that may be prey, predator, competitor, or cooperator. The rules are applied through the political process in state legislatures or by appointed state commissions, under heavy lobbying pressure from fishing organizations. Opinions of state fishery biologists may be ignored because their case has not had the funds or manpower to be developed with scientific certainty. Most states have no salt water sportfish license to provide an internal source of funds for management or research on sport fishing problems. State commissioners and the general constituency of the fishery agency want to see money spent for visible structures—boat ramps, artificial reefs, and so forth—rather than advance planning, research, or administration. Consequently, the agencies are under-financed and short handed.

As a result, coast sport fisheries management is typically a series of ad hoc responses to immediate situations. In only a few states, such as California, Florida, and Massachusetts, is there any continuing management research program to serve as the basis for longer-term strategies that include environmental protection. If there is to be an effective strategy for comprehensive coastal fisheries management, there must be clearly defined long-term goals. The goals must be translated into policies consistent with social needs as determined through the political process.

The following planning framework suggests major elements that need to be considered:

1. *Resource optimization:* Devise a system of estuarine resource management that involves both harvest control and ecosystem management. Harvest control includes: bag limits, size limits, gear restriction, access limits, and closed areas and seasons. Ecosystem management includes: control of chemical and industrial pollution, protection of vital habitat areas, control of land clearing and site preparation in shorelands, maintenance of freshwater inflow, control of dredging and filling, and control of boat traffic.

2. *Access:* Provide a system of access that will guarantee an optimum pattern of fishing activity consistent with economic, sociologic, and ecologic constraints. Physical development should incorporate roadways and public transportation as well as beaches, bridges, piers, marinas, ramps, and charter boats. Social factors to be balanced should include: geographic distribution, income level, race, and availability of alternative recreation opportunity.

3. *Allocation:* Plan for a balanced pattern of allocation of fish resources including. (1) competing user groups such as commercial anglers, skin diving, and foreign fishermen; (2) the various demographic elements (see 2); (3) preferred sizes of the catch; and (4) preferred times and areas of fishing.

4. *Monitoring*: Design a system for measuring catch and monitoring user satisfaction to guide the management program.

5. *Revenue*: Examine the recreational fishery (along with commercial) to determine the revenues gained for different patterns of use and for different levels of production.

6. *Institutional*: Determine the optimum mix of federal, state and local jurisdictions, and the best methods of implementation of management actions through existing and new legislation.

It appears that this is an appropriate time for each coastal state to review its situation, to examine federal-state-local jurisdictions, to decide upon a unified set of goals, and to establish a clear set of policies for use and protection of coastal fishery resources.

The Federal government would need to participate in this process where migratory fishes and interstate environments are involved, and to provide a mechanism for coordinating activities of all federal agencies dealing with the coastal environment and coastal resources. There is now no federal policy or program on migratory fish resources. Such a role must be suitably defined by Congress through legislation, funding, and study.

The new federally sponsored Coastal Zone Management program would seem a logical framework for such a cooperative planning study, providing that sufficient importance and funds are given to the individual states to conduct comprehensive plans for land and water resource management. It is clear that only through this kind of comprehensive planning can recreational fishery resources be properly maintained and equitably shared among all Americans.

REFERENCES

1. Deuel, David G. 1973. The 1970 Salt-Water Angling Survey. U.S. Dept. of Comm., Ntl. Mar. Fish. Serv., Current Fishery Stats. No. 6200

2. U.S. Bureau of Sport Fisheries and Wildlife (undated). National Survey of Fishing and Hunting 1970. U.S. Dept. of the Int., Bur. Spt. Fish, and Wildlife, Res. Publ. 95.

3. Personal communication. Edwin A. Joseph

4. Clark, John. 1974. Coastal Ecosystems: Ecological Considerations for Management of the Coastal Zone. The Conservation Foundation, Washington, D.C.

5. Clark, John. 1966. Fish and Man: Conflict in the Atlantic Estuaries. American Littoral Society, Special Publication No. 5

6. Sartor, J. D. and G. B. Boyd. 1972. Water Pollution Aspects of Street Surface Contaminants. USEPA, Env. Prot. Tech. Serv. EPA R2-72-081.

7. Midwest Research Institute. 1973. Methods for Identifying and Evaluating the Nature and Extent of Nonpoint Sources of Pollutants. Draft Report. USEPA. Contr. No 68-01-1839.

8. Copeland, B. J., H. T. Odum, and Frank N. Mosely. 1974. Migratory Subsystems Chapter F, Coastal Ecological Systems of the United States, edited by H. T. Odum, B. J. Copeland and E. A. McMahan. Volume III. pp. 422-453

9. Personal Communication. Timothy Stuart, Florida Department of Water Pollution Control, Tallahassee, Fla.

10. National Marine Fisheries Service. 1972. Druid's Island Phase I: A short-term ecological survey of Western Long Island Sound. U.S. Dept. of Comm. NOAA, Nat. Mar. Fish. Serv., Sandy Hook Marine Laboratory. (See Table 37).

11. Simon-tov, M. 1973. Testimony to U.S.A.E.C. Licensing Board Hearing—Indian Point No. 2, Feb. 8, 1973.

12. Roessler, Martin A. and Joseph C. Zieman. 1969. The effects of thermal additives on the biota of Southern Biscayne Bay, Fla. Proc. of Gulf and Carib. Fisheries Inst., 22nd Session. pp 136–145

13. Smith, Edmund H., et al. 1971. Physical, chemical, microbial, and hydrographic characteristics of Tomales Bay. Final Rept. to EPA. Project No. 18050 DFP. August, 1971.

14. Clark, John. 1974. Rookery Bay: Ecological Constraints on Coastal Development. The Conservation Foundation, Washington, D.C.

15. Sincock, John L., et al. 1962. Back Bay—Currituck Sound Data Report, U.S. Bureau of Sport Fisheries and Wildlife. 4 Volumes (Mimeo).

16. Commoner, Barry. 1970. Threats to the Integrity of the Nitrogen Cycle: Nitrogen Compounds in Soil, Water Atmosphere and Precipitation. In Global Effects of Environmental Pollution, S. F. Singer, ed. (D. Reidel Publishing Co., Dordrecht, Holland). pp 70–95.

17. Sprague, J. B. 1971. Measurement of pollutant toxicity to fish. *III. Sublethal effects and "safe" concentrations.* Water Research, 5: No. 6, pp 245–266.

18. Unpublished information supplied by Walter Thomsen, *previously with the California Dept. of Fish and Game.*

19. Information supplied by David Young, The Southern California Coastal Water Research Project, Los Angeles, Calif.

20. Personal communication, Rimmon C. Fay, Pacific BioMarine Supply Co., Venice, Calif.

21. Mahoney, John B., Frederick H. Midledge and David G. Deuel. 1973. A fin rot disease of marine and euryhaline fishes in the New York Bight. Trans. Amer. Fish. Soc., Vol. 102, No. 3: pp 596–605.

22. Personal communication, Richard Williams, Smithsonian Institution.

23. Anderson, Richard R. 1969. Temperature and Rooted Aquatic Plants. Chesapeake Science, Vol. 1, Nos. 3 and 4: pp 157–164.

LIMITING FACTORS AFFECTING COMMERCIAL FISHERIES IN THE MIDDLE ATLANTIC ESTUARINE AREA

J. L. McHUGH
State University of New York
Stony Brook, New York

ABSTRACT

Landings of fish and shellfish by domestic commercial fishermen in the Middle Atlantic Estuarine Area (Rhode Island–Virginia inclusive) nearly doubled in weight from 1969 to 1973, from about 586 million to more than 1,074 million pounds. The increase was not accompanied by a similar increase in fishing effort, but by distinct increases in abundance of certain coastal fishes like menhaden, weakfish, summer flounder, and bluefish. In the area north of Chesapeake Bay blue crab was more abundant than it has been for more than a decade and scup also was more plentiful. It is tempting to attribute these increases to pollution abatement, but no direct proof is available. For example, the return of blue crab to the New York Bight area may have been made possible by the decline in use of DDT. All these species are known to vary widely in abundance from natural variations in environmental factors and it is difficult to separate natural from manmade causes. The only certainly adverse effects of water pollution on abundance or catches of living marine resources are those which produce obvious and measurable effects, usually catastrophic, or which result in closure of shellfish beds. Because so many important living resources use the estuaries as spawning, nursery, or feeding grounds it is prudent to avoid additional deterioration of water quality and, where possible, to reduce dumping of wastes.

INTRODUCTION

This review of the fisheries of the Middle Atlantic Estuarine Area includes estuaries and coastal waters from Cape Cod to Cape Hatteras and out to the edge of the continental shelf. This area (Figure 1) lies between latitudes 41°20′ N. Lat. and 35°15′ N. and extends seaward to the 200m. depth contour.

The offshore boundary is approximately where the shelf meets the continental slope. Although this is not exactly the definition given in section 104 (n) (4) of Public Law 92-500, it is the only rational definition for adequate consideration of the living resources upon which the fisheries of the Middle Atlantic Bight depend. Most commercial fishery resources in the area are highly migratory, and perform extensive seasonal movements east and west as well as north and south. Thus, many living resources of the area are about equally dependent upon the inshore and the offshore estuarine environment. In winter and spring many of the major migratory living resources are concentrated in relatively deep water at the edge of the shelf, some apparently favoring the major canyons. Conditions along these outer boundaries must play an important role in determining future abundance and availability of these resources to the inshore fisheries.

The definition of the Middle Atlantic Estuarine Area adopted here is similar to the definition of the Middle Atlantic estuarine region used in the "National Estuarine Pollution Study" (Anon. 1970a), although that study did not include Chesapeake Bay, but considered it as a separate region. "The National Estuary Study" (Anon. 1970b) defined the Middle Atlantic Estuarine Zone as the estuaries, bays, and coastal waters from Cape Cod to Cape Charles, Va. Chesapeake Bay was considered separately, and the area from Cape Henry, Va. to Cape Hatteras was included with the South Atlantic Estuarine Zone. None of these arrangements is entirely satisfactory for a fishery study because basic data on domestic commercial landings are recorded by states, whereas foreign and recreational catches are recorded by broader regions. The fishery resources of Chesapeake Bay are sufficiently different from those to the north that it is best to examine them separately. Because North Carolina fishery resources are transitional between Middle and South Atlantic Estuarine Areas, the commercial fisheries of North Carolina have been omitted. Thus, the two subareas of the Middle Atlantic Estuarine Area considered in the present study are Rhode Island to Delaware inclusive, and the Chesapeake states, Maryland and Virginia.

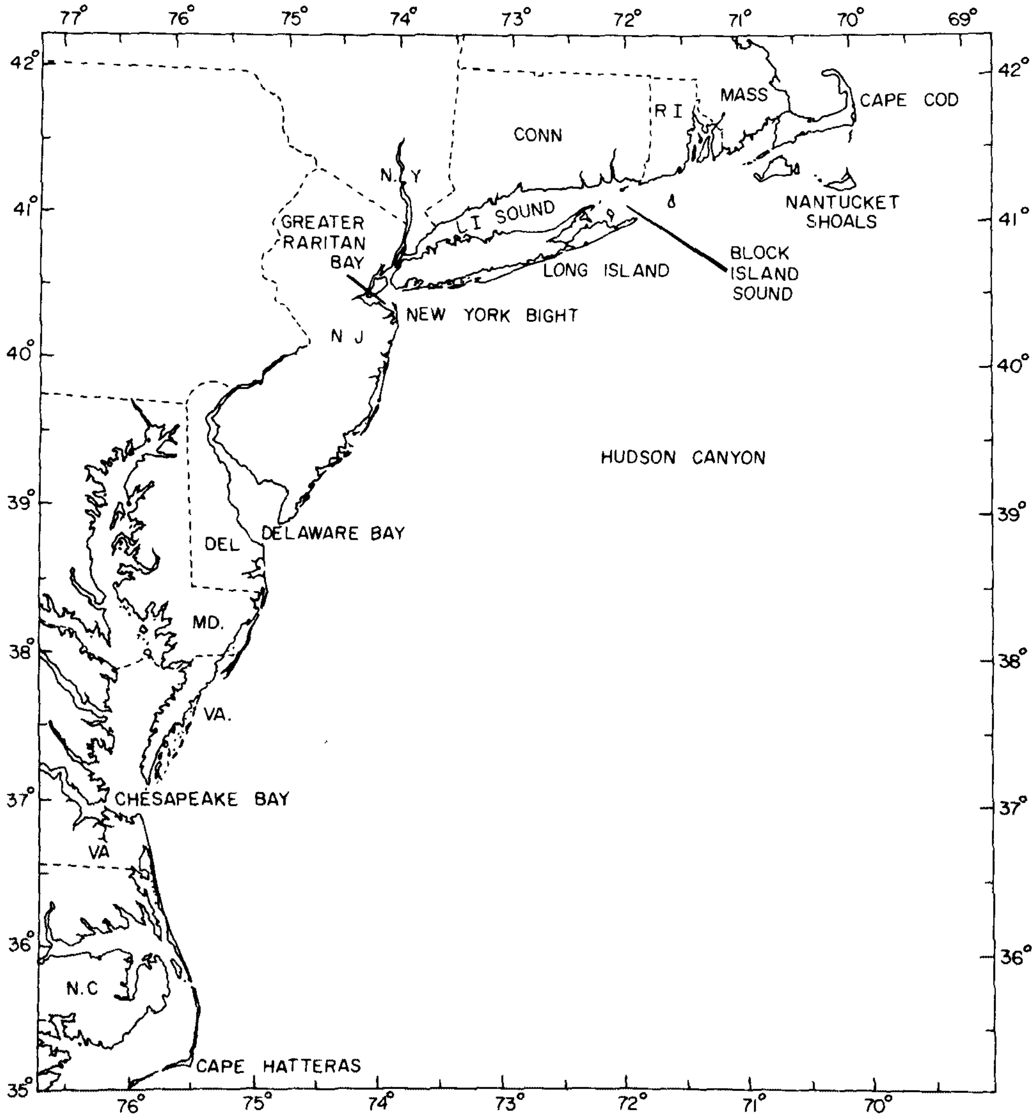


FIGURE 1.—The Middle Atlantic Estuarine Area of the United States. Not all place names mentioned in the text are included. The long narrow east-west peninsula near the southeast end of Long Island and the similar north-south peninsula at the north end of the New Jersey seacoast are Rockaway Point and Sandy Hook, respectively. A line drawn between these points separates Greater Raritan Bay from New York Bight. The Potomac River is the large river entering Chesapeake Bay from the west. The Maryland-Virginia boundary follows its southern bank. The Patuxent River lies immediately north of the Potomac and the Rappahannock River immediately south.

Within waters under national jurisdiction, from inland limits of estuarine waters to seaward limits of domestic fishery control, living marine resources are subject to many natural and manmade hazards. Subtle or catastrophic natural environmental variables can alter abundance and availability of the resources to fishermen. Various stresses created by man include not only relatively uncontrolled fishing, but also domestic and industrial wastes and engineering works which alter the environment, usually for the worse. Farther out on the continental shelf, especially at or near the edge, many of these resources remain concentrated for several months in winter and early spring. Here they are highly vulnerable to fishing, mainly by foreign fleets, but less susceptible to water pollution and other indirect human influences.

The fishery resources of the area from Cape Cod to Cape Hatteras provided a domestic commercial catch in 1973 of about 1.6 billion pounds[1], for which

[1] To convert millions of pounds to metric tons, multiply by 453.6.

American fishermen received about $119 million. The retail value of this catch could be $300 million or more. They also provided 820 million pounds to fishing fleets of at least 10 other nations. Not to be ignored is the substantial recreational catch. Surveys of saltwater sport fisheries have not been made every year, but in 1970 recreational fishermen were reported to have taken about 447 million pounds from the same community of resources, and the sport catch in the area probably was larger in 1973. The distribution of catch and fishing effort on individual stocks varies between recreational, domestic commercial, and foreign fisheries. Not included in the recreational catch are clams, bay scallop, crabs, and some other invertebrates taken in large numbers by non-commercial fishermen. The recreational catches of invertebrates have never been assessed for the area as a whole. These three segments of the fisheries of the Middle Atlantic Estuarine Area have been taking about 2.9 billion pounds of fish and shellfish annually, and perhaps more.

This essay reviews briefly the status of the commercial fisheries of the Middle Atlantic Estuarine Area in 1969, when the report pursuant to the requirements of Public Law 89-753 was completed ("National Estuarine Pollution Study"), and makes a comparison with the situation five years later, in 1974. The comparison considers what has happened in the interim, what improvements and adverse developments have been noted, what important issues need attention, what the future may bring, and what are the chances for improved management of the resource. Particular attention has been given to the effects of estuarine pollution, as directed by Public Law 92-500, section 104(n), but it has not been possible to ignore other sources of variation in condition of the commercial fishery resources. This has required, among other things, brief attention to the saltwater sport fisheries, which are properly the subject of another chapter in this volume. Assuming that other sources of attrition are, or will be, under control, continued productivity of the coastal fisheries will still depend upon appropriate control of all forms of fishing.

THE RESOURCE

Coastal fishery resources can be subdivided usefully into several categories, based not only on their value to man and to the ecosystem, but also on their geographic distributions, migratory habits, and vulnerability to manmade environmental change. One such arrangement might be:

1) *endemic resources*, like oyster, hard clam, and perhaps some migratory species of limited scope, like blue crab, white perch, tautog, and some stocks of winter flounder (category Ee in Tables 1 and 3);

2) *migratory coastal species* that do not move offshore in significant numbers beyond national fishery jurisdiction, like menhaden, croaker, and weakfish (Em);

3) *anadromous and catadromous species*, which spawn in fresh water but spend most of their lives at sea, or vice versa, like American shad, alewife, striped bass, and American eel (A);

4) *living resources of the continental shelf*, which at the harvestable stage either are immobile on or under the sea bed or are unable to move except in constant physical contact with the sea bed or the subsoil, like surf clam or rock crab (S);[2] and

5) *highly migratory resources* that move seasonally not only north and south, but also inshore-offshore between estuarine waters proper and the outer continental shelf, like red and silver hakes, summer flounder, scup, and butterfish (Om). A sixth category in this arrangement might be made up of truly oceanic species, like tunas and the great whales, which penetrate waters of the inshore estuary seldom, if at all (O).

Most of these living resources are subject to manmade stresses in the inshore estuarine environment, some throughout life, others at important stages. Assessment and control of the effects of water pollution, engineering works, and other human environmental influences, including fishing, upon the living resources is extremely difficult because at least four other major complicating forces may be operating at the same time: 1) natural variations in environmental quality, sometimes subtle, like changes in water temperature or salinity—sometimes catastrophic, like the effects of hurricane winds or heavy rains; 2) self-generated (endogenous) oscillations within individual stocks; 3) complicated and major effects of fishing operations; and 4) opinions, emotions, and political pressures generated by the effects of natural and manmade phenomena indiscriminately, which influence the regulatory process

Status of the Resource in 1969

Judged by the total weight of fish and shellfish landed in the Middle Atlantic Estuarine Area in 1969 as compared with the past, the domestic commercial fisheries of the area had never been in worse condition. Total weight of landings was at an all-time low in recorded history, less than 37 percent of

[2] American lobster has been declared by the United States Congress a creature of the shelf, but it does not fit the definition.

the 1956 high of 1.59 billion pounds. But for most of the period up to 1956 and for some years after, industrial fish and shellfish (used for purposes other than human food) had dominated the catch, thus trends in total landings reflect principally the fortunes of the industrial fisheries, harvesting mostly menhaden for manufacture of oil and meal. When edible species are considered separately, the peak in landings came about 1930. By 1969 landings of food fish and shellfish, all species combined, in the area had been dropping fairly steadily for about 40 years.

The 1930 maximum in production of edible fish and shellfish came shortly after it was discovered that many of the resources which migrate into Middle Atlantic estuaries in spring and summer move outward to the edge of the continental shelf and southward in late fall and winter. A winter trawl fishery rapidly developed offshore to take advantage of this discovery. Major disturbances in the long-term trend since 1930 came when prices and landings dropped sharply during the economic depression of the early 1930s, rose sharply toward the end of the second world war when acute shortages of red meat at home and abroad increased the demand for protein from the sea, and fell again in the 1950s. In 1968 total weight of edible fish and shellfish landed in the Middle Atlantic Estuarine Area was lower than in any year on record except 1933, when the full force of the depression had hit the fisheries, with adverse effects on demand and prices. Total landings of edible fish and shellfish were only moderately higher in 1969 than in the low year 1968.

Table 1.—Major species in domestic commercial fishery landings in the Middle Atlantic Estuarine Area 1969–1973 (Rhode Island to Delaware inclusive). Weights in millions of pounds. Shells of molluscan shellfish not included. Species with total annual catch 50,000 pounds or less not included. Symbols: Ee = estuarine endemic; Em = estuarine migratory; A = anadromous or catadromous; S = creatures of the continental shelf; Om = oceanic migratory, usually moving between international and territorial waters; O = truly oceanic

Species		1969	1970	1971	1972	1973	1972–73 as % of 1969–70
Menhaden	Em	43 8	40.6	80.4	158.3	172.5	392
Surf clam	S	42.2	52.6	40.3	32.7	31.6	68
Yellowtail flounder	Om	13 5	15.4	20.8	28.0	25.1	184
Hard clam	Ee	11.4	11.9	12.5	12.1	10.2	96
Silver hake	Om	8.9	8 0	8.2	10.9	11.5	133
American lobster	Om	8.0	9.3	9.0	6.3	5.4	68
Scup	Om	7.4	7.4	6.2	7.4	9.4	114
Winter flounder	Om	7.2	8.1	8 1	6.6	6.6	86
Butterfish	Om	3.6	2.2	2.7	1.2	3.0	72
Atlantic cod	Om	3 4	3.8	3.1	2.7	3.4	85
Squids	Om	2.3	1.4	1.3	1.9	2.8	127
Summer flounder	Om	2.2	3.2	3 2	3.2	5.6	170
Bluefish	Om	2.0	3.1	2.5	2.2	2 7	96
Weakfish	Om	2.0	2 4	4.8	5.6	4.3	225
Striped bass	A	1.9	1.7	1.6	1.7	3.6	147
Atlantic mackerel	Om	1.4	2.3	1.7	2.8	2.8	151
American oyster	Ee	1.4	1.5	2.1	3.4	3.3	231
Red hake	Om	1.2	1.6	1.3	1.6	1.9	125
Blue crab	Em	1.1	1.2	2.2	4.0	5.0	391
Sea scallop	Om	0.9	0.7	0.5	0.5	0.6	69
Conch	Ee	0.6	0.5	0.5	0.5	0 4	82
American shad	A	0.5	0.5	0.5	0.6	0.5	110
American eel	A	0.5	0.5	0.4	0.5	0.6	110
Black sea bass	Om	0.5	0.4	0.4	0.6	0.9	167
Tilefish	O	0.1	0.1	0.1	0.3	0.8	550
Bluefin tuna	Om	0.1	3.1	2.0	2.2	1.3	109
Sea mussels	Ee	0.2	0.2	0.3	0.5	0.7	300
Subtotals		168 3	183.7	216.7	298.3	316.5	175
Grand totals		231.9	224.2	253.5	326.0	379.7	155

RHODE ISLAND-DELAWARE SUBAREA

Major species by weight in 1969 landings in this subarea are listed in Table 1. Surf clam dominated the edible catch, accounting for 35.6 percent by weight of all food fish and shellfish. Next in order were yellowtail flounder, hard clam, American lobster, scup, and winter flounder. Together, these six species made up nearly 82 percent of the total weight of edible fish and shellfish.

By landed value (Table 2) hard clam dominated the edible catch (nearly 29 percent of the total), followed in decreasing total landed value by lobster, surf clam, and oyster. The first four species by landed value were shellfish, and they made up 68 percent of the total landed value including industrial species. Major edible finfish species by landed value were scup, yellowtail flounder, summer and winter flounders, striped bass, and butterfish. The 10 leading species by landed value, including shellfish and industrial species, produced a gross income to domestic commercial fishermen of over $30 million, nearly 86 percent of the landed value of the entire domestic commercial catch from this subarea, in 1969. This probably represents a retail value of $100 million or more.

Although landings in Rhode Island to Delaware in 1969 were almost the lowest on record, they might have been even lower if commercial fishermen had not constantly shifted to new resources as the supply of traditional resources declined. Outstanding examples of such declines were menhaden landings, which fell from a maximum of over one billion pounds in 1956 to a 1966 low of only 22 million pounds. By 1969 the menhaden catch in the subarea had increased to about 46 million pounds. The American oyster, which was reported to have produced a maximum of about 60 million pounds of meats in the early part of the 20th century dropped from about 35 million pounds in 1929 to a low of one million in 1965, and in 1969 had recovered only slightly to about 1.4 million pounds of meats. Scup was the dominant food finfish for almost two decades, reach-

Table 2.—Major species in domestic commercial fishery landings in the Middle Atlantic Estuarine Area 1969–1973 (Rhode Island to Delaware inclusive). Landed values (price paid to fishermen) in millions of dollars, not adjusted to standard dollars. * = $50,000 or less

Species	1969	1970	1971	1972	1973
Hard clam	10.3	11.5	13.5	16.0	13.9
American lobster	7.4	9.5	10.2	8.7	8.5
Surf clam	5.0	6.1	5.4	4.2	3.9
American oyster	1.5	2.0	2.8	4.4	5.1
Scup	1.5	1.8	1.7	1.7	2.7
Yellowtail flounder	1.4	1.7	2.1	3.7	4.4
Sea scallop	1.0	0.9	0.8	1.0	1.1
Menhaden	0.8	0.7	0.3	2.5	4.3
Summer flounder	0.8	1.2	1.2	1.3	2.3
Silver hake	0.7	0.8	0.7	0.9	1.4
Winter flounder	0.7	0.9	1.0	1.1	1.2
Striped bass	0.5	0.4	0.5	0.6	1.2
Butterfish	0.5	0.4	0.5	0.3	0.7
Bay scallop	0.4	0.5	0.3	0.2	0.5
Atlantic cod	0.3	0.4	0.4	0.5	0.6
Bluefish	0.3	0.3	0.3	0.3	0.3
Squids	0.2	0.2	0.2	0.3	0.6
Black sea bass	0.2	0.2	0.2	0.2	0.4
Blue crab	0.1	0.2	0.4	1.0	1.3
Weakfish	0.1	0.2	0.5	0.7	0.7
Conch	0.1	0.1	0.1	0.1	0.2
Soft clam	0.1	0.1	0.1	0.2	0.2
American eel	0.1	0.1	0.1	0.1	0.1
Atlantic mackerel	0.1	0.1	0.1	0.2	0.2
American shad	0.1	0.1	0.1	0.1	0.1
Red hake	0.1	0.1	0.1	0.1	0.1
White perch	*	0.1	*	0.1	0.1
Subtotals	34.3	40.6	43.6	50.4	56.1
Grand totals	35.6	42.5	46.7	53.0	58.6

ing a maximum of over 34 million pounds in 1960 and a minimum of 6.2 million in 1971. Landings of scup in 1969 were near this minimum, at about 7.4 million pounds. Several other species, like weakfish, had produced relatively large catches earlier and had fallen to minima in or about 1969.

To balance these substantial declines commercial fishermen turned to other species, notably surf clam. This fishery was negligible prior to the mid-1940s, but began to grow in 1945 off Long Island, N.Y. Landings from waters off Long Island reached a peak quickly and the center of operations shifted to the New Jersey coast. By 1968 and 1969 landings in New Jersey had declined slightly from a peak of over 43 million pounds of meats in 1966, and the fishery had just begun to shift to beds off the Delaware and Maryland coasts. The history of this fishery has been one of heavy exploitation of known clam stocks, entry of more capital and labor, substantial reduction of the stocks, exploration for unexploited segments of the resource, and a constant shifting toward the south. The surf clam industry provides an excellent case history of what happens to a living resource when harvesting is essentially unregulated.

CHESAPEAKE SUBAREA

Total domestic commercial landings in the Chesapeake Bay states in 1969 were lower than they had been since 1953. As in the area to the north, industrial fisheries have dominated the catch, but the 1969 catch was not an all-time low, as it was from Delaware to Rhode Island. The smallest reported total weight of landings in the Chesapeake subarea was in 1942, at just over 200 million pounds, and the trend has been upward ever since.

Landings of edible fish and shellfish in the Chesapeake area reached a peak by weight in 1930, as they did farther north, then declined, but reached even higher levels in the middle 1940s, with a maximum of about 205 million pounds. An unusual abundance of croaker and weakfish, coupled with high demand for food fish during the war and immediately after, were largely responsible for this second peak. Blue crab, alewife, and oyster dominated the edible catch in the Chesapeake subarea in 1969, accounting for about 67 percent by weight of all edible fishery products. Next in order by weight were soft clam, striped bass, surf clam, northern puffer, American shad, scup, hard clam, and white perch (Table 3).

Together, these 11 major species made up over 90 percent of total edible landings. By landed value (Table 4) the first five species were shellfish, accounting for nearly 83 percent of all edible species by value.

A steady shift from one resource to another, already noted in landings in the Rhode Island–Delaware subarea, was characteristic of the Chesapeake subarea also. Catches of the following species declined substantially prior to 1969: Atlantic croaker, down from a maximum of 57.7 million pounds in 1945 to a low of about six thousand pounds in 1968; scup down from a peak of 13.5 million pounds in 1960 to about 2.5 million in 1968; sea bass from a maximum of 10.1 million pounds in 1952 to about 1.9 million in 1969; weakfish from a 1945 peak of 24.7 million pounds to a low of 0.7 million in 1967; and American oyster from over 100 million pounds of meats before the turn of the century to a record low of 18.3 million in 1963. Countervailing upward trends occurred in landings of other species: menhaden from a low of about 64 million pounds in 1942 to record highs in the late 1950s and early 1960s, then a decline to about 180 million in 1969; striped bass, an upward trend since 1934, when the catch was only 0.6 million pounds, to a maximum of 7.8 million in 1969; blue crab from a low of 30.2 million pounds in 1942 to a high of 94 million in 1966; and soft clam from insignificant catches prior to the second world war to a peak of over 8 million pounds of meats in 1964.

Table 3.—Major species in domestic commercial fishery landings in the Middle Atlantic Estuarine Area 1969–1973 (Chesapeake Bay). Details as in Table 1. * = 50,000 pounds or less

Species		1969	1970	1971	1972	1973	1972–73 as % of 1969–70
Menhaden	Em	181.6	449.8	400.1	555.6	503.9	168
Blue crab	Em	60.9	69.8	76.1	74.5	56.1	100
Alewife	A	33.9	21.1	13.1	12.1	11.3	43
American oyster	Ee	22.2	24.7	25.6	24.1	23.9	102
Soft clam	Ee	7.9	6.2	6.0	1.9	0.6	18
Striped bass	A	7.8	5.8	4.0	5.8	7.4	97
Surf clam	S	7.3	14.6	12.3	30.7	50.8	372
Northern puffer	Ee	4.6	1.5	0.6	0.1	*	3
American shad	A	3.5	5.1	2.5	3.0	3.0	70
Scup	Om	2.9	2.1	1.9	1.3	0.8	42
Hard clam	Ee	2.7	1.8	2.2	1.5	1.4	64
White perch	Ee	2.7	1.9	2.0	1.4	1.0	52
Black sea bass	Om	1.9	1.7	0.8	1.0	1.5	69
Summer flounder	Om	1.7	2.5	2.0	2.1	3.7	138
Catfish and bullheads	Ee	1.6	1.3	1.8	1.9	1.5	117
Sea scallop	O	1.4	0.7	0.5	1.0	0.8	86
Spot	Ee	1.1	6.4	0.5	3.0	2.6	75
American eel	A	1.1	1.5	1.5	0.7	0.4	42
Butterfish	Om	1.1	1.6	0.7	0.3	0.2	19
Weakfish	Om	1.0	2.5	2.7	2.9	5.6	243
Winter flounder	Om	0.5	0.1	0.1	*	*	17
Squids	Om	0.4	0.4	0.4	0.3	0.2	62
Bluefish	Om	0.3	0.7	0.8	1.3	3.1	440
Conch	Ee	0.3	0.4	0.1	0.3	0.4	100
Carp	Ee	0.3	0.2	0.2	0.2	0.2	80
Atlantic mackerel	O	0.3	0.3	0.1	0.1	*	25
American lobster	Om	0.2	0.2	0.3	0.9	0.2	275
Sharks	Om	0.2	0.1	0.1	0.1	0.1	67
Atlantic croaker	Om	0.1	0.1	0.3	0.5	1.4	950
Spanish mackerel	Om	0.1	0.2	0.1	*	*	33
Black drum	Em	0.1	0.1	0.1	*	*	50
Yellow perch	Ee	0.1	0.1	0.1	0.1	*	75
Silver hake	Om	0.1	0.1	0.1	*	*	50
Hickory shad	A	0.1	0.1	*	0.1	0.1	100
Atlantic herring	Om	0.1	*	2.5	0.7	0.4	------
Sea robins	Om	0.1	*	0	0	*	--------
King whiting	Om	*	0.1	*	*	*	--------
Spotted sea trout	Om	*	0.1	*	*	*	--------
Harvestfish	Om	*	*	0.1	0.1	0.2	--------
Gizzard shad	Ee	*	*	0.1	0.1	0.1	--------
Subtotals		351.1	625.9	562.4	729.7	682.9	145
Grand totals		354.1	630.4	578.4	735.1	694.6	145

Table 4.—Major species in domestic commercial fishery landings in the Middle Atlantic Estuarine Area 1969–1973 (Chesapeake Bay). Landed values (price paid to fishermen in millions of dollars, not adjusted to standard dollars). * = $50,000 or less

Species	1969	1970	1971	1972	1973
American oyster	14.0	15.1	16.0	15.2	15.9
Blue crab	7.0	5.5	7.2	7.4	7.7
Menhaden	2.8	7.6	6.5	9.3	20.6
Soft clam	2.8	2.4	3.0	1.0	0.5
Hard clam	1.7	1.1	1.6	1.2	1.3
Sea scallop	1.5	1.0	0.8	1.9	1.3
Striped bass	1.4	1.2	1.1	1.5	2.2
Surf clam	0.9	1.6	1.5	3.7	5.9
Alewife	0.7	0.4	0.3	0.3	0.3
Summer flounder	0.5	0.7	0.6	0.7	1.0
White perch	0.4	0.3	0.3	0.2	0.2
Scup	0.4	0.4	0.2	0.2	0.2
Black sea bass	0.3	0.4	0.2	0.2	0.4
American shad	0.3	0.4	0.3	0.3	0.5
Catfish and bullheads	0.2	0.2	0.2	0.3	0.3
American eel	0.2	0.3	0.4	0.2	0.1
Northern puffer	0.2	0.1	*	*	*
American lobster	0.1	0.2	0.2	1.1	0.3
Weakfish	0.1	0.3	0.3	0.3	0.7
Butterfish	0.1	0.2	0.1	0.1	*
Spot	*	0.6	0.1	0.3	0.4
Conch	*	0.1	*	*	0.1
Bluefish	*	0.1	0.1	0.1	0.2
Atlantic croaker	*	*	*	0.1	0.2
Subtotals	35.6	40.2	41.0	45.6	60.3
Grand totals	36.1	40.5	41.5	45.9	60.7

Status of the Resource in 1974

The record for 1973 must serve as an index of the condition of the fisheries of the Middle Atlantic Estuarine area in 1974, because complete statistics for 1974 were not available at the time of writing. Where appropriate, incomplete statistics (by months or reports in the literature can be used to extend the analysis into 1974. In the area as a whole since 1969 total landings have almost doubled (Tables 1 and 3), from about 585 million to 1,054 million pounds. Most of this increase has come about through a substantial increase in menhaden landings, which in 1973 were three times the 1969 catch. The remainder of the increase was made up of substantial growth in catches of surf clam, yellowtail flounder, weakfish, summer flounder, oyster, bluefish, and some other species like croaker and tilefish for which the increase in pounds was relatively small but the percentage increase was large. Landings of Atlantic croaker, for example, were 14 times as large in 1973 as in 1969, and according to a recent report young croaker are exceedingly abundant in Chesapeake Bay in 1974, which suggests that catches will continue to increase. The relatively large increase in tilefish landings was caused by recent development of a specialized fishery out of New Jersey. These substantial increases were partially offset by decreased landings of other resources. Included in this group were alewife, soft clam, northern puffer, American lobster, hard clam and a few others. No substantial increases in domestic fishing effort or techniques have occurred in the 5-year period, except perhaps for menhaden. This knowledge, and other lines of evidence e.g. increased recreational catches and personal observations, can be taken as strongly supporting the view that there has been a real increase in abundance of some species of the estuaries and a real decrease in others. For species like alewife the decline in domestic landings was balanced by increased foreign catches.

RHODE ISLAND–DELAWARE SUBAREA

Landings in this subarea increased by about 55 percent from 1969 to 1973 (Table 1). Menhaden landings increased nearly fourfold and fairly large gains were recorded also for yellowtail flounder, blue crab, summer flounder, silver hake, weakfish, scup, oyster, and striped bass. These increases were partially offset by declines in landings of surf clam, American lobster, and a few other species. The decline in lobster catches may have been a result of decreasing fishing effort.

CHESAPEAKE SUBAREA

Domestic commercial fishery landings in this subarea almost doubled from 1969 to 1973. The major increase here was also in menhaden landings, which almost tripled in this subarea. The increase in total landings had been even greater in 1972, from about 354 million pounds in 1969 to about 735 million, more than doubling the 1969 catch. Food fish and shellfish landings were moderately higher in the Chesapeake subarea in 1973 than in 1969, largely because surf clam production rose by more than 43 million pounds of meats, almost a sevenfold increase. But this substantial increase was partially offset by a major drop in alewife catches, catastrophic declines in production of soft clam and northern puffer, and moderate drops in catches of several other species (Table 3).

PROBABLE CAUSES OF CHANGES

Most living resources of the coastal zone fluctuate widely in abundance from natural causes. Natural changes in environmental conditions at critical stages in the life history obviously affect survival and future abundance, but our understanding of cause and effect is very poor and probably always will be. When the fortunes of the fisheries are viewed against this background of natural change it is difficult to determine the relative contributions of fishing, water pollution and other manmade effects, and natural environmental variations. The effects of fishing can be measured if accurate information is available on catches and amount of fishing effort over a reasonably long period of time. But similar information on most other manmade effects, and on naturally-caused changes in abundance, is not available. Thus, conclusions about the causes of changing abundance of living resources are likely to be largely intuitive.

To assess the reasons for the changes observed between 1969 and 1973 in commercial fishery landings in the Middle Atlantic Estuarine Area it is helpful to retreat to the narrower and more commonly used definition of an estuary: 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 derived by land drainage. It is in such bodies of coastal water that effects of human activities are most pronounced. This includes Long Island and Block Island Sounds, Greater Raritan Bay (inside a line joining Rockaway Point and Sandy Hook), Delaware Bay, Chesapeake Bay, and all estuaries and bays lying inside the fringe of barrier beaches along the south shore of Long Island and the ocean coasts of New Jersey, Delaware, Maryland, and Virginia. Because it has been a major waste disposal site for many years, the apex of New York Bight is also included, although it does not fit the conventional definition.

This separation of estuarine and shelf waters eliminates some major living resources in Tables 1 to 4 from consideration insofar as strictly estuarine processes are concerned. These resources are: surf clam, yellowtail flounder, cod, haddock, Atlantic mackerel, sea scallop, tilefish, bluefin tuna, and probably a part of the lobster resource. It is assumed for the purposes of this study that these essentially oceanic species, and perhaps some others which do not reside in coastal waters close to shore for any great length of time, are not presently affected significantly in abundance by human alteration of the estuarine environment. However, it must be remembered that large oceanic fishes like tunas and billfishes have been shown to accumulate relatively large residues of heavy metals and other contaminants which may have come from estuarine sources via the food web. Changes in abundance of these species must be assumed to be caused by natural environmental changes, or by the effects of fishing, or both. This leaves about 25 species, more or less, depending upon how one defines importance to the domestic commercial and recreational fisheries, about which we should be particularly concerned with respect to the effects of manmade environmental modification. These resources have been identified by code letters in Tables 1 and 3.

Species Which Have Produced Major Changes in Landings 1969–74

Of this group of about 25, nine have shown considerable increases in landings in the area as a whole, and these increases are almost certainly associated with real increases in abundance, for reasons already given. Another eight, or perhaps nine, have shown considerable declines in landings, some of which have been associated with real decreases in abundance. Two additional species have produced major increases in landings in the Rhode Island–Delaware subarea only, and another three have declined only in the Chesapeake subarea. Before discussing specific environmental alterations which may have been responsible it is helpful to examine briefly most of these species to find out whether it is possible to identify all or some of the reasons for the major increases and declines.

American Oyster

The oyster industry of the area now produces much less than it once did, but this still is the most important oystering area in the nation. In the late 1950s and early 1960s one calamity after another hit the industry, first a massive invasion of sea stars in Long Island Sound, then specific diseases of oysters in Delaware Bay and later in Virginia. It is not known whether reduced water quality was a factor in these epizootics, but it is possible that the new stresses exerted on the resource by manmade environmental changes may have made the oyster more susceptible. These outbreaks almost destroyed the industry in all major producing areas from New York to Chesapeake Bay except in Maryland. The relatively low-salinity waters of the northern part of Chesapeake Bay are particularly favorable for oyster growing, and a massive rehabilitation program, consisting mainly of replanting shell and transplanting live oysters, by the State of Maryland on public oyster grounds has more than doubled production there since the low year 1963. This has demonstrated that oyster production can be increased if governments are willing to spend the time and money to do so. Whether this has contributed any increased revenue to the local economy apparently has not been demonstrated.

In the New York and Chesapeake areas some success has been attained at raising seed oysters in hatcheries. At this stage, however, opinion is divided as to whether this is an economically sound method of resolving the problem of highly variable natural seed production. In the other Middle Atlantic states private enterprise, sometimes with help from the states, has been improving oyster production slowly. In the area as a whole landings have increased about 15 percent from 1969 to 1973. In Maryland the increase has been more than 19 percent in the 5-year period, but this and the modest gains in other states have been partially off-set by a drop in Virginia oyster production.

Much of the blame for the long-term decline in oyster production has been attributed to careless oystering practices, but water pollution also has hurt the industry by forcing closure of more and more areas for public health reasons, and by adversely affecting survival of larvae and young. But aside from setbacks by severe storms, and severe outbreaks of predation or disease, industry and government probably will be able to continue improving the volume of oyster production to satisfy existing demand.

Hard Clam

Hard clam is harvested in all states in the Middle Atlantic Estuarine area. but New York now is by far the largest producer. Most of this production comes from Great South Bay on Long Island. From 1929 to 1957 Rhode Island and New York vied for first place in volume of hard clam landed, but since 1957 landings have been rising in New York and falling in Rhode Island. The decline in Rhode Island probably has been caused by over-harvesting, but the rise in New York landings almost certainly has represented a large increase in abundance in Great South Bay over the past 15 years. In both states the industry has been plagued by water pollution, which has led to progressive closing of productive clam beds, especially on Long Island, where the human population is growing more rapidly than in any other area of the United States. Large areas of clam bottom are closed or restricted along the New Jersey coast, as in other states of the area. Where clam digging is permitted the harvest is intense because demand is good and prices high.

Many experienced baymen believe the available resource is being overharvested. That conclusion is hard to escape with respect to the Rhode Island hard clam industry, which now produces only about 20 percent of the catch of 20 years ago. The harvest in New York reached a peak in the period 1969 to 1973 and this is reflected in the record of landings for the subregion (Table 1). Clam diggers in Great South Bay report that they now must work harder to make the same catch. Clam fisheries in the area generally are subject to a negative form of management, in which water quality is checked frequently and grounds are closed to harvesting when coliform bacteria numbers exceed minimum values. This is important, but is not likely to maintain yields of clam resources when the total catch needs to be controlled also. The towns that have jurisdiction over clam beds in Great South Bay, especially the town of Islip, are now beginning to develop model research and management programs based on improved law enforcement, better understanding of the dynamics of the resource, and transplantation from polluted to clean areas. They deserve to be encouraged and supported adequately.

SOFT CLAM

The soft clam industry of the area developed in Maryland waters in the 1950s to supply markets that could no longer be satisfied by a declining catch in New England. The abrupt decline in landings from 1971 to 1972 and 1973 (Table 3) was caused by the effects of tropical storm Agnes, in June 1972, which brought down such a load of contaminants from land drainage after heavy rains that the State of Maryland found it necessary to prohibit harvesting in the interest of public health. Before water quality had recovered to safe levels, low salinities and high water temperatures had killed most soft clams in commercial clamming areas. Restrictions were placed on the catch in 1972 and 1973 because it was feared that the sharply-reduced resource could not withstand an intense fishery. It was expected that landings would be considerably better in 1974, and monthly statistics received to date have borne this out.

WHITE PERCH

This species also is most abundant in the Chesapeake segment of the area. Commercial landings in Chesapeake Bay have dropped to almost one-third of the 1969 level, but this may not have been a consequence of declining abundance. White perch is taken in large quantities by sport fishermen in the area, especially from New Jersey south, and the estimated recreational catch is much larger than the commercial catch. White perch is endemic to the inshore estuary, and in Maryland waters of Chesapeake Bay it is considered to be underexploited. The decline of the commercial fishery there probably has been caused by overcrowding and slow growth, which has affected prices. In Virginia, on the other hand, the species is believed to have been affected adversely by water pollution, especially in the James River.

NORTHERN PUFFER

The major fishery for puffer in the area also has been in Chesapeake Bay. Peak landings were reached in 1965, and landings have been erratic and generally downward since that time. The initial decline was caused by excessive catches in 1965, and in 1966 a considerable supply of puffer was held over in cold storage from the previous year. The species is notably variable in abundance, apparently from wide variation in success of spawning, which is especially evident in short-lived species; but, as with other species, the causes of fluctuation are not known. Commercial landings dropped from 4.6 million pounds to less than 50,000 from 1969 to 1973 (Table 3). Considerable numbers are taken by sport fishermen in the area as a whole, and the recreational catch has dropped sharply in New York and New Jersey as well as in Chesapeake Bay.

SPOT

This is a fish of estuaries and inshore coastal waters. It was once fairly important along the western end of Long Island and the New Jersey coast, but commercial catches have been relatively minor since the middle 1940s. The reason for the decline is not known. Spot is a short-lived fish, and wide variations in success of spawning are reflected in catches almost immediately. The increase of about 1.5 million pounds in the commercial catch from 1969 to 1973 probably merely reflects such variations, for the 1970 catch was much higher (Table 3).

BLUE CRAB

The blue crab fishery has been centered in Chesapeake Bay, and landings to the north have historically been much smaller. Abundance and catches have varied widely in the Chesapeake, but the long-term trend in landings has been upward since the 1930s, although the peak catch of about 97 million pounds in 1966 has not been exceeded. From Delaware north the maximum catch was 6.6 million pounds in 1950, and fluctuations have been relatively much wider north of Chesapeake Bay. The northern fishery declined after about 1957 and in New York no commercial catch has been reported since 1961. In the 1970s blue crab began to increase in abundance in bays along the south shore of Long Island, and although commercial fishing has not resumed in New York, recreational catches of blue crab are reported to have been substantial. Similar increases have occurred in New Jersey and Delaware also. The increased commercial catches in those states are shown in Table 1.

It has been speculated that recovery of the resource in New York has been caused by the ban on use of DDT and other chlorinated hydrocarbons for mosquito control. Suffolk County, New York, was reputed at one time to have the most massive spraying program in the country. Partial recovery of the fishery in New Jersey and Delaware also might have had the same cause, but there is no proof that this was so in any state. Whatever the cause, landings by commercial and recreational fishermen north of Chesapeake Bay have certainly increased substantially, and the reported commercial catch has now recovered to about 76 percent of the all-time high. Because the recreational catch probably is much larger now, the condition of the resource probably is better than indicated by commercial landings alone.

ATLANTIC MENHADEN

The 5-year increase in landings of menhaden north of Chesapeake Bay was substantial, but 1973 landings were still far short of the maximum reached in 1956. In the Chesapeake subarea, however, menhaden landings in 1972 were the highest on record, in 1973 second highest. The 1970 Chesapeake catch was the third best year on record and 1971 the sixth. The intense fishery in the Chesapeake subarea now takes mostly 1-and-2-year-old immature fish, and allows relatively few to survive long enough to migrate farther north. The increased catch to the north may have been related to greater abundance in the south, or survival from local spawning may have been better because competition from migrating southern menhaden had been largely eliminated for a while. That the menhaden resource has been able to produce bumper crops despite the very heavy drain on the stock by commercial fishing is reasonably good circumstantial evidence that levels of water pollution in the area and other manmade environmental changes have not been great enough to affect the menhaden resource. If water pollution or other human influences have affected the resource in the past, it could be assumed that conditions have improved recently as far as menhaden is concerned. Virtually nothing is known about the environmental variables that control the size of the menhaden stock. It is difficult to understand how this resource has been able to survive such a heavy fishery, and indeed produce such large catches after it appeared that the stocks of menhaden had been seriously overfished. It has been noted by several workers that just before a fish stock collapses it may produce one or more very large year classes. No explanation has been advanced, except speculation that in some way the internal regulatory mechanisms of the stock break down. Thus, the recent large catches of menhaden in the area may be more a matter for concern than for optimism. Events in the fishery in the last five years illustrate as well as any case history of a fishery how poor is our capability to explain and predict what is happening. Among other things it also demonstrates why it is so difficult to assess the effects of a specific pollutant, or even of water pollution generally. If pollution control is able to prevent further deterioration of the estuarine environment; or even better, if estuarine pollution can be reduced; the inevitable decline of the menhaden fisheries of the area, when it comes, will most likely be caused by overfishing, abetted by the effects of natural environmental changes. A decline is assumed to be inevitable if the present high demand for the product continues, and the fishery remains essentially unregulated.

STRIPED BASS

Abundance and catches of striped bass in the area have been following an upward trend for some 40 years, although the Chesapeake catch appears to have leveled out for the past decade. This trend shows in commercial and recreational landings, and there is no good reason to doubt that abundance has increased substantially, although the evidence is circumstantial, as it is for most of the species under discussion. This upward trend may not be evident to the short-term observer, and it is not clearly evident in the period 1969 to 1973 (Tables 1 and 3), because the trend is superimposed upon a background of wide variations in spawning success which have caused large short-term fluctuations in abundance. Thus, in any period of a few years landings are about as likely to be dropping as they are to be rising.

The long-term trend in commercial landings can be recognized clearly in the progression of highs and lows. Since 1930 each major high in commercial landings in the area as a whole has been higher than the previous one, and each low also has been successively higher. It is very unlikely that this increasing commercial harvest reflects only an increase in fishing effort, for striped bass historically has been a popular food fish. Sport catches also have been trending upward, although a part of this increase must have been associated with the demonstrated increase in sport fishing effort.

It has been suggested that, because they spend the first two years of their lives in the estuaries, striped bass have been able to take advantage of the increased nutrient supply contributed by domestic wastes. This is only an hypothesis, which cannot be confirmed by existing evidence that links cause and effect. Nevertheless, it seems that striped bass has so far been able to cope successfully with human alterations of the environment, as well as with continued intensive fishing.

This is not cause for complacency, however, for it is not known for certain why striped bass apparently has been increasing in abundance for more than a quarter-century, nor even why, along with this trend, abundance has fluctuated so widely in the short run. It explains nothing to say that such fluctuations are to be expected in resources which live in a rich but highly variable and sometimes hostile environment, although a more rational approach toward fishery management might be possible if this fact of variation were more clearly recognized. It would be a matter of concern, of course, if the magnitude of such fluctuations were to increase. Nor is it cause for complacency, even if proof were available that added nutrients had favored striped bass abundance, for the process is likely to be reversible if the nutrient supply continues to increase.

ALEWIFE

Of all species which have declined in commercial landings in the area since 1969, alewife landings have dropped most sharply. In the Middle Atlantic Estuarine Area the species is important commercially only in Chesapeake Bay. Recently, from 80 to 90 percent of the catch is landed in Virginia. Chesapeake landings of alewife dropped from about 34 million pounds in 1969 to slightly more than 11 million in 1973, largely because large quantities have been taken by foreign fleets offshore. As a consequence, the United States, by negotiating bilateral agreements with some nations, has imposed strict quotas on some catches. There is no evidence that manmade environmental changes other than fishing have affected the resource in this area, but anadromous species like alewife are especially vulnerable to estuarine water pollution.

AMERICAN SHAD

The decline in landings of shad in the area, especially north of Chesapeake Bay, does not necessarily signify a decline in abundance of the species. It is known that economic factors rather than a scarcity of fish have been the primary cause of the recent decline of the Hudson River shad fishery. Modern transportation and preservation facilities have made it easier to ship shad from early runs to southern rivers for marketing in New York at high prices. By the time shad runs begin in the Hudson River local demand has been sated because shad traditionally has been a short-term seasonal delicacy, which forces the price too low for profitable fishing. Actually, it is reported that water quality in the Hudson River has improved in most areas, and off-flavors of shad are less prevalent now. Like other anadromous species, shad always will be vulnerable to environmental deterioration. Foreign catches of shad have not been reported.

MIGRATORY COASTAL FOOD FISHES

Several once important food fishes have made encouraging recoveries in abundance in the period since 1969, although commercial landings of these species are still far below historic maximum levels. Included are scup, weakfish, bluefish, summer flounder, and Atlantic croaker. All five are important recreational species as well, and the saltwater sport fisheries have benefited particularly from this partial recovery. The magnitude of the recovery probably was greater than commercial landings suggest, because although statistics are not available on recreational catches of these species in the area except for 1970, it is demonstrated that the popularity of saltwater sport fishing has been increasing. It must be recognized that increased commercial or recreational landings do not by themselves demonstrate an increase in abundance, for increased catches may simply signify greater fishing effort or improved availability of fish to fishermen for some reason. Assumption beyond reasonable doubt that these species, and some others, have truly increased in abundance comes from personal experience, conversations with scientists and fishermen, and innumerable reports in trade magazines and sport fishermen's publications. Bluefish apparently have been particularly abundant recently, as demonstrated by large sport catches, and by unusual numbers taken by commercial and research trawlers offshore. Croaker have been appearing again off the coasts of Delaware and New Jersey, where they have been virtually absent for years. As mentioned already, recent reports suggest that croaker catches may increase dramatically in 1975 and subsequently.

Wide variations in abundance of all these species have been noted several times in the past. No one has identified the reasons for these fluctuations, and no one can predict what will happen in the future. The recent increase in weakfish abundance appears already to have been temporary, as might be expected from past experience. Weakfish appear to be scarcer in 1974. All spend important parts of their lives in the inshore estuary throughout the area, and it can be assumed that they are affected in various ways by what man does to the estuarine environment, but the extent of such effects is not known except when major kills of obvious origin occur. Two of the five, scup and summer flounder, are highly vulnerable to foreign fishing. All, however, are taken by domestic commercial and recreational fishermen at all seasons, in various places, and by various gears. Present laws and regulations, and the means to enforce them, are totally inadequate to manage these fisheries effectively, even if the necessary scientific knowledge were available. It is theoretically possible to regulate the harvest to maintain optimum yields, but it is questionable whether the necessary public cooperation and adequate funds will be available.

Silver Hake

Rather surprisingly, domestic commercial landings of this species have increased since 1969 in the area. For several years the International Commission for the Northwest Atlantic Fisheries (ICNAF) has been concerned about the stocks of silver hake and has placed quotas on the catch. The species is not abundant south of New Jersey, and commercial catches from the area are determined more by the market than by the supply of raw material. The increase of about 2.5 million pounds in area landings in the 5-year period cannot be interpreted necessarily as an indication of increased abundance. Demand for silver hake as human food is limited, and the price is highly sensitive to market conditions. The incentive to fish for this species varies accordingly. However, successful spawnings in 1971 and 1972 had led to predictions of increased catches later.

American Lobster

The lobster harvest south of Cape Cod has been growing for about a decade. This has been attributed to two developments, a southward shift of lobster stocks and increased abundance to the south in response to declining coastal water temperatures, and new fisheries on hitherto under-exploited lobster stocks in relatively deep water on the continental shelf. As with so many popular explanations based on observations of general environmental change, the drop in water temperature and the increase in lobster abundance were real, but the cause and effect hypothesis has not been proven. Many lobstermen think that the harvest has been too intense and that the resource has been overfished. This is quite likely, for in common with most other fisheries of the area, the states have many fishery laws and regulations, but there has been no control on the amount of fishing. Uncertainty about the catch of lobster by foreign fleets and by recreational fishermen further complicates the problem.

Others think that a reversal of the environmental trend that originally led to the growth of the fisheries south of Cape Cod is now responsible for declining catches. There is no evidence that manmade changes other than fishing have affected lobster abundance in the area. It is to be hoped that the relatively new federal-state lobster research and management program will help to answer these questions and prevent overharvesting of lobster. Whatever the cause, landings in the area by domestic commercial fishermen dropped from a reported 8.2 million to 5.6 million pounds from 1969 to 1973 (Tables 1 and 3).

Winter Flounder

This coastal species does not make extensive migrations, and it tends to be subdivided into local populations which do not intermingle freely. It has a history of wide fluctuations in abundance which appear to have been caused by natural environmental changes. Winter flounder is not very abundant south of New York. The decline in commercial landings since 1969 (Table 1) has no great significance in terms of abundance of the resource.

Butterfish

In the late 1960s butterfish was considered to be a very much underharvested species. Foreign fleets, especially those seeking squid, now are taking increasing quantities, and it is believed that the harvestable surplus is now being fully utilized. Under such circumstances it could be expected that domestic catches will be smaller than before, and this may explain the drop of about 1.5 million pounds in domestic commercial landings since 1969 (Tables 1 and 3). Possible effects of estuarine pollution cannot be ruled out, however.

Estuarine Pollution

Water pollution probably shares top place with uncontrolled fishing as the most serious threat to the economic well-being of the domestic commercial fisheries. The sessile endemic resources, like oyster, clams, and mussels, are particularly vulnerable because, once the free-swimming larvae have settled to the bottom, these resources are non-migratory. For practical purposes conch also falls in this category. Other estuarine endemic species can to some extent avoid gross pollution unless they become trapped for some reason. Little is known about sublethal effects, although there is evidence that they can be serious.

The most obvious damaging effects of estuarine pollution to living resources and to commercial and recreational fishing are the threats to human health caused by intake and retention of human pathogens by molluscan shellfish. The principal reason is that shellfish such as oyster and hard clam frequently are eaten raw. Many formerly productive shellfish grounds in Rhode Island, along the Connecticut shoreline, around the coast of Long Island, along ocean coasts from New Jersey to Virginia inclusive, and in Raritan, Delaware and Chesapeake Bays, are now closed to shellfishing, or are open only under special permit to take shellfish for further processing. The areas so restricted include substantial parts of coastal waters of the seven states in the Middle Atlantic Estuarine Area, and the total area closed is still increasing. The State of New York controls about 425,000 acres of shellfish bottom, of which about 100,000 acres are closed because water quality does not meet minimum standards. Thirteen percent of these waters were closed in 1973. This not only progressively reduces the area of bottom approved for shellfish harvesting and therefore the potential yield, but also increases the likelihood that consumption of shellfish taken illegally will cause outbreaks of hepatitis or other human disease. Such outbreaks not only are dangerous to public health, but also can have disastrous immediate and long-term effects on the economy of the industry through erosion of consumer confidence. Oysters and clams to be eaten raw bring the highest prices, so are harvested selectively. Thus, the economic threat to the industry is ever-present and very great. In the period 1969 to 1973 molluscan shellfisheries of the inshore estuaries of the Middle Atlantic Estuarine Area produced a harvest for which fishermen received more than $35 million a year, on the average, which was more than 38 percent of the landed value of all fish and shellfish caught commercially in the area.

In addition to these non-migratory resources, several other species remain within the inshore estuaries throughout their lives, and thus may be more vulnerable to water pollution than the highly migratory species which come and go. Blue crab is the most important of these, especially in Chesapeake Bay, where it is the most important edible species by weight and second most important in landed value. Among the highly migratory species, the anadromous fishes are especially vulnerable because the young are born in those parts of the estuaries most susceptible to pollution. Included are such valuable species as striped bass, alewife, and shad. Sublethal effects in the natural environment are extremely difficult to detect and their influence on the living resources difficult to evaluate. Thus, it should not be assumed that such effects are insignificant.

Mass mortalities of menhaden and other species sometimes occur in estuaries. Such mortalities in Chesapeake Bay often have been associated with a natural deficiency in dissolved oxygen content of the water in the central part of the bay and in the lower parts of the major rivers in that area, especially the Rappahannock, Potomac, and Patuxent. Domestic and industrial waste disposal has aggravated this natural condition by creating an additional oxygen demand. A similar condition, which has become more serious as the human population has grown, exists in summer in the western part of Long Island Sound. Interpretation of the effects of these man-made changes is very difficult for at least two reasons, both of which have been demonstrated dramatically in Chesapeake Bay in the 1969-1973 period. Hurricane Agnes in 1972 caused heavy mortality of molluscs, partly, but not entirely, from intensification of natural conditions. Unusually great abundance of certain species, such as menhaden, will per se increase the numbers of fish killed, and perhaps the frequency of kills, even if the environment has not changed. These interactions of natural and man-made forces make it extremely difficult to measure cause and effect, because we do not know specifically how these factors operate individually, or how they interact.

At some places in the area, e.g. in Barnegat Bay, N.J., and Long Island Sound, N.Y., waste heat from power plants has had beneficial effects on sport fishing. Species such as bluefish, striped bass, white perch, menhaden, and others become entrained in the warm plume of discharged cooling water and support recreational fisheries in winter where none existed before. Plant shutdowns or sudden weather changes sometimes cause sudden mortalities. The power companies are seldom praised for such fortuitous creation of new sport fisheries, but they are immediately vilified when a kill occurs. It seems unlikely that such kills can have significant permanent or even immediate effects on the resources involved, although local effects can be catastrophic.

In summary, the only certainly identifiable effects in the natural environment of estuarine water pollution on the living resources and their fisheries are: 1) transfer of human pathogens; 2) closure or restriction of harvesting on molluscan shellfish beds; and 3) catastrophic releases of pollutants in which cause and effect are obvious.

It follows that we have no positive explanation why many important species in the Middle Atlantic Estuarine Area have increased substantially in abundance in the period 1969–1973, and thus cannot attribute these recoveries to pollution abatement, where abatement has occurred. However, many laboratory studies and some controlled field studies have shown that all species studied are affected adversely by many components of water pollution. This is sufficient to support the conclusion that many pollutants are deleterious to fishery resources and to human health.

Domestic Management of the Fisheries

A primary objective of fishery management is to maintain the resource in a condition to produce the optimum sustainable yield, which means economic as well as biological health. Despite the short-term increase in landings from 1969 to 1973, which apparently was not the result of an equivalent increase in fishing effort, it is fairly obvious from the long-term record that we have not achieved effective fishery management in the Middle Atlantic Estuarine Area. The declining total catch of food fish and shellfish, despite constant and progressive shifting from resource to resource, is sufficient evidence of that. There has been no dearth of opinion as to what is wrong with the fisheries of the area and what are the remedies. Many of these views have been translated into laws, and all of the states have voluminous codes of fishery statutes, few of which have any basis in fact.

The only exceptions in the seven-state area are the oyster and soft clam management programs of the State of Maryland, already mentioned. These have more than doubled oyster production in that state in 10 years, 25 percent of which increase occurred from 1969 to 1973 (masked in Table 3 by a concurrent drop in Virginia); and are bringing about recovery of the soft clam resource and fishery. In New York State the town of Islip, which controls about one-third of the bottom of Great South Bay, has embarked on a promising program to manage the hard clam resource. If successful, these programs will be models for other local communities and states to follow. The difficulties should not be underestimated, however. Not the least of these is the extreme difficulty and cost of law enforcement associated with resources in shallow water, near shore, and easily accessible to the public generally. Without adequate enforcement, the best program in the world will fail.

Foreign Fishing

Fishing by other nations on the continental shelves surrounding the United States has become the major concern of domestic fishermen. It has overshadowed all the other problems of the coastal fisheries of the nation and of the Middle Atlantic Estuarine Area. This dominance of foreign fishing over all other fishery problems probably occurred because it presented an obvious "villain" which could be blamed, rightly or wrongly, for most of the ills of the domestic commercial and recreational fisheries. This scapegoat has no means of fighting back at the domestic level. Foreign fishing has seriously affected some traditional American fisheries, such as Georges Bank haddock and Pacific halibut, to name only two. Foreign fishing as a serious problem for the domestic fisheries of the area began in 1965 and 1966, when the Soviet Union took a large harvest from the strong 1963 year class of haddock on Georges Bank, and then began to extend its operations to the south and west. As early as 1963, however, the USSR did some fishing south of Georges Bank. Now at least 10 nations besides the United States are fishing in the Middle Atlantic Bight.

Of some 47 major species in the domestic commercial and recreational fisheries of the Middle Atlantic Estuarine Area, 18 are also being taken by foreign fleets on or over the continental shelf. The other 29 domestic species either do not enter the high seas beyond the 12-mile zone of national fishery jurisdiction or do so in such small numbers or for so short a time that incidental catches by foreign fishermen would not be a serious problem. The only exceptions are menhaden, which sometimes are found beyond 12 miles in substantial numbers, especially off Virginia and North Carolina in winter, and surf clam, which is widely distributed on the continental shelf in the area. It does not seem likely that specialized foreign fisheries for these species will develop. The surf clam has been declared a creature of the continental shelf under the provisions of the 1958 Geneva Convention, which thus reserves this resource to the United States.

Table 5 shows reported landings of the 18 species or groups of species fished jointly by domestic and foreign fleets in the area. The foreign catches are probably higher than they should be for direct comparison, because they include Georges Bank. Virtually none of the domestic landings listed comes from Georges Bank.

Some of the species migrate between waters over Georges Bank and the Middle Atlantic Estuarine Area (e.g. Atlantic herring and mackerel), others, such as winter flounder, probably do not. The alewife resources of Chesapeake Bay definitely have been affected by the foreign fisheries, as the decline in domestic landings illustrates. Foreign catches of scup have been relatively small, but even these small catches are of concern because the scup resource has

Table 5.—Domestic (upper row) and foreign (lower row—ICNAF subareas 5z and 6) commercial catches of major species taken by both groups in Middle Atlantic Estuarine Area 1966-73. Weights in millions of pounds. * = 50,000 pounds or less. — = no catch reported

Species	1966	1967	1968	1969	1970	1971	1972	1973
Alewife	34.4	30.7	36.5	33.9	21.1	13.1	12.1	11.3
	—	14.3	49.1	79.8	43 6	47.8	27.5	14.0
Scup	25.9	18.6	13.9	10.3	9.5	8.1	8.7	10.2
	2.0	1.8	5.1	1.1	0.4	2.2	3.7	3.9
Summer flounder	9.8	8.1	6.3	3.9	5.7	5.2	5.3	9 3
	—	—	—	—	*	1.5	0.9	*
Yellowtail flounder	9.5	11.4	12.3	13.5	15.4	20.8	28.0	25.1
	0.2	0.2	0.2	42.1	6.8	4.6	12.1	1.4
Silver hake	9.2	11.0	9.7	9.0	8.1	8.3	10.9	11.5
	472.4	195.4	132.0	166.4	72.6	162 0	233.0	254.7
Winter flounder	9.2	9.0	7.6	7.7	8.2	8.2	6.6	6.6
	0.2	0.2	0.2	15.0	1.1	3.7	5.5	3.4
Atlantic herring	7.4	1.7	0.8	0.1	*	2.5	0.7	0.4
	305.1	479.5	822.1	674.4	540.8	570.3	377.8	435.9
Butterfish	5.4	4.9	3.4	4.7	3.8	3.4	1.5	3.2
	8.6	5.1	11.9	33.0	19.8	13.9	12.3	39.3
American lobster	4.0	4.8	6.5	8.2	9.5	9.3	7.2	5.6
	—	—	—	—	—	0.2	0.4	0.5
Black sea bass	3.2	2.5	2.4	2.4	2.1	1.2	1.6	2.4
	—	—	—	—	—	—	—	—
Squids	2.6	2.9	3.0	2.7	1.8	1.7	2.2	3.0
	*	*	3.7	15.6	33.0	44.7	104.5	121.4
Atlantic mackerel	2.4	2.1	2.9	1.7	2.6	1.8	2.9	2.8
	15.0	41.9	123.7	239.8	450.6	517.5	843.0	836.3
Red hake	1.5	1.4	1.1	1.2	1.6	1.3	1.6	1.9
	239.4	117.5	29.3	108.5	16.1	59.3	162.4	137.7
Atlantic cod	1.2	2.2	2.9	3.4	3.8	3.1	2.7	3.4
	90.8	52.0	61.5	46.7	23.8	26.0	25.8	28.0
Sea robins	0.9	0.6	0.5	0.1	*	*	*	*
	3.1	1.1	19.8	4 2	*	1.8	8.1	6.2
Tilefish	0.9	0.1	0.1	0.1	0.1	0.1	0.3	0.8
	—	—	—	—	—	—	*	—
Sharks	0.9	0.5	0.4	0.2	0.1	0.1	0.1	0.1
	19.4	5.3	8.8	19.2	12.3	24.2	46.3	33.8
Bluefin tuna	0.5	3 2	0.2	0.1	3.1	2.0	2.2	1.3
	—	—	—	—	—	1.1	0.4	0.2

decreased sharply in abundance since the 1950s. Summer flounder catches by foreign fishermen also have been small, but foreign catches may be larger than reported because some summer flounder may have been included in unclassified catches. Relatively large foreign catches of yellowtail flounder have led to quota limits on this species by ICNAF, but the effects on the fisheries of the Middle Atlantic Estuarine Area are not evident in the record of domestic landings. Yellowtail flounder in the area probably belong to a distinct stock, and catches on Georges Bank probably would not affect this stock. Although landings of yellowtail flounder in the area from 1969 to 1973 do not reflect it, this flounder has been seriously reduced in abundance.

Catches of silver hake by foreign fleets in the area have been very large. This fishery also is regulated by ICNAF quotas. Domestic landings show no apparent effects from foreign fishing, but the catch of silver hake is determined more by demand than by abundance of the resource, and thus commercial catches will not reflect variations in abundance. Since foreign fishing began in the area, catches of winter flounder have been relatively small, although pulse fishing produced a large foreign catch in 1969 and a fairly large catch in 1972. The decline in domestic catches of winter flounder may have been a consequence of foreign fishing, but the demonstrated existence of local stocks and wide natural variations in abundance make such a conclusion questionable. The domestic fishery for Atlantic herring in the area is negligible because there is little demand for adults of the species. The large foreign catches are apparently of little importance to the domestic fisheries, although it is not certain that the Maine sardine fishery will be unaffected. It would be interesting to know whether this large catch of an abundant species has had any indirect effects on other living resources of importance to the domestic fisheries. It appears that the domestic fisheries have been harvesting only a small fraction of the butterfish resource, but with the development of large foreign fisheries the resource now is believed to be fully utilized.

Reported foreign catches of northern lobster have been relatively small, but it has been suspected that incidental, unreported, catches are larger. Lobster supports an important traditional American fishery, and any foreign catch is a matter of concern. Recent declaration of lobster as a creature of the continental shelf by the United States may correct the situation, if other nations are willing to accept the rather strained definition as it applies to this species.

No foreign catches of black sea bass have been reported, except in 1964, when about 1,500 metric tons were listed, but sea bass migrate to the outer continental shelf in winter and incidental catches are suspected. Demand for squid is very limited in the United States, and this species has been much underexploited by the domestic fisheries, but squid are important in the diet of many resources of major interest to domestic fishermen. The large recent foreign fishery is of relatively minor concern to the domestic fisheries at present. At least 50 percent, and perhaps a greater proportion of the catch of the foreign squid fleet is butterfish.

Atlantic mackerel, like Atlantic herring and squids, is not in great demand in the United States. It has been a part of domestic strategy in negotiating with other nations that fish off this area to encourage them to concentrate on such abundant species of minor value to Americans. This strategy probably is less palatable to American recreational than commercial fishermen.

The domestic harvest of red hake probably is much underestimated by official catch statistics. This is the major species in the industrial trawl fisheries of Nantucket Shoals, a catch which is not reported by species. Red hake also supports a minor sport fishery. Most of the foreign catch of Atlantic cod comes from Georges Bank and north. In total catch domestic landings in the area have shown no obvious effects of foreign fishing. Sea robins are not of great importance to the domestic commercial fisheries of the area, but are apparently much more important in the sport fisheries. Only small catches of tilefish have been reported by foreign fleets, but the species occupies a very specialized habitat at the edge of the continental shelf, and incidental foreign catches are suspected. The domestic commercial fishery for sharks is small, but sharks are of interest to sport fishermen. The effects of the relatively large foreign catch on the sport fisheries are not known; the relatively large recent fisheries for bluefin tuna in the North Atlantic Ocean have brought that resource to a dangerously low level. Vigorous attempts now are being made to limit catches stringently.

In summary, it is clear that foreign fishing in the area has had measurable adverse effects on some fishery resources of interest to domestic commercial and recreational fishermen, and that foreign catches of some others are a matter of concern. In addition, as long as foreign fishing continues in the area, incidental catches of some resources will reduce to some extent the probability of measuring the effects of other variables on the abundance and condition of estuarine stocks. On the other hand, it must be noted that a number of important fishery resources of the area are not subject to foreign fishing, and that stocks of some of these, like soft clam and northern puffer, have declined in the last five years much more sharply than some which are taken by foreign fleets. This is not to say that foreign fishing is not having its effects, but it does emphasize the complexities of the situation and the need to pay more serious attention to domestic fishery management.

Social-political Issues

In the United States, the individual states, and sometimes counties or even towns, have broad jurisdiction over fisheries in adjacent waters. Local governments make the laws and regulations and are responsible for surveillance and enforcement. Federal jurisdiction over fisheries is restricted to international waters or to interstate commerce in fishery products. In the Middle Atlantic Estuarine Area the federal government takes the lead in ICNAF affairs and bilateral negotiations as they relate to the fisheries of the area, but this places many migratory resources under double jurisdiction, because important species like scup, summer flounder, sea bass, and others move seasonally between territorial and international waters.

International fishery management in the area has been criticized as inadequate or ineffective, but in reality this is too extreme a view. For one thing, it ignores what should be obvious, that domestic fishery management, which among other things includes pollution control, has failed almost completely. International agreement is difficult to achieve, and arrangements under ICNAF and the various bilateral agreements that apply to the area have not been perfect. However, it cannot be denied that the fisheries would have been in much worse condition today if the federal government had not entered into negotiations with other nations fishing off this section of the coast. The results of these arrangements have shown that the interests of the United States fisheries have been served best when we can present reasonable scientific evidence that a problem exists. Scientific research has been the basis of most of our international fishery agreements, but scientific evidence has played a very small role in determining fishery policy or in developing laws and regulations for most fisheries of territorial waters. This most important point has not been clearly recognized by many.

State and sometimes local governments in the area support scientific research on fishery resources and their environment. Some of the information developed has been used as a basis for regulating domestic fisheries, but usually fishery laws and regulations have been based on opinion rather than fact, and are much more likely to be concerned with who makes the catch than how the catch should be limited. In other words, domestic fishery management in estuarine waters is much more likely to be based on struggles between vested interests than on scientific objectivity. This contrast between international and domestic management strategies does much to explain why international arrangements, difficult as they are, have been much more successful than domestic.

Many state and local fishery laws and regulations tend to perpetuate inefficiency and prohibit or restrict efficient harvesting methods. This adds to the cost of catching fish, which is already relatively high because vessel construction, fishing gear, repair and maintenance, insurance, and other costs are greater than anywhere else in the world. In addition, most of the domestic fisheries suffer from overinvestment of capital and labor, another form of economic inefficiency. In the absence of scientifically-based catch quotas, or better still, limitations on numbers of fishermen and units of gear, there is no effective management of the resource. This, coupled with wide natural variations in abundance of individual resources, makes it virtually impossible to detect the effects of other manmade environmental changes.

Communication Between Fishery Interests

Commercial fishery interests in the United States have many protagonists and some antagonists. Commercial fishermen, processors, and distributors have many organizations, local, state, and national, which represent their interests in various ways. These include groups of fishermen, boat owners, unions, and trade organizations of various kinds. At the political level, commercial fisheries have surprisingly strong support, especially in such key fishing areas as the Pacific Northwest, Alaska, New England, and the Gulf of Mexico. In fact, some believe that in certain regions political interest and support at the national level is far greater than the economic value of the industry warrants.

On the administrative side the National Marine Fisheries Service of the Department of Commerce has the major federal responsibility for fishery research, development, and services to the commercial fishing industry and to recreational saltwater fishing interests. Other responsibilities reside in the Departments of State, Interior, Treasury, Agriculture, Labor and other departments and specialized agencies. Each state has an agency with prime responsibility for marine fishery management and research. Some coastal states have separate agencies for finfish and shellfish management, and often jurisdiction over anadromous fisheries is divided between coastal and inland fish and wildlife agencies. As already mentioned, research and management are sometimes further complicated by delegation of certain responsibilities to local governments.

In the Middle Atlantic Estuarine Area efforts have been made to coordinate research and management between states through the Atlantic States Marine Fisheries Commission (ASMFC), an interstate organization of more than 30 years standing, to which all 15 Atlantic coastal states belong. The Commission has made progress in certain directions, but has not yet succeeded in getting the states to cooperate in effective fishery management programs. The compact which created the Commission named the Fish and Wildlife Service of the Department of the Interior as its primary research agency. When the National Oceanic and Atmospheric Administration was created this function was transferred to the Department of Commerce. All of these agencies, groups, and key individual members exert influence in a variety of ways, through the communications media, by serving on advisory committees or commissions, testifying before congressional or state assembly committees or at public hearings, lobbying, and so on. Vested interests and inadequate or out-of-date information often stimulate controversy rather than solutions. It would be interesting to determine how much human energy and economic resources have been devoted to these ends, to no avail.

Sources of Information

Knowledge about the fisheries and the living resources and their environment resides in various forms in all individuals and groups described above, in conservation organizations, in universities, in the staffs of international fishery commissions, and in the United Nations family of organizations, especially FAO and UNESCO. The amount of knowledge available through such diverse groups is considerable, but it varies widely in accuracy, quality, and breadth, depending on the experience, competence, and interests of individuals and groups, and on the amount of information and expertise readily available to them. Between them, these individuals and institutions know, or have access to information on, abundance, distribution, and biology of the resources, including latent or underutilized species; the condition of those resources and the effects of manmade or natural environmental variables; fishing grounds and fishing methods; markets, prices, and economic structure of the industry; processing, distribution, and consumption of fishery products; imports and exports; the world fishery picture; and major problems of the marine fisheries.

None of this information is complete, and its adequacy and accuracy vary between resources and between specific fisheries. Much of it has been gathered by indirect methods and by scanty sampling and it may be difficult or impossible to estimate levels of accuracy. For example, statistics of commercial fishery landings published by the federal government, sometimes in cooperation with individual states, are generally considered to underestimate the catch, whereas the national surveys of saltwater sport-fishing probably have produced overestimates of the sport catch. Some attempts have been made to measure the accuracy of these estimates, and these have tended to confirm the statements made above, but these attempts have been confined to limited regions and short periods of time.

The literature on pollutants and their effects on fish and shellfish is voluminous, and has been accumulating at an accelerating pace. Experimental studies in the laboratory have demonstrated that many constituents of domestic and industrial wastes do specific damage to estuarine organisms. Such substances may kill fish and shellfish directly or exert less obvious, but sometimes much more damaging, effects on the resource as a whole, including modification of spawning habits, decreased growth and increased mortality of larvae and young, retention and transfer of human pathogens, concentration of heavy metals and pesticides, and increased incidence of deformities such as fin rot and crooked vertebral columns. It has been shown conclusively that DDT and other pesticides, developed to kill insects, are particularly harmful, in very low concentrations, to marine animals related to insects, such as crabs and shrimps. But pesticides kill or otherwise affect other invertebrates and fishes too. When it comes to measuring the effects of pollutants on fish and shellfish in the natural environment the problem is much more difficult because natural environmental variables, some seasonal, some longer-term, and fishing as well, have substantial effects on abundance. Against this background of fluctuating abundance it is nearly impossible to detect the effects of a single factor. Laymen are prone to be much more positive about cause and effect than scientists, but some scientists have further complicated the issues by making hasty judgments or by drawing unwarranted conclusions.

Much published work on effects of water pollution or of specific pollutants on fish and shellfish resources is fragmentary and inconclusive and not of much help for interpreting what is happening in the natural environment. Many agencies and individuals are doing research and gathering data. Some of the work is good, some mediocre, some trivial. Better coordination and review would be desirable. Since 1969 several useful reviews have been published An example is "The Water's Edge," sponsored by the Institute of Ecology and the Woods Hole Oceanographic Institution in 1972. This and some other pertinent publications are listed in the bibliography, which makes no pretense of being comprehensive. The conclusions and recommendations in this report are worth study. Too often such documents are published and then forgotten.

Factors of natural human origin that affect survival, abundance, and general health of fish and shellfish in the natural environment are probably so numerous, and reinforce or buffer each other in so many complicated ways, that it probably is unrealistic to pretend that our understanding of cause and effect will ever be very clear. This is not necessarily a deterrent to effective control. If we know from laboratory studies that DDT or other similar compounds are lethal in small doses to blue crab or shrimps, then that should be sufficient cause to decide that DDT should not be allowed to contaminate the waters of the Middle Atlantic Estuarine Area or anywhere else. If we know from laboratory studies and from analysis of animals collected in the natural environment that heavy metals, pesticides, and other toxins are concentrated in living tissues at levels higher than concentrations in the environment, that should be sufficient cause to prohibit additions of such substances to the waters of the coastal zone. If we know that addition of oxygen-demanding substances to a body of water will reduce the dissolved oxygen content to levels below that necessary for survival or for normal biological functioning, then that should be sufficient cause to prohibit excessive manmade oxygen demand in fish and shellfish spawning, nursery, or feeding areas.

Available data for understanding the effects of water pollution on commercial fishery stocks are reasonably good for some species or stocks of fish and shellfish. For example, it cannot be denied that water pollution destroyed the oyster industry of Greater Raritan Bay in New Jersey and New York, and is responsible for closure of most of the clam beds there. In the early 1960s a serious outbreak of hepatitis was traced to clams illegally harvested from Raritan Bay. There is no question that water pollution played a role in reduced marketability of shad from the Hudson River. In some places in the area it is clear that water pollution was at least partially responsible for declining runs of shad and other anadromous fishes. Aside from clear-cut examples like these, or accidents in which cause and effect is beyond reasonable doubt, presumption of pollution-associated effects on commercial fisheries is largely hypothetical. It is just as logical to suppose that the long-term upward trends in abundance of striped bass and blue crab in Chesapeake Bay were caused by nutrient enrichment from domestic wastes, as that the decline and recovery of blue crab stocks in New Jersey and New York were caused by heavy use and then prohibition of use of DDT. Data do not exist to support or to deny these hypotheses, and it is difficult to conceive of ways in which direct confirmation could be obtained.

SUMMARY AND CONCLUSIONS

In the 5-year period since the "National Estuarine Pollution Study" was completed landings of domestic commercial fish and shellfish in the Middle Atlantic Estuarine Area have almost doubled in weight. Although landings alone are not a very accurate index of abundance of the living resources of an area, other evidence demonstrates beyond reasonable doubt that, although the supply of some resources in the area has declined substantially since 1969, others are much more abundant today. Generally, the domestic commercial fisheries in the area appear to be in better condition now than they were five years ago, but this may be transitory and more apparent than real. Certainly, many stocks are much less abundant than they were. It has been demonstrated that the total living weight of fishery resources in the ICNAF area is substantially less than it was a decade ago.

It is tempting to attribute this general increase in abundance and catches to the beneficial effects of estuarine pollution control and abatement. Although there is no evidence to refute this hypothesis, neither is there evidence to support it. The short-term improvement in commercial fishing in the area must be reviewed against a long-term decline in catches of most food fish and shellfish, in which short-term fluctuations often have masked long-term trends. Among the most important sources of short-term fluctuations are some partly-understood and many unknown natural variations in the environment, the effects of which cannot be distinguished from the effects of manmade changes. Also unknown for most species are the effects of essentially unregulated domestic commercial fishing, and of deliberate or incidental catches by foreign fleets. Totally unknown, but certainly important, are the effects of removals of fish and shellfish by recreational fishermen. Sport catches of some species, such as bluefish and striped bass, are many times as great as the commercial catch. Unless these fishery-associated sources of attrition can be brought under control, the odds are high that domestic catches of traditional fishery resources will continue to decline in the long run, and that commercial fishing will continue to shift to underutilized resources. Such latent resources are not limitless, and they probably are underutilized either because markets are limited or the cost of harvesting is too high.

The extreme difficulty of measuring the effects of water pollution or pollution control on the commercial fisheries of the area as a whole need not be a deterrent to positive action. Molluscan shellfish are an important segment of the commercial fishing industry in this area, and they are worth preserving and enhancing. The molluscan shellfish resources also are important because they can be considered as endemic resources in the waters of each state, and therefore can be managed unilaterally without the need for interstate or international cooperation. Theoretically, management of these resources should be relatively easy, but as a practical matter it obviously has not been in most states of the area. In some of the states it is not certain that a real incentive exists.

The area of bottom closed to shellfishing, and trends in closures or reopenings of such areas, may be a useful index of the condition of estuarine waters. If effective management of molluscan shellfisheries can be achieved, and the effects of natural environmental change and economic trends in the shellfish industries are sufficiently well understood, it may then be possible to evaluate the benefits of pollution control by monitoring estuarine shellfish grounds and measuring the condition of the living resource. In this connection, a better index of environmental quality on shellfish beds is needed, to replace the standard coliform bacteria count now in use.

It is possible that nutrient enrichment from waste disposal has increased the biological productivity of certain estuarine fishery resources in the area. If this is so, it was entirely serendipitous. The experience of the oyster industry in Great South Bay, N.Y., has demonstrated that uncontrolled additions of nutrients can also destroy an estuarine commercial fishery. For these reasons, and in the interest of public health as well, control and abatement of estuarine water pollution must have high priority. At the same time, the possibility of benefits to commercial and recreational fisheries from controlled addition of nutrients merits investigation. Where deliberate enrichment has been tried elsewhere, the results have been promising.

AUTHOR'S NOTE

Since this paper was written, information about commercial fishery landings in 1974 has become available. The figures are preliminary, and for some states have not yet been published, but it is clear that the upward trends noted for some estuarine species are continuing, especially for scup, summer flounder, and blue crab. In New York State commercial landings of blue crab were reported in 1974 for the first time in eleven years, and direct observations confirm the increased abundance of this species. Increasing abundance of summer flounder has been confirmed by a recent study of sport catches and effort in New Jersey (Festa, 1975). Black sea bass can be added to the list of resources increasing in abundance. The commercial catch of this species north of Chesapeake Bay has almost tripled since 1970, and sport catches are increasing also (Berrafato, 1975). On the other hand, the effects of foreign fishing on yellowtail flounder were first noted south of Cape Cod in 1974. Landings of this species dropped sharply from Rhode Island south.

Recovery of the blue crab resource may not be a good omen for the hard clam industry. Blue crab is a serious clam predator. Interactions between species, as populations wax and wane, create a shifting background against which the effects of water pollution are difficult to measure.

An encouraging note was sounded in July 1975 when the New York Department of Environmental Conservation announced that it would reopen some 9,200 acres of shellfish bottom in Long Island Sound because water quality has improved.

REFERENCES

This is not intended to be an exhaustive list of pertinent literature. It contains principally references to publications from which supporting data or statements were drawn and a few papers which seemed to cover broadly the subject of water pollution and fisheries. Other sources may be found in the literature cited by these papers, and in the other papers in this volume.

Anonymous. 1970a. National Estuarine Pollution Study. U.S. Dept. Interior, Fed. Water Poll. Control Agency, Washington, D.C.: ix+633 p.

Anonymous. 1970b. National Estuary Study. U.S. Dept. Interior, Fish & Wildl. Serv., Washington, D.C., 7 volumes.

Anonymous. 1974. New Jersey Landings, Annual Summary 1973. U.S. Dept. Commerce, NOAA, Natl. Marine Fish. Serv. & N.J. Dept. Envir. Protect., Div. Fish, Game & Shellf: 7 p. and earlier reports in this series for 1971 and 1972.

Anonymous. 1974. New York Landings, Annual Summary 1973. U.S. Dept. Commerce, NOAA, Natl. Marine Fish. Serv. & N.Y. Dept. Envir. Conserv.: 8 p. and earlier reports in this series for 1971 and 1972.

Anonymous. 1974. Virginia Landings, Annual Summary 1972. U.S. Dept. Commerce, NOAA, Natl. Marine Fish. Serv., Va. Marine Resources Comm., & Potomac River Fish. Comm.: 9 p. and 1971 report in this series.

Berrafato, Frank. 1975. Return of the sea bass. Long Island Fisherman 10(28), July 1975:16.

Boone, Joseph. 1974. The hardheads are back. Comm. Fish. News, Md. Dept. Nat. Resources 7(6):3.

Brey, William L. 1974. Maryland Landings, Annual Summary 1972. U.S. Dept. Commerce, NOAA, Natl. Marine Fish. Serv., Md. Dept. Chesapeake Bay Affairs, and Potomac River Fish. Comm.: 11 p. and 1971 report in this series.

Butler, P. A. 1971. Influence of pesticides on marine ecosystems. Proc. Roy. Soc. London B177:321-329.

Calabrese, Anthony. 1972. How some pollutants affect embryos and larvae of American oyster and hard-shell clam. Marine Fish. Rev. 34(11–12):66–77.

Davis, Dr. Jackson. 1974. Telephoned information about soft clam, alewife, croaker, and northern puffer in Chesapeake Bay. Va. Inst. Marine Science, Gloucester Point, Va.

Deuel, David G. 1973. 1970 Salt-Water Angling Survey. U.S. Dept. Commerce, NOAA, Natl. Marine Fish. Serv., Current Fish. Statistics No. 6200:iii+54 p.

Dewling, R. T., K. H. Walker, and F. T. Brezenski. 1972. Effects of pollution: Loss of an $18 million/year shellfishery. In: Marine Pollution and Sea Life. M. Ruivo (ed.) Fishing News (Books) Ltd., London: 624 p.

Festa, Patrick. 1975. Creel census of the summer flounder sport fishery in Great Bay, New Jersey. N J. Dept. Envir. Protection. Div. Fish, Game and Shellf., Nacote Creek Research Sta., Prog. Rept. for 1974.

Gates, John M. and Virgil J. Norton. 1974. The benefits of fisheries regulation: A case study of the New England yellowtail flounder fishery. Univ. R. I. Marine Adv. Serv., Tech. Rept. 21:35 p.

Ginter, Jay J. C. 1974. Marine fisheries conservation in New York State: Policy and practice of marine fisheries management. N.Y. State Assembly Scientific Staff and N.Y. State Sea Grant Program: vi+64 p.

Grosslein, M. D., E. G. Heyerdahl, and H. Stern, Jr. 1973. Status of the international fisheries off the Middle Atlantic coast. Tech. Ref. Doc. prepared for the bilateral negotiations of USA with USSR and Poland, May 1973. Natl. Marine Fish. Serv., N.E. Fish. Center, Lab. Ref. No. 73-4:117 p. (xerox).

Hamons, Frank L., Jr. 1973. Survey indicates threefold increase in clamming areas for 1974 season. Comm. Fish. News, Md. Dept. Nat. Resources 6(6):1-2.

Hodder, V. M. 1975. Statistical Bull Vol. 23 for the year 1973. Internatl. Comm. Northwest Atl. Fish., Dartmouth, Canada: 277 p. and earlier reports in this series since 1966.

Jensen, Albert C. 1974 Managing shellfish resources under increasing pollution loads. Proc. Gulf & Caribb. Fish. Inst., 26th Ann. Sess., Oct. 1973: 173-180.

Jensen, Albert C. 1974. New York's fisheries for scup, summer flounder and black sea bass. N.Y. Fish & Game J. 21(2):126-134.

Ketchum, Bostwick H. (ed). 1972. The Water's Edge. Critical problems of the coastal zone. MIT Press, Cambridge, Mass: xx+393 p.

Knapp, William E. 1974. Marine commercial fisheries of New York State: An analysis by gear. Unpublished M.S. Research Paper Marine Sciences Research Center State Univ. of N.Y., Stony Brook, N.Y.: 108 p. + appendices (to be published).

Medeiros, William Henry. 1974. Legal mechanisms to rehabilitate the Hudson River shad fishery. N.Y. State Assembly Scientific Staff and N.Y. State Sea Grant Program, Albany, N.Y.: xiv+65 p.

Murphy, William J. 1974. Rhode Island Landings, Annual Summary 1972. U.S. Dept. Commerce, NOAA, Natl. Marine Fish. Serv., and R.I. Dept. Nat. Resources, Div. Conserv.: 11 p. and 1971 report in this series.

Rice, T. R. and J. P. Baptist. 1974. Ecologic effects of radioactive emissions from nuclear power plants. Chap. 10 in: Human and Ecologic Effects of Nuclear Power Plants. Leonard A. Sagan (ed). Charles C. Thomas, Publisher, Springfield, Ill.: 373-439.

Riley, Frank. 1974. Personal communication: information on domestic commercial fishery landings 1971-1973. National Marine Fisheries Service, Gloucester, Mass.

Schaaf, W. E. and G. R. Huntsman. 1972. Effects of fishing on the Atlantic menhaden stock: 1955-1969. Trans. Am. Fish. Soc. 101(2):290-297.

Slobodkin, L. B. 1973. Summary and discussion of the symposium. In: Fish Stocks and Recruitment. B. B. Parrish (ed). Cons. Int. Expl. Mer, Rapp. Proc.-Verb., 164:7-14.

Waldichuk, Michael. 1974. Coastal marine pollution and fish. Elsevier Pub. Co., Ocean Management 2(1):1-60.

Wheeland, Hoyt A. 1973. Fishery Statistics of the United States 1970. U.S. Dept. Commerce, NOAA, Natl. Marine Fish. Serv., Stat. Dig. 64:489 p. and earlier reports in this series by various authors in various predecessor agencies back to 1880.

OUR ESTUARIES AND COMMERCIAL FISHING TRENDS

GORDON C. BROADHEAD
Living Marine Resources, Inc.
San Diego, California

ABSTRACT

The estuarine habitat of fish and shellfish is eroded by both natural and man-caused environmental changes. Shrimp and menhaden are discussed principally, noting the effects on them of salinity, temperature, and turbidity. The soft-bottomed embayments peripheral to the estuaries offer preferred living conditions. They are more productive—and more vulnerable—than the open waters of the estuaries. Recommendations are made for preserving these estuarine habitats.

INTRODUCTION

Coastal marshes are among the most productive areas of the world, largely because they function as nutrient traps, occupy stable areas which are sheltered from destructive wave action and are nearly free of desiccation hazards. Nourishment is supplied by freshwater rivers and streams carrying loads of rich silt. At the same time, highly dependable tidal currents remove undesirable wastes and bring in larvae and oxygen-rich waters. Because of these characteristics, our coastal estuaries support a great variety and abundance of organisms. Perhaps even more important is that estuarine areas function as nurseries for a great many fish and other marine animals—including many commercial species—which spend most of their adult lives in deeper, offshore waters.

During 1973, the United States landings of seafood items totaled 4.7 billion pounds, valued at just over $900 million to the fishermen. Many of the important species of commercially important fish and shellfish depend significantly upon estuarine environment during at least a portion of their life cycle. Various authors have estimated that about two-thirds of our total commercial fish harvest is made up of estuarine-dependent species. The list is lengthy and, therefore, I am confining my examples to two important fisheries, penaeid shrimp and menhaden, which each support commercial operations along the east and gulf coasts of the United States. Each of these resources has residence in estuarine areas during portions of their life history, and are thus exposed to the potentially detrimental effects of estuarine degradation.

THE RESOURCES AND THEIR ENVIRONMENT

Shrimp

There are three commercially important species of shrimp in the gulf and south Atlantic areas: the brown shrimp, *Penaeus aztecus;* the white shrimp, *P. setiferus*; and the pink shrimp, *P. duorarum*. Two lesser important species are the seabob, *Xephopenaeus kroyeri* and the royal red shrimp, *Hymen openaeus robustus*.

During 1973, the gulf and south Atlantic landings of penaeid shrimp were 207 million pounds, valued at $199 million to the fishermen.

Adult penaied shrimp spawn offshore. The eggs hatch within hours and the nauplii become part of the zooplankton. Within three to five weeks the young shrimp enter the bays and estuaries as postlarvae and there they grow rapidly, moving seaward and into the commercial fisheries within months.

In the estuaries, shrimp form part of the mobile benthos. Brown and white shrimp prefer soft muddy substrate, while pink shrimp prefer the firmer sandy bottoms. The species are omnivorous, eating plants, animals and organic and inorganic detritus. Penaeid shrimp are essentially an annual crop with only a small percentage of individuals surviving more than one year.

A number of factors influence the occurrence and success of spawning and the subsequent growth and survival of the young shrimp. Unseasonally low temperatures which occur following spawning are a significant factor in the survival of metamorphosing shrimp and postlarval shrimp in the estuarine nursery areas.

Salinity appears to be a dominant factor in the distribution and growth of brown shrimp in the estuarine systems. Rainfall is the primary factor which influences bay and upper estuarine salinities. Runoff is the major factor influencing salinities in the lower estuaries. Barrett and Gillespie (1973) showed that years of above average discharge of the Mississippi River have been associated with poor production years for brown and white shrimp, while below average discharges resulted in good production years for the species. They noted that rainfall, combined with river water, may dilute estuarine and near-shore salinities to below the tolerance limits for penaeid shrimp and, therefore, substantially limit available optimum nursery areas. Other environmental factors such as turbidity, unseasonal meteorological conditions and pollution may affect shrimp populations.

No definitive studies have been conducted which relate the effects of turbidity to shrimp abundance and distribution. However, casual observations by several authors suggest that bays and coastal areas which are turbid produce the greatest concentrations of shrimp. Ingle (1952) and Viosca (1958, cited in Mackin, 1961) have both mentioned the fact that shrimp are apparently attracted to the turbid waters near shell dredges in Louisiana and Alabama. Kutkuhn (1966) felt that turbid estuaries and bays provided shrimp with both a supply of nutritive detritus and protection from predation. Lindner and Bailey (1969) established a qualitative relationship between turbid plumes and shrimp in the Gulf of Mexico using Gemini spacecraft photography and commercial catch statistics for the brown shrimp in the northwestern Gulf of Mexico. Their conclusions were conjectural because of the lack of "ground-truth" data on the fishing grounds.

Mock (1966) noted that the abundance of small white and brown shrimp was substantially greater along a natural coastline than along an adjacent area altered by bulkheading.

Menhaden

The United States landings of menhaden are comprised of four species: *Brevoortia tyrannus* and *B. smithi* on the Atlantic coast and *B. patronus*, *B. quentri* and *B. smithi* in the Gulf of Mexico. *B. tyrannus* dominate the catches in the Atlantic and *B. patronus* in the gulf. During 1973, menhaden landings for the Atlantic and gulf coasts totalled 1.9 billion pounds, valued at $73 million.

Commercial landings of menhaden in the Gulf of Mexico are largely 1- and 2-year-old fish. These ages also dominate in the Atlantic landings, although there are considerable volumes of 3-, 4- and 5-year-old fish in certain years.

Menhaden are euryhaline. The adults spawn offshore during the fall and winter and the larvae migrate inshore and live in the estuaries for five to 10 months, at which time they return to the offshore waters for further growth, followed by sexual maturity and spawning. Their early life history pattern is remarkably similar to that of the penaeid shrimp.

Reintjes (1970) noted "menhaden are an important component in an estuary. After they transform from the slender, transparent larvae to juveniles, they become filter feeders. They swim about in schools, usually with their mouths gaping open, to filter the small planktonic animals and plants from the water. They have a complex gill apparatus that forms a basketlike sieve that removes all but the smaller particles from the water. As the bulk of the organisms eat algae or the remains of higher plants, menhaden are principally herbivores. Menhaden are one of the few fishes (mullet is another) that live by grazing on the plants in the estuaries. They are at one of the lowest trophic levels near the bottom of the food chain and provide food, in turn, for nearly all the carnivores that are large enough to eat them. This then forms both sides of the coin: The role of estuaries in the life cycle of menhaden and the role of menhaden in the ecology of estuaries."

Reintjes and Pacheco (1966) discussed physical, chemical and biological factors affecting the survival and growth of young menhaden. Mass mortalities have been attributed to sudden temperature changes, low concentrations of dissolved oxygen, very high salinities, and toxic pollutants.

Gunter and Christmas (1960) noted that surface temperatures of coastal waters are a major factor in the migration patterns of menhaden. Harper (1973) stated that menhaden indicated a preference for clear water. However Tagatz and Wilkens (1973) found that more juvenile menhaden were caught in clear water estuaries at night than during the day while there was no such diurnal difference in turbid waters. They suggest that the turbid waters offer the young menhaden protection against predation. Kroger and Guthrie (1972) found indications of higher predation rates on young menhaden taken in clear water estuaries than in turbid areas.

Kemmerer et al. (1973) and Maughn and Marmelstein (1974) established a qualitative correlation between turbid plumes in the shallow Mississippi Sound observed from the ERTS-1 satellite and the commercial catch of menhaden. Surface salinity, temperature, and chlorophyll were also correlated with the manhaden catches made in turbid water. The cause of the apparent correlation was not determined. However, the relationship is a well-known phenomenon that is utilized extensively by the fishermen and their spotter aircraft pilots in locating schools of menhaden.

Spotter pilots report that schools of menhaden are capable of creating turbid clouds ("dragging mud") as they pass over muddy bottoms. The fact that these clouds appear in water as deep as 100 feet as well as in shallow water, suggests that this behavior may be either a feeding response or a protective measure (Lichtenheld, 1970). Thus. in the shallow area of the Mississippi Sound, menhaden schools could have been responsible for the turbid plumes observed by Maughn and Marelstein.

The Estuaries

The destruction of estuarine zone wetlands as a result of natural processes and the activities of man is a continuing and serious problem. Except for a few estuaries in Alaska, every one of the nation's estuaries has been modified by man. Twenty-three percent have been severely modified, 50 percent moderately modified and 27 percent slightly modified. "The National Estuary Study," carried out by the United States Department of the Interior, concluded that the destruction of estuaries is proceeding at a rate that will spell their end within a few decades.

The most severe adverse environmental impact to estuaries has resulted from sewage pollution, dredging and filling to create land, channel dredging for navigation, industrial wastes, and ditching and draining wetlands. Additionally, there is river impoundment and flow control, pesticide pollution, solid waste disposal, seawalls, dike and levee construction to prevent flooding, mining and oil pollution. Chapman (1972) noted that for the south Atlantic, Caribbean and Gulf of Mexico estuarine regions, about 50 percent of the area has been moderately impacted and in the gulf, 34 percent has been seriously impacted. Important legislative steps have been taken in recent years to halt this irreversible trend.

PROBLEMS IN DETECTION OF ADVERSE EFFECTS

Despite documented degradation of the estuaries, there are few examples where changes in the overall productivity of shrimp and menhaden can be related directly to these environmental changes. One case may be the sharp decline in the shrimp production of Sabine Lake, Tex., concurrent with the completion of the Toledo Bend Dam on the Sabine River. A substantial portion of the runoff to the shrimp nursery grounds in the Sabine Lake area was reduced during late 1966 and 1967 during the filling of the reservoir. During the 5-year period following the closure of the dam, river discharge as measured at Ruliff, Tex., was one-third lower than an earlier 5-year period, 1955–1959, prior to closure. In addition, the seasonal pattern of runoff was altered substantially with the peak period occurring in April rather than May. The discharge data and catch information are shown in Figure 1. Shrimp catches from Calcasieu Lake, an adjacent estuary not under the influence of the Sabine drainage, are included for comparative purposes. There, the shrimp production has been maintained while the Sabine Lake production has fallen to near zero.

Such relationships are extremely difficult to isolate and verify on a real time basis. The measurement of the abundance of commercial species of fish and shellfish is, at best, a very crude science.

Measures of apparent abundance are always indirect. That is, an index of commercial fishing vessel success, adjusted for seasonality and standardized for vessel efficiency, becomes the standard for year-

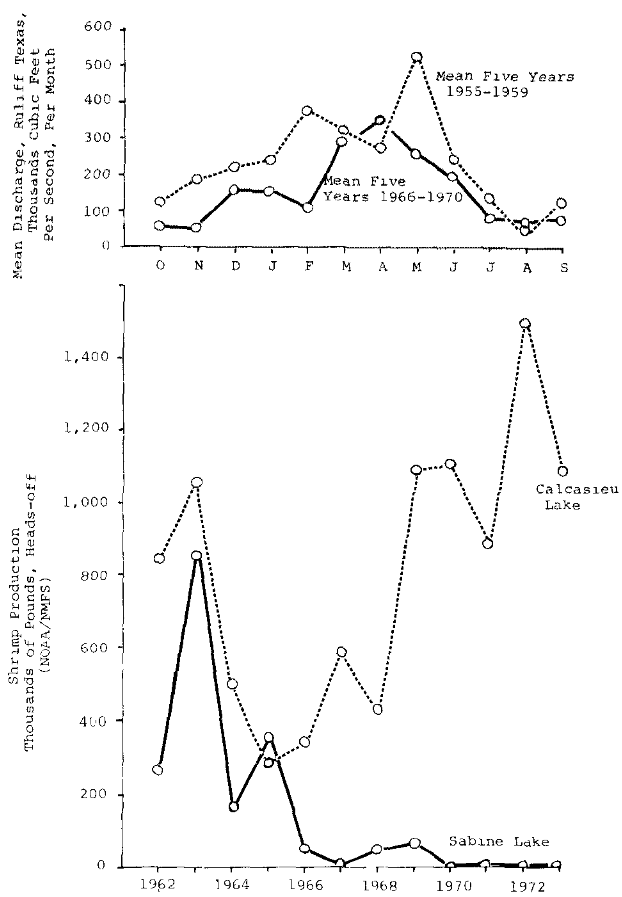


FIGURE 1.—River discharge and shrimp production.

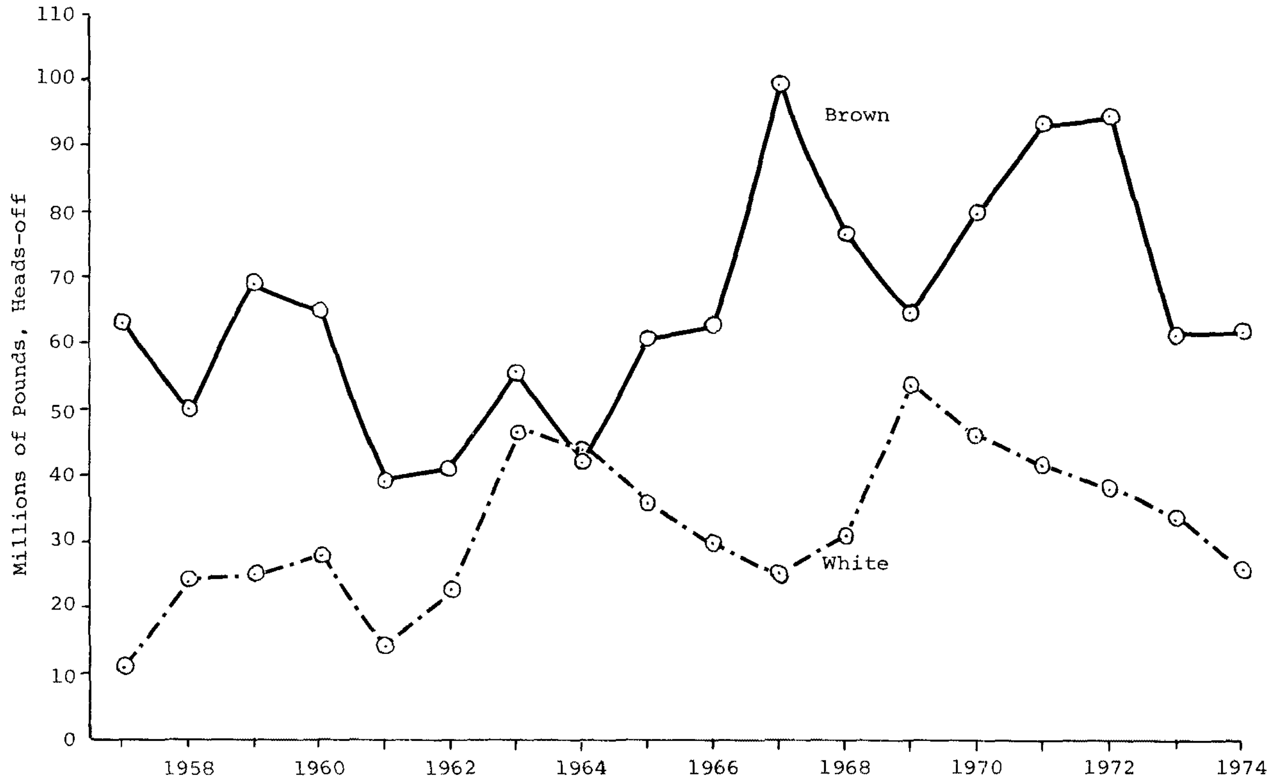


FIGURE 2.—Landings of brown and white shrimp, Gulf of Mexico ports, 1957–74.

to-year comparisons. However, the abundance of marine fish and shellfish populations are influenced by a complex of factors:

- Broad natural changes in marine climatology.
- Short-term variations in spawning and survival of young due to changes in ocean and estuarine conditions.
- Commercial fishing operations.
- Manmade changes in estuarine habitat.

National Marine Fisheries Service maintains long-term historical series on catch, effort and apparent abundance for gulf menhaden and shrimp fisheries. Changes in overall shrimp production levels are complex to analyze, as there are three principal species, taken by thousands of vessels, on a number of fishing grounds. Figure 2 depicts the historic catches of brown and white shrimp along the gulf coast since 1957. The 19-year trend in production is upward. However, substantial year-to-year fluctuations make it difficult to detect any real change in the average level of productivity until long after such a change has occurred.

The most recent data for menhaden is shown in Figure 3 (from Anonymous, 1974). Several important points are illustrated. First, there is a good long-term correlation between the amount of fishing effort and the resulting catch. Second, there appear to be cyclical deviations, since 1956, of the individual years about this average relationship. These fluctuations are about eight years' duration and are

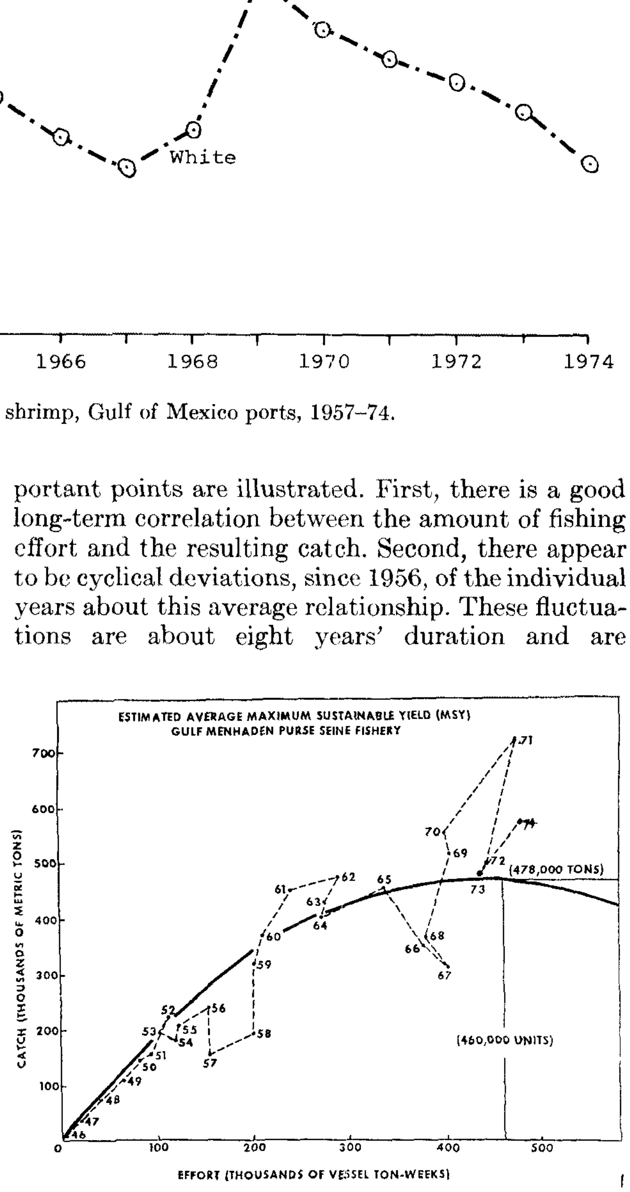


FIGURE 3

probably the result of changes in ocean and estuarine climate on the spawning and survival of the very young menhaden. The extreme values (1957, 1958, 1961, 1962, 1967 and 1971) exhibit an average deviation of 35 percent from the line of best fit. Thus, the trend in population abundance after the 1968 season suggests that the definite downtrend in catches since 1961 was signaling overfishing or detrimental effects of habitat degradation or a combination of both. However, the following year, catches began to increase again and peaked in 1971. With much the same level of effort, catches have been substantially lower in the 1971–1974 period. Is the present decline part of the cycle or is the decline signaling problems with the population? Obviously, we will not be able to say until four or five more years of information have been added to the data base.

The instability of marine populations has been noted by Longhurst et al. (1972). They emphasize the difficulties in sorting out and identifying the myriad of factors affecting marine fish populations. They also demonstrate that these changes can only be revealed and measured by deliberately mounted and well-sustained monitoring programs. They note a real lack of understanding that pollution monitoring schemes, in the ocean, can succeed only if the natural effects of the changing physical environment are both monitored and understood on a continuing basis. Natural fluctuations are often incorrectly ascribed to the effects of pollution; conversely, the effects of a modified environment frequently pass undetected in the system.

Erosion of habitat on a broad scale is gradual in nature and thus direct effects upon populations of commercial species of fish and shellfish are almost impossible to detect on a real time basis, amid the noise of short-term variability and long-term effects of fishing pressure and climatic change. Thus, we may be faced with the fact that these habitat modifications are completed and nonreversible by the time we can measure and document specific relationships for important species.

WHAT SHOULD WE DO

It is obvious that major research studies designed to document the direct relationship between estuarine habitat degradation and the deterioration of our major fisheries for shrimp, menhaden and other commercially important species will not be too useful in preventing these losses, but will prove largely an interesting historical documentation for later analysis.

What is required is an approach which states flatly that the shallow, turbid, soft-bottomed embayments in the interior of marsh areas around the periphery of the estuaries are the preferred habitats of many important migrating marine animals. These areas are much more productive per unit area than the open waters of the bays and estuaries. They represent about 30 percent of the total of 26 million acres of estuarine waters in the United States. These shallow areas, mostly less than six feet in depth, are the most vulnerable to man's activity.

Fishery dollar values per acre of nursery ground must be computed and adjusted for their renewability and for their direct and indirect impact upon our economy. Commercial values must consider not only the initial revenue to the fishing vessels (the traditional reporting method) but also the ripple economic impact upon the broad supporting infrastructure of the industry. Economists project that each dollar of primary industry income results in fivefold impact on our nation's economy. A dollar of landed catch value is divided among fishermen, shipyards, equipment and machinery suppliers, fuel dealers, provisioners, the insurance industry, the financial community, and many other smaller support elements. Sport-fishing and recreational values are more difficult to compute and compare with commercial values which are primary in nature. They are large, nevertheless, and the dollar impact (discounting the aesthetic values) is at least equal to that of the commercial industry.

Tihansky and Meade (1974) provide an excellent review of the problems associated with measurement of the economic values of estuaries to United States commercial fisheries.

The placing of a real fishery value, per acre, on the critical shallow estuarine areas, is not an easy task but it should and can be done on a region-by-region basis, utilizing currently available information. A research team of fishery biologists and marine economists, with practical business orientation, could expect wide-scale fishing industry cooperation, both commercial and sport, in such an endeavor. The results would provide agencies, legislature, and industry with a sound basis for decisions with respect to estuarine zone usage where conflicts of interest arise.

REFERENCES

Anonymous. 1974. A Discussion Paper on the Current Status of the Gulf Menhaden Fishery and Some Resource Management Issues. Report to Gulf States Mar. Fish. Comm. by NMFS Atlantic Estuarine Fisheries Center.

Barrett, B. B., and M. C. Gillespie. 1973. Primary Factors Which Influence Commercial Shrimp Production in Coastal Louisiana. Tech. Bull. No. 9., La. Wildl. and Fish. Comm.

Chapman, Charles R. 1972. The Impact on Estuaries and Marshes of Modifying Tributary Runoff. Proceedings Second Symposium 1972. Coastal Marsh and Estuary Management. LSU Division of Continuing Education, Baton Rouge, Louisiana. p. 235–258.

Gunter, G., and J. Y. Christmas. 1960. A Review of Literature on Menhaden with Special Reference to the Gulf of Mexico Menhaden, *Brevoortia patronus* Goode. U.S. Fish Wildl. Serv., Spec. Sci. Report Fish. 363.

Harper, D. E., Jr. 1973. Effects of Siltation and Turbidity on the Benthos and Nekton, In: Texas A & M Research Foundation, Environmental Impact Assessment of Shell Dredging in San Antonio Bay, Tex., Vol. 5, Appendix D5.

Ingle, Robert M. 1952. Studies on the Effect of Dredging Operations Upon Fish and Shelfish, Technical Series No. 5, October, 1952. State of Florida Board of Conservation, the Division of Oyster Culture, Tallahassee, Fla.

Kemmerer, Andrew J., Joseph A. Benigno, Gladys B. Reese and Frederick C. Minkler. 1973. Summary of Selected Early Results from The ERTS-1 Menhaden Experiment. Fishery Bulletin Vol. 72, No. 2, 1974. p. 375–389.

Kroger, Richard L. and James F. Guthrie. 1972. Effect of Predators on Juvenile Menhaden in Clear and Turbid Estuaries. Marine Fisheries Review, Nov.-Dec., 1972. Vol. 34, Nos. 11–12. p. 79–80.

Kutkuhn, Joseph H. 1966. The Role of Estuaries in the Development and Perpetuation of Commercial Shrimp Resources. A Symposium of Estuarine Fisheries, American Fisheries Society Special Publ. No. 3; p. 16–36.

Lichtenheld, Richard W. 1970. Schooling and Migratory Behavior. U.S. Fish Wildl. Serv. Circ. 350. p. 26–29.

Lindner, Milton J., and James S. Bailey. 1969. Distribution of Brown Shrimp (*Penaeus aztecus aztecus IVES*) as Related to Turbid Water Photographed from Space. U.S. Fish Wildl. Serv. Fish. Bull: Vol. 67, No. 2. p. 289–293.

Longhurst, Alan, Michael Colebrook, John Gulland, Robin Le Brasseur, Carl Lorenzen, Paul Smith. 1972. The Instability of Ocean Populations. New Scientist, 1 June, 1972.

Mackin, John G. 1961. Canal Dredging and Silting in Louisiana Bays. In: Publications of the Institute of Marine Science, Univ. Texas, Port Aransas, Tex. Vol. 7. p. 262–314.

Maughn, Paul M., and Allan Marmelstein. 1974. Application of ERTS-1 Data to the Harvest Model of the United States Menhaden Fishery. For: Goddard Space Flight Center, Greenbelt, Md. p. 1–49.

Mock, Cornelius R. 1966. Natural and Altered Estuarine Habitats of Panaeid Shrimp. Proc. of the Gulf and Caribbean Fisheries Institute, 19th Annual Session. p. 86–98.

Reintjes, John W. 1970. The Gulf Menhaden and Our Changing Estuaries. Proc. Gulf and Caribbean Fisheries Institute, 22nd Annual Session. p. 87–89.

Reintjes, John W., and A. L. Pacheco. 1966. The Relation of Menhaden to Estuaries. In: R. F. Smith, A. H. Swartz and W. H. Massmann (editors), A Symposium on the Estuarine Fisheries, p. 50–58. Am. Fish. Soc. Spec. Pub. 3.

Tagatz, Marlin E., and E. Peter H. Wilkens. 1973. Seasonal Occurrence of Young Gulf Menhaden and Other Fishes in a Northwestern Florida Estuary. NOAA Tech. Rep. NMFS SSRF 672.

Tihansky, D. P., and N. F. Meade. 1974. Estimating the Economic Value of Estuaries to United States Commercial Fisheries. Manuscript.

Viosca, Percy, Jr. 1958. Report of the Seafood Section, Oysters, Water Bottoms and Seafood Division, Seventh Biennial Report. Wildl. and Fish. Comm. 1956–1957, p. 96–106.

LIMITING FACTORS AFFECTING THE COMMERCIAL FISHERIES IN THE GULF OF MEXICO

SEWELL H. HOPKINS
SAM R. PETROCELLI
Texas A&M University
College Station, Texas

ABSTRACT

The gulf coast, with 13 percent of the U.S. coastline producing one-third of the Nation's fisheries catch, is enriched by the Mississippi and many smaller rivers. The same river water that brings in food and fertility also brings pollutants from cities, industries and agricultural areas. So far, this pollution has not provably affected the commercial fisheries, except that closure of some bay areas by health authorities has hurt the oyster fishery. But over 95 percent of gulf fisheries production is based on species that depend on estuarine nursery areas and are therefore vulnerable to pollution and other man-made changes in estuaries. Fish kills and decreased reproduction in some areas warn of what could happen if conditions get worse. Research is needed on the costs as well as the benefits of man's activities, including pollution and pollution control, as population increases.

DESCRIPTION OF THE COAST OF THE GULF OF MEXICO

Inshore Waters and Estuaries

Some 1,000 miles of the gulf coast has an excess of precipitation over evaporation, and all of the nearshore gulf waters are strongly diluted by fresh water from floods or heavy local rains. All gulf coast rivers together flow into the gulf at the average rate of approximately 829,000 cubic feet per second or roughly 600,000,000 acre-feet of fresh water annually. Approximately 80 percent of this flows into the gulf on the Louisiana coast. Alabama contributes 8.3 percent, Florida 6 percent, Texas 4.4 percent, and Mississippi 1.3 percent of the fresh water entering the northern Gulf of Mexico.

The northern gulf is dominated by the Mississippi River, which flows into the gulf at the average rate of 620,000 cubic feet per second. The river water brings with it large quantities of dissolved nutrients, suspended organic matter, and nutrients absorbed on clay and silt particles, so that there is a broad area (over 400 miles) of enriched estuarine water surrounding the mouth of the Mississippi. Gunter (1963, 1967) called this the "Fertile Fisheries Crescent" and pointed out that 21 percent of the total fisheries catch of the United States was landed within this area. The percentage is higher now.

Estuarine waters on the gulf coast include large areas of low marsh that are flooded by fresh water in rainy weather and by salty water during high tide periods. Also, estuarine waters do not end at the "passes" (bay mouths), but continue into the gulf for variable distances. St. Amant (1973) estimated the gulf coast estuarine area, including only areas with water of salinity 5 parts per thousand (ppt) or higher, at 7.84 million acres (12,250 square miles). Chapman (1973) gave a figure of 12.4 million acres (19,375 square miles). Gunter (1967) counted 33 "bay systems and sounds" averaging about 550 square miles, or a total of 18,150 square miles, but pointed out that the actual area of estuarine waters normally includes parts of the gulf that have low salinities, and varies according to season and weather conditions from 17,000 to 20,000 square miles (10.88 to 12.80 million acres). (See Fig. 1.)

Commercial Fisheries of the Gulf States

Although it makes up only 13 percent of the total coastline of the United States, the gulf coast in 1972 produced 32 percent of the total U.S. fisheries catch, based on value, and 34 percent of the volume. In 1973, gulf coast fishermen landed 1,229 million pounds of marine and estuarine fish worth $63 million, and 246 million pounds of salt water shellfish worth $170 million. The total value of gulf fisheries landings was $223 million in 1972 and $233 million in 1973, based on prices paid fishermen at the dock.

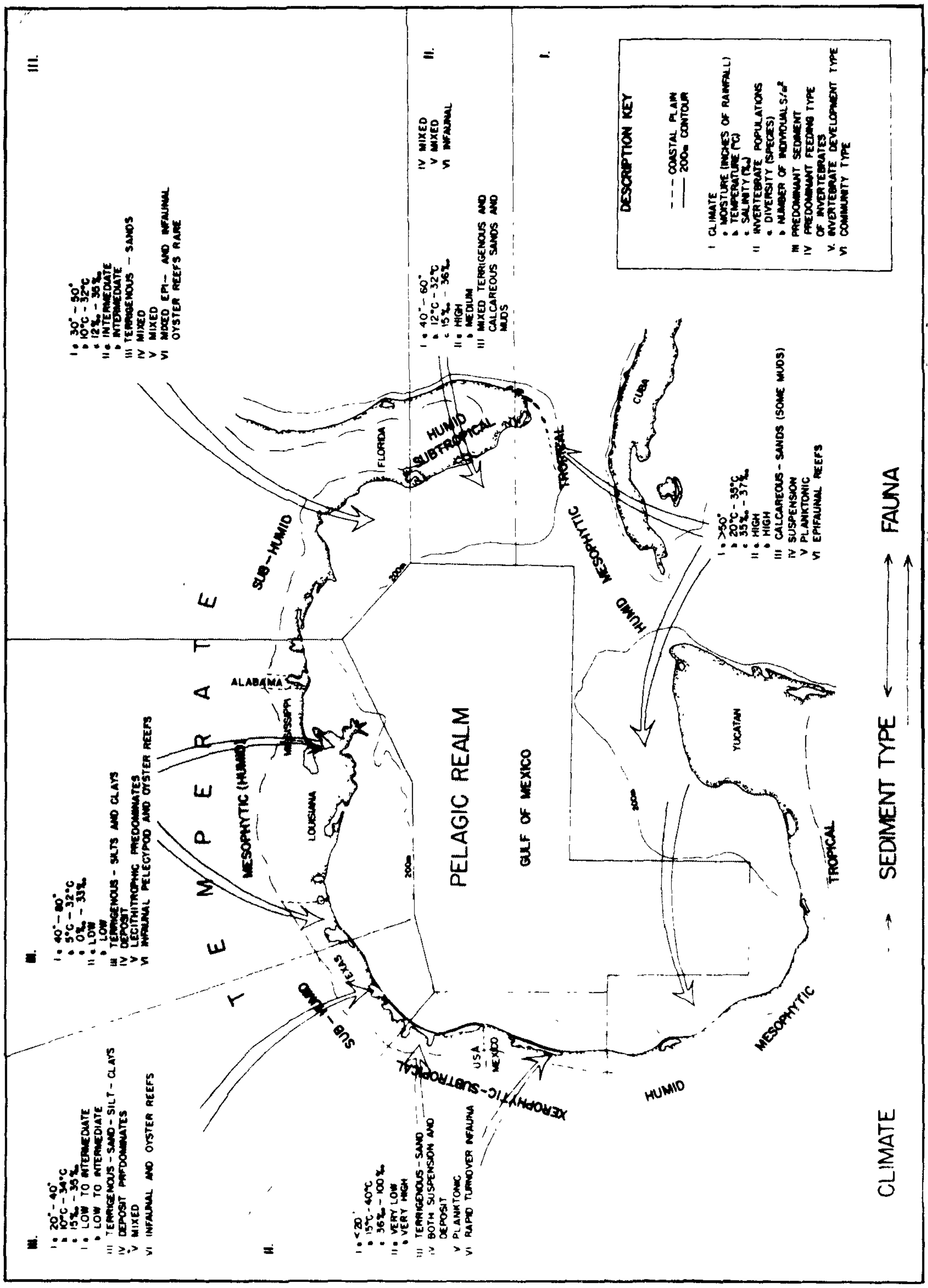


FIGURE 1.—Ecological chart: Gulf of Mexico (from Parker, 1974. Elsevier).

(Of course the wholesale value was higher, and the value of processed fishery products was much higher; retail value is roughly three times dock value.)

Several features of the gulf coast commercial catch are worth noting here.

(1) It is dominated by the shellfisheries, and especially by shrimp, crabs and oysters, usually worth three to four times more than the much greater volume of finfish.

(2) The finfish volume is dominated by menhaden. This industrial fish, which is processed to produce oil, fish meal and solubles worth ultimately many times the original value of the catch, is the number one fish of the United States in volume and among the top five in value. Approximately 60 percent of the U.S. menhaden catch is landed on the gulf coast.

(3) Nearly all of the gulf coast catch, including practically all of the menhaden, is made within the waters of the United States, or in international waters within a few miles of the U.S. coast. Of the important commercial fishes, only groupers and red snappers are caught mainly beyond the 12-mile limit, and they make up only 1 percent of the volume and 2 percent of the value of the total gulf coast catch.

(4) As Gunter (1967) has pointed out, 97.5 percent of the total commercial fisheries catch of the gulf states is made up of fishes and shellfishes that spend all or part of their lives in estuaries. A few species, such as the commercial oyster, live their entire lives in estuarine waters.

(5) Because gulf coast commercial fisheries are based on species that are mostly estuary-dependent, they are especially vulnerable to pollution. The fresh water of gulf coast rivers brings in residues of pesticides, defoliants, fertilizers, et cetera, used to produce crops on millions of acres of farmland. On the way to the gulf the rivers receive discharges from many city sewage systems and industrial plants, drainage from oil fields and mines, and so forth. So far, these contaminants do not seem to have reached the gulf in concentrations sufficient to conspicuously harm commercial fisheries, but that seems possible in the future if pollution continues to increase.

The typical gulf life cycle involves spawning in or near the gulf, in water of near-oceanic salinity, migration of the newly hatched juveniles to estuarine waters, then growing up in the shallows where young fish are protected from predators by vegetation, by poor visibility due to muddy water, or by salinity too low for most predacious fishes. These estuarine shallows are known as nursery areas. Some fishes leave the bays before becoming mature and others spend all or almost all of their lives in estuarine waters. The commercial fisheries can be maintained only by keeping the nursery areas productive.

Gunter (1967) and others have pointed out that most of the gulf commercial catch is made close inshore (inside the 12-mile limit, or within sight of shore), in waters that can be considered estuarine since they are affected by the fresh water and turbidity from rivers. For instance, the menhaden fishery, the most important commercial fishery in the gulf by volume of catch, is conducted entirely in estuarine waters of the gulf, according to Gunter (citing Christmas, Gunter and Whatley, 1960); catches are made in salinities from 6 to 32 ppt (compared to 34–36 ppt in the open gulf). Most of the drums, croakers, sea trouts, flounders, king whiting, and sheepshead are caught even closer inshore, or in the bays themselves.

The shellfishes, by far the most valuable part of gulf coast commercial fisheries, are even more estuarine than the finfishes. The principal commercial species of shrimp (white, pink, and brown) spawn in the gulf, but most of the progeny that survive to complete the life cycle are those that find their way into the estuaries and grow up in the low-salinity nursery areas (Venkataramiah, Lakshmi, and Gunter, 1974). Shrimp are worth roughly 10 times as much as all finfishes combined, excluding menhaden. The second most important crustacean, the blue crab, also spawns in the gulf and grows up in the estuaries; females return to the gulf (or lower ends of bays) when mature, but most males spend their entire lives in estuarine waters.

The third most important shellfishery is that based on the commercial oyster, which spends its entire life cycle in estuarine waters. Oyster production has been hurt more by pollution than any other fishery. When a bay is closed or condemned because of contamination by domestic sewage or industrial wastes, the oyster is the main species affected, and it is oyster fishermen and oyster farmers that are hurt (not to mention oyster dealers and consumers). Other commercial molluscs are of relatively minor value on the gulf coast.

What is the productivity of gulf coast estuarine waters in pounds of commercial fish and shellfish per acre? Depending on whether one accepts the 12.4 million acres of estuarine water (including gulf waters of lowered salinity) calculated by Chapman (1973) or the 7.84 million acres of St. Amant (1973), the present commercial production is 117 or 185 pounds per acre per year. Mullet, croaker, spot, sea trouts and drums could probably stand up under heavier commercial fishing. Present commercial catches of some species are small compared to mortalities from natural causes, as pointed out by Simmons and Breuer (1962), and by Gunter in several publications. It seems possible that a commercial fisheries production of 200 pounds per acre per year could be reached and maintained in the gulf coast estuarine area.

NATURAL FACTORS LIMITING GULF COAST FISHERIES

Climatic and Physical Conditions

Temperature has two important effects on gulf coast fisheries: the high average temperature of the water hastens sexual maturity and shortens life of some fishes, and the extreme low temperatures of the shallow bays during northers cause mass mortality of fish every few years.

Gunter (1950) pointed out that such abundant fishes as the croaker, spot, spadefish, butterfish and harvestfish, which are important commercial food fish in the Chesapeake Bay and Middle Atlantic states, seldom reach marketable size on the gulf coast.

The most spectacular effect of temperature is the killing of millions of fish by extreme cold spells about once per decade in Texas (Gunter, 1941, 1945, 1952a, 1956; Simmons, 1957; Breuer, 1962; Simmons and Breuer, 1962) and in Florida (Storey and Gudger, 1936; Storey, 1937, and others). The best documented cold kill, in 1951, was estimated by Texas Game and Fish Commission biologists to have killed 60 to 90 million pounds of fish on the Texas coast. Simmons and Breuer (1962) stated that "Catastrophic freezes occurring about every 10 years have each destroyed more fish than have been harvested commercially for the past 50 years." Actually the bay water does not freeze, but drops quickly to about 4°C (39°F) and remains there for several days. Observed mortalities have included very few animals other than fish. Fish catches return to normal levels in two or three years.

Salinity extremes also affect some gulf fisheries adversely at times. The Laguna Madre of Texas and Mexico is one of the few places in the world where hypersalinity becomes so extreme as to cause mass mortality. Before the Intracoastal Waterway was dredged through the 120-mile length of the Laguna Madre of Texas, about 1949, this shallow lagoon, in a region where evaporation is normally twice as high as precipitation, often developed salinities of over 80 ppt, and sometimes over 100 ppt. The mass fish kills that were formerly caused by extreme hypersalinity have been practically eliminated by the improved circulation via the Intracoastal Waterway, according to Simmons (1957) and Hedgpeth (1967).

Low salinity caused by heavy rains during hurricanes sometimes kills fish and crustaceans in the Laguna Madre, where salinity may drop from 50 ppt to nearly zero on such occasions. In the more normal estuaries fish, shrimp and blue crabs are not killed by heavy rains or flooding, but are swept downbay by floods and escape into saltier waters by swimming with the current.

Oysters in normal estuaries are often killed by low salinity in all gulf states. The most spectacular oyster kills on the gulf coast occur in Mississippi Sound and the waters of the Louisiana marshland on the eastern side of the Mississippi River delta. In bad flood years it is necessary to open the Bonnet Carré spillway in order to prevent flooding New Orleans. Millions of oysters are killed by fresh water on these occasions, over an area of many square miles. Predators and parasites of oysters are also killed out. Then the oyster reefs are repopulated by larvae brought in by currents, and the next two or three years may see unusually large crops of oysters before the pests become reestablished (Gunter, 1952a, b, 1953, 1967).

Although such local freshwater kills seem at the time to be disasters, in the long run they are beneficial. The largest and densest populations of oysters develop in these areas that are frequently cleared of predators, pests and diseases, and not in the areas of higher and more stable salinity, because the same waters of near-oceanic salinity that are physiologically most favorable to oysters also favor a diversity of marine organisms, many of which are harmful to oysters.

For this reason, "salinity intrusion" in estuaries worries oyster biologists. Other fishery biologists also worry, fearing that increases in salinity will make the estuarine nursery areas less suitable for the survival and growth of juvenile fishes and crustaceans (blue crab, shrimp). Gradual increase in salinity, year by year, occurs when there is rise in sea level, sinking of land, and erosion of shores, making bays and passes wider. All of these processes are going on along the gulf coast, but faster in some parts than in others. Local subsidence of land makes estuaries larger, deeper and saltier.

In southeastern Louisiana the entire coastal area is sinking. New sediments used to be deposited in the swamps and marshes and along the shores by the annual floods of the Mississippi River. All distributaries except Atchafalaya River are now cut off by levees, so there are no longer new deposits of sediments (Morgan, 1973). The inevitable result of reduced freshwater inflow, increased land subsidence and erosion, and rising sea level is an increase of salinity in the waters of the marshland estuaries. Consequently, marine animals, including predacious fishes that feed on juvenile fishes, crabs and shrimp, and the numerous enemies of oysters, penetrate farther and farther into the bays.

There are a few bays on the gulf coast with sandy shores and bottoms, and clear water. These are less productive than the typical gulf coast estuary, which has a mud bottom and highly turbid water rich in nutrients and organic sediments, either from a river or from surrounding marshes (Day, Smith, and Hopkinson, 1973; Odum, Zieman and Heald, 1973). It is the large area of muddy, low-salinity water that makes the northern gulf so productive of fish and shellfish.

The oyster is the only important gulf coast fisheries species that is known to be adversely affected by high turbidity and sedimentation; it is well adapted to turbid waters, but oyster beds are sometimes killed when buried in sediments. This happens naturally when floods deposit thick layers of sediment or storms shift the bottoms. It can also be caused by nearby dredging operations.

Gulf coast bays are so shallow (most are less than 10 and some less than 5 feet deep) that they are well aerated by wave action and seldom have pockets or layers of water deficient in oxygen. A famous exception is Mobile Bay. When deoxygenated water from deeper layers invades the shallows, thousands of fish, crabs and shrimp swim on the surface and concentrate in the shallows along the shoreline. This phenomenon has been known for at least a century as "the Jubilee" (Loesch, 1960). Apparently the deoxygenation of the water results from decay of plant debris occurring naturally on the bottoms, but organic pollution, if present, could make "jubilees" more frequent, more extensive, or more intense.

Red Tide (Phytoplankton Blooms)

A mass mortality of fish and shellfish on the southern part of the west coast of Florida occurs at intervals of several years, accompanying an area of discolored water. In recent years this has been called "red tide," although the water is not always really red. Since 1947 the gulf red tide has been known to be caused by a "bloom" of one particular dinoflagellate, *Gymnodinium breve*. All of the factors that must occur together to make this normally scarce organism explode into a population density of millions per liter are not yet known. During a red tide outbreak millions of fish die and many drift ashore, where they pile up on the beach in windrows and decay. Lesser red tide outbreaks have also been reported as rare phenomena on the Texas coast. Like the Mobile Bay "Jubilee," red tide outbreaks seem to be strictly natural phenomena that probably occurred when America was uninhabited. See Gunter, Williams, Davis and Smith (1948), Wilson and Ray (1956), Ray and Wilson (1957), Ingle and Martin (1971), Baldridge (1974), Wilson, Ray and Aldrich (1974), and Steidinger (1973, 1974).

Diseases of Fish and Shellfish

All animals have parasites and diseases. Fishes, crustaceans and molluscs are no exceptions, having the usual diversity of parasitic worms, protozoans, fungi, bacteria and viruses, plus some little crustacean parasites and parasitic algae. Gulf fishes are not known to have any disease or parasite that causes mass mortality or epidemics such as those that control sea herring in the Atlantic (Sindermann, 1970).

Oysters have many parasites and diseases, in various parts of the world. The most important parasite on the gulf coast is a fungus, or perhaps several closely related species of fungus, causing a tissue-destroying disease commonly known as "dermo." This disease starts to kill oysters in spring as soon as water temperatures rise above 20°C and continues to kill them until cool weather lowers water temperatures in autumn (Mackin, 1962). Mortality is highest in the higher salinities and at the higher temperatures. Annual mortality from this cause often exceeds 50 percent. This mortality is in addition to the more obvious killing by predators such as the stone crab, the blue crab, the boring snail, and several species of fish. All of these agents of oyster mortality are most abundant and most active in high salinity, which is the reason oysters survive better in the low salinities. Oystermen therefore fear "salinity intrusion" and oppose engineering activities that may cause increase in salinity.

MANMADE FACTORS LIMITING COMMERCIAL FISHERIES

Man has introduced new factors that limit commercial fisheries in gulf estuarine areas. These manmade factors will be discussed under three headings: engineering activities, pollution, and laws.

Engineering Activities

Most of the types of human alteration of coastal environment that are here called "engineering activities" have been discussed in a report by Cronin, Gunter and Hopkins (1971). That report also makes recommendations for the kinds of research needed on each of the problems caused by these works of man. Among the engineering activities analyzed in the 1971 report are: channel dredging, filling and spoil disposal, damming and diversion of rivers, levees and spillways, land-cut canals, jetties at passes between bays and the gulf, hurricane barriers, oceanic disposal of dredged materials and other wastes, "finger-type" (canal and fill) real estate developments, and various types of wetland modification.

To us it seems that the changes caused by engineering activities have possibilities of more serious damage to commercial fisheries than other effects of man's activities, because the changes tend to be permanent and irreversible. Fishery populations soon recover from overfishing if allowed to, and polluted waters return to normal when the pollution is stopped (even long-lasting pesticides and toxic metals becoming buried in sediments), but when open bay or marsh is destroyed by a real estate development that replaces vegetated shallows or marshes with stagnant, dead-end, vertical-walled canals, an area of nursery ground is partly taken out of production for many years (Trent, Pullen and Moore, 1972).

The gulf coast has the most highly developed estuarine and offshore oil fields in North America and perhaps in the world (with some 8 to 10 thousand wells in the gulf and thousands more in bays and marshes). The engineering activities in coastal oil field development in Louisiana and Texas involve the dredging of channels, including canals through marshlands, to develop fields in the marsh and bay areas. The damage done (especially to oyster beds) by activities of this type is probably more important than oil spillage. Exploitation of oil fields in the gulf, often many miles offshore, is conducted by drilling a number of wells from each drilling platform. If oil or gas is found, pipelines must be laid connecting the producing wells with shore installations. Shore installations must be built to receive and process petroleum production and to harbor, load and unload the vessels used in offshore operations. All of this necessarily causes some modification of the shore and shallow sea environment. Excepting oystermen, gulf commercial fishermen have not complained of any losses attributed to oil field operations other than damage to trawl nets from pipes, dropped tools, and other obstructions left on the bottom by the oil men.

Pollution

As a result of the increased utilization of the coastal zone for domestic residence, recreation and industrial production, the possibility of pollution of the environment has increased. The population of the gulf coastal zone has increased about 2 percent per year since 1960; at least a million people have been added during this period.

Increases in domestic wastes necessitate the construction of sewage treatment plants. Raw sewage released into rivers and eventually into the gulf, partially treated sewage, detergents, phosphates, nitrates, pesticides, petroleum hydrocarbons, and other compounds are all discharged into estuaries as "municipal wastes." Many of these compounds are directly toxic to commercially important species; some are toxic in combination with others; some cause excessive nutrient enrichment resulting in an abnormal proliferation of certain species, many of which are considered undesirable by man; and some have high biochemical oxygen demands (BOD) requiring large amounts of oxygen for their breakdown and producing oxygen-depleted water masses.

The development of recreational facilities to serve coastal residents and vacationers presents related problems. More than 2 million visitors vacation on the gulf coast of Florida alone. Certain types of recreational use place a heavy pollution load on a relatively small area. Marinas, for example, may result in large amounts of gasoline, oils, lead, phenols and organic wastes being added to the estuary. Boat use in Florida has more than doubled since 1960.

Industry has long recognized the value of estuaries for waste disposal. Among the industrial wastes which have been introduced into gulf coast estuaries are heavy metals, plasticizers including PCBs and phthalates, petroleum hydrocarbons, pesticides (organochlorines, organophosphates, carbamates and dioxins), and various other compounds. In most cases, relatively little is known regarding the toxicity of these materials to fish and shellfish. Virtually nothing is known of the sublethal effects of these compounds on chronically exposed organisms.

Agricultural practices may also result in pollution of the coastal zone through the addition of fertilizers and organic wastes. Pesticide usage on agricultural and livestock producing lands or in the abatement of insect nuisances in populated areas adjacent to estuaries has resulted in contamination of estuarine organisms, including some commercially important species.

The need for power to supply coastal inhabitants has increased. Power plants require large areas of land and large volumes of water for their operation. Many commercially important species, especially their larval and juvenile forms, are trapped and killed on the intake screens of power plants, in their passage through the plant itself or in discharge ponds or canals where heated water (thermal pollution) and chemicals such as chlorinated algicides are released (Chesapeake Science, Volume 10, pages 125–296 (1969); personal observations). More specific and detailed information on pollution is presented in a later section of this paper.

Laws

In general, two kinds of laws limit commercial fisheries: public health laws intended to safeguard the health of the consumers of seafood, and conservation laws intended to prevent over-exploitation of commercial species.

Public health laws include those providing for inspection of shellfish, and the waters in which they grow, by state sanitation officers. If coliform bacteria (bacteria similar to those in the human intestine) are found to be too abundant in water or shellfish, or if inspection of the shoreline shows possible sources of pollution, a certain estuarine area or an entire bay may be closed, meaning that no shellfish can legally be taken in that area. Although such closures of shellfishing areas are often hard on local fishermen, in the long run they are beneficial to the fishing industry. These laws and their enforcement not only protect consumers, but help maintain public confidence in the wholesomeness of seafoods.

Conservation laws are more controversial. Often they are products of political pressures, and of prejudices and emotions rather than science. The worst restrictions on commercial fisheries are those demanded by sport fishermen to maintain a monopoly for themselves. Pressure by sport fishermen has resulted in closing Texas bays to netting for fish. There is even a movement on foot to outlaw the sale in Texas and Louisiana of such marine fishes as spotted trout and red drum because they are game fishes. As Gunter and other fishery biologists have pointed out, at least some food and game fish populations are probably underfished at present, and the numbers of fish killed by natural causes (freezes, red tides, predators, and old age) may far exceed those caught by all sport and commercial fishermen combined.

TRENDS, EFFECTS OF TRENDS, AND SPECIFIC CASES OF POLLUTION

In 1959 Gordon Gunter reported on "pollution problems along the gulf coast." He mentioned sewage pollution, pulp and paper mills, fish processing plants, chemical plants, sugar refineries, oil refineries, and so forth, but commented "I am happy to say that the gulf coast is probably freer from pollution than any other area of the United States coast at present." Gunter stated that Galveston Bay was "the only heavily industrialized area on the coast of the Gulf of Mexico," but pointed out that 38 percent of the sport fishing in Texas was done in the Galveston Bay area, that 36.5 percent of the Texas catch of four common sport fishes was caught in Galveston Bay and its branches, and that this area still contained some of the best oyster reefs in Texas. The conditions in Galveston Bay are nearly the same today. Approximately half of the bay area has long been closed to shellfishing because of sewage pollution, yet the remaining half has produced more oysters annually during the last decade than in any period prior to 1960, and there is still excellent sport fishing in the bay.

Biglane and Lafleur (1967) revealed the appearance of some gulf coast pollution problems not mentioned by Gunter, especially the beginning of fish kills in Louisiana fresh and coastal waters that were shown by U.S. Public Health Service scientists to be caused by insecticides such as endrin. The other pollution problems they mentioned were attributed to what we have called engineering activities: leveeing of the Mississippi River, change of marshland drainage patterns by dredged channels, and so forth.

The most obvious effect of pollution is the direct mortality in what has been termed "fish kills." According to Environmental Protection Agency (EPA) statistics, the numbers of reports of fish kills and the number of fish killed have increased since the survey was begun in June 1960. The number of fish kill reports increased from 465 in 1969 to 634 in 1970 and to 860 in 1971. There has also been a general upward trend in estimated numbers of fish dying in fish kills, at least through 1971 (when 74 million fish were reported killed).

Every one of the Gulf Coast States has experienced significant fish kills which have been attributed to agricultural, industrial or domestic wastes. Since 1965, either municipal wastes (sewage) or industrial wastes have been reported as the principal cause of fish kills in the United States for each year. In 1971 the major identifiable cause of fish kills was reported to be "sewage system wastes" with "pesticides" second at about one-half that level (US EPA, 1972). These data do not exactly pinpoint the problem since municipal sewage contains significant amounts of petroleum products, metals, pesticides, and other industrial materials as well as organic wastes.

Most fish were killed in fresh water from 1965 to 1969. However, in 1971 there was a decrease in the number of dead fish reported from freshwater bodies and a sharp increase in the numbers from estuarine areas for the first time since these statistics were first compiled (1960). During recent years, a single kill or relatively few accounted for a considerable percentage of the total kills for that year. Statistics for 1971 reveal 29 million fish killed in 12 incidents in Florida (Escambia Bay) and 16 million in six incidents in Texas (Galveston Bay).

Three points need to be made here. The first concerns the kinds of fish killed. When kills are caused by sewage pollution, the first fish killed in estuaries are likely to be menhaden, which though important because of their abundance, are cheap fish (worth four cents a pound in 1973). Second, the numbers of fish reported killed on the gulf coast by pollution are less impressive when compared with the 50 to 90 million pounds (perhaps equal to 200 to 360 million fish) killed by a single freeze on the Texas coast in 1951, or the 500 million fish estimated to have been killed by a single red tide outbreak off Florida in 1946–1947 (Gunter, Williams, Davis and Smith, 1948), not to mention the 1.2 to 1.8 billion pounds of fish caught annually by commercial fishermen and the 400 to 500 million pounds taken by sport fishermen. Third, fish kills are important not because of the loss of fish, but because they serve as warnings that the environment is in danger. If the condition that caused the kill is only temporary, other fish will quickly replace the ones killed and there will be no real loss. If it is persistent, replacement may be prevented, or the replacements may be less desirable species. Massive fish kills impress the general public much more than increases in bacterial counts or metal content of fish and shellfish, and are more likely to stimulate action against degradation of the aquatic environment.

Another demonstration of the effects of pollution of the environment on commercial fisheries is the closing of estuarine areas to the taking of shellfish. In most cases, closure is ordered by the state department of health based on bacteriological criteria. These criteria are based on levels determined by the state and on levels allowed by the Food and Drug Administration (FDA) for interstate shipment.

The largest Texas area permanently closed to shellfishing is in the Galveston Bay area, nearly half of which has long been closed. There have been no significant changes in the acreage permanently closed in Texas bays since 1970, but some bays have been closed temporarily after floods, as in the spring of 1972 (Texas State Department of Health). The Louisiana Department of Wild Life and Fisheries (Perret et al., 1971) reported 139,905 acres closed to shellfishing, and in 1972 additional areas were temporarily closed after flooding (NOAA-NMFS Louisiana Landings, 1974). Varying acreages of Mississippi bays have been closed in recent years; Biloxi Bay has apparently been permanently lost for oystering (Christmas, 1973). The Alabama Conservation Department reported almost 74,000 acres permanently closed to shellfishing, with additional acreages temporarily closed when floods carried sewage contamination into other areas (Crance, 1971; May, 1971). During 12 of the 18 years from 1952 to 1970, lower Mobile Bay was closed for taking of shellfish at least part of the year because coliform bacteria counts exceeded 70 per 100 ml of water. Each such closing causes economic loss; the loss in 1969 was estimated to be $500,000. In 1972, after floods, Mobile Bay oystering areas remained closed 217 days (NOAA-NMFS Alabama Landings, 1974). McNulty et al. (1972) reported that on the Florida gulf coast 170,698 acres of estuarine areas were closed for shellfishing.

Any general trend that may exist in the closing of estuarine areas to shellfishing on the gulf coast as a whole is obscured by the local changes (opening and closing) from year to year or month to month as pollution conditions change back and forth. Closures were especially harmful to the oyster fishery in 1973 because of extensive flooding, but the increased production in 1974 tended to compensate for this.

Pollution of estuaries, besides causing the closing of fishing areas, also results in the seizure and condemnation of commercial fisheries products when pollutant residue levels or bacterial counts are above the tolerances established by the FDA for interstate shipment. The contamination of estuarine species by various pollutants has been well documented. Residues of the DDTs (including DDT, DDD and DDE), dieldrin, mirex and other organochlorine insecticides have been detected in oysters, other bivalves, blue crabs, shrimp and fishes collected from estuaries along the gulf coast (Butler, 1973; Petrocelli et al., 1973, 1975a, 1975b; Childress, 1968, 1971). DDT and PCB residues have been detected in the tissues of fish, crabs, shrimp and squid collected from offshore waters of the Gulf of Mexico (Giam et al., 1972).

Butler (1973) in a monitoring study during the period 1965 to 1972 found that DDT was the most common pesticide and dieldrin the second most common in molluscs. The incidence of DDT residues (the percentage of samples in which DDT or products of its decay could be detected) was 63 percent and that of dieldrin 15 percent. Butler described a general decline in both the number and magnitude of DDT residues in oysters over the 7-year period. The data for the gulf coast samples are as follows:

State	*Frequency (%) of residues detected in samples and (maximum value in ppb)*				*Date of survey*
	DDT		*Dieldrin*		
Alabama	100%	(616)	18%	(21)	1968–1969
Texas	73%	(1249)	18%	(87)	1965–1972
Florida	62%	(5390)	7%	(28)	1965–1972
Mississippi	61%	(135)	4%	(20)	1965–1972
Louisiana	no data				

Heavy metal residues have also been found in the tissues of estuarine species (Saha, 1972; Eisler 1973). According to public health officials, relatively few seizures or condemnations of commercial fishery products due to pesticide or heavy metals contamination are made compared with seizures resulting from elevated bacteriological levels. However, as research better defines the sublethal effects of these compounds, human tolerance limits, as set by law, may be lowered thus increasing the possibilities of commercial fishery products exceeding these levels. Assuming no further input of these compounds into estuaries, this situation would significantly decrease the amount and value of marketable products. Any increases in the levels of pollutant added to estuaries in the future would even further complicate this problem

UNKNOWN EFFECTS

Possibly the most insidious effect of pollution on the commercial fisheries is one which is the least understood and is only now being considered on a broad level. This is the effect of pollution on the ability of organisms to reproduce and for their larvae and juveniles to develop normally to mature adults fully capable of successful reproduction.

It has been hypothesized that high concentrations of DDT in the ovaries of sea trout are responsible for declines in their population through decreased reproductive success or decreased survival of juveniles on the Texas coast (Butler et al., 1972, Childress, 1971). Monitoring of pesticide residues in oysters (*Crassostrea virginica*) and fish of various species from bays on the Texas coast began in July 1965 and January 1967, respectively. Childress (1965, 1966, 1968, 1971) reported DDT incidence in oysters remaining at about the same level from 1965 to 1967 with a slight decrease from 1967 to 1968. The incidence of dieldrin residues (the percentage of oyster samples in which dieldrin residues could be detected) increased from 1 percent in 1965 to 23 percent in 1967. The incidence of endrin residues increased from .02 percent in 1965 to 1 percent in 1966–1967 in the oysters sampled by Childress. (The oyster is a good test animal for monitoring pesticides or metals in the estuarine environment because it filters huge quantities of water and tends to accumulate materials in its tissues.)

During this study period Breuer (1971, 1972), reported on the historical and recent abundance of spotted sea trout (*Cynoscion nebulosus*) in the lower Laguna Madre. Sea trout juveniles were abundant in 1958–1959 but declined in abundance through the 1971 sampling period. In 1969, only 21 juvenile sea trout were identified in a total of 21,473 marine organisms collected. In 1971, five juveniles and no adults were captured using the same sampling techniques. Pesticide residue analysis of juvenile menhaden, on which sea trout feed, revealed whole body concentrations of 1.520 ppm of DDT in 1966 and 5.180 ppm in 1967 (Breuer, 1971). Ovaries of adult sea trout in the Arroyo Colorado area (lower Laguna Madre) contained DDT residues as high as 7.980 ppm, dieldrin residues to 0.170 ppm and endrin levels of 0.054 ppm (Childress, 1968). Distribution of insecticide residues (ppm) in these fish were:

	DDT	*Dieldrin*	*Endrin*
ovaries	6.280	0.028	0.017
brain	0.958	—	—
liver	7.560	—	—

From the data it appears that DDT has had an adverse effect on the reproductive success of the local sea trout. It should be explained that the Arroyo Colorado is a waterway draining part of the intensely cultivated farmland and citrus groves in the irrigated area known as "The Valley" in Texas.

Behaviorally, it has been reported that some aquatic species are actively attracted or repelled depending on other interacting parameters by pollutants such as copper and petroleum hydrocarbons (Kleerekoper, et al., 1973; Jacobson and Boylan, 1973).

Still another effect which has recently come to light is the interaction among pollutants and between pollutants and natural stresses. Nimmo (pers. comm.) and recent work by Petrocelli (not yet published) have shown that salinity shock, such as occurs in the estuary in the course of heavy rainfall or river flooding, combined with exposure to sublethal concentrations of pollutants results in mortalities not predictable on the basis of the salinity change or toxicity of the pollutant alone (Petrocelli et al., unpublished data; Anderson et al., 1974; Roesijadi et al., 1974). In some cases, this effect can be attributed to changes in the physiological response of the animals to these stresses. For example, shrimp exposed to heavy metals or PCBs and salinity shocked have been shown to be less efficient than controls in the regulation of blood chloride ion levels to compensate for these changes. Overstreet (1974) described a kill of estuarine fishes, mainly mullets, in Mississippi, which was apparently caused by interaction between low salinity and low temperature, possibly complicated by pesticide contents somewhat higher than in surviving mullets. Interaction has also been observed in the case of other physiological factors. For example, crustaceans during molting are much more susceptible to pollutants than are the same animals during the intermolt stages (Petrocelli et al., 1974, unpublished data). In other studies, sheepshead minnow (*Cyprinodon variegatus*) juveniles chronically exposed (63 days) to sublethal concentrations of mercury (1.0 ppb) were observed to have a respiratory rate which was significantly lower than that of control fish (Petrocelli et al., 1974, unpublished data).

The biological effects of petroleum and its products are still largely unknown, in spite of all the literature. The problems are complex because the hundreds of crude oils are complex, each containing hundreds of compounds, and refining adds many more. Crude and refined oils change upon exposure to air and water, in different ways under different conditions. Though difficult, the many problems involved in the biological effects of petroleum products should be studied by more laboratories. Atlantic coast oil fields will soon be added to those in the gulf and Pacific. More important, we will soon have supertanker ports with possibilities for much greater oil spills than have ever occurred up to now.

The famous Santa Barbara oil loss was estimated at 3 million gallons (Holmes, 1969). The largest of the four big oil spills in the Gulf of Mexico fields was about 5 million. According to a 1974 report of the U.S. Bureau of Land Management, all oil losses of 50 barrels or more in gulf fields during the 10-year period beginning 1964 add up to 320.000 barrels (13.4 million gallons) out of 2.9 billion barrels produced. But these figures are dwarfed by the estimated 90,000–100,000 tons (27 to 30 million gallons) of crude oil spilled into the English Channel by the "Torrey Canyon" (Smith, 1970), which was smaller than the new supertankers. Nevertheless, if we continue to import oil we will have supertanker ports, so we should learn more about the ecological effects of petroleum.

To look at the bright side, the thousands of oil wells now producing in the gulf and in gulf coast bays have not caused any decline in commercial fisheries production. Louisiana, which has most of the oil wells, has had its largest production of shrimp and menhaden during the years when gulf oil fields were developing. (Of course we all know this was a mere coincidence, but would we have known this if catches had declined during that period?) Oyster production has suffered, mainly from damage done by channel dredging and other engineering activities and from loss of sales when oysters taste oily (as they do occasionally). The Louisiana experience shows that the petroleum and fishery industries can coexist, even though not in perfect harmony. Earlier studies on oysters in oil fields are summarized by Mackin and Hopkins (1962), and more recent reports on ecological effects of oil are reviewed by Moore, Dwyer and Katz (1973) and by Mackin (1973). See also Anderson, Neff, Cox, Tatem and Hightower (1974) and other reports by Anderson, Neff and colleagues, still in press but available as reprints.

NEEDED RESEARCH AND FUNDING

There appears to be a great deal of "fad" research being conducted. Particular pollutants are picked up, some papers published and then work begun on other compounds before definitive research has been completed. Recent examples of this include DDTs, then other organochlorine pesticides, metals, organophosphates, PCBs, petroleum hydrocarbons, plasticizers such as phthalates, et cetera. National priorities should be determined in workshops which include ecologists, physiologists, and analytical chemists who are interested in working with environmental pollution problems. These priorities should then be implemented through research grants or contracts. A central clearing office should be established to coordinate the whole effort, to insure adherence to overall goals and to prevent the current wasteful and unnecessary duplication of work funded by the various governmental agencies.

Funding should be on a minimum of a two year basis so that time and efforts will not be wasted in unnecessary proposal and report writing or in switching projects to obtain continued funding. Progress should be reviewed periodically (every six months), unproductive programs dropped, and program gaps filled by addition of new programs.

With regard to directions for research, it would be helpful to study sublethal as well as lethal effects of pollutants on physiological responses. It is the physiological responses that determine survival in the environment (as opposed to the laboratory), get the animal to its spawning grounds, determine the success of mating and egg-laying, and so forth. Survival in the laboratory does not necessarily mean that survival in nature is probable. For the same reason, effects of manmade factors on biochemical composition and activity, microscopic structure of tissues and cells, and other indicators of health of estuarine animals should be studied. Ability to reproduce and success of larval and juvenile stages in surviving, growing and developing, obviously should be included in any study of lethal and sublethal effects. Toxicity studies should include tests on animals at various stages of development, not just adults. Multifactor interactions (effects of various combinations of pollutants, salinity and temperature, for instance) should be more enlightening than studies of effects of single factors. To get still closer to the complex situations found in nature, field experiments (for instance, holding animals at various distances from a suspected toxic source, in pens or cages) are often useful. The object of all such studies is to find out what happens to the organisms in nature. In order to do this properly, field surveys and catch statistics, field experiments, and laboratory experiments are all needed, and should preferably all be done by one coordinated team.

Funding should be on the order of at least $100,000 per year for a moderately ambitious research project at a major university. This level would allow part-time salary for the principal investigator, salaries for about four graduate research assistants and technical help, small pieces of equipment and supplies. Narrower scale projects could be funded at a reduced rate. Broader projects including both field and laboratory studies would require more funding, roughly in proportion to the number of people involved.

SUMMARY

A natural pollutant, fresh water, excludes most marine animals from the inshore waters and shallow bays along much of the northern coast of the Gulf of Mexico. This makes these waters ideal for survival of animals that can tolerate lowered salinity, including the young of fishes and crustaceans that require gulf salinity when mature. Most species important in gulf fisheries spawn in the gulf or saltier bay areas, but the young migrate to the less saline estuarine waters and grow up in these nursery areas.

The same river water brings in the huge quantities of food, in the form of dissolved and suspended organic substances, that enable the northern gulf to produce 32 percent of the U.S. commercial fisheries production on 13 percent of the coast. The number of species is held down by the extremes of temperature and salinity, the high turbidity close to shore, and the frequent kills of marine species from natural causes: freezes, floods, red tides, et cetera. Dense populations of a few species are essential for good commercial fishing. Most gulf species are prolific and have short life cycles—1, 2, 3 or 4 years from reproduction to reproduction so that losses from natural disasters or from heavy fishing pressure are soon made up.

Unfortunately, the same river water that reduces salinity and contributes food also brings in manmade pollutants, both microbial and chemical. Man further endangers the fisheries by engineering activities—leveeing, dredging and filling, damming and diverting streams, and so forth. Gulf coast fisheries are especially vulnerable to such manmade changes because most of the catch is made within 12 miles of the shore, and over 95 percent of it consists of species that depend on estuarine nursery areas.

Destruction or poisoning of nursery areas could destroy most of the gulf coast commercial fisheries. So far, these fisheries have not been perceptibly hurt, excepting the oyster which is confined to estuaries. The damage to the oyster fishery has been mainly from engineering works, from oil contamination occasionally making oysters in a small area unsalable for a few weeks or months, and from closure of bay areas by health authorities because of sewage pollution.

Although gulf commercial fisheries other than the oyster fishery have apparently not yet been hurt by manmade changes, including pollution, they are in danger. There have been warning incidents - pollution kills of fish in a few areas, apparent prevention of reproduction of sea trout because of pesticide concentration in one area- to show what can happen. If shores continue to be altered by real estate developers, stream flow continues to be interfered with by levees, dams and diversions, and man's wastes and poisons continue to increase the gulf commercial fisheries will eventually be badly hurt. Research is needed to determine when the costs of man's activities reach the point where they exceed the benefits. We do not yet know all of the environmental costs, in a quantitative way, as we should. In the meantime, every effort should be made to avoid engineering activities and polluting that we know to be harmful.

REFERENCES

Anderson, J. W., J. M. Neff, B. A. Cox, H. E. Tatem and G. M. Hightower. 1974. Characteristics of dispersions and water-soluble extracts of crude oil and their toxicity to estuarine crustaceans and fish. Marine Biol. 27: 75–88.

Anderson, J. W., J. M. Neff and S. R. Petrocelli. 1974. Sublethal effects of oil, heavy metals and PCBs on marine animals. In: M.A.Q. Khan (ed), The Mechanisms of Survival in Toxic Environments. Academic Press, London and New York.

Baldrige, H. D. 1974. Temperature patterns in the long-range prediction of red tide in Florida waters. (Abstract.) In: First International Conference on Toxic Dinoflagellate Blooms. M.I.T., Cambridge, Mass.

Biglane, K. E. and R. A. Lafleur. 1967. Notes on estuarine pollution with emphasis on the Louisiana gulf coast. In: G. H. Lauff (ed), Estuaries. Publ. No. 83, AAS, Washington.

Breuer, J. P. 1962. An ecological survey of the Lower Laguna Madre of Texas, 1953–1959. Publ. Instit. Marine Sci., Univ. Texas 8: 153–183.

Breuer, J. P. 1971. A survey of the spotted sea trout nursery areas of the lower Laguna Madre. Coastal Fisheries Project Reports 1969–1970, Texas Parks and Wildlife Dept., Austin: 141–146.

Breuer, J. P. 1972. Juvenile and adult food and game fish of the Laguna Madre. Coastal Fisheries Project Reports 1971, Texas Parks and Wildlife Dept., Austin: 125–134.

Butler, P. A. 1973. Organochlorine residues in estuarine mollusks, 1965–1972—National Pesticide Monitoring Program. Pesticides Monit. J. 6 (4): 238–362.

Butler, P. A., R. Childress and A. J. Wilson, Jr. 1972. The association of DDT residues with losses in marine productivity. In: M. Ruivo (ed), Marine Pollution and Sea Life. Fishing News (Books), London.

Chapman, C. R. 1973. The impact on estuaries and marshes of modifying tributary runoff. Proc. Coastal Marsh and Estuary Management Symposium, 1972, Baton Rouge, La.: 235–258.

Childress, U. R. 1965. A determination of source, amount, and area of pesticide pollution in some Texas bays. Coastal Fisheries Project Reports 1965, Texas Parks and Wildlife Dept., Austin: 245–255.

Childress, U. R. 1966. An investigation into levels of concentration, seasonal variations, and source of pesticide toxicants in some species from selected bay areas. Coastal Fisheries Project Reports 1966, Texas Parks and Wildlife Dept., Austin: 39–53.

Childress, U. R. 1967. An investigation into levels of concentration of various pesticide toxicants in some species from selected Texas bay areas. Coastal Fisheries Project Reports, 1967, Texas Parks and Wildlife Dept., Austin: 1–17

Childress, U. R. 1968. Levels of concentration and incidence of various pesticide toxicants in some species from selected bay areas. Coastal Fisheries Project Reports 1968, Texas Parks and Wildlife Dept., Austin: 1–21.

Childress, U. R. (1971 unpublished.) Levels of concentration and incidence of various pesticide residues in Texas. (Manuscript report).

Christmas, J. Y. (ed). 1973. Cooperative Gulf of Mexico Estuarine Inventory and Study, Mississippi. Phases I–IV. Gulf Coast Research Laboratory, Ocean Springs, Miss.

Christmas, J. Y., G. Gunter, and E. C. Whatley 1960. Fishes taken in the menhaden fishery of Alabama, Mississippi and eastern Louisiana. U.S. Fish and Wildl. Serv., Spec. Sci. Report—Fisheries No. 339.

Crance, J. H. 1971. Description of Alabama estuarine areas—cooperative Gulf of Mexico estuarine inventory. Alabama Marine Resources Bull. 6: 1–85.

Cronin, L. E., G. Gunter and S. H. Hopkins. 1971. Effects of engineering activities on coastal ecology. Report to the Office of the Chief, Corps of Engineers, U.S. Army, Washington.

Day, J. W., Jr., W. G. Smith and C. S. Hopkinson, Jr. 1973. Some trophic relationships of marsh and estuarine areas. Proc. Coastal Marsh and Estuary Symposium, 1972, Baton Rouge, La.: 115–135.

Eisler, R. 1973. Annotated bibliography on biological effects of metals in aquatic environments. U.S. EPA Ecol. Research Ser. EPA-R3-73-007, Washington.

Giam, C. S., A. R. Hanks, R. L. Richardson, W. M. Sackett and M. K. Wong. 1972 DDT, DDE, and polychlorinated biphenyls in biota from the Gulf of Mexico and Caribbean Sea, 1971. Pesticides Monit. J. 6 (3): 139–143.

Gunter, G. 1941. Death of fishes due to cold on the Texas coast, January 1940. Ecology 22 (2): 203–208.

Gunter, G. 1945. Studies on marine fishes of Texas. Publ. Instit. Marine Sci., Univ. Texas 1 (1): 1–190.

Gunter, G. 1950. Correlation between temperature of water and size of marine fishes on the Atlantic and Gulf coasts of the United States. Copeia, 1950 (4): 298–304.

Gunter, G. 1952a. The import of catastrophic mortalities for marine fisheries along the Texas coast. J. Wildl. Man. 16 (1): 63–69

Gunter, G. 1952b. Historical changes in the Mississippi River and the adjacent marine environment. Publ. Instit. Marine Sci., Univ. Texas 2 (2): 119–139.

Gunter, G. 1953 The relationship of the Bonnet Carré Spillway to oyster beds in Mississippi Sound and the "Louisiana Marsh," with a report on the 1950 opening. Publ. Instit. Marine Sci., Univ. Texas 3 (1): 17–71.

Gunter, G. 1956. Should shrimp and game fishes become more or less abundant as pressure increases in the trash fish fishery of the Gulf of Mexico? Louisiana Conservationist, January 1956: 11, 14–15, 19.

Gunter, G. 1959. Pollution problems along the gulf coast. Trans. Second Seminar on Biological Problems in Water Pollution, 1959. U.S. PHS, Robert A Taft Engineering Center, Cincinnati, Ohio.

Gunter, G. 1963. The fertile fisheries crescent Mississippi Acad. Sci. 9:286–290.

Gunter, G. 1967. Some relationships of estuaries to the fisheries of the Gulf of Mexico. In: G. H. Lauff (ed), Estuaries. AAAS Publ. 83, Washington: 757 p.

Gunter, G., R. H. Williams, C. C. Davis, and F. G. W. Smith. 1948. Catastrophic mass mortality of marine animals and coincident phytoplankton bloom on the west coast of Florida, November 1946 to August 1947. Ecol. Monogr. 18: 309–324.

Hedgpeth, J. W. 1967. Ecological aspects of the Laguna Madre, a hypersaline estuary. In: G. H. Lauff (ed), Estuaries AAAS Publ. 83, Washington

Holmes, R. W. 1969. The Santa Barbara oil spill. In: D. P. Hoult (ed), Oil in the Sea Plenum Press, New York and London.

Ingle, R. M., and D. F. Martin. 1971. Prediction of the Florida red tide by means of the iron index. Environ. Lett. 1 (1): 69–74. (Contrib. 151, Marine Research Lab., Florida Dept. of Natural Resources, St. Petersburg, Fla.)

Jacobson, S. M. and D. B. Boylan. 1973. Effect of seawater soluble fraction of kerosene on chemotaxis in a marine snail, *Nassarius obsoletus* Nature, 241 (5386): 213–215.

Kleerekoper, H., J. B. Waxman and J. Matis. 1973. Interaction of temperature and copper ions as orienting stimuli in the locomotor behavior of the goldfish *Carassius auratus*. Fish. Res. Board Canada 30 (6): 725–728

Loesch, Harold 1960. Sporadic mass shoreward migrations of demersal fish and crustaceans in Mobile Bay, Alabama. Ecologhy 41 (2): 292–298.

Mackin, J. G. 1962. Oyster disease caused by *Dermocystidium marinum* and other microorganisms in Louisiana. Publ. Instit. Marine Sci., Univ. Texas 7:132–229.

Mackin, J. G. 1973. A review of significant papers on effects of oil spills and oil field brine discharges on marine biotic communities. Texas A&M Research Foundation Project 737. (With annotated bibliography in appendix.)

Mackin, J. G. and S. H. Hopkins 1962. Studies on oysters in relation to the oil industry. Publ. Instit. Marine Sci., Univ. Texas 7.

May, E. B. 1971. A survey of the oyster and oyster shell resources of Alabama. Alabama Marine Resources Bull. 4:1–53.

McNulty, J. D., W. N. Landall, Jr. and J. E. Sykes. 1972. Cooperative Gulf of Mexico estuarine inventory and study, Florida: Phase I, Area description. NOAA Tech. Report, NMFS Circ. 368.

Moore, S. F., R. L. Dwyer and A. M. Katz. 1973. A preliminary assessment of the environmental vulnerability of Machias Bay, Maine, to oil supertankers. Dept. Civil Engineering, M. I. T., Cambridge, Mass., Report No. 162.

Morgan, J. P. 1973. Impact of subsidence and erosion on Louisiana coastal marshes and estuaries. Proc. Coastal Marsh and Estuary Management Symposium, 1972, Baton Rouge, La.: 217–233.

Odum, W. E., J. E. Zieman and E. J. Heald. 1973. The importance of vascular plant detritus to estuaries. Proc. Coastal Marsh and Estuary Management Symposium, 1972, Baton Rouge, La.: 91–114.

Overstreet, R. M. 1974. An estuarine low-temperature fish-kill in Mississippi, with remarks on restricted necropsies. Gulf Research Reports 4 (3): 328–350.

Perret, W. S., B. B. Barrett, W. R. Latapie, J. F. Pollard, W. R. Mock, G. B. Adkins, W. J. Gaidry, and C. J. White. 1971. Cooperative Gulf of Mexico Estuarine Inventory and Study, Louisiana. Phase I, Area Description. Louisiana Wild Life and Fisheries Commission, New Orleans, La.: 1–27.

Petrocelli, S. R. and J. W. Anderson. 1973. Distribution and accumulation of chlorinated hydrocarbons in estuarine organisms. Pp. 21–77 In: Environmental Impact Assessment of Shell Dredging in San Antonio Bay, Texas, Vol. IV of V. U.S Army Engineer District, Galveston, Tex.

Petrocelli, S. R., J. W. Anderson and A. R. Hanks. 1975a. DDT and dieldrin residues in selected biota from San Antonio Bay, Texas—1972. Pesticides Monit. J. (in pres).

Petrocelli, S. R., J. W. Anderson and A. R. Hanks. 1975b. Seasonal fluctuations of dieldrin residues in the tissues of the marsh clam, *Rangia cuneata*, from a Texas estuary. Texas Journal of Science, Vol. 26, No. 1 (in press).

Ray, S. M. and W. B. Wilson. 1957. Effects of unialgal and bacteria-free cultures of *Gymnodinium brevis* on fish. U.S. Fish and Wildlife Service, Spec. Sci. Report-Fisheries 211:50.

Roesijadi, G., S. R. Petrocelli, J. W. Anderson, B. J. Presley and R. Sims. 1974. Survival and chloride ion regulation of the porcelain crab, *Petrolisthes armatus*, exposed to mercury. Marine Biol. 27: 213–217.

Saha, J. G. 1972. Significance of mercury in the environment. Residue Reviews 42:103–163.

Simmons, E. G. 1957. Ecological survey of the upper Laguna Madre of Texas. Publ. Instit. Mar. Sci., Univ. Texas 4 (2): 156–200.

Simmons, E. P. and J. P. Breuer. 1962. A study of redfish, *Sciaenops ocellata* Linnaeus and black drum, *Pogonias cromis* Linnaeus. Publ. Instit. Marine Sci., Univ. Texas 8:184–211.

Sindermann, C. J. 1970. Principal Diseases of Marine Fish and Shellfish. Academic Press, New York and London

Smith, J. E. (ed) 1970. "Torrey Canyon" Pollution and Marine Life. Cambridge Univ. Press, Cambridge, England.

Steidinger, K. A. 1973. Phytoplankton ecology: A conceptual review based on eastern Gulf of Mexico research. CRC Critical Reviews in Microbiology 3 (1): 49–68.

Steidinger, K. A. 1974. Basic factors influencing red tides. (Abstract.) First International Conference on Toxic Dinoflagellate Blooms. M. I. T., Cambridge, Mass.

St. Amant, L. S. 1973. Shellfish and crustacean productivity in marshes and estuaries. Proc. Coastal Marsh and Estuary Management Symposium, 1972, Baton Rouge, La.: 151–161.

Storey, M. 1937. The relation between normal range and mortality of fish due to cold at Sanibel Island, Florida. Ecology 19: 10–26.

Storey, M., and E. W. Gudger. 1936. Mortality of fishes due to cold at Sanibel Island, Florida, 1886–1936. Ecology 17: 640–648.

Texas State Department of Health, Division of Marine Resources. 1970–1973. Classification of shellfish harvesting areas along the Texas coast.

Trent, W. L., E. J. Pullen and D. Moore. 1972. Waterfront *housing developments: their effect on the ecology of a* Texas estuarine area. In: M. Ruivo (ed), Marine Pollution and Sea Life. Fishing News (Books), London.

U.S. Dept. Commerce, NOAA, NMFS Current Fisheries Statistics. (For each state, monthly reports plus annual summary each year.) Alabama Landings, Florida Landings, Louisiana Landings, Mississippi Landings, Texas Landings.

U.S. Dept. Commerce, NOAA, NMFS. Current Fisheries Statistics: Fisheries of the United States. (Annual summary volume.)

U.S. Dept Commerce, NOAA, NMFS. Current Fisheries Statistics. Gulf Coast Shrimp Data (monthly reports plus annual summary each year).

U.S. EPA. Fish kills caused by pollution. (Annual reports.)

Venkataramiah, A., G. J. Lakshmi, and G. Gunter. 1974. Studies on the effects of salinity and temperature on the commercial shrimp, *Penaeus aztecus* Ives, with special *regard to survival limits, growth, oxygen consumption and* ionic regulation. U.S. Army Engineer Waterways Experiment Station, Vickburg, Miss., Contract Report H-74-2.

Wilson, W. B. and S. M. Ray. 1956. The occurrence of *Gymnodinium brevis* in the western Gulf of Mexico. Ecology 37 (2): 388.

Wilson, W. B., S. M. Ray and D. V. Aldrich. 1974. *Gymnodinium breve:* population growth and development of toxicity in cultures. (Abstract.) First International Conference on Toxic Dinoflagellate Blooms. M. I. T., Cambridge, Mass.

DREDGING EFFECTS

MAN'S IMPACT ON ESTUARINE SEDIMENTATION

J. R. SCHUBEL
R. H. MEADE
State University of New York
Stony Brook, New York

ABSTRACT

Estuaries are ephemeral features on a geological time scale being rapidly filled with sediments. Although most estuarine sedimentation rates are naturally high, man's activities have greatly accelerated the rates of filling of many estuaries, thus shortening their geological lifetimes. More importantly, the increased influxes of fine-grained sediments have degraded some estuaries, or segments of them, to the extent that their useful biological and recreational lifetimes have been cut drastically shorter than their geological lifetimes.

Much more effort should be directed at reducing the most manageable source of sediment to most estuaries—soil erosion. This would not only result in an improvement of water "quality," but would, within a few decades, result in significant reductions in the amounts of dredging required for channel maintenance. Dredging will, however, continue to be a persistent problem because the supply of sediments cannot be eliminated.

A new approach to dredging and spoil disposal is required. Regional plans must be developed to ensure that maintenance channel dredging can be carried out without prolonged delays. The present standards for characterization of dredged materials do not have a sound scientific basis, and should be reevaluated. While they were intended to be environmentally conservative, they may be unduly restrictive.

INTRODUCTION

Estuaries are the major sites for the accumulation of sediment along our coastline. Their positions at the mouths of rivers make them the ready recipients of sediment eroded from the land, and the characteristic circulation patterns produced by the mingling of fresh water from the land and salt water from the sea that takes place in estuaries makes them effective sediment traps. The rate of sediment accumulation in estuaries, which is already naturally high in many situations, has been increased by man's activities.

The primary purposes of this report are: (1) to review some of the characteristic estuarine sedimentation processes; (2) to look at some of the ways in which man has altered these processes; (3) to assess the significance of the effects of these changes on the estuarine milieu; and (4) to recommend the types of research needed for significant advances in our understanding of estuarine sedimentation processes.

For this discussion, we adopt the definition of an estuary most commonly used by physical oceanographers—an estuary is a semi-enclosed coastal body of water freely connected to the ocean within which seawater is measurably diluted by freshwater runoff from land.

SEA LEVEL, SEDIMENTATION, AND THE LIFE EXPECTANCY OF ESTUARIES

All present day estuaries were formed by the most recent rise in sea level which began approximately 15,000 to 18,000 years ago. During the last glacial stage (the Wisconsin) the level of the sea was about 125 m (410 ft) below its present level (Fig. 1) and most of the continental shelves of the world were exposed to the atmosphere. With the melting and retreat of the great ice sheets, sea level rose, rapidly at first, from about 15,000 years ago until about 9,000 years ago when it reached a position approximately 20 m (66 ft) below its present level. By 3,000 years ago the level of the sea was within 3 m (10 ft) of its present position, and since then the sea has risen even more slowly, averaging less than 1 m per 1,000 years.

The rising sea invaded numerous coastal embayments and produced estuaries in those that received enough fresh water to measurably dilute the encroaching seawater. Many of these coastal basins were former river valley systems. Examples are Chesapeake Bay, Delaware Bay, and the estuaries around the Mississippi Delta. Other basins, formed by glacial scour, were the fjords such as those found along the coasts of Alaska and British Columbia.

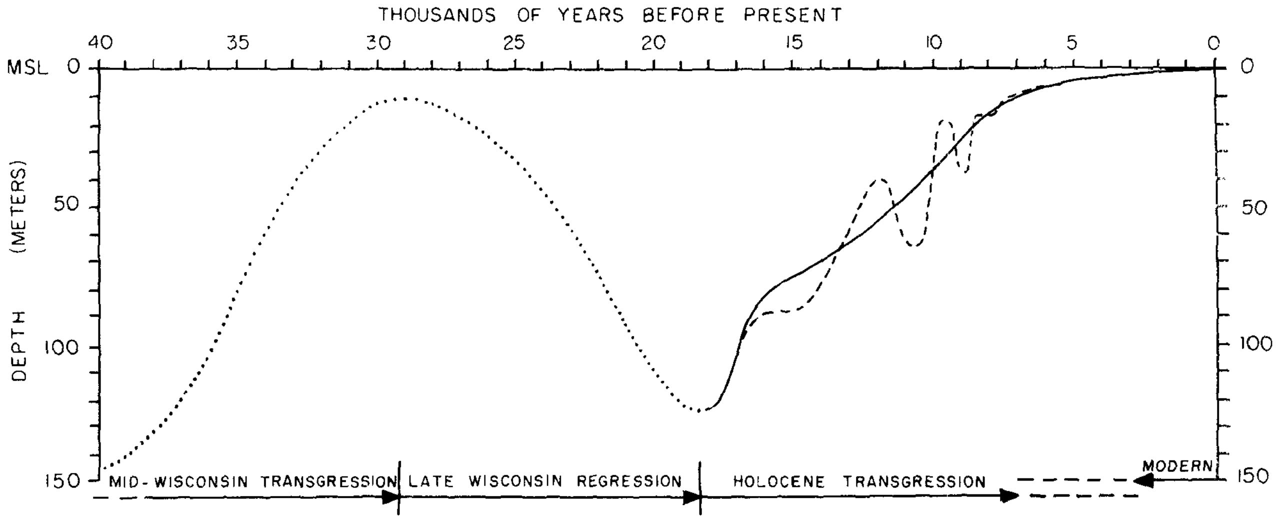


FIGURE 1.—Fluctuations of mean sea level from present to 40,000 before the present (B.P.). The curve was compiled from published and unpublished radiocarbon dates and other geologic evidence. Dotted curve estimated from minimal data. Solid curve shows approximate mean of dates computed. The dashed curve is slightly modified from Curray (1960, 1961). Probable fluctuations since 5,000 years B.P. are not shown (J. R. Curray, Late Quaternary History, Continental Shelves of the United States in the Quaternary of the United States, 1965).

Wave action and littoral drift formed bars off the mouths of some rivers thereby creating embayments which were later transformed into estuaries. Examples are Pamlico and Albemarle Sounds. Still other coastal basins that later became estuaries were formed by tectonic processes. San Francisco Bay is an example.

The rapidity of the rise of sea level was a major factor in the formation and maintenance of estuaries. Sedimentation could not keep pace with the rapidly rising sea that invaded numerous coastal basins. For the past few thousand years, however, the relative rate of infilling has been much greater than during the preceding several thousands of years. The rate of sea level rise has been slower, and within the past few hundred years the rate of sediment input has increased as a result of man's activities. It is, of course, the relative sea level rise—the rise relative to the sedimentation rate—that determines the geological lifetime of an estuary.

All modern estuaries then, are quite young geologically; certainly less than 15,000 years old. The relative youthfulness of many estuaries, particularly of drowned river valley estuaries like Chesapeake Bay, is indicated by their highly irregular, dendritic shorelines. As estuaries mature there is a progressive rectification or straightening of their shorelines; headlands are attacked by waves and current, and re-entrants in the coastline are filled by drifting sand. Once formed, estuaries are ephemeral features on a geologic time scale, being rapidly filled with sediments. Sediments are introduced not only by shore erosion, but also by rivers, by the wind, by the sea, and by biological activity. The sources are thus external, internal, and marginal. Typically, estuaries fill from their heads and their margins. An estuarine delta generally forms in the upper reaches of the estuary—near the new river mouth. The estuarine delta grows progressively seaward, extending the realm of the river and thereby expelling the intruding sea from the semi-enclosed coastal basin. Lateral accretion by marshes may also play a major role. As a result of these processes, the estuarine basin is converted back into a river valley. Finally, the river reaches the sea through a depositional plain and the transformation is complete.

While depositional rates in estuaries are naturally high, man's activities both within the estuarine zone itself, and throughout the drainage basin (sometimes hundreds of kilometers away) can greatly increase the sediment yields and the rates of filling, can alter the natural sedimentation patterns, and can shorten the geological lifetimes of estuaries—sometimes appreciably. More importantly, the indirect effects of increased inputs of sediments, particularly of fine-grained sediments, can degrade an estuary, or segments of it, to the extent that its useful biological and recreational lifetimes are cut drastically shorter than its geological lifetime—perhaps several orders of magnitude shorter.

It has been reported that when John Adams, a Democrat, was President, he swam in the upper Potomac at Washington, D.C. Lincoln, a Republican, not only did not swim in the upper Potomac, but remarked that the stench from it was sometimes so bad that on warm summer evenings when the wind was off the Potomac he had to flee the White House. This indicates either that the quality of the upper Potomac had been seriously degraded by man's activities over this period of about 60 years; or as a Republican friend of ours, H. H. Carter, points out, merely that "a Democrat will swim in anything."

ESTUARINE CIRCULATION AND SEDIMENTATION PATTERNS

Because of their characteristic circulation processes, estuaries are effective sediment traps. The tidal circulation is important in the formation of channels, tidal flats, and tidal deltas, but it is the net non-tidal circulation that is of primary importance in determining the rates and patterns of filling of most estuaries.

It is in the estuary where the mixing of fresh water from the land and salt water from the ocean produces dynamic conditions that lead to the eventual discharge of the river water to the ocean. The mixing may be due primarily to the action of the river, the wind, or the tide. There is a sequence of estuarine circulation types displaying different degrees of mixing of the fresh water and the sea water. The position that an estuary occupies in this sequence depends primarily upon the relative magnitudes of the riverflow and the tidal flow, and upon the geometry of the basin that contains the estuary. Changes in any of these factors may produce changes in the estuarine circulation pattern and may thereby alter the resulting sedimentation patterns. One end member of this sequence is the poorly mixed (highly stratified) salt-wedge estuary—that so-called Type A estuary. The other end member is the thoroughly mixed, sectionally homogeneous estuary—the Type D estuary. Two intermediate types which have been described are the partially mixed, Type B, estuary, and the vertically homogeneous, Type C, estuary.

Estuaries are actually continuously varying in their characteristics and may shift from type to type as conditions change. Also, at any given time, different circulation types may be observed within different segments of an estuary, depending on the relative magnitudes of the tidal flow and the freshwater flow, and upon the local geometry of the basin. The four types of estuarine circulation patterns are shown schematically in Fig. 2. In general, an estuary changes from Type A (Fig. 2A) to Type D (Fig. 2D) as the magnitude of the tidal flow increases relative to the riverflow and/or as the width of the basin increases relative to the depth.

The Salt-Wedge (Type A) Estuary

The Type A estuary, Fig. 2A. is a river-dominated estuary. It is also called a salt-wedge estuary because there is little mixing between the seawater and the fresh water, and the encroaching seawater is present as a wedge underlying the less dense, fresher river water. Salt-wedge estuaries occur where the ratio of width to depth is relatively small and the ratio of riverflow to tidal flow is relatively large. At locations upstream from the tip of the salt-wedge, the flow is downstream at all depths. Seaward of the tip of the wedge, the flow throughout the upper layer is still downstream at all times because of the dominance of the river over the tide. In the lower layer, the instantaneous flow may be upstream at all times, or it may reverse with the tide, but the net flow is upstream.

Fine suspended particles that are brought into the estuary by the river and settle into the lower layer are brought back upstream to the tip of the wedge by the slow net landward flow of the lower layer and accumulate in the vicinity of the tip of the wedge. This fluvial sediment may also be supplemented by fine particles from other sources. Heavier particles transported along the riverbed accumulate upstream of the wedge. The region surrounding the tip of the wedge, then, is a zone of rapid shoaling. The position of the tip of the salt-wedge is determined primarily by the freshwater discharge and the channel depth.

The Southwest Pass of the Mississippi River is a classic example of a salt-wedge estuary. The average flow through Southwest Pass is more than 5,100 m^3/sec (180,000 ft^3/sec), and peak flows may exceed 8,500 m^3/sec (300,000 ft^3/sec). The river completely dominates the circulation. The tidal range in the Gulf of Mexico is only about 36 cm (1.3 ft). The tip of the wedge migrates more than 235 km (126 n. miles) in response to changes in the discharge of the Mississippi. During periods of minimum flow, the tip may be about 40 km (22 n. miles) above New Orleans—nearly 235 km (126 n. miles) above the mouth of Southwest Pass. During periods of moderate flow, the tip of the wedge is located near the river's mouth, and the shoaling problem is so serious in this region that around-the-clock dredging is required to keep the navigation channel open.

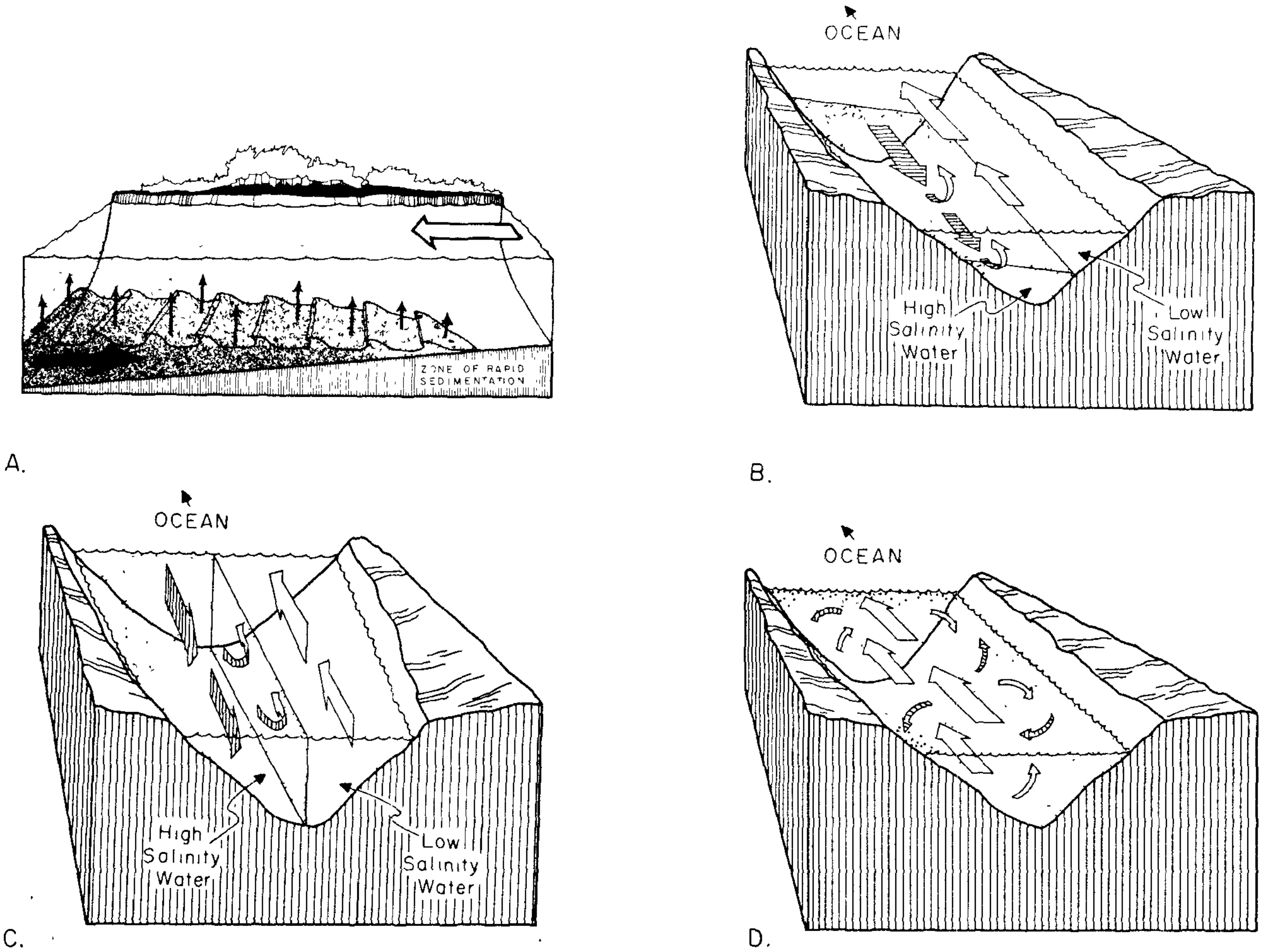


FIGURE 2.—*Four distinct examples in the sequence of estuarine types. A. Type A estuary. B. Looking seaward in Type B estuary in N. Hemisphere. C. Looking seaward in Type C estuary in N. Hemisphere. D. Looking seaward in Type D estuary in N. Hemisphere.*

The Partially Mixed (Type B) Estuary

If the tidal flow is increased relative to the riverflow so that the tide is sufficiently strong to prevent the river from dominating the circulation, the added turbulence provides the mechanism for erasing the salt-wedge. This occurs when the volume rate of flow up the estuary on a flood tide is on the order of 10 times the volume rate of inflow of fresh water from the river. There is both advection and turbulent mixing across the freshwater-saltwater interface. The sharp interface which separated the fresh water of the upper layer from the sea water of the lower layer in the salt-wedge estuary is replaced by a region of more gradual change in salinity. Such an estuary is called a partially mixed, Type B, estuary. The difference in salinity between top and bottom remains nearly the same over much of the length of the estuary. The Coriolis force—an apparent deflecting force caused by the earth's rotation—produces a slight lateral salinity gradient across the estuary. The boundary between the seaward-flowing upper and landward-flowing lower layers is slightly tilted. In the Northern Hemisphere, the upper layer is deeper and the flow slightly stronger to the right of an observer facing seaward. The lower layer is nearer the surface and its flow is slightly stronger to the left of the seaward-facing observer.

Fine suspended particles that settle into the lower layer are carried upstream by its net landward flow, leading to an accumulation of sediment on the bottom between the upstream and downstream limits of salt intrusion. Because of the mixing which is more intense than in a salt-wedge estuary, there is generally an accumulation of fine suspended sediment in the landward reaches of the estuarine circulation regime. Such features, called "turbidity maxima," have been reported in the upper reaches of a large number of partially mixed estuaries throughout the world. These turbid zones characteristically begin in the estuary where a vertical gradient of salinity first appears and commonly extends downstream for 20–40 km (10–20 n. miles). Within a turbidity maximum the concentrations of suspended sediment and the turbidities are greater than either farther upstream in the source river or farther seaward in the estuary. Their formation has been attributed to the flocculation of the fluvial sediment, to the deflocculation of fluvial sediment, and to hydrodynamic processes. We believe that turbidity maxima are produced and maintained by physical processes—specifically the periodic resuspension of bottom sediments by tidal scour, and the estuarine circulation pattern—and that the importance ascribed to the role of flocculation in estuarine sedimentation is not supported by field evidence.

The most rapid shoaling in partially mixed estuaries normally is between the flood and ebb positions of the limit of sea salt intrusion. Rapid shoaling may also occur where the upstream flow of the lower layer is interrupted by entering tributaries, by abrupt changes in cross-sectional area, or by meandering or bifurcation of the channel. The Chesapeake Bay is a good example of a partially mixed estuary.

The Vertically Homogeneous (Type C) Estuary

If the role of the tide, relative to the river, is increased over that in the partially mixed estuary, the tidal mixing may be sufficiently intense to completely eradicate the vertical salinity gradient and produce a vertically homogeneous water column. The longitudinal salinity gradient still remains with the salinity increasing seaward. And, because of the Coriolis force, the lateral gradient in salinity also remains with the higher salinity water to the left of an observer facing seaward in the Northern Hemisphere. The boundary between the lower salinity water flowing seaward and the higher salinity water flowing up the estuary becomes more nearly vertical, and may intersect the water surface. In the Northern Hemisphere then, the net flow and sediment transport are generally upstream on the left side of the estuary facing seaward and downstream on the right side. Shoaling is generally most rapid near the upstream limit of sea salt, in regions of large cross-sectional area, adjacent to islands, and in channel bifurcations where the flow is interrupted. The wider reaches of the Delaware and Raritan (New Jersey) Bays are examples of vertically homogeneous estuaries.

The Sectionally Homogeneous (Type D) Estuary

If the tidal flow is increased even more so that it is very large relative to the riverflow, it may almost completely overwhelm the effect of the river. The tidal mixing may be so intense that not only is the vertical salinity gradient eradicated, but so also is the lateral gradient, producing a sectionally homogeneous estuary. The movement of water is essentially symmetrical about the main axis of the estuary with a slow net seaward flow at all depths. Truly sectionally homogeneous estuaries may not exist in nature. In estuaries that are approximately sectionally homogeneous, the most rapid sedimentation occurs in areas where the slow net seaward flow is interrupted by tributaries or obstacles. The Piscataqua estuary in New Hampshire appears to be nearly sectionally homogeneous, but observations in estuaries of this type are limited.

As pointed out previously, the position that an estuary occupies in this sequence of estuarine types depends primarily upon the relative magnitudes of the riverflow and the tidal flow, and upon the geometry of the basin. Relatively subtle changes in any of these factors may produce changes in the estuarine circulation pattern and thereby alter the resulting sedimentation patterns. In general, an estuary's sediment trapping efficiency is increased as the riverflow increases relative to the tidal flow, or as the depth increases. Most of the fluvial sediment is generally introduced into an estuary when the riverflow is high, when its trapping efficiency is greatest. When the riverflow subsides and the relative importance of the tidal flow increases, the estuary shifts in its circulation pattern toward one of greater mixing. During these more prolonged periods of low to moderate riverflow the sediment is redistributed.

ALTERATION OF PREVAILING SEDIMENTARY PROCESSES

Sources

Although sediment in estuaries comes from many sources—including the erosion of the margins of the estuarine basins, and the beaches and sea floor outside the estuary mouths—the sources most affected by the hand of man are the rivers that carry sediment from upland areas into the estuaries. Our discussion will focus mainly on the sediment loads of rivers, which are increased by such activities as farming, mining, and urbanization; and which are decreased by reservoirs and other protective works.

Man's Activities That Increase River Sediment Loads

Ever since the first European settlers landed, man has affected the amount of sediment in streams draining North America. The influence of man on sedimentation is especially well documented in the Chesapeake Bay region, where clearing of forests and wasteful farming practices (especially those used in raising tobacco) contributed enormous loads of sediment to the rivers. Clear streams became muddy and once relatively deep harbors at the heads of a number of the tributaries were filled with sediment. The Potomac River, whose waters were already somewhat turbid but which were still suitable for municipal use in 1853, had become so muddy by 1905 that the city of Washington had to install its first filtration plant. A comparison of the 1792 and 1947 shorelines of the upper Potomac (Fig. 3) shows that large areas of the Potomac near Washington have been filled with sediments stripped from farmland farther upstream. The Lincoln and Jefferson Memorials now stand on what was described in 1711 as a harbor suitable for great merchant vessels. Even today, an average of about 2 million m^3 (2.6 million yds^3) of sediment is deposited every year near the head of tide in the Potomac; not all of this sediment is the result of agriculture, as we shall see. There are other former seaport towns on the western shores of Chesapeake Bay where decaying docking facilities are now separated from navigable water by several miles of sediment-filled lowland.

Streams that drain modern day farmlands in many of the mid-Atlantic states carry about 10 times as much sediment as streams that drain equivalent areas of forest land. And this relation is by no means unique. In the Coastal Plain of northern Mississippi, sediment yields from cultivated lands are 10 to 100 times the yields from equivalent areas of forested lands. In two other areas where studies have been made—the Tobacco River Valley of Michigan and the Willamette Valley of Oregon—streams draining farmland carry two to four times as much sediment as streams draining equal areas of forested land.

Mining is another activity that has increased the sediment loads of rivers that flow into some estuaries. San Francisco Bay, for example, contains nearly a billion cubic meters of sediment washed from the Sierra Nevada during the 30-odd years of intensive hydraulic mining for gold. Even after the hydraulic processing was stopped in 1884, the mining debris continued to choke the valleys of the Sacramento River and some of its tributaries for many decades. Gradually, over the years, the debris has been moved downriver to be deposited more permanently in the marshes and shallower areas around San Francisco Bay. The mining debris that was released in only three decades is more than the total sediment from all other sources (including farmland) that the Sacramento River has carried in the twelve-and-a-half decades since 1850. It has been shown that this sediment had an important effect on the bay; the tidal prism was decreased, and the flushing regime significantly changed.

Urbanization is the most recent of man's activities to contribute large amounts of sediment to streams. Sediment loads derived from land being cleared or filled for the building of houses, roads, and other facilities are best documented in the area between Washington, D.C. and Baltimore, Md. During periods when housing developments, shopping centers, and highways are being built, the soil is disturbed and left exposed to wind and rain. The concentration of sediment in storm runoff from construction sites is a 100 to 1,000 times what it would be if the soil had been left in its natural vegetated state. Even though the soil is left exposed to erosion of this intensity for only a short time—a few years at most—the amount of land cleared for

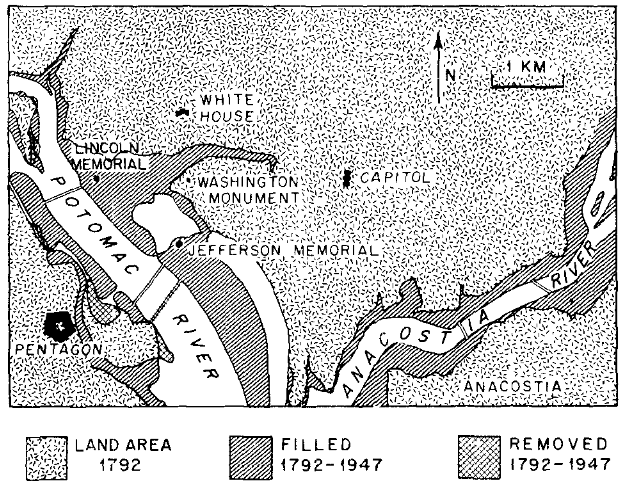


FIGURE 3.—Accumulation of sediment at Washington, D.C., near the head of tide in the Potomac and Anacostia Rivers, between 1792–1947.

new housing and ancillary uses in the Washington-Baltimore area has been so great in recent years that the contribution of sediment is significantly large. Harold Guy of the U.S. Geological Survey has estimated that the Potomac River receives about a million tons of sediment per year from streams that drain the metropolitan Washington area. This is about the same amount of sediment that the Potomac River brings into the Washington area from all its other upland sources.

Another of man's activities that increases the sedimentation rates of estuaries is the disposal of dissolved phosphorus, nitrogen, and other plant nutrients into rivers and estuaries. Municipal sewage effluents, including effluents that have received secondary treatment—the highest degree of conventional treatment—contain high concentrations of nutrients. In some areas, agricultural runoff from fertilized croplands and animal feedlots also contributes nutrients to river waters and estuaries. These nutrients promote the growth of diatoms and other microscopic plants (phytoplankton) both in the rivers and in the estuaries that the rivers flow into. The mineral structures formed by many of these organisms persist after the organisms die and become part of the sediment loads of the rivers and the sedimentary deposits of the estuaries. The Army Corps of Engineers estimates, for example, that the diatom frustules produced in the Delaware River and Delaware Bay contribute about the same amount of sediment (a million-and-a-half tons per year) to the Delaware estuary as all other upland river sources. The effects of nutrient loading from municipal wastes on primary productivity are readily observable in the Potomac estuary, in Baltimore Harbor and the Back River estuary (Maryland), in Raritan Bay, in the Arthur Kill estuary, in the Hudson estuary, in the Delaware estuary, in San Francisco Bay, and in many other estuaries around the country. Stimulation of plant growth by nutrient-enriched runoff from agricultural areas is apparent in the upper Chesapeake Bay, the estuary of the Susquehanna River.

MAN'S ACTIVITIES THAT DECREASE RIVER SEDIMENT LOADS

Reservoirs probably cause the most significant interruptions in the natural movement of sediment to estuaries by rivers. Reservoirs are built on rivers for a number of purposes: for hydroelectric power, for flood control, for water supply, and for recreation. Regardless of their purpose, reservoirs share in common the ability to trap sediment. Even small reservoirs can trap significant proportions of river sediment. For example, a reservoir that can hold only one percent of the annual inflow of river water is capable of trapping nearly half the river's total sediment load. A reservoir whose capacity is 10 percent of the annual river water inflow can trap about 85 percent of the incoming sediment. Although a river will tend to erode its own bed downstream of a reservoir to partly compensate for the sediment it has lost, the net effect of the reservoir is to decrease the overall amount of sediment carried by the river. In the larger river basins of Georgia and the Carolinas, the sediment loads delivered to the estuaries are now something like one-third of what they were about 1910, mainly because of the large number of reservoirs that have been built since then for hydroelectric power and, to a lesser extent, for flood control.

On some rivers, settling basins and reservoirs have been built specifically as sediment traps to improve the quality of water farther downstream. In 1951, three desilting basins were constructed on the Schuylkill River of Pennsylvania to remove the excessive sediment that resulted from anthracite coal mining in the upper river basin. The basins are dredged every few years, and the dredged material is placed far enough from the river to be out of reach of floods. As a result of these basins, the sediment load carried by the Schuylkill into the Delaware estuary has been reduced from nearly a million tons per year to about 200,000 tons per year.

NET EFFECT OF MAN'S ACTIVITIES ON SOURCES OF SEDIMENT

The net effect of man's activities has no doubt been an increase in the sediment supplied to most of the estuaries of the United States, but we cannot say by how much. Although reservoirs and other controls have reduced the sediment in rivers in recent years, they have only partly offset the influences that caused the increases in the first place.

Added to this is the fact that sediment takes decades to move through a river system. Much of the sediments released by past mistakes—such as by poor mining practices and by poor soil conservation practices associated with agriculture—are still in the river valleys in transit storage between their sources and the estuaries. Even if the active supply of sediment to rivers were completely checked today, many decades would pass before the sediment loads would drop to their natural, pre-colonial, levels.

CONTROL OF RIVER SEDIMENT INPUT

The ultimate method of controlling the sediment that rivers contribute to estuaries is to control erosion at the source. The possibility of complete control, however, is remote. Erosion is basically a natural phenomenon. All land, whether in its natural state or altered by man's activities, yields a certain amount of sediment. Because the natural processes of erosion are less subject to control than are man's influences on these processes, perhaps the best that one can hope for is to keep erosion down to its natural level. But even this is probably a vain hope. In spite of the marked reduction that conservation measures have caused in soil erosion since they began to be applied in earnest over 30 years ago, cultivated farmland in the eastern United States, for example, continues to yield sediment at about 10 times the rate of equivalent areas of forested land. In places where former croplands and grazing lands have been replanted in forests and grasses, sediment yields have been considerably reduced. Although it is true that as long as men cultivate land, there seems to be little hope of reducing sediment yields to their natural rates—rates typical of heavily vegetated lands—much more effort should be directed at reducing sediment yields through appropriate soil conservation practices. If these controls are enforced not only for agriculture, but also for strip mining, urbanization, and highway construction, significant reductions in sediment inputs to estuaries will result. These reductions will, within a period of decades, be manifested in reductions in the dredging activity required to maintain many shipping channels; and may result in improvement in water quality of the estuarine zone, particularly if nutrient inputs are decreased.

ROUTES AND RATES OF TRANSPORT

Once sediment reaches an estuary, it may move directly to a site where it will remain permanently, but it is more likely to be deposited in a series of temporary storage areas or "parking lots" before coming to its final resting place. Although we have some idea of the kinds of places where sediment is most likely to eventually accumulate in estuaries, we are generally unable to predict the detailed route that sediment will follow between the point where it enters the estuary and the place where it finally comes to rest. Furthermore, we know little about how often sediment moves—whether it moves a short distance every day, or moves mainly during short but severe events such as storms and floods. We suspect that infrequent severe events are more important in delivering sediment to the estuary in the first place, but that the slower day-to-day processes are more important in redistributing sediment from one part of an estuary to another to determine the final depositional patterns. In upper San Francisco Bay, for example, the sediment brought in by the Sacramento River during the rainy winter months is initially deposited in broad shallow areas of the estuary. During the dry summer months the daily breezes that blow across the bay stir up the shallow waters and resuspend the sediments blanketing the shoal areas. The tidal currents transport this material to deeper areas, mostly farther up the bay. The deeper areas, in and near Mare Island Strait, are the location of the most intensive dredging of navigation channels in San Francisco Bay. About two million cubic meters, or about a third of all the sediment dredged in the entire San Francisco Bay system, are removed every year to maintain adequate channels into and within the Mare Island Naval Shipyard.

If we have only a limited knowledge of the routes of transport within the estuary, we know even less about the rates of transport. We have some measurements of the rates at which sediment is supplied to the estuary from selected sources, mostly rivers. And, we have some knowledge of the rate at which some of the sediment accumulates in specific parts of estuaries, particularly in the dredged navigation channels. But we have only a limited picture of the rates of input from other sources and the rates of accumulation at other less obvious places, and a particularly limited picture of the rates at which a given particle of sediment might be expected to move from one part of the estuary to another on its way to a permanent resting place.

Patterns of Deposition

The pattern of deposition of sediment in an estuary is determined mainly by the non-tidal circulation patterns of the water. As pointed out previously, an estuary's net circulation pattern is determined primarily by the relative magnitudes of the river and tidal flows, and by the geometry of the estuarine basin. The circulation pattern can be altered, sometimes drastically, by changes in any of these factors.

TRAINING WORKS

Training works such as jetties and dikes are built for the expressed purpose of changing the pattern of flow and deposition in estuaries: specifically, to discourage the deposition of sediment where it is not wanted, or to facilitate its deposition in other places. The deposition of sediment is discouraged by channeling flows to increase their velocity and scouring potential. Deposition is encouraged by providing quiescent areas where suspended particles can settle to the bottom.

Although in theory training works should be an efficient means of controlling sediment, in practice their results are often difficult to predict. Works constructed in the early years of this century along the main shipping channel in Liverpool Bay in England, for example, were successful in increasing the velocities and the depths in the channel. However, they caused an unexpectedly rapid increase in sedimentation in the areas of the bay outside the channel as well as in the tributary estuary of the Mersey River.

DREDGING

Since problems associated with dredging are discussed at length in several other papers in this volume, our comments will be limited. Dredging of navigation channels is the most pervasive of man's activities in estuaries that affect the circulation of water, and consequently, the pattern of deposition of sediment. In many estuaries, dredging seriously disrupts the natural equilibrium that formerly existed between river inflow, tidal exchange, sediment supply, and the configuration of the estuary floor. The response to dredging is frequently to "heal" the disruption by filling the dredged channel with sediment.

If left to itself, the healing might proceed in the following way. Suppose we have an estuary where the sediment inflow and the bottom geometry are in some kind of steady-state balance with respect to each other. This might be a large estuary, such as Delaware Bay, that is slowly and steadily being filled with sediment, mainly in its upper reaches, or it may be a narrow estuary, such as the Savannah River between Georgia and South Carolina, that flows in a river-size channel through sediment-filled lowlands to the sea. When a deep channel is dredged in such an estuary, it allows salt water to penetrate farther inland than formerly and it shifts the nodal point of the upstream flowing seawater farther up the estuary. This nodal point becomes the locus of most rapid sedimentation and remains so until the channel at that point is filled with sediment. When that part of the channel is filled and the salt water can no longer penetrate that far inland, the nodal point is progressively shifted seaward and another part of the channel is filled. This process continues until the entire navigation channel is healed—provided that enough sediment and time are available. If the navigation channel is dredged repeatedly, as are most channels where the supply of sediment is heavy, the sediment continues to accumulate at or near the first nodal point which continues to be the location of maximum dredging effort in the estuary. The maintenance of navigation channels in many estuaries, therefore, is a battle between man's efforts to disrupt a pre-existing state of equilibrium, and the estuary's tendency to restore that equilibrium.

A major problem in dredging is the disposal of the dredged material (spoil). In many cases, spoil is dumped in places where sediment of that texture would not have accumulated naturally, or at least not nearly as rapidly in the natural course of events as in spoiling. This applies to disposal sites both inside and outside of estuaries.

Spoil is commonly dumped inside the estuary, sometimes directly alongside the channel. The spoil may remain where it is dumped, especially if it is dumped in deep spots out of reach of strong currents. Often, however, dredge spoil returns to the channel. In recent years, according to estimates made by the U.S. Army Corps of Engineers, about half the sediment dredged from the navigation channels in Charleston Harbor and San Francisco Bay is material that has already been dredged at least once before and has made its way back into the channels from the place where it was dumped.

In some estuaries, spoil is dumped on fringing land areas. A principal advantage is that these areas can be diked to prevent the return of the spoil to the estuary. The main disadvantage is that the marginal areas are often salt marshes that are valued for their role in the protection and production of fish and other forms of estuarine life. Dumping spoil on these areas usually destroys their original plant and animal communities.

Spoil is also taken by barge or hopper dredge and dumped in the ocean outside estuaries. In 1968, for example, about 50 million tons of dredged spoil was dumped in ocean waters off the coast of the United States. In many ocean areas, such as off New York city where some 7 million tons of spoil are dumped every year, the spoil is a markedly different type of sediment from the natural bottom material and it is introduced at a rate many times greater than the natural rate of local sediment input to the ocean. This is perhaps man's greatest alteration of the pattern of deposition—taking material that was destined by nature to be deposited in estuaries and dumping it at sea.

Modification of Prevailing Sedimentation Processes By Engineering Projects: A Mistake and A "Success"

CHARLESTON HARBOR

Charleston Harbor, one of the finest natural harbors on the Atlantic seaboard, has served the needs of the region since the town was settled in 1670. It is an interesting example of an estuary whose circulation and sedimentation were markedly altered by changing the freshwater input to the estuary. The Charleston Harbor estuary receives freshwater inflow from the Ashley, Cooper, and Wando Rivers. The mouth of the estuary is restricted, and entrance from the Atlantic Ocean is gained through a single, jettied-channel. Prior to 1942, the freshwater input was very small, averaging less than 20 m^3/sec (700 ft^3/sec), and the harbor was somewhere between a vertically homogeneous and sectionally homogeneous estuary. Fine-grained sediment was moved slowly through the estuary to the ocean, and little dredging was required. Maintenance dredging to keep the main channel at a depth of 9 m was only about 60,000 m^3/yr (80,000 yds^3/yr) at a cost of about $11,600/yr.

In late 1941, a hydroelectric dam was completed which diverted most of the flow of the nearby Santee River, the largest river on the south Atlantic seaboard, into the upper Cooper River which flows into Charleston Harbor. The average freshwater input to the harbor rose from less than 20 m^3/sec (700 ft^3/sec) to more than 400 m^3/sec (14,000 ft^3/sec). The inflow of fluvial sediment was increased by about a factor of four. More importantly, the marked increase in the freshwater discharge shifted the circulation pattern in the harbor from a well-mixed estuary to a two-layered circulation pattern characteristic of a partially-mixed (Type B) estuary. Fine sedimentary particles which would previously have been carried completely through the estuary to the ocean were now entrapped in the estuary by the net upstream flow of the lower layer and accumulated in the inner harbor—in the upper reaches of the non-tidal estuarine circulation regime. Shoaling became a serious problem. Dredging required to maintain the inner harbor channel jumped to an average of 1.8 million m^3/yr (2.3 million yds^3/yr) at an average cost of about $380,000/yr during the 9 year period from 1944 to 1952. More recently, dredging has averaged about 7.5 million m^3/yr (10 million yds^3/yr).

Nearly half of the currently dredged material represents older dredged spoil that has returned to the channel. Another 10 percent or so of the new spoil is due to the deepening of the main navigation channel from 9.1 to 10.7 m (30 to 35 ft) between 1941 and 1943. The major factor in the increased shoaling rate was the change in estuarine circulation produced by the diversion of water from the Santee River into the harbor. This was conclusively demonstrated by hydraulic model studies.

The shoaling problem has become so difficult and expensive to control that plans are well underway for rediversion of the Santee back to its original channel.

DELAWARE BAY

Delaware Bay has also served maritime commerce since colonial times, providing access between the sea and such cities as Philadelphia and Trenton. In recent years some fairly successful measures have been taken to control sediment, both in the inflowing rivers and in the bay itself. The desilting works in the Schuylkill River need no further discussion here except to point out that they have resulted in a fivefold decrease in the sediment brought by the Schuylkill to the upper estuary at Philadelphia.

Within the Delaware estuary, the Corps of Engineers has been able to decrease the amount of dredge spoil that has returned to the navigation channels. Before 1954, when spoil was dumped overboard in the Delaware estuary 15 to 20 million m^3 (20 to 26 million yds^3) of sediment were dredged in an average year, and the navigation channel could not always be maintained at its specified depth. Beginning in 1954, all dredge spoil was placed in diked areas to prevent its return to the channels. Since then, only about 6 million m^3 (8 million yds^3) of sediment are dredged every year, and the navigation channels are consistently deeper. Although this is one of the more successful instances of coping with estuarine sedimentation, it is only a temporary expedient in the long run. Peripheral lands for spoil disposal are becoming scarcer and more costly because of competing demands such as development or conservation, and the end of available land for spoil disposal around the fringes of the Delaware estuary is already in sight

The Effects of Sediments on the Biota and on the Aesthetics of the Estuarine Environment

Clearly, man has affected the input of sediments to estuaries by land-use practices throughout their drainage basins, by the construction of dams and reservoirs on tributary rivers, by diversion of rivers, and by engineering projects to control shore erosion of the margins of estuaries. He has also affected the distribution patterns of sediments within estuaries, both in the water column (suspended sediments) and on the bottom (deposited sediments), by changing the estuarine circulation patterns either through alteration of the freshwater inputs, or through modification of their geometry by dredging or by other engineering projects. Man's impact on depositional patterns has already been described briefly in the previous section. In addition to the obvious effects of shoalings on basin geometry and therefore on circulation, and on the geological lifetimes of estuaries, changes of the rate of sedimentation and of the character of the sedimentary material can have significant effects on organisms, particularly the animals that live on the bottom. Fine-grained sediments may also affect the chemical character of the interstitial water and, when resuspended by waves and currents, that of the overlying waters.

EFFECTS ON THE BIOTA

Dredging and the disposal of dredged materials have generated a great deal of concern, discussion, and speculation about the impacts of such activities on the quality of the estuarine environment. During active dredging and spoiling there are increases in the concentrations of suspended sediment. Substantial increases—increases of more than a 100 mg/l—are generally local, restricted to an area within a few hundred meters of the activity, and any biological or aesthetic effects of these increased turbidities are not persistent.

Dredging can, of course, alter the estuarine circulation pattern and, in doing so, also change both the general sediment distribution patterns and the concentrations of suspended sediment. Changes in these factors can persist after dredging and spoiling have been completed.

Increases in the concentrations of suspended sediment above some threshold level that result from any activity can have significant environmental effects—on aesthetics, on water quality, and on the biota. The available literature indicates, however, that direct effects of suspended sediment on most estuarine organisms of the higher trophic levels occur only at relatively high concentrations, concentrations greater than 500 mg/l, and generally greater than 1,000 mg/l. Such concentrations are rare in most estuaries, even during dredging and spoiling activities except at or very near the source. Even in the immediate vicinity of dredging activity, the increased suspended sediment concentrations may not be lethal to important organisms of the higher trophic levels. Studies of caged fish and crustaceans placed within 8 to 15 meters of active dredges and overboard spoil discharges failed to produce any evidence of increased mortality or damage to gill epithelium compared to control organisms.

It has also been reported that there was no increase in the mortality of oysters adjacent to dredging operations in the intercoastal waterway near Charleston, S.C. The same investigators also found that oysters could survive even when suspended directly in the turbid discharge, and that the organisms died only when they were actually buried. Other investigations indicated that oysters decrease their pumping rates when subjected to relatively high concentrations of suspended sediment. It has been reported that a concentration of suspended silt of only 100 mg/l reduces the pumping rate of adult oysters by about 50 percent. If the pumping rate were reduced below some critical threshold for an extended period, the oyster would obviously die from starvation. It is unlikely that this would happen as a result of dredging activity. Furthermore, concentrations greater than 100 mg/l occur naturally over many productive oyster bars whenever bottom sediments are resuspended by normal tidal currents. These periodic increases of suspended sediment do not appear to seriously affect growth rates.

Sublethal effects of chronic exposure to moderate excess concentrations of suspended sediment—concentrations above those that would occur naturally—have not been convincingly documented for any estuarine species. Such effects will be difficult to establish unequivocally. One would anticipate that sensitivity to suspended sediment would be a function not only of species, but of life stage, and of other environmental stresses.

Increases in the concentration of suspended sediment that are large enough to markedly change the visibility of the waters of segments of an estuary can produce shifts in the fish population. Since game fish feed by sight, some minimum visibility is required for successful feeding. If visibility falls below this threshold, fish such as carp which feed in a vacuum-cleaner fashion are favored. This probably occurs only when concentrations of fine suspended sediment exceed several hundreds of mg/l. Visibility is a function not only of the concentration of total suspended solids, but also of their size distribution and composition.

The disposal of dredged materials generally results in the initial destruction of many, perhaps most, of the bottom dwelling organisms (benthos) at the disposal site through burial and smothering. It has been documented in a number of estuaries, however, that the spoil is recolonized relatively rapidly by organisms from surrounding areas except when the spoil differs markedly in texture from the host sediments. Studies of overboard disposal sites in the upper and lower Chesapeake Bay showed that within one-and-one-half years the population density and species diversity of the spoil areas could not be distinguished from those of surrounding areas. In the upper Chesapeake Bay recovery of the channel—the dredged area—was not complete, but in the lower bay complete recovery of both the dredged and spoil areas was documented. Where marked textural changes result from the dredging or spoiling activity, recolonization may be limited. The dredged canals of Boca Ciega Bay, Fla., are examples.

If dredging or spoiling produce substantial changes in the depth distribution of an estuary, or segments of it, significant changes may occur in habitat space and therefore in the distribution of organisms. Areas of the bottom can be removed from the euphotic zone by dredging, and areas can be built-up by spoiling from a relatively deep position into the surface layer where they are subjected to stirring by currents and waves. Clearly such alterations are not necessary consequences of dredging and spoiling.

The magnitude of the impact of dredging and spoiling is also a function of the time of year they are done. These activities should be scheduled when there will be the least probable impact on the most "important" indigenous species. Generally, for any given species the early life history stages are more sensitive to environmental stresses than later stages.

Studies indicate that substantial dredging and spoiling projects can be carried out in estuaries without any gross biological effects or any persistent aesthetic degradation. Any chronic biological effects that might arise either from exposure of organisms to spoil and associated contaminants for long periods, or from exposure to relatively subtle, but persistent, changes of the physico-chemico milieu have not been documented. Much of the research that has been done and is still being done to determine the effects of dredging and spoil disposal is ill conceived and will not provide answers to the pertinent questions.

EFFECTS ON WATER QUALITY AND AESTHETICS

Fine-grained suspended sediment can affect the distribution of dissolved oxygen in estuarine waters both directly and indirectly. The oxygen demand of organic-rich sediments may produce a sag in the oxygen distribution. It has been reported that in the Arthur Kill, for example, when dredged spoil was resuspended oxygen levels were reduced from 16 to 83 percent below their average levels. Other investigators reported that when surface sediments from Wassaw Sound, Ga., were suspended in the estuarine water, they were capable of removing "533 times their own volume of oxygen from the water." No such effect was observed in the upper Chesapeake Bay, and studies of Louisiana marshes did not demonstrate any significant oxygen depletion as a result of dredging activities. Since the concentration of suspended sediment affects the transparency of water, increases in suspended sediment levels decrease the depth of the euphotic zone and therefore the production of oxygen by phytoplankton.

Increased suspended sediment concentrations may also affect the production of oxygen by rooted aquatic plants. Areas of the bottom formerly within the euphotic zone can be removed from it as a result of man's activities. Prior to about 1920 much of the bottom of the upper Potomac outside of the channel was covered with a dense growth of rooted plants. During the 1920's this vegetation almost completely disappeared and lower oxygen levels were reported in this area. The effects of the disappearance of these plants on the distribution of dissolved oxygen were confounded by the effects of other significant environmental changes on oxygen levels.

Fine sedimentary particles can act as both a source and a sink for nutrients and other constituents. Nutrients may be sorbed onto fine-grained particles, or desorbed from them depending upon a variety of physico-chemico conditions. These include salinity, pH, temperature, the chemical composition of the particles, and the concentrations of nutrients in the water. The mechanisms that control these exchange processes are poorly understood, and should be investigated.

It is well known that fine-grained particles concentrate a variety of pollutants, including: petroleum byproducts, heavy metals, pesticides, and some radionuclides. In the water column the bulk of each of these contaminants is usually associated with fine suspended particles, and therefore the distribution, transportation and accumulation of these substances are determined primarily by the suspended sediment dispersal systems. Filter-feeding organisms which ingest these particles and associated contaminants agglomerate the smaller particles into larger composite particles in their feces and pseudofeces thereby providing the contaminants in a more concentrated form to deposit feeders. Laboratory experiments have demonstrated the ability of oysters to concentrate DDT in their pseudo-feces. Increases in the concentration of DDT and other pesticides in detritus particles of fine-grained bottom sediment of estuaries of up to 100,000 times those in the overlying waters have been reported. These residues can sometimes be transferred to detritus feeding organisms. Increases in the concentration of contaminants at each trophic level are well documented for radioactive isotopes and some pesticides. This phenomenon has been referred to as "biological magnification."

Fine sediments can also serve as a temporary sink for radioactive contaminants. It has been shown, for example, that ^{65}Zn may be held by fine-grained sediments for months with a continual low level release to the interstitial and overlying waters.

The effects of fine-grained particles and their associated contaminants on the composition of both the interstitial and overlying waters, and on the biota are poorly understood. This is an area that should receive considerable attention. From the standpoint of dredging, it is particularly important. Appropriate standards for permissible levels of contaminants in spoil should be based, not on the total concentration of each contaminant, but on the concentration that is available for biological uptake—the concentration of the reactive fraction. While standards based on totals are safe they place undue restrictions on the disposal of dredged materials. It is becoming clear that fine-grained particles play a significant role in determining the quality of the estuarine environment, and the composition of its biota.

Increases in the levels of suspended particulate matter can also have a significant aesthetic effect. Above some threshold level, suspended matter is aesthetically displeasing and inhibits recreational use. This level is a function not only of the total concentration, but also of the size distribution and the composition of the suspended material. A concentration of 100 mg/l of fine quartz sand does not have the same effect on water color and transparency as does the same concentration of organic-rich silt and clay. Individuals also have different aesthetic thresholds.

SOME RECOMMENDATIONS FOR FURTHER STUDY

Some of the types of studies we feel must be done if we are to understand how estuaries operate sedimentologically; if we are to be able to predict the consequences of manmade alterations of the prevailing sedimentary processes; and if we are to manage estuaries for the greatest use of man, are described below.

Sources of Sediment to Estuaries

One of our principal needs in understanding the sources of sediment brought to estuaries is for more complete data on the sediment loads carried by rivers—the principal source of sediments to most estuaries. In less than half of the estuaries of the country do we have any kind of regular measurement of the input of river sediment. Furthermore, the records we do have are mostly too short. Only a few river sediment stations have been in operation long enough to have documented the extreme events that are so important in the introduction of sediment: events such as the hurricane flood of August 1955 when the Delaware River carried more sediment past Trenton in two days than in all five years combined in the mid-1960's drought; or the three days in December 1964 when the Eel River in northern California transported more sediment than in the preceding eight years; or the week following Tropical Storm Agnes in June 1972 when the Susquehanna discharged 20–25 times as much sediment as during the previous year. Events of this magnitude occur only rarely—a few times a century at most—but their importance to estuarine sedimentation is so great that programs should be designed to record their effects when and where they do occur.

Daily sampling stations should be established on the lower reaches of all major rivers—upstream from the landward limit of measurable sea salt intrusion—to measure the inputs to estuaries of water, sediment, nutrients, and other substances. These stations should be permanently maintained to catch the large events, and permit an assessment of their relative importance. In addition, a funding mechanism should be developed to support research of the effects of events on the estuarine environment.

We also need to further our understanding of sources of estuarine sediments other than rivers. In a recent study of the sources of shoaling material in the navigation channels of the Delaware estuary, for example, the U.S. Army Corps of Engineers estimated that only one-fourth of the shoaling material could be accounted for by present day river sources. The remaining three-fourths was attributed to erosion of the bed and banks of the estuary, diatoms produced in the estuary in response to an excess supply of nutrients, and other sources (some of which could not be identified). It has been suggested that shore erosion is the principal source of sediment to the middle and lower reaches of the Chesapeake

Bay estuary. These sources deserve more of our attention so that we can identify them more accurately, assess the rates at which they add sediment to the estuaries, and find out to what degree they are subject to manipulation and control by man.

Routes and Rates of Sediment Transport

Tracers offer a promising approach to studying the routes and rates of sediment movement. Tracers such as fluorescent particles can be added to the sediment, and the sediment can be sampled repeatedly to determine the routes and rates of sediment movement; or one can make opportunistic use of distinctive contaminants, such as radioactive isotopes or heavy metals, that are dumped into estuaries either intentionally or inadvertently. These compounds sometimes can be used as labels to follow sediments from known sources to sites of deposition. Releases from nuclear power plants should be investigated as possible tracers. An attempt should be made to assess the impact of man on the prevailing sedimentary processes. Such an assessment would have to come primarily from an examination of the sedimentary record.

Patterns of Sediment Accumulation

In the past we have relied mainly on dredging records as a measure of sediment accumulation, but they tell us little about how sediments accumulate in the large areas of estuaries that lie outside the dredged channels. For some estuaries, modern day navigation charts have been compared with older ones (some dating back to the mid-1800's) to estimate the accumulation of sediment. Because the charts are already available, a systematic comparison of old and recent survey sheets could be made for most estuaries of the country at relatively little expense. Some newer techniques can also be applied—particularly those techniques that use the decay rate of naturally radioactive material to measure the age of sediment and how long ago or how rapidly it may have accumulated. An effort should be made to refine those radiometric dating techniques that are particularly applicable to estuarine deposits, and to apply the techniques to a variety of estuarine systems. The two methods that have the greatest promise are Pb^{210} which has a useful range of 10 to 100 years and C^{14} which can be used to date events that occurred in the past 1,000 to 10,000 years.

Another difficult aspect of the sediment budget of most estuaries is the question: on a net basis, does more sediment move out of the estuary into the sea than moves into the estuary from the sea? We know that sediment escapes from estuaries on outgoing tides, and we know that sediment is moved into estuaries from the sea floor on incoming tides; but we do not know enough about the quantity or kind of sediment that moves either way to be able to say whether, on balance, more moves out than in. Here again, well-designed tracer studies might be useful.

An estuary's sedimentary deposits contain the history of that environment, and it is only through the examination of this sedimentary record that one can assess the impact of man on the distributions of both naturally occurring substances and of man-made pollutants, such as PBCs (polychlorinated biphenyls) and pesticides. Naturally occurring substances include not only innocuous sedimentary particles, but also some pollutants; pollutants such as heavy metals which are present in the earth's crust and are carried into the estuarine environment both in solution and adsorbed to fine suspended particles by rivers and streams. Heavy metals are, of course, also introduced into the environment as a result of man's activities.

The sedimentary record also contains the most reliable information of the frequency of natural catastrophic events such as floods, droughts, and hurricanes that have occurred during the past several thousand years. The importance of episodes in the development of estuaries has not been well documented because of the infrequency of such events and the difficulty of sampling during most storms and floods.

Model Studies

Physical and mathematical models can provide valuable insight into a variety of sedimentary processes. They are not, however, a panacea for all estuarine sedimentation problems, and are only as good as the prototype data and theoretical assumptions on which they are based. Perhaps the greatest need is for more attention to be directed at the formulation of conceptual models of estuarine sedimentation. Conceptual models should, in any case, precede the construction of mathematical or physical models.

Characterization of Fine-Grained Sediments

Appropriate field and laboratory studies should be conducted to characterize the chemical and mineralogic nature, and the reactivity of the fine-grained, carbon-rich particles. It is clear that fine-grained particles can play a major role in determining the quality of coastal waters, and the distribution of organisms. These studies should also include investigations that would lead to the establishment of meaningful diagnostic standards for the disposal of dredged materials. While the present standards used by the EPA to characterize dredged materials were intended to be environmentally conservative they may be unduly restrictive with respect to the designated parameters, while they ignore a large number of important contaminants such as PCBs, pesticides, and others. In any event, they are clearly not based on sound scientific evidence. Standards for dredged materials should not be based on the total concentrations of contaminants, but rather they should reflect the total masses of contaminants that are available for biological uptake. These masses are the concentrations of the reactive fractions of these contaminants—the fractions available for biological uptake—times the total mass of dredged material. Even with such standards, decisions on dredging and spoil disposal should be based on the physical, chemical, biological, and geological characteristics of the particular estuary. The uniform application of Federal standards has little merit other than simplicity of enforcement.

We know far too little about the effects of sediment-borne contaminants on estuarine life. We need an extensive series of laboratory experiments to test the effects of a variety of contaminants on different organisms. It is particularly important that these experiments simulate field conditions; too many of the experimental results we already have cannot be extrapolated beyond the laboratory. Only after such a series of experiments can we establish diagnostic standards and criteria for such things as dredged materials. Increased emphasis should be directed at studies to determine the chronic effects of exposure to moderate excess concentrations of a variety of contaminants.

The new Dredged Materials Research Program (DMRP) of the U.S. Army Corps of Engineers is an important step in the right direction. The DMRP should provide a great deal of valuable information for the more effective mangement of estuarine dredging and spoil disposal.

Alternatives to Present Practices

Even if we succeed in reducing sediment inputs to estuaries through enforcement of strict soil conservation measures, dredging will continue to be a persistent estuarine activity. Not only are estuaries naturally areas of relatively rapid sedimentation, but much of the material dredged from navigation channels is material previously introduced, and redistributed by prevailing estuarine circulation processes. Further, the increasing use of deeper draft vessels, and the increasing demand for pleasure boat marinas and facilities will require additional dredging.

Estuary-wide dredging and spoil disposal plans should be developed to ensure that maintenance channel dredging can be carried out without undue delays. Such plans should include the designation of a variety of types of sites (overboard, diked, et cetera) for disposal of different types of spoil. Certain kinds of spoil may have a greater environmental impact if disposed of in aerobic (oxygenated) diked areas, than if disposed of by conventional overboard methods within oxygen-deficient areas of an estuary. If regional plans are not developed promptly, the activities of a number of major ports will be seriously affected and will result in serious economic perturbations. These dredging and spoil disposal plans should be significantly flexible to provide a mechanism for decision making on requests for other types of dredging permits. The suggestion that a number of our major ports are "poorly located" is to some extent correct, but the suggestion that they should be moved is naive at best. Major ports could not be moved without serious economic upheaval, and the lead time to implement any such proposals would have to be decades. The growth of some ports located near the heads of estuaries should perhaps be controlled.

We should also direct more attention to more productive means of disposing of spoil. An example is the process developed by Professor Donald Rhoads of Yale University to make construction bricks from estuarine mud. Or we might consider taking railroad cars that haul coal to seaports and filling them on the return trip with dredge spoil that can be used to fill or reclaim lands that have been strip mined. Formation or nourishment of islands for recreational use is another possibility. Surely there must be other more ingenious ways of disposing of dredged material than dumping in estuaries or transporting it out to sea.

SOME CLOSING OBSERVATIONS

The great value of the estuarine zone is in the multiplicity of uses it serves, but herein also lies its vulnerability. Estuaries can support certain levels of shipping and transportation without a loss of commercial and recreational fish landings. Estuaries can tolerate some dredging and disposal activities without persistent damage to the biota or aesthetic degradation. Estuaries also have a capacity to tolerate some human, industrial, and municipal wastes; and to assimilate some waste heat without suffering persistent and significant ecological damage. And, the biological resources of estuaries can be harvested at certain levels without seriously affecting future yields. Estuaries can serve all of these uses and still remain aesthetically pleasing environments for man's recreation—for his re-creation. But an estuary's capacities to support these varied activities are finite. The ability of an estuary to tolerate each "environmental insult" before suffering significant ecological or aesthetic damage not only varies from estuary to estuary but varies in different parts of a given estuary as well. And, within any segment of an estuary it varies temporally. Uniform, invariant regulations and standards for the disposal of wastes, whether they are heat, nutrients, or dredged spoil, are environmentally naive. The only justification for their enactment is that it simplifies enforcement. A uniform speed limit of 25 mph is as irrational as one of 100 mph is irresponsible. Uniform estuarine regulations are wasteful of valuable natural resources—resources that should be used, and used responsibly. The philosophy of those crusaders who espouse cessation as the solution to all environmental problems is not viable. People live. They eat, they defecate, they procreate, and yes, they also need to recreate. This is not to imply that we should not insist on good waste treatment, on carefully supervised methods of dredging and spoil disposal, and on controlled mining of bottom and subbottom mineral resources. We should. We should insist on more.

Estuaries should be zoned. To date, formal zonation of the estuarine environment has been restricted primarily to that associated with military activities. Man zones his terrestrial environment into residential and industrial areas, and he sets aside portions of it for parks and forests for recreation. He identifies other segments of it for the disposal of his waste products. He does not make it an official policy to spread his garbage and trash uniformly over the landscape. He neither demands nor expects all parts of his terrestrial environment to be of equal quality.

Should he expect to be able to swim and harvest seafood in every part of every estuary? Segments of some estuaries should be identified as spoil disposal areas, other segments as the receiving waters for municipal and industrial wastes, others as sinks for the heated effluents from power plants, others as spawning and nursery areas, others for military activities, and others as fishing and recreational areas; still others should be preserved, or at least conserved in a wild state. These segments are not all mutually exclusive; there would be considerable overlap. And the spatial boundaries of the various zones should be defined as a function of time.

Because the primary reasons for the management of estuaries are to protect their biological resources and to conserve their aesthetic and recreational values, certain activities should be restricted more severely in some areas than in others and also during those periods when organisms are most vulnerable. During these vulnerable periods—generally the egg and larval stages—temperature standards should perhaps be more stringent, and dredging and spoil disposals should perhaps be restricted or prohibited in the important spawning and nursery zones. The zonation of estuaries would be much more difficult than zoning man's terrestrial environment, and some of these suggestions may not be applicable to small estuaries. The establishment and enforcement of an estuarine zoning system would require more than simple policing. It would require careful and intelligent planning and management. But planning and management by whom?

The establishment of a zoning system is contingent upon the assignment of priorities to the various uses. These decisions require not only scientific inputs but social and economic inputs as well. Decisions as to which activities are "most important" and what water quality standards are "good" or "acceptable" are largely value judgments—important to whom? . . . good or acceptable for what purpose? Natural scientists have no peculiar talents for making value judgments. Scientists can incontestably determine neither what uses of an estuary are most important nor even which are most desirable. In terms of gross monetary return, the most important uses of the estuarine zone are, according to the "National Estuarine Pollution Study," for military activities, for shipping, and for industry. But the monetary values of commercial and recreational fisheries are also very high although they are more difficult to estimate. And, if indeed, communication with nature is one of man's ultimate sources of happiness as Dubos and others have suggested, then the true worth of the recreational value of estuaries cannot be measured in dollars and cents.

Through science, we can learn to understand estuaries and even to control them in part, but scientists cannot unequivocally and decisively determine the ways in which we should control them. These decisions should be made by the citizens who are affected—by all of them.

REFERENCES

Barnes, R. S. K. and J. Green, 1972. The Estuarine Environment. Applied Science Pub. Ltd., London.

Folger, David W., 1972. Characteristics of Estuarine Sediments of the United States. U.S. Geological Survey Professional Paper 742.

Ippen, Arthur T., ed., 1966. Estuary and Coastline Hydrodynamics. McGraw Hill, New York.

Lauff, George H., ed., 1967. Estuaries. American Association for the Advancement of Science, Pub. 83. Washington D.C.

Nelson, Bruce W., ed., 1972. Environmental Framework of Coastal Plain Estuaries. Geological Society of America Memoir, 133.

Schubel, J. R., ed., 1971. The Estuarine Environment: Estuaries and Estuarine Sedimentation. American Geological Institute, Washington, D.C. Short Course Lecture Notes.

ACKNOWLEDGEMENTS

We thank M. Nichols, D. Hubbell, J. Conomos, and C. Zabawa for their suggestions. Contribution 116 of the Marine Science Research Center of the State University of New York.

SIGNIFICANCE OF CHEMICAL CONTAMINANTS IN DREDGED SEDIMENT ON ESTUARINE WATER QUALITY

G. FRED LEE
The University of Texas at Dallas
Richardson, Texas

ABSTRACT

During the past several years, there has been a major change in dredged material disposal in some estuarine waters in the U.S. This change is largely the result of finding that many of the sediments of rivers and harbors contain potentially significant concentrations of chemical contaminants. Some water pollution control regulatory agencies have adopted dredged material disposal criteria which have caused more expensive methods of disposal.

A review of the information available today on the relationship between the presence of chemical contaminants in dredged sediments and water quality shows no technical justification for the general adoption of alternate methods of disposal at this time. Further, it is shown that some of the alternate methods of disposal may be more ecologically damaging than those previously used.

The U.S. Army Corps of Engineers initiated in 1973 the 5-year, $30 million Dredged Material Research Program, designed to provide a technical base of information for the determination of the most ecologically sound, technically, and economically feasible methods of disposal. This program shows great promise in providing needed information.

It is recommended that the overly restrictive dredged material disposal criteria advocated by some environmental activist groups not be adopted. The results of the Army Corps of Engineers Dredged Material Research Program and other studies should be used for establishing criteria.

INTRODUCTION

Many American waterways have a significantly recurring problem of accumulating sediments which eventually interfere with navigation. It is of economic and social interest to Americans to maintain the navigable waterways at a depth sufficient to allow the water transport of goods. Generally, the question is not one of whether or not the U.S. waterways should be dredged but is one of what method of dredging and dredged material disposal is in the best overall interest of society.

The process of removing settled solids from one location and depositing them in another has an environmental impact on both locations. The potential impact includes turbidity (cloudy water) stirred up at the dredging and dredged material disposal sites mechanical damage to the aquatic organisms due to pumping for hydraulic dredging operations, burial of organisms at disposal sites, as well as toxicity to organisms arising from chemical contaminants in the sediments. It is the latter that causes sediments to be classified as polluted.

In the mid to late 1960's, increasing amounts of information were gathered which showed that the sediments in many estuarine environments contained amounts of chemical contaminants which could potentially lower water quality. By the early seventies, many Americans were caught up in the environmental quality movement. During this period, at the mere discovery of a chemical contaminant in the environment, activists would advocate large expenditures of funds for corrective action. In that spirit, the Federal water pollution regulatory agencies developed criteria which changed the method of disposal of dredged sediments for some areas of the country.

The new methods of disposal were predicated on the fact that the sediments contained amounts of chemical contaminants, which caused them to be classified as polluted. The alternate methods of disposal generally required a much greater expenditure of funds for the dredging operation. In some areas, the lack of a suitable alternate method of disposal has caused the dredging of the waterway to be stopped or greatly curtailed. As a result, the cargo vessels using the waterway had to either lighten their loads or seek an alternate port.

The situation that exists today in San Francisco Bay is a good example of this problem. The cost of dredging and dredged material disposal in the bay region has doubled during the past several years, largely as a result of environmental considerations. One would expect some problems associated with the presence of chemical contaminants in the sediments of the bay which, when dredged and disposed of in bay waters, have a significantly adverse effect on water quality. However, upon examination of the situation in the bay region, one finds that no one, including the water pollution control regulatory agencies and the environmental activist groups, has yet attributed any problems to the presence of chemical contaminants in sediments, which have a deleterious effect on water quality as a result of dredging and dredged material disposal activities.

Individuals knowledgeable in the behavior of chemical pollutants in natural waters examined the federal criteria which forced alternate methods of disposal; they raised serious questions about the validity of these criteria. As a result, the U.S. Army Corps of Engineers, which is one of the major dredgers of waterways in the U.S., initiated a program to determine which methods of dredging and dredged material disposal are in the nation's best interests. Their headquarters for this project is at the Waterways Experiment Station (WES) in Vicksburg, Miss. In addition, a number of Corps of Engineers districts have initiated regional research programs designed to evaluate the potential problems of dredging and dredged material disposal. This report discusses the progress that has been made in the control of chemical pollutants in waterways to be dredged.

This report is not intended to be a discussion of all of the various problems associated with dredging and dredged material disposal. It instead focuses exclusively on one of the most significant problems of the past few years in the area of estuarine water quality. This problem requires congressional attention in order to develop a more meaningful approach to the protection of water quality in U.S. estuaries with dredging and dredged material disposal activities. It should be emphasized that other aspects of dredging and dredged material disposal should also receive congressional attention. These problems include the development of a more effective land erosion control program to reduce the need for dredging, the selection of a few harbors and waterways as principal ports for deep draft vessels, the more effective control of chemical and biological contaminants arising from domestic, industrial, and agricultural activities, and the development of more effective means for allocation of the nation's estuarine and marine resources. Many of these topics are covered in other authors' contributions to the U.S. EPA overall report to Congress on estuarine water quality. They are beyond the scope of this paper.

This report does not attempt to provide detailed documentation of each point raised. Instead, it consists of a synthesis of the author's views, which are based on his having been actively involved as a teacher, researcher and advisor to governmental agencies and industry on the environmental impact of dredging and dredged material disposal. The U.S. Army Corps of Engineers Dredged Material Research Program (DMRP) includes comprehensive literature reviews prepared by various contractors, which provide documentation of the various points covered in this report. Anyone interested in additional discussion and documentation should contact the author and/or the Corps of Engineers Dredged Material Research Program at the Waterways Experiment Station, Vicksburg, Miss.

Two Corps reports are especially pertinent as backup information to the discussion presented in this report. The first is by Boyd et al. (1972), and presents a review of the overall problems associated with dredging and dredged material disposal. The second report, by Lee and Plumb (1974), presents a detailed review of the literature on the potential significance of chemical contaminants in sediments as influenced by dredging and disposal activities.

HISTORY OF THE PROBLEM

Prior to the environmental movement, dredged material was generally disposed of in the most economic manner possible, usually transportation to and disposal in deeper waters. By the late 1960's, and early 1970's, environmental activist groups and some federal and state pollution control agencies were advocating on-land disposal. Large amounts of funds have been expended for land disposal areas.

During the past three years, there have been several attempts on the part of federal and state water pollution control regulatory agencies to develop dredged material disposal criteria. These criteria were based on a limited scope study conducted in the Great Lakes, and were unfortunately made applicable to estuarine and marine systems as well. In retrospect, it appears that such criteria were not suitable for the Great Lakes, much less other waters throughout the country. As a result of the use of these criteria, sediments in many parts of the country were classified as polluted when significant doubt exists as to whether this was the case.

NATURE OF THE PROBLEM

The rapid changes in dredging and dredging material disposal methods during the past few years have probably created as many problems as solutions. In some areas, dredging has stopped. In other areas, escalating costs are forcing private dredgers out of business. Those who continue operating must absorb the increased costs. Yet, some of the more expensive alternate methods of disposal are probably more ecologically harmful than the previous methods.

It is difficult to estimate at this time the total magnitude of the additional cost of alternate methods. However, in a survey of the various Corps of Engineers districts, it was found that environmental quality factors raised the cost of dredging by 10 to 20 percent. For some Corps of Engineers districts, the increase represented 50 to 60 percent additional cost.

It is impossible to estimate the total cost for alternate methods of dredged material disposal in estuarine waters. However, it is reasonable to expect that several tens of millions of dollars are being spent each year for alternate methods of disposal because of arbitrarily adopted criteria which cause dredged sediments to be classified as polluted. Yet, there is no evidence that the relatively economical sediment disposal methods used in the past had significant adverse effect on water quality.

Many areas are not finding the alternate methods of disposal, such as on-land disposal, feasible, and as a result must barge the dredged material further out into the open ocean. For example, the New York District of the Corps of Engineers estimates that they are spending about 1.2 million dollars per year out of a total dredging cost of 5 million dollars for additional transport of dredged material to open water. The New York District Corps of Engineers points out that these figures do not include the increased cost of goods such as oil, because partly loaded or shallow draft vessels must be used.

The New York District also reports that several marinas and small volume dredging companies have had to go out of business because they cannot afford the increased costs of transporting the material to the open ocean. Also, because of environmental concerns, dredging has ceased in some east coast harbors, such as Baltimore. Although the total increase in cost is unknown, alternate disposal methods place a substantial burden on the public without any apparent benefit in terms of improved environmental quality.

PROBLEMS WITH ON-LAND DISPOSAL

In many areas, on-land disposal with complete containment of the water associated with the sediments is not possible; so near shore diked area disposal was adopted. Generally, on-land and in-water diked disposal areas have overflows that enter nearby watercourses. Thus, this disposal approach may be more harmful to aquatic ecosystems than the disposal of dredged sediments in deeper waters.

Those knowledgeable about the behavior of pollutants in natural waters have known for some time that the primary area of concern for chemical contaminants in natural water systems is fine particles. Coarse particles readily settle to the bottom. The fine particles often contain the greatest concentration of chemical contaminants and, because of their slower settling rates, have greater opportunity for interactions with aquatic organisms.

Some of the on-land or dike disposal areas nearshore have been operated in such a way as to allow only a relatively short period of time for the settling of finer particles before returning the excess water to the nearby watercourse. This means that if there is any adverse effect from dredged material, it would occur to the maximum possible extent with on-land or contained disposal. By contrast, any adverse effects of chemical contaminants associated with dredged sediments would generally be expected to be minimized in open water disposal because, in general, open waters allow much greater mixing of the contaminants with the surrounding waters. This mixing would tend to rapidly dilute the chemical contaminants below critical threshold concentrations for the organisms present in the water column. Moreover, on-land disposal would bring contaminant concentrations into contact with the most sensitive forms of aquatic organisms, since nearshore waters serve as the nursery grounds for the juvenile forms of many aquatic species. Thus, it is possible that in some areas the more expensive on-land disposal methods in use during the early 1970's, have done more ecological damage to the water bodies than have the traditional deep water disposal methods. In addition, on-land disposal may also lead to contamination of terrestrial ecosystems as well as nearby watercourses. However, at this time, little is known about the uptake of chemical contaminants by terrestrial plants grown on polluted dredged sediments.

It is clear that, as normally practiced today, many of the alternate, more expensive ways of dredged material disposal may not be less ecologically damaging. Frequently, those who advocate alternate methods based on the presence of chemical contaminants, justify the increased expenditure by citing the lack of knowledge of the environmental impact of aquatic disposal. They assert that the conservative approach should be used in those situations where there are questions about the impact on aquatic ecosystems. This argument has some validity where the concern is over the introduction of a chemical contaminant into the environment. It is not technically valid, however, for dredging and dredged material disposal since the contaminants are already present in the environment and most importantly, since the alternate methods of dredged material disposal could produce significant environmental quality problems.

DREDGED MATERIAL DISPOSAL CRITERIA

In 1972, two developments of major potential significance to the disposal of dredged materials occurred. The first was the passage of the 1972 Amendments to the Federal Water Pollution Control Act. This act required the U.S. Environmental Protection Agency (EPA) to propose water quality criteria by October 1973. The other important event was the 1972 release of the National Academies of Science and Engineering (NAS-NAE) Water Quality Criteria (NAS-NAE, 1972). These criteria represent several years of work on the part of scientists and engineers throughout the U.S. in assessing the significance of various physical, chemical, and biological contaminants to potential uses of fresh and marine waters. The two events are closely related in that the criteria proposed by EPA in October 1973, were essentially based on the July 1972 NAS-NAE water quality criteria. Both documents are potentially crucial to dredging because they suggest that agencies which regulate water quality standards significantly reduce the permissible concentrations of chemical contaminants.

The most crucial change stemmed from the discovery that pollutants could be chronically toxic. Previous water quality standards throughout America had been based on acute lethal toxicity (i.e., the relatively high levels of chemicals that cause the death of organisms within a few days of continuous exposure). However, researchers found that continuous lifelong exposure of aquatic organisms to relatively low levels of chemical contaminants would result in impaired growth and/or reproduction. The NAS-NAE concluded that, in order to provide the ultimate protection to aquatic life, water quality criteria must also be based on chronic toxicity levels.

The full impact of the NAS-NAE water quality criteria is yet to be manifested. The main problem is that although the National Academies released the criteria in 1972, it took two and one half years for EPA and the Government Printing Office to print them.

The importance of the new NAS-NAE criteria is that they will eventually become water pollution control standards because they are essentially being adopted by EPA as a basis for their October, 1973 Proposed Water Quality Criteria. It is likely that attempts will be made to use these standards to govern dredging and dredged material disposal. For example, EPA Region IX has recently proposed revised dredged material disposal criteria for which they use as a justification the EPA October 1973 Proposed Water Quality Criteria. However, this presents a problem in that the criteria developed by the NAS-NAE and promulgated by EPA are applicable to forms of chemicals in a relatively simple chemical state. In natural waters, chemical contaminants exist in a wide variety of forms, many of which are much less toxic than those simpler forms frequently used to test aquatic toxicity. For instance, the chemicals associated with the solids in sediments being dredged would generally be in the least toxic form. Therefore, any attempts to apply the EPA proposed criteria to dredging would likely be highly over-restrictive in assessing the potential toxicity of chemical contaminants associated with sediments.

In developing dredged material disposal criteria, emphasis must be given to the role that dredging and dredged material disposal plays in affecting the significance of chemical contaminants on water quality in a particular region. The problem is not one of determining whether or not the sediments are contaminated. The sediments of the majority of the U.S. harbors and waterways are contaminated by chemicals of municipal, industrial, and agricultural origin. These contaminants do have an adverse effect on water quality in many U.S. estuaries. The basic question, however, is what is the impact of dredging and dredged material disposal in altering the significant adverse effects of these chemical contaminants on water quality in the region.

CURRENT RESEARCH

By the early 1970's, the funds supporting research in the development of water quality criteria had been greatly curtailed in an attempt to cut back on federal spending. Currently, little work is being conducted on the development of new criteria for the hundreds of new compounds that are being produced each year, much less the thousands of compounds that have been produced and are being introduced into the environment today. It appears that, unless a major change takes place in the approach to funding in the water quality criteria development area, it will be difficult to develop meaningful criteria which can be used to properly evaluate the full significance of chemical contaminants associated with sediments in rivers and harbors.

With respect to dredged material disposal problems as they affect estuarine pollution, perhaps the most significant event of the past three years was the funding of the $30 million, 5-year research program being conducted by the U.S. Army Corps of Engineers, Vicksburg Waterways Experiment Station. In many parts of the country, typical costs of dredging have increased from 30 to 40 cents per cubic yard to 50-60 cents per cubic yard. In some cases, because of environmental considerations, the costs of dredging and dredged material disposal approach $10 per cubic yard. The U.S. Army Corps of Engineers' current annual budget for dredging and dredged material disposal is approximately $200,000,000 a year. While the dollar magnitude of the 5-year research program is substantial, it should be noted that if this program results in savings of one to two cents per cubic yard, it will pay for itself during its lifetime.

The Corps of Engineers Dredged Material Research Program (DMRP), while originally motivated primarily by a lack of knowledge on environmental impact of dredging and dredged material disposal, is providing information on constructive use of dredged materials, such as in the development of wildlife habitat. Most importantly, from the point of view of this discussion, this research project will provide valuable information that can be used to develop meaningful dredging and dredged material disposal criteria. These will enable those responsible for environmental resource management to evaluate the potential environmental impact of chemical contaminants in sediments which are scheduled to be dredged. From these studies, criteria will be developed which will be transformed into standards for dredging and dredged material disposal.

CURRENT SITUATION

At present, although dredged material disposal criteria are supposed to be uniform across the U.S., there is considerable confusion in the estuarine dredging field concerning the criteria which determine whether a given sediment contains sufficient concentrations of chemical contaminants to warrant alternate methods of disposal. A situation exists whereby each EPA region is able to promulgate its own criteria irrespective of EPA's efforts to establish uniform criteria. To develop their criteria, the regional EPA districts often resort to the bulk analysis approach rather than attempt to assess what part of the chemical contaminants may adversely affect water quality or aquatic life as a result of being made available by dredging or dredged material disposal.

It is apparent that one of two things must take place in order to eliminate the dredged material disposal criteria chaos that exists today. Either the EPA regions must utilize the criteria established by EPA national headquarters, or Congress must appropriate sufficient funds to strengthen the technical competence of the regional staffs so that these staffs could develop meaningful criteria for their particular regions. Frequently, the individuals responsible for making decisions of this type have limited knowledge of the environmental chemical behavior of pollutants in natural water systems. These individuals usually play it safe by taking the conservative approach and assuming that everything is polluted. Thus, they cause the public to spend large amounts of money for alternate methods of disposal. Since dredging is largely funded by tax dollars, such an approach leads to increased government spending and accelerated inflation. In the opinion of many, the adoption of arbitrary bulk chemical criteria which have no relationship to potential effects on water quality may do much greater harm to the financial and ecological resources of a particular area than the utilization of the available information to determine whether a particular chemical contaminant present in sediments is likely to have an adverse effect on water quality.

Another significant problem with water pollution control agencies adopting arbitrary dredged material disposal criteria is that this will eventually further erode the public's confidence in the ability of the agency to act on its behalf. Many individuals already question whether the approaches being used by water pollution regulatory agencies are in the overall best interest of the public. There is an urgent need for these agencies to gain credibility in the environmental quality control area.

The first attempt to establish criteria relative to the pollutional tendencies of a given concentration of chemical contaminants in sediments utilized what is termed "bulk criteria." Bulk criteria are based on an examination of the total content of the sediments for a particular element or compound. Use of these criteria generally assumes that all the forms of that element are equally toxic. Those familiar with aquatic toxicity know that this is certainly not the case. There is no relationship between the bulk composition of sediments and the water pollution tendcies of the chemical contaminants present in the sediments.

In an effort to eliminate the problems associated with bulk criteria, EPA and the Corps of Engineers developed the elutriate test. This test exposes the sediment sample to a known volume of water and then allows the chemical contaminants to be leached from the sediments. The elutriate test is primarily designed to examine potential problems due to the release of chemical contaminants from sediments during the dredging and dredged material disposal process. The primary problem with the elutriate test is that it has not yet been properly evaluated for the wide variety of sediments that occur in various estuaries and waters throughout the country. This leads to confusion over the interpretation of the test results. The Corps of Engineers DMRP is devoting considerable effort to finding a remedy for this situation. It is likely that within a year or so the elutriate test will become a standard tool to evaluate the potential deleterious effects of chemical contaminants such as copper, DDT, et cetera, on the water near dredging and dredged material disposal sites.

In addition to developing the elutriate test, the Corps of Engineers DMRP is funding studies which are designed to evaluate the potential deleterious effect that will occur on benthic organisms at the dredged material disposal site. It is likely that a standardized bioassay procedure will be developed as part of this research program. Within a few years, water pollution control regulatory agencies will likely have the tools necessary to evaluate, prior to dredging, whether the chemical contaminants present in the sediments will have an adverse effect on water quality at the dredging and dredged material disposal sites.

It is in the best interests of the public, overall, to adopt interim dredged material disposal criteria which prevent the deposition of dredged materials in ecologically sensitive areas, such as significant fish spawning areas and shellfish beds. The interim criteria should be based on all available information on the significance of chemical contaminants present in dredged sediments to aquatic ecosystems. If alternate methods of dredged material disposal are advocated because of these criteria, a careful review should be conducted to ensure that the alternate methods do, in fact, minimize environmental impact of the chemical contaminants in sediments in both terrestrial and aquatic ecosystems. These interim criteria should be modified according to information developed as a result of the Corps of Engineers Dredged Material Research Program and other studies.

RECOMMENDATIONS

The following recommendations are proposed to serve as the basis for developing the technical information needed to evaluate the environmental impact of dredging and dredged material disposal in estuarine waters of the U.S.

1. The U.S. Army Corps of Engineers Dredged Material Research Program, devoted to evaluating the environmental impact of dredging and dredged material disposal (including the evaluation of various beneficial uses of dredged material) should be continued, at least at the currently programmed funding level, for the duration of the program.

2. The overly restrictive position based on bulk chemical criteria advocated by some environmental activist groups and water pollution control regulatory agencies at the local, state, and federal level, should not be adopted.

3. The current fragmented approach toward establishing dredged material disposal criteria and standards at the various regions of the EPA should be eliminated and national criteria should be adopted. The national criteria should provide a basis for evaluating the potential significance of chemical contaminants present in dredged sediments. In applying these criteria, consideration should be given to local factors which would influence the significance of chemical contaminants at a particular dredging and/or dredged material disposal site. These criteria should be developed jointly by individuals representing the EPA, Army Corps of Engineers, and others knowledgeable about the environmental impact of dredging and dredged material disposal.

REFERENCES

Boyd, M. B., R. T. Saucier, J. W. Kelley, R. L. Montgomery, R. D. Brown, D. B. Mathis and C. J. Guice. Disposal of Dredge Spoil. Problem Identification and Assessment and Research Program Development. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Miss., Technical Report H-72-8, (1972).

Lee, G. F. and R. B. Plumb. Literature Review on Research Study for the Development of Dredged Material Disposal Criteria. U.S. Army Corps of Engineers Waterways Experiment Station Vicksburg, Miss., Contract No. DACW-39-74-C-0024, (1974).

National Academy of Sciences, National Academy of Engineering, Water Quality Criteria 1972. U.S. Government Printing Office, Washington, D.C.

LIMITING FACTORS THAT CONTROL DREDGING ACTIVITIES IN THE ESTUARINE ZONE

JAMES H. CARPENTER
University of Miami
Miami, Florida

ABSTRACT

The current level of dredging activity for navigation channels (250,000,000 cubic yards annually) is producing substantial effects in the United States estuaries. These effects derive from 1) physical changes at the dredge site and release of substances from the sediment during the dredging; and 2) physical changes at the disposal area—filling of deeper areas and smothering of bottom dwelling organisms—and release of substances to the waters of the disposal area. The recent increased use of diked disposal areas, along the shorelines at increased costs, does not eliminate all of the environmental effects. Since soil erosion throughout the watershed is the primary source of the sediments, the obvious management strategy is control at the source. In addition to the recognized desirability of soil conservation, erosion control should be identified as essential to prevent continuing damages to estuaries.

INTRODUCTION

Navigation and cargo transport are valuable uses of estuaries that must be considered in formulating strategies and policies for management of U.S. estuaries. The optimization of policies to meet multiple-use objectives for estuaries presents intriguing and perplexing challenges with unavoidable intertwining of scientific and political considerations. Policy development that does not adequately consider both kinds of considerations may lead to the extremes of thoughtless waste of natural resources or to excessive preservation. Examples of both extremes can be found in the United States today.

Creation and maintenance of navigation channels in the United States is a substantial activity of the Federal government through projects carried out by the U.S Army Corps of Engineers. The scope of recent activities and associated partially understood environmental effects have been reviewed by the Army Corps of Engineers[1]. The level of dredging activity has been approximately 250,000,000 cubic yards annually in recent years for just maintenance, and the magnitude has led to questioning of the acceptability of the various environmental effects. The rather high level of activity has developed as the result of two different processes. Increased land utilization for agricultural, industrial, and domestic purposes in the watersheds that feed the estuaries has led to increasing amounts of soil introduction. Consequently, new and expanded ports have been developed, along with increasing use of deeper draft cargo vessels. In some cases the construction of dams to produce reservoirs has reduced the flow of soil to the estuaries but the reservoirs are rapidly accumulating sediment. Past and present failure to control erosion has led to a continued filling of the estuaries. In many cases, fine-grained sediment has been introduced to the point where resuspension by wind, waves and tidal currents leads to rapid transfer into the quieter waters of deep channels and rapid filling of navigation works.

Failure to develop effective policies will impact the economics and natural resources of many coastal states. As shown in Table 1, nearly every coastal state had maintenance and new projects proposed for FY 72. Many of the proposed work programs were not carried out, either for a lack of funding priority or because of questions concerning environmental effects and whether or not the optimal approach had been proposed. The economic consequences of the projects are not related to proposed yardage of dredging by a constant proportionality. For example, Maryland's project of 0.4 million cu yd, (a small part of the national program), was not carried out in FY 72 and the Baltimore Evening Sun recently headlined, "Port Dredging Delay Costs City $30 Million."[2] This article describes the economic impacts of the continued delay in maintenance dredging with 42-foot authorized channels having shoaled to 36 feet and at some points to 27 feet. Similar substantial economic impacts are occurring in other regions, notably San Francisco, Mobile, Galveston and the Great Lakes. Continued stalemates will have increasing impacts on the citizens affected and the adversary postures of national and

Table 1.—Dredging proposed for Fiscal Year 1972

State	Maintenance	New Projects
New Hampshire	1.7 million cu yd	4 million cu yd
New York	2.4	5.4
Pennsylvania, Delaware, New Jersey	1.8	8.6
Maryland	0.4	—
Virginia	2.0	0.1
North Carolina	6.0	0.1
South Carolina	6.9	—
Georgia	1.7	—
Florida	2.8	—
Alabama	16.5	3.2
Mississippi, Louisiana	74.4	21
Texas	28.7	17.6
California	4.9	2.9
Oregon	0.4	4.2
Washington	0.1	1.1

Data source: reference 1.

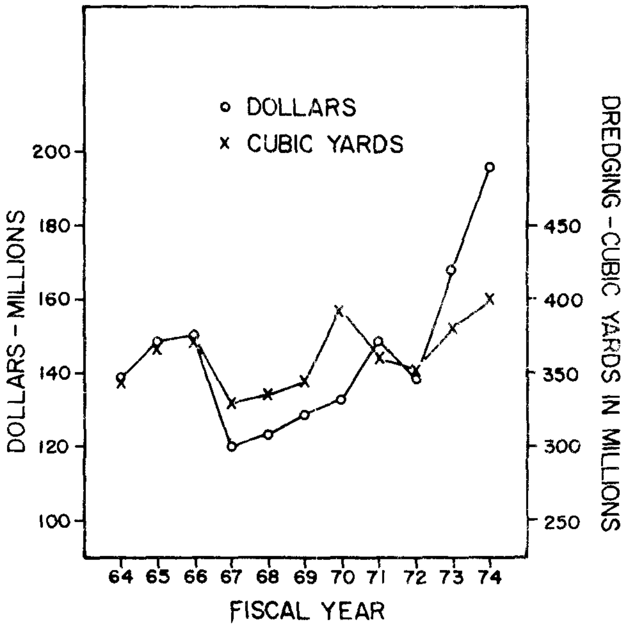


FIGURE 1.—Recent federal dredging activities in volume and costs. Data supplied by U.S. Army Engineer Waterways Experiment Station.

state agencies will have to be modified toward collaboration to develop multiobjective policies that balance economic and conservation considerations.

The national dredging effort during the past decade is shown in Figure 1 in terms of yardage and dollars. The decrease following FY 66 was the result of a twofold decrease in new projects and the increases since FY 69 are primarily associated with maintenance dredging. The rapid rise in costs since FY 72 appears to be due to changes in disposal practices to meet presumed environmental requirements. It should be noted that in some localities increased costs have been much greater than average increases shown in Figure 1 and the national effort cost statistics are ballasted by the high volume-low cost operations in Mississippi. Local project costs have gone as high as 10 times the national average or up to $5 per cu yd. In some cases where costs have increased drastically, the projects cannot be justified on the basis of a cost-benefit analysis and the projects have not been undertaken. The national trend, shown in Figure 1, appears to be substantial and the following discussion attempts to outline the considerations that are leading to the increasing costs and delays.

OBSERVED AND POTENTIAL EFFECTS OF DREDGING AND DISPOSAL

The effects of channel construction and maintenance occur at the construction location and at the disposal location. Considering first the construction activities, the effects may be categorized as follows.

Direct Effects of Dredging

The excavation of channel includes the removal of the living organisms and the loss of a fraction of the total local population of benthic (bottom-dwelling) organisms. Harvestable species, such as oysters, clams, shrimps, and so forth, may be involved as well as species that are eaten by bottom grazing fishes. The presence of a particular species is strongly related to the physical character of the bottom, particularly with respect to grain size, degree of compaction or firmness and organic content. When a channel is cut, the newly exposed material is usually firmer than the previous surface and repopulation is limited to those species that find the new conditions amenable. While channel construction reduces the area available to some species, channels in the nation's estuaries occupy only a small fraction of the total area. The effects on the local populations are of questionable quantitative significance and the losses appear to be outweighed by the usefulness of the channels.

Indirect Effects of Dredging

The bottom materials of estuaries are composed primarily of quartz (sands), aluminosilicates (clay) and calcium carbonate (skeletal fragments). These materials are predominantly inert. However, organic materials are also present and many elements (including transition or heavy metals) are present in lesser abundance in association with the surfaces of the bulk material and the organics. The organic materials may come from plant and animal life on the watershed, plant and animal life in the estuary, and discharges from domestic and industrial activities. As the estuarine sediments are being deposited, much of the organic material is metabolized by microorganisms that flourish at the sediment surface. However, not all of the organic material is metabolized and some becomes buried as additional materials accumulate at the sediment surface. Metabolism occurs within the sediment and, at some variable depth below the sediment surface, the supply of oxygen is inadequate to support the metabolic rate and the metabolism is dominated by anaerobic or oxygen-free processes. The predominant anaerobic process is the use of sulfate ions to support the oxidation of organic materials with the result that hydrogen sulfide is produced and mineral sulfides may be formed in the sediments, and hydrogen sulfide (rotten egg or swamp gas) accumulates in the waters within the sediment.

As the metabolism proceeds, nitrogen and phosphorus compounds (plant nutrients) are released to the waters within the sediment. Some metals, particularly manganese and iron, are solubilized from the minerals and appear in sediment waters in concentrations greater than that of the overlying waters. The net result of these processes is that many sediments that are considered for dredging have relatively high concentrations of biologically and chemically active substances. For example, hydrogen sulfide reacts rapidly with dissolved oxygen and contributes substantially to the so-called chemical oxygen demand of the sediments as well as acting as a direct toxicant.

The presence of growth promoting (nutrients) and growth inhibiting compounds (toxicants) leads to questions concerning the effects of release of these substances during the disturbances associated with dredging. It is pertinent to note that molecular diffusion naturally transports these substances to the overlying water and the dredging disturbance is primarily a local, intense acceleration of the transport process. Most of the dredged material is transported to the disposal site and effects of nutrients and toxicants are usually more important at the disposal site.

While it should be trivially obvious that environmental effects are quantitative in character, for example, the release of one pound of an active substance per day may have discernible effects in a particular estuarine location and almost imperceptible effects in another estuarine location, efforts continue to classify sediments and dredging activities on the basis of the composition of the materials involved. Inspection shows that a guideline or standard that would protect all estuarine locations from environmental effects would be unnecessarily restrictive and lead to a waste of public monies.

The point to be made is that release of active chemical compounds is a potential limiting factor on the acceptability of any particular dredging operation, but the substantialness of the limitation can only be determined for each particular location and specific activity.

A second kind of indirect effect that persists after the channel construction has been completed derives from changes in the currents and circulation caused by the presence of the channel. The intrusion of seawater into an estuary depends on the freshwater flow rates, the strength of tidal mixing and the depth of the estuary. A new channel has the potential for increasing the intrusion and therefore the saltiness along the length of the estuary. Many activities and requirements of estuarine organisms are related to the salinity of their environment. Some fishes spawn in fresh water and others spawn in salt water but require brackish or low-salinity waters during their maturation into adults. Increases in salinity have the potential for reducing the amount of habitat available to these species Success of some estuarine organisms, notably the oyster, reflects the intolerance of some predators, the oyster drill, to low salinities and increasing salinities potentially extend the range of the predators into the estuary. Once again, the potential of these effects can be recognized but only evaluated in the context of a specific location with its particular biota and physical characteristics.

Turning next to the effects of open water disposal, they may be categorized as follows.

Filling of Deeper Areas—Open Water Disposal

The deep regions of estuaries may play a unique role in supporting fish by providing havens during the winter cold season, as has been observed for striped bass and croakers in northern Chesapeake Bay. The deeper water is saltier but warmer than the surface waters in the winter and the existence of the deep water refuges may be critical in avoiding "cold kill" of these fishes or migration of the fishes to the ocean. The significance of this consideration varies from estuary to estuary and no generalizations are possible. While the values of naturally occurring deep regions have been identified, there does not seem to have been justification for deliberately over-deepening stretches of navigation channels but this approach might be considered to mitigate the loss of the natural areas, if the water quality in the navigation channels is suitable.

Smothering of Bottom-Dwelling Organisms and Repopulation

Open water disposal of dredged material may result in covering rather large areas with the spoil. Discharged materials have been observed as deposits in areas manyfold larger than the nominal disposal site.[3,4] The potential for this effect is substantial since the annual volume of dredging could cover 268 square miles to a depth of 1 foot. The degree of dispersal depends on the nature of the spoil, the strength of the currents at any particular disposal site, and on the kind of dredging operations since hopper dredging produces less opportunity for dispersal than hydraulic dredging.

If the dredged material is similar to the existing material at the disposal site, the effects of smothering may be transient and repopulation to replace the killed organisms could occur. This may be the case frequently for new work, but maintenance dredging commonly involves fine-grained material that accumulates preferentially in the dredged channels. Transfer of fine-grained materials to locations with existing firmer, coarse-grained sediments may be expected to produce long-term population changes as reported in reference 3, and, even though some species reappear in large numbers, the community structure will be changed. Such changes in the bottom of a habitat may be a major limitation on spoil disposal in estuaries.

Smothering may be a particularly severe limitation in areas of high water clarity, since benthic grasses may be an important part of the community and repopulation of denuded areas will be slow. Even in the warm waters of Florida, the return of seagrasses to damaged areas has been observed to require many years. Similarly, corals regenerate slowly and losses are not readily replaced.

Modification of Currents and Flushing Rates

At locations where the dredged material is not widely dispersed, filling to substantial depths will occur and such environments have obviously weak currents. The reduction in cross-sectional area through which the water can flow may reduce the total flow and, thus, the flushing or renewal of the waters in the estuary. Since the salinity distribution in an estuary depends on rates of river water input and the circulation, the reduction in depths may have an additional effect in terms of changes in the salinity distribution. The potential for these effects is rather easily identified, but there do not seem to be examples where it has been quantitatively significant.

Release of Sediment Constituents to the Water

As noted above, sediments contain biologically active substances, both nutrient and toxic materials. The possible release of these substances during open water disposal and following deposition of the discharged materials has led to questioning the acceptability of such operations and is a major source of current arguments.

The Environmental Protection Agency has put forth "criteria for determining acceptability of dredged spoil disposal to the Nation's waters" (reference 1, page 32). Criteria (h) reads, "...when concentrations, in sediments, of one or more of the following pollution parameters exceed the limits expressed below, the sediment will be considered polluted in all cases and, therefore, unacceptable for open water disposal."

SEDIMENTS IN FRESH AND MARINE WATERS

	Conc. % (Dry Wt.)
Volatile solids	6.0
Chemical oxygen demand	5.0
Total Kjeldahl nitrogen	0.10
Oil-grease	0.15
Mercury	0.001
Lead	0.005
Zinc	0.005

Some of the deficiencies associated with numerical concentration limits may be seen from consideration of the zinc "criterion." The average abundance of zinc in rocks and soils on the surface of the earth is 0.01 percent[5] and most naturally occurring materials would fail to meet the criterion but it is difficult to consider them polluted. The sediments being discharged to the Chesapeake Bay in the Susquehanna River flow average 0.05 percent zinc[6] and nearly all of the sediment in Chesapeake Bay would not meet the criterion. However, there is no evidence that these concentrations impair the environment of the aquatic organisms in Chesapeake Bay.

There appear to be two major deficiencies in the concentration criteria. The first is that the quantity involved in any particular activity is not considered; i.e., disposal of 100 tons of sediment with 0.05 percent zinc could potentially result in the release of 0.05 tons or 100 pounds of zinc to an estuary and, similarly, with numerical criterion of 0.005 percent zinc, the release could be 10 pounds. Whether or not the resulting environmental perturbation in either case would be significant depends on the particular estuary and the rate of the release. Each particular operation should be considered in terms of the time and spatial intensity of the perturbation and whether or not appropriate water quality criteria will be exceeded in a sufficient area for a sufficient time to produce an unacceptable effect on the aquatic populations in the estuary.

For sediments, the gross or total composition does not seem to be the appropriate aspect for consideration and this is a serious deficiency in the existing criteria. Using zinc as an example, the pertinent information is the availability of the zinc to the biological systems, both during the disposal operations and after the dredged material has been deposited, i.e., both short and long-term release. Much of the sediment zinc may be immobile and, thus, innocuous. An approach to evaluating the short term release is the elutriate test described under the EPA Ocean Dumping Final Regulations and Criteria 227.61 (C)[7] in which the material proposed for disposal is shaken with water from the disposal site and the resulting solution is analyzed for released substances. At present, there is no accepted way of evaluating the potential long-term release or effects on bottom-dwelling organisms. A possible procedure would be the examination of the characteristics of the material at the proposed dredge site by analysis of the pore or interstitial waters of the sediment and the bottom-dwelling, deposit feeding organisms. If substances are being released to the overlying waters, the pore waters will be greatly enriched and an estimate of the rate of release can be found from the contrast between the concentrations in the pore waters and the overlying waters. If substances are entering the biological food chains through deposit feeding organisms, the significance of this process could be judged from the amounts appearing in such organisms.

The purpose of drawing attention to the inadequacy of numerical concentration limits for dredged materials (that are analogous to effluent standards) is that such an approach will frequently either not properly protect environmental values or unnecessarily restrict some useful activity. Just as a responsible physician will not make a diagnosis or prescribe treatment without studying the individual patient, limitations on estuarine dredging due to release of materials to the water can only be developed on the particulars of each individual proposed activity. Environmental requirements of estuarine organisms can be established in a straightforward way and be broadly applied as water quality criteria, but the meeting of those requirements cannot be mandated by adoption of arbitrary input concentration limits, despite administrative enthusiasm for simple, universal regulations.

Creation of Land Along Shorelines and Islands

In view of the above effects of open water disposal, confined or diked disposal areas have been increasingly used. Frequently, the shallow areas along the estuary shorelines have been used. Such use causes a permanent loss of valuable estuarine environment and, in some cases, has produced land that has only limited usefulness for long periods of time. Current research directed by the Army Corps of Engineers is aimed at developing techniques and engineering practices to improve the quality of the land in the diked disposal areas. However, in view of the limited area of estuaries in the United States, conversion of present estuarine water bodies to fast land is not an attractive long-term strategy.

One limitation on the use of shoreline diked disposal is the necessity of retaining sufficient width to permit the discharge of storm runoff without excessive upstream flooding. The Potomac estuary below Washington, D.C., is a good example in that past diking produced useful land for Washington National Airport, Blue Plains Treatment Plant, and so forth, but further diking would likely produce an unacceptable reduction in the capacity to discharge flood waters. Changes in the width of an estuary also will have effects on the circulation, flushing, and salinity distribution to change the character of the estuary.

In addition to the ready generalization that destruction of shallow water and marshland habitats on a large scale and continuous basis is a waste of our limited resources, few property owners view with favor the construction of a diked spoil disposal facility adjacent to their lands and the states are reluctant to enter into condemnation proceedings. This is a practical limitation that is limiting dredging in estuaries and will also be a serious limitation to upland or dry land disposal.

The use of diked disposal areas has been proposed for materials that have been classified as polluted. As noted above, such classification may not be an accurate evaluation of the environmental hazards associated with the materials, but, in addition, it is not clear that diked disposal solves the problem. The process of dredging unavoidably involves the mixing of the sediment with large quantities of water. If biologically active materials are released to the water, the discharge of the water from the diked area into shallow waters with little dilution capacity would be expected to display greater environmental effects than would have occurred with open water disposal. Many estuaries have sediments with high concentrations of iron sulfides that are stable in the absence of oxygen. With diked disposal, the percolation of oxygenated waters through the material may produce the familiar acid mine drainage waters that result from the production of sulfuric acid upon oxidation of iron sulfides. Evaluation of the significance associated with these potential effects requires quantitative considerations; i.e., what fraction of the habitat is modified, for how long, to what degree from water quality criteria.

SHORT-TERM AND LONG-TERM POSSIBILITIES

The current research program directed by the Army Corps of Engineers should provide improved, factual information upon which assessment of new short-term options can be based. Where open water disposal is not suitable (habitat modification through physical effects may be expected to be a more severe restraint than pollutional effects[1], diked disposal with adequate engineering practices may be a viable option. Reduction in environmental damage due to runoff and leaching from the disposal sites may lead to increased costs and more complex disposal technology. The acceptability of such operations should be increased as techniques for making the disposal areas useful as land for human activities or wildlife habitat are developed. The optimal procedures will have to be developed for each estuary with due regard to its socio-economic setting.

However, these approaches to ameliorating damages to estuaries from dredging will be increasingly costly as the cheaper options are exhausted. This trend is clearly shown in the pattern illustrated by Figure 1. As appropriate open water estuarine sites and adjacent shoreline areas are fully utilized, upland and deep ocean disposal become the only alternatives and costs can be expected to increase by tenfold or more. As costs move to tens of dollars per cubic yard, the alternate of vigorous action to attack the root of the problem becomes more attractive. Failure to regulate human activity has led to well-documented increases in the rates of soil erosion[8]. Problems in the national dredging program are inversely related to successes in the national soil conservation program. It has long been the view of this writer that sedimentation at increased rates poses the most serious threat to the nation's estuaries and the dredging problems simply highlight the continuing damage being done through failure to control erosion.

Substantial progress has been made in the research, development, and application of procedures to reduce erosion. Many examples of successful use of such knowledge could be cited; however, more obvious are the failures to use such knowledge. Poor agricultural practices, slipshod road construction, and aggravated stream erosion due to storm water from paved areas are easily observed. The federal program of advice and information dissemination to the states, counties and individuals has been sound, but action is primarily at the county and individual level. At present there are only local incentives and the pollutional aspects of the soil erosion in one county harming the estuarine resources, including navigation, of an adjacent county have received little attention. With increasing costs and greater recognition of damages due to upstream negligent or improper practices, the need for action should be a matter for federal concern and activity by the appropriate agencies.

REFERENCES

1. Boyd, M. B., R. T. Saucier, J. W. Keeley, R. L. Montgomery, R. D. Brown, D. B. Mathis and C. J. Guice, "Disposal of Dredge Spoil—Problem Identification and Assessment and Research Program Development," Tech. Report H-72-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., 1972

2. *The Evening Sun*, December 12, 1974, Baltimore, Md.

3. Cronin, L. E., "Gross Physical and Biological Effects of Overboard Disposal in Upper Chesapeake Bay, *NRI* Special Report No. 3, (U.S. Department of Interior, Washington, D.C., 1970).

4. Saila, S. B., S. D. Pratt and T. T. Polgan, Providence Harbor Improvement Spoil Disposal Site Evaluation Study, Phase II, (University of Rhode Island, Kingston, R. I., 1971).

5. Rankama, K. and Th. G. Sahama, Geochemistry, (The University of Chicago Press, Chicago, 1950).

6. Carpenter, J. H., W. L. Bradford and V. Gant, "Processes Affecting the Composition of Estuarine Waters (HCO_3, Fe, Mn, Zn, Cu, Ni, Cr, Co and Cd)," Recent Advances in Estuarine Research, (Academic Press, Spring, 1975).

7. Environmental Protection Agency, "Ocean Dumping Final Regulations and Criteria," Federal Register, Washington, D.C., October 15, 1973.

8. Brown, C. B., "Effects of Soil Conservation," Applied Sedimentation, Ed. by P. D. Trask, John Wiley, New York, 1950.

ENVIRONMENTAL ASPECTS OF DREDGING IN THE GULF COAST ZONE WITH SOME ATTENTION PAID TO SHELL DREDGING

WILLIAM H. ESPEY, JR.
Espey, Huston & Associates, Inc.
Austin, Texas

ABSTRACT

The coastal zone is a rich national asset closely tied to our economy. Man's activity in the coastal zone has caused this rich national asset to be placed in jeopardy. "The National Estuarine Study" (1970) estimated that approximately 85 percent of the estuaries located on the gulf coast have been modified because of man's activities.

Shell dredging activities in the gulf coast region indicate a slight downward trend and are expected to decline as a whole in the future. The reasons for the reduction in shell dredging activity reflect both alternative raw materials and environmental concern. However, the overall USCE dredging activities as well as private dredging are expected to increase in the near future. Insufficient data are available on the extent of dredging and filling in the gulf coast, where it is a major environmental problem. Many of the environmental aspects of dredging are not well understood.

The federal permit system that deals with dredging activities in the coastal zone needs to be centralized and streamlined to expedite the efficient processing of permits. Environmental criteria used in evaluating USCE dredging permit applications should be clarified and quantified to the extent possible.

INTRODUCTION

The coastal zone constitutes one of our most valuable and vulnerable natural resources, an asset closely related to our national economy. As the economic value of the coastal zone rises and population pressure increases, the conflict between competing uses of the coastal zone becomes a complex problem. Today, we have almost six times as many people in the United States as we had a century ago. Since all of these people, in some fashion, call upon and derive some benefit from the coastal zone, the "nation has been forced to recognize that what it had in surplus, it now has in jeopardy" (Singer, 1969). Even seemingly unrelated uses of a coastal zone can have dire consequences; a solution to one irritating problem may engender far more pressing problems. For example, pesticides that help citrus growers in South Texas could result in fish kills in the Laguna Madre. While supertankers transport oil economically to all parts of the world, a massive oil spill can result in severe environmental damage. Modifications of estuaries through dredging operations, filling for real estate development, discharge of wastes from a city, fertilizer and pesticides in runoff from nearby land, are capable of disfiguring and destroying the coastal zone.

These estuarine systems are generally more fertile and productive of plant and animal life than either land or sea, due in part to the dynamics of the tidal cycle, which mixes incoming fresh water, with its nutrient burden from the land, with the mineral-rich water from the sea. Thus is formed a kind of rich broth fed by both the land and sea, resulting in a cradle of marine life. The estuary provides a sheltered environment for organisms which forms an abundant food supply for higher members of the food chain. Some estuaries are the spawning grounds and nurseries for many commercially important species. The United States Fish & Wildlife Service (Cain, 1968) estimated that approximately 90 percent of the total harvest of sea food taken by American fishermen comes from the continental shelf, and approximately two-thirds of the species involved depend in one way or another on estuaries.

In addition, estuaries serve other beneficial needs, such as important nesting and wintering habitat for migratory waterfowl, as well as resting and feeding places during migration. Estuaries also provide many forms of recreation to people who boat, camp, explore, picnic, nature walk, or merely enjoy the natural beauty of the coastal environs. Nowhere else do nature and urban conglomeration occur in such close proximity. Approximately 30 percent of the total population of the United States is located within a 50-mile coastal belt, while this area represents only about 8 percent of the total United States.

The U.S. Department of Commerce (1970) made an intensive study of the economic activity of the U.S. continental shelf for calendar year 1964. Eight major economic activities were identified: mining and petroleum; marine engineering; recreation; health and welfare; transportation; food and agriculture; defense and space; and research and development. The level of economic activity was estimated at $21.4 billion, a total that included operating expenses, investments, and income. A little more than half the money was spent for transportation activities; nearly $4 billion was spent for recreational activities; and about $330 million was the dockside value of the U.S. Fishery catch from the continental shelf area. The harvest of shellfish constituted the largest single portion of the U.S. Fishery catch value, about 38 percent. If the investment for harvesting and processing the entire U.S. Fishery catch for 1964 were included, then the total economic activity in fisheries increased to $1.4 billion, a very respectable industry (Singer, 1969).

A significant segment of the United States coastal zone is the gulf coast, from the Mexican border on the west to the tip of Florida on the east. This 1,500 miles of coastline constitutes the border of five states where they meet the Gulf of Mexico. The economic importance of this region is reflected in the commercial fishery production. In 1973, gulf coast landings represented 30 percent of the estimated $907 million in U.S. commercial fisheries landings. The value of commercial fisheries along the gulf coast has steadily increased in terms of both total poundage and dollar value (Table 1) as compared to other coastal areas of the U.S.

Approximately 85 percent of the gulf coast, as compared to like percentage of the Atlantic and 15 percent of the Pacific coast, is composed of estuaries (Singer, 1969). Gunter (1967) estimates that the total area of gulf coast estuaries ranges from approximately 17,000 to 20,000 square miles, or five to six times the size of Chesapeake Bay and its tributaries. The principal bays of the Gulf of Mexico are shown in Figure 1. "The National Estuarine Inventory, Handbook of Descriptors" (Wastler and de Guerrero, 1968) lists 39 primary estuarine systems in the Estuarine Register Areas and 175 secondary-tertiary systems along 3,670 miles of the shoreline.

Multiple utilization of gulf coast estuaries has resulted in significant modification and loss of valuable marsh and open water areas. "The National Estuary Study" (1970) determined the areas of gulf coast estuaries that had been modified by man's activities. Approximately 15 percent had been slightly, 51 percent moderately, and 34 percent severely modified by man's activities (see Figure 2). Unfortunately, many people do not realize the profound influence on the ecology of an estuary which can result from modifications in the watercourse. Oftentimes, even when they do understand the consequences, the short-term gain, rather than the overall or long-term effects, may be the overriding consideration for making such modifications.

Table 1.—U.S. commercial fisheries landings Gulf Coast Region compared to other major coastal regions.[1] (From U.S. Dept. Comm. 1970; 1973)

	1940	1950	1960	1970	1972	1973
	Total Poundage					
Percent	6%	12%	26%	35%	34%	33%
Rank	6th	3rd	2nd	1st	1st	1st
	Total Value					
Percent	11%	15%	24%	27%	32%	30%
Rank	3rd	3rd	1st	1st	1st	1st

[1] Chesapeake
South Atlantic
Gulf
Alaska
New England & Middle Atlantic
Washington & Oregon
California
Great Lakes & Mississippi River
Hawaii

DREDGING ACTIVITIES

One area of significant activity which results in modification of the coastal zone and its estuarine regions is dredging. Whether to provide channels for navigation or materials for construction, dredging operations can represent a substantial alteration to natural coastal environments. Moreover, the intensity of dredging activities in the coastal zone is anticipated to increase as a result of pressures such as exploration, drilling, and transportation in response to the energy crisis; the need for development of superports; increased demand for housing and commercial sites; and demands for additional coastal recreational facilities.

Dredging is the process by which sediments or other materials are removed from the bottom of streams, lakes, and coastal waters, transported by ship, barge, or pipeline, and/or discharged to land and/or open water. The common purposes of dredging are to maintain, improve, or create new navigable waterways, or to provide construction materials such as sand, gravel, or buried shell. In the majority of dredging operations, the solids are hydraulically transported from the bottom of the waterway to a dredge and then to a disposal site. This mixture of suspended solids and water is called dredge soil. It

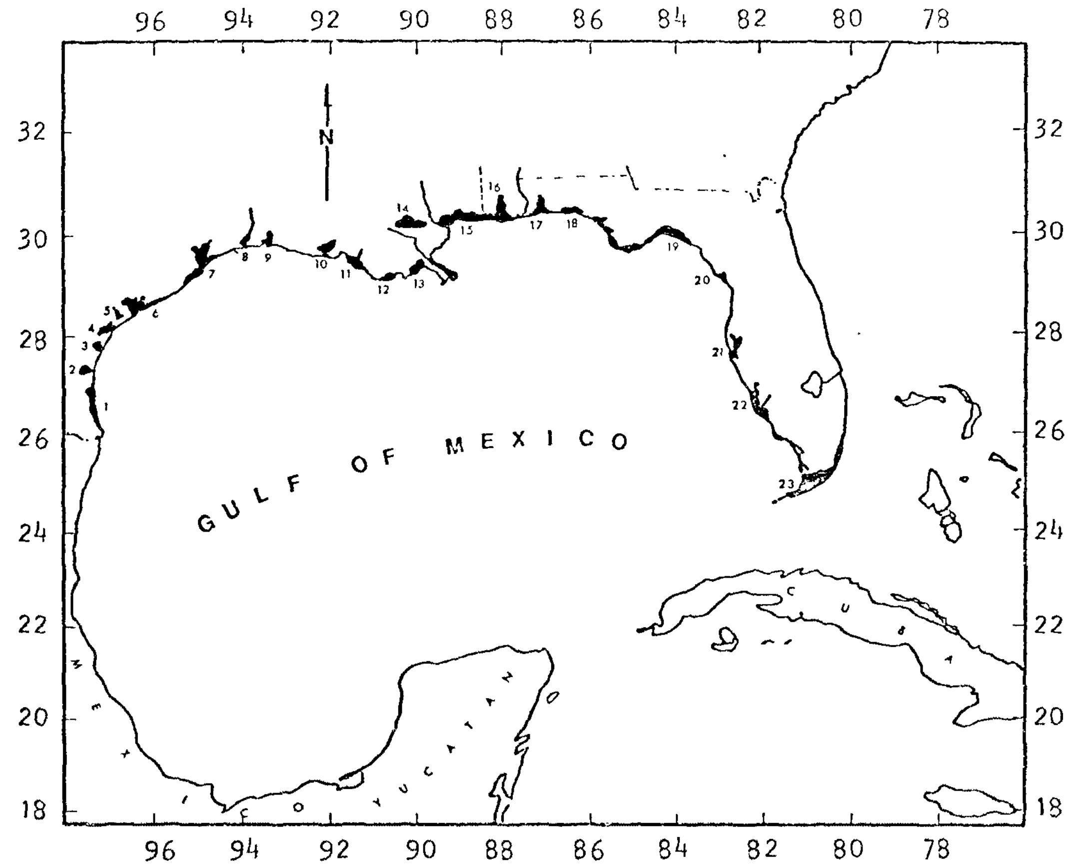


FIGURE 1.—Major bays of the gulf coast of the United States.

1. LAGUNA MADRE
2. BAFFIN BAY
3. CORPUS CHRISTI BAY
4. COPANO BAY
5. SAN ANTONIO BAY
6. MATAGORDA BAY
7. GALVESTON BAY
8. SABINE LAKE
9. CALCASIEU LAKE
10. VERMILLION LAKE
11. ATCHAFALAYA BAY
12. TERREBONNE BAY
13. BARATERIA BAY
14. LAKE PONTCHARTRAIN
15. MISSISSIPPI SOUND
16. MOBILE BAY
17. PENSACOLA BAY
18. CHOCTAWHATCHEE BAY
19. APALACHEE BAY
20. WACCASASSA BAY
21. TAMPA BAY
22. CHARLOTTE BAY
23. FLORIDA BAY

is typically about 5 to 20 percent solids by weight and 98 percent water by volume. The suspended solids vary in size from rather large rocks, bricks and debris (e.g. cans, tires, and steel cable) to extremely small particles of clay. When given the opportunity, the larger material quickly settles out of the water, but the smaller and lighter particles settle very slowly and dewater poorly. To protect the quality of the waterway, large volumes of spoil must be transported and then stored for some time in a disposal site before the water can be returned to the waterway. Transport and storage of spoil is expensive and difficult when the disposal site is of insufficient size or near capacity. Moreover, in urban areas adequate disposal sites are becoming increasingly difficult to acquire.

Types of Dredges

In general, dredging in the coastal zone is accomplished by "floating dredges" which can be classified as hydraulic or mechanical. Hydraulic dredges include suction pipeline dredges, with a suction or cutterhead for digging in hard material, and the self-propelled hopper dredge. Mechanical types include dipper and bucket dredges. Hydraulic channel dredging and shell dredging make use of essentially the same equipment although there are differences in operations. Channel dredges construct or maintain navigation channels. In this operation, recent alluvium and water are pumped from the bottom of the channel and the spoil is discharged by pipeline usually some distance away from the channel. Shell

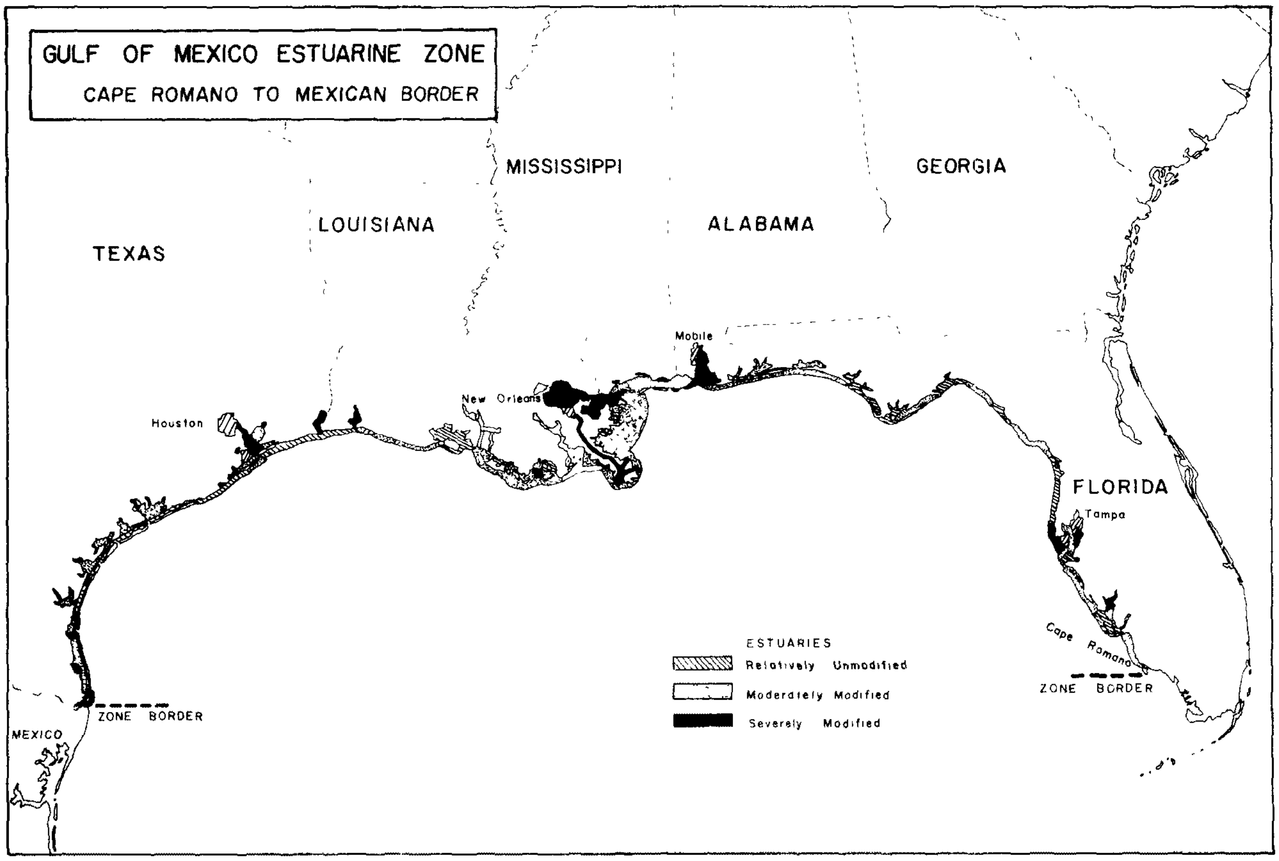


FIGURE 2.—Extent of effects of man's activities on gulf coast estuaries (from "National Estuary Study," 1970).

dredges generally operate outside of channels in the open estuary. Dredged material is screened and washed to remove the shell. The discharge, composed mostly of original bottom material is returned overboard in the immediate vicinity of the dredge.

Required Dredging Permits

The basic permit that is required for dredging activities in the coastal zone is under Section 10 of the River and Harbors Act of 1899, which is administered by the United States Corps of Engineers (USCE). This permit is required when any dredging or filling is done in navigable waters of the United States or in areas which may affect navigable waters. New Federal guidelines (Federal Register, April 3, 1974) require that the environmental aspects of these dredging permits be considered. In addition, the Environmental Protection Agency requires permits under Section 404 of the Federal Water Pollution Control Act Amendments of 1972 for the discharge of dredged or filled material. In each of the federal permits, review and approval is required from various state agencies. Also, along the gulf coast, each state requires permits for dredging in the coastal zone. As a result of the 404 dredging permit system, considerable questions have arisen with regards to its relationship with the existing Section 10 permit system. These questions concern jurisdiction as well as specific engineering and environmental requirements. The present Section 10 permit system, because of other federal agency review in many cases, results in considerable time and money being expended by the applicant because of the time delay and lack of coordination.

Shell Dredging

Buried shell is an important natural resource found in the coastal zone. Industrial demand for this almost pure source of calcium carbonate is significant and several major industries depend upon it. Private companies annually dredge about $30 million worth of unprocessed clam and oyster shells from gulf coast estuaries and the resource makes a substantial contribution to the economy of many coastal areas.

Table 2.—Shell production in cubic yards by State (1965–74)

	Florida (Jan. 1–Dec. 31)	Alabama (Oct. 1–Sept. 30)	Mississippi	Louisiana (Jan. 1–Dec. 31)	Texas (Sept. 1–Aug. 31)	Total
1965	1,675,557	1,972,499	208,222	N/A	N/A	N/A
1966	1,796,561	1,842,737	187,028	8,681,177	11,702,553	24,210,056
1967	1,492,102	1,766,611	206,333	9,500,285	12,512,977	25,478,308
1968	1,102,052	1,867,794	228,183	10,921,101	10,033,221	24,152,351
1969	1,949,668	N/A	119,662	10,097,148	9,108,682	22,975,160**
1970	1,480,472	N/A	165,144	10,283,276	9,097,316	22,726,208**
1971	1,539,299	1,685,445	135,008	10,901,371	8,198,153	22,459,276
1972	1,611,403	1,543,217	281,129	11,708,035	7,791,577	22,935,361
1973	1,046,988	1,275,603	339,513	11,996,579	7,444,232	22,102,915
1974	325,806*	1,608,997	98,033	N/A	7,027,909	N/A

* Five months only.
** Estimated 1,700,000 for Alabama.
Florida—William Witfield, Florida Department of Natural Resources, Division of Marine Resources and Jack Dull, Fiscal Office, pers comm, Nov. 1974
Alabama—Mr. Swingle, Alabama Department of Conservation and Natural Resources, Marine Resources Division; Revenue Department, pers comm, Nov 1974; May, 1971
Mississippi—Mr. Quinn, Mississippi Marine Conservation Commission, pers comm Nov. 1974.
Louisiana—Joseph Cuadrado, Louisiana Wildlife and Fish; Revenue Department, pers comm, Nov 1974
Texas—Chester Harris, Texas Parks and Wildlife Department; Revenue Division, pers comm, Nov. 1974

In addition, royalty from shell dredging contributes about $3 million each year to conservation activities in the gulf states (May, 1971). Shells from this source are extensively used for cultch (attachment material for new oysters) on public oyster beds in many states and the practice has greatly increased oyster production.

Along the gulf coast shell dredging is a major industry. Most of the shell is used for manufacture of cement, masonry blocks, road materials, poultry feed, and in some cases for the creation or establishment of oyster beds. Summarized in Table 2 are shell production figures for each of the gulf coast states as determined from published records and by personal communications with various state agencies. The total production for the gulf coast for the period 1966 through 1973 shows a slight downward trend. In Mississippi shell production has recently been stopped. In Texas (along with Louisiana, the major producer) shell production has been declining. In Texas, production has shifted from the Galveston Bay area to Matagorda and San Antonio Bays (see Figure 3). The change from the Galveston Bay system to Matagorda Bay is a result of changes in Texas Parks and Wildlife dredging policies coupled with significant reductions in the shell reserve in Galveston Bay.

Extent of USCE Dredging Activities

The majority of dredging activities in the coastal zone is accomplished by the U.S. Corps of Engineers in the development and maintenance of navigable waters. Within this authority, the USCE is responsible for the dredging of a large volume of material in the gulf coast each year. Boyd, et al. (1972) present a compilation of data on the magnitude of dredging operations. It is important to note that this data does not reflect dredging activities of other agencies or private industry under the permit program administered by the USCE. The majority of the dredging operations in connection with USCE projects are done by pipeline and hopper dredgers. The USCE is responsible for dredging and maintain-

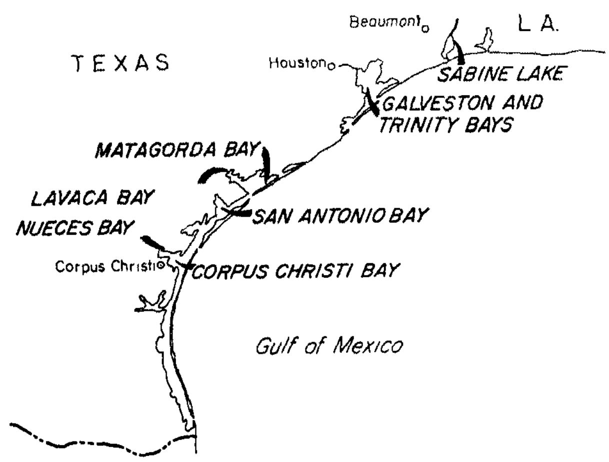


FIGURE 3.—Percentage of shell production in the State of Texas for major bays by year (from Eifler, 1968 and Texas Parks & Wildlife, Revenue Division, 1974).

Year	Sabine Lake	Galveston	Matagorda	San Antonio	Lavaca	Nueces
1965–66	1.4	62.8	0	23.7	1.6	11.0
66–67	2.1	62.2	0	24.5	1.8	9.4
67–68	0.1	41.7	0	42.8	5.8	9.6
68–69	0.2	4.9	0	80.5	6.1	8.4
69–70	0.9	0.9	11.2	81.5	0.2	5.4
70–71	0.6	0	24.8	69.1	0	5.6
71–72	0	0	33.8	59.9	0	6.4
72–73	0	0	41.3	51.0	0	7.8
73–74	0	0	62.8	34.0	0	3.3

ing approximately 4,000 miles of navigation channels on the gulf coast. Gulf coast dredging represents historically 48 percent of all USCE dredging activities. Total dredge spoil generated in maintenance dredging annually averages 143.0 million cubic yards. Average quantities of spoil for each Corps of Engineers District in the gulf coast is shown by disposal type in Table 3.

The USCE (Boyd, et al., 1972) estimated that approximately 177.6 million cubic yards of spoil material would be dredged in 1972 in the gulf coast zone, of which 55.2 million cubic yards would be new work. Of these activities 61 percent of the dredging was proposed in the New Orleans District, 26 percent in the Galveston District, 11 percent in the Mobile District and 2 percent in the Jacksonville District.

ENVIRONMENTAL ASPECTS

A variety of studies (Masch and Espey, 1967; Chapman, 1968; May, 1973; Cronin et al., 1970; U.S. Army Corps of Engineers, 1974) describe the environmental aspects of shell dredging, channelization, and spoil disposal. Unfortunately, the impact of these operations on the gulf coast ecosystem is incompletely known. However, enough is known about the ecology of estuarine systems to evaluate, in general, the major ecological consequences involved. Figure 4 is a generalized flow chart which diagrams the manner in which ecology is affected by dredging. Three main categories resulting in four principal pathways are involved. This is a simplification of the complex interactions which actually occur. However, some of the other more obscure interactions form pathways which may or may not occur in a particular system, or are poorly understood. Attention given them would only serve to confuse the basic cause and effect relationships.

The following subsection will deal with the primary effects of dredging separately.

TABLE 3.—Average Quantity of Spoil Material (million cubic yards) Dredged in the Gulf Coast by Disposal Method and District*

	Galveston	*New Orleans*	*Mobile*	*Jacksonville*
Undifferentiated†	18.2	None	13.6	None
Confined	8.7	20.3	2.5	0.2
Open Water	21.0	40.5	13.7	2.5
Upland	None	None	0.4	1.4

* From Boyd, et al. (1972)
† Disposal Method Not Defined

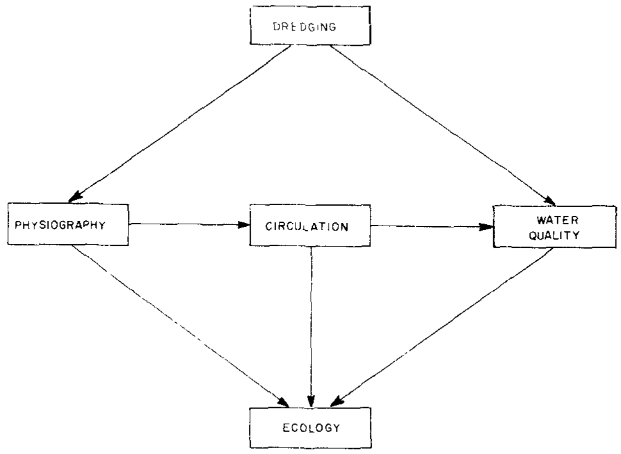


FIGURE 4.—Environmental aspects of dredging.

Physiography

All dredging operations involve the physical modification of the environment by removal of bottom material and its disposal. Such actions result in the loss of habitat for benthic organisms, including oysters and a multitude of other creatures of significant value in the food chain. The extent of the area in the gulf coastal zone which has been impacted by dredging is difficult or impossible to determine.

Table 4 is a compilation of data from the various segments of the Cooperative Gulf of Mexico Estuarine Inventory and Study for the Gulf States, and Chapman (1968). Historically, Cain (1967), Chapman (1968), and the "National Estuarine Study" (1970), have all estimated the amount of estuarine habitat and acreage modified. The inconsistencies in the acreage values listed from one report to another are based primarily on the use of differing criteria in defining the limits of estuarine areas, period of record, and incomplete data. The latest total estuarine acreage value is 13,898,978 acres taken from Table 4. The NES (1970) lists 655,900 acres of important habitat that had been lost to dredging and filling for the period 1950 to 1969.

Due to siltation, dredged areas usually require periodic maintenance dredging which disturbs any recolonization by benthic organisms which may have occurred. In many channels, however, the substrate stabilizes enough to allow the establishment of a benthic community.

It is important to note that some estuarine areas are more valuable than others. Thus a simple acreage figure of dredged areas may not tell the entire story. Areas of submerged aquatic vegetation (turtle grass, widgeon grass), emergent marsh grass areas (salt-

Table 4.—Alteration of estuarine areas in the Gulf Coast Zone (acres)

	Florida[1] (West Coast)	Alabama[2]	Mississippi[3]	Louisiana[4]	Texas[5]
Total					
Estuarine area	3,003,213	431,967	500,380	7,289,568	2,673,830
Tidal marsh	921,688	34,614	66,933	3,910,644	1,141,400
Open water	2,081,525	397,353	433,447	3,378,924	1,532,430
Alteration					
Emergent spoil banks	1,135	17	9,000†**	25,369	—
Filled causeways	3,977	76	—	—	—
Housing, industry, and other	18,409	2,059	—	1,246	—
Drained tidal marsh	26,676	—	—	47,792	—
Spoil area	—	—	—	40,000	78,500[6]
Miles of Corps of Engineers channel	1,500†	144	300†	1,000† (4,572.6*)	990
Surface area of Corps channels	—	3,420	—	— (42,104*)	20,260[6]

[1] McNulty, Lindall, and Sykes, 1972
[2] Crance, 1971
[3] Christmas, 1973
[4] Perret, et al, 1971.
[5] Diener, R. A., 1974.
[6] Chapman, 1968.
* Estimate of total length and area of channels and canals in Louisiana.
** All filled areas combined
† Approximate.

marsh, cordgrass), mangrove swamps, and shell reefs all rank higher in ecological value and sensitivity than do soft open bay bottoms. Estuarine areas are centers of production for many commercially or recreationally important species and for the organisms on which they depend for food. Measures must be taken to perpetually protect such areas from destruction. Indeed, a worthwhile endeavor is the creation of new habitat, e.g., marshland areas, when possible. The feasibility of such procedures is discussed by Woodhouse (1972).

Another area of concern is the loss of habitat through sedimentation. The dredging processes suspend part (1 percent according to Mackin, 1962) of the dredged material into the water column. The resulting suspension forms a plume of turbid water at the surface and turbidity currents along the bottom. Masch and Espey (1967) noted that, while shell dredging does not introduce sediments into the bay water, the dredging does resuspend materials already present on the bay bottom. The suspended sediment load in the vicinity of even a single dredge is at least an order of magnitude greater than the suspended load produced by currents, strong wind and wave action, ship and barge traffic, and ship swells in Galveston Bay, Tex. The levels of nitrates and phosphates in the immediate vicinity of the dredge were 50 to 1,000 times greater than the ambient levels; however, no detectable effects on photosynthesis of plankton were noted (Cronin, 1970).

Masch and Espey (1967), O'Neal and Sceva (1971), and May (1973) have all delineated density flows of sediment along the bay bottom associated with dredging operations. These turbidity currents seem to be principally affected by tidal currents, bottom sediments, topography and dredge discharge characteristics. The hydrodynamics of these currents are not well understood; however, they can cover broad areas of bay bottom before flocculating out, thus substantially reducing benthic populations by smothering them. Studies of the effect of shell dredging on live oyster populations have shown these turbidity currents are capable of covering and smothering live reefs. The U.S. Army Corps of Engineers (1974) in San Antonio Bay, Tex., showed that although nektonic organisms easily escaped turbidity flows, sessile benthic populations were adversely affected. While deposition of spoil on bay bottoms and in dredge cuts substantially reduces benthic populations over time periods ranging from several months to several years, these populations, if undisturbed, slowly recover.

Circulation

CURRENT PATTERN AND SPEED ALTERATION

Within this category are the effects of density currents and topographic changes which modify both the current pattern and speed. Many of the migratory species (e.g., white and brown shrimp, crabs, various fish) utilizing the estuaries are dependent on salinity for their navigation. The stable long-term density gradients (in salinity) set up by a dredged canal could possibly redirect the migratory route of species and potentially negatively impact the standing crop of those organisms.

Topographic changes associated with dredging can affect current velocities. Such changes can alter the distribution of current-dependent plankton organisms. Where current velocity is significantly reduced, established pathways for the distribution of planktonic organisms may be blocked. Also, increased sedimentation associated with velocity alterations may smother benthic populations and reduce the suitability of the substrate for such populations. Kutkuhn (1966) notes that, because of new circulation and water quality regimes, the creation of "fish passes" may increase the ecological carrying capacity of an area.

Water Quality

Water quality parameters fall into two categories, physical and chemical. Factors such as turbidity, light penetration, and temperature are important physical parameters, while salinity, nutrient loading, dissolved oxygen, and toxic substances are chemical parameters.

Physical Parameters

Increased turbidity is one of the more noticeable short-term effects of dredging. This was discussed in the physiography section, where it was pointed out that while nekton and plankton can escape from turbidity plumes, benthic organisms are negatively impacted by the settling out of the suspended solids. Reduced light penetration (euphotic zone) due to turbidity plumes is documented by Sherk (1971).

Odum and Wilson (1962) state that "the turbid mixtures of organic and inorganic matter both interfere with photosynthesis and stimulate it by indirectly raising inorganic nutrient levels." Depending on location, dredge spoil may or may not contain nutrients. It is important to note that estuarine productivity is primarily dependent upon organic and inorganic nutrient loading from the rivers and marshes emptying into them rather than upon local photosynthesis. Thus turbidity does not impact estuarine production to the extent that it would in a system having phytoplankton as the primary base of the food web. In addition, these effects are transient, being in evidence only during the actual operation of the dredge. Over longer periods of time, some increase in turbidity may occur in the vicinity of spoil banks. This is possible because the decreased depth of water over these areas may facilitate stirring of soft bottom materials by current and wave action.

Temperature changes as a result of dredging operations are probably relatively unimportant to the estuarine ecosystem when compared to those in other physicochemical parameters. Most gulf coast estuaries are shallow bodies of water which are not thermally stratified. Deep dredged channels represent an area where stratification can occur. The ability of a deep water mass to resist very rapid temperature changes associated with winter storms known as "northers" occasionally prevents fish kills, which sometimes occur in the shallow bays of Texas (Gunter, 1941; Gunter and Hildebrand, 1951), by providing a thermally stable haven for fish.

Chemical Parameters

Salinity is a critical chemical parameter potentially affected by dredging activities. The distribution of many species within an estuary is closely tied to the salinity pattern. In the case of many species (e.g., blue crab, brown and white shrimp), the distribution of various stages in the life cycle is tied to different salinity levels. In some instances the intrusion of more saline water due to channelization may not be extremely detrimental; however, in general, increasing salinity intrusion reduces the necessary low and mid-range salinity areas required for the development of juveniles of many estuarine species. Salinity wedges moving up and down channels depending on freshwater inflow prevent the establishment of a stable benthal community.

The salinity pattern of an estuary can be impacted by deep channels through the formation of density gradients. Such gradients are long-term phenomena which provide a series of decreasing isohalines as the distance from the channel increases. Migratory routes of animals such as shrimp might well be interfered with by these density gradients.

Due to sorption and ionic processes bay sediments represent effective traps for a wide variety of potentially hazardous industrial and natural chemicals. Dredging and spoil deposition may release many such substances (e.g., herbicides, pesticides and heavy metals) into the aquatic ecosystem. Lee and Plum (1974) describe an elutriate test designed by the USCE and the EPA to detect the release of chemical contaminants in dredged materials into the water column.

Deeper channels often display anoxic conditions due to benthal oxygen demand. Dredging in recreational developments with dead end canals with depths of over five to six feet often produces stagnant conditions because of poor water circulation, low light penetration and high nutrient loading. Such conditions often foster plankton blooms which ultimately raise biological oxygen demands and sometimes produce fish kills.

CONCLUSIONS

The following is a summary of major conclusions.

1. Eighty-five percent of the Gulf of Mexico estuaries between Cape Romano, Fla. and Brownsville, Tex., has been moderately or severely modified by man's activities.
2. The energy crisis and the resulting increased oil exploration, production, and transportation activities further threaten the environment of the coastal zone.
3. Important estuarine habitats have been destroyed by dredging and/or filling.
4. Approximately 48 percent of U.S. Corps of Engineers dredging activities occur along the gulf coast.
5. Insufficient data is available on the extent of dredging and filling operations in the gulf coast for both the Corps of Engineers and private industries.
6. Shell dredging production data indicates a slight reduction in the gulf coast zone for the period 1966–1973.
7. Texas shell production for the period 1966–1974 indicates an approximate 40 percent reduction.
8. The direct overboard disposal of washwater from shell dredging operations is a major environmental problem.
9. Additional information is required on the release of chemicals from bottom sediments as a result of dredging activities.
10. Environmentally acceptable spoil areas should be identified in major estuarine areas.
11. Additional information is also needed on the movement and fate of sediments suspended by dredging activities.
12. Salinity is a critical chemical parameter potentially affected by dredging activities. However, insufficient information is available on the effect of channel dredging and spoil deposition on salinity modifications.
13. The Dredged Material Research Program of the USCE should provide additional information on the environmental aspects of dredging in the coastal zone.
14. Clarification of environmental criteria used in the evaluation of USCE dredging permits is needed.
15. Streamlining and centralization of the federal permit system is required for dredging activities in the coastal zone.

REFERENCES

Boyd, M. B., R. T. Saucier, J. W. Keeley, R. L. Montgomery, R. D. Brown, D. B. Mathis, and C. J. Guice. 1972. Disposal of dredge spoil problem identification and assessment and research program development. Technical Report H-72-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Breuer, Joseph P. 1962. An ecological survey of the lower Laguna Madre of Texas, 1953–1959. University of Texas. Pub. Inst. Mar. Sci. 8:153–183.

Cain, S. A. 1967. Statement before the Subcommittee on Fisheries and Wildlife Conservation of the Committee on Merchant Marine and Fisheries House of Representatives 90th Congress. March 6, 8, 9, 1967. Serial No. 90–3. p. 28–76.

Chapman Charles R. 1968. Channelization and spoiling on gulf coast and south Atlantic estuaries. In Proceedings of the Marsh and Estuary Management Symposium. Baton Rouge, 1967. p. 93–106. LSU, Baton Rouge, La.

Christmas, J. Y. 1973. Cooperative Gulf of Mexico estuarine inventory and study, Mississippi, Phase I: area description. Gulf Coast Research Laboratory, Ocean Springs, Miss.

Crance, J. H. 1971. Description of Alabama estuarine areas—Cooperative Gulf of Mexico estuarine inventory. Alabama Marine Resources Bulletin No. 6. Alabama Marine Resources Laboratory. Dauphin Island, Ala.

Cronin, L. E. 1970. Gross physical and biological effects of overboard spoil disposal in upper Chesapeake Bay, Summary, Conclusions, and Recommendations. Special Report No. 3, Natural Resources Institute, University of Maryland.

———, Gordon Gunter, and S. H. Hopkins. 1969. Effects of dredging activities on coastal ecology. Interim Report to the Office of the Chief of Engineers, Corps of Engineers, U.S. Army.

Diener, R. A. MS. 1974. Cooperative Gulf of Mexico estuarine inventory and study, Texas: area description. U.S. Dept. of Commerce. NOAA Technical Report. NMFS CIRC, xxiv+265 ms. p. (in press)

Eifler, G. K., Jr. 1968. Industrial carbonates of the Texas Gulf Coastal Plain. In Proceedings, Fourth Forum on Geology of Industrial Minerals, L. F. Brown, Jr. (ed) Bureau of Eco-Geology, University of Texas. Austin, Tex. pp 45–56.

Gunter, Gordon. 1941. Death of fishes due to cold on the Texas coast. Ecology. 22(3):203–208.

———. 1967. Some relationships of estuaries to the fisheries of the Gulf of Mexico. In *Estuaries* edited by George H. Lauff, America Association for the Advancement of Science, 621-638.

———, and H. H. Hildebrand. 1951. Destruction of fishes and other organisms on the South Texas coast by cold wave of January 28-February 3, 1951. Ecology, 32(4): 731–736.

Kutkuhn, J. H. 1966. The role of estuaries in the development and perpetuation of commercial shrimp resources. American Fisheries Society Special Pub. # 3, p 16–36.

Lee, G. F., and R. H. Plumb. 1974. Literature review on research study for the development of dredged material disposal criteria. Contract Report No. D-74-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Mackin, J. G. 1961. Canal dredging and silting in Louisiana bays. Publ. Inst. Mar. Sci. (Tx.) 7:262–314.

Masch, Frank D. and W. H. Espey, Jr. 1969. Shell dredging—A factor in sedimentation in Galveston Bay. Center for Research in Water Resources, University of Texas.

May, Edwin B. 1971. A survey of oyster and oyster shell resources of Alabama. Alabama Marine Resources Bulletin No. 4, Alabama Marine Resources Laboratory, Dauphin Island, Ala.

———. 1973. Environmental effects of hydraulic dredging in estuaries. Alabama Marine Resources Laboratory—Prepared for National Marine Fisheries Service, April 1973. COM-73-11271 NTIS.

McNulty, J. K., W. N. Lindall, Jr., and J. E. Sykes. 1972. Cooperative Gulf of Mexico estuarine inventory and study, Florida: Phase I, area description. NOAA Technical Report NMFS CIRC-368, Seattle, Wash.

Odum, H. T., and R. F. Wilson. 1962. Further studies on reaeration and metabolism of Texas bays, 1958–1960. University of Texas, Pub. Inst. of Mar. Sci. 8:23–55.

O'Neal, Gary, and Jack Sceva. 1971. The effects of dredging on water quality in the northwest. EPA Region 10, Seattle, Wash.

Perret, W. S., B. B. Barrett, W. R. Latapie, J. F. Pollard, W. R. Mock, G. B. Adkins, W. J. Gairdry, and C. J. White. 1971. Cooperative Gulf of Mexico estuarine inventory and study, Louisiana: Phase I, area description. Louisiana Wildlife and Fisheries Commission, New Orleans, La.

Sherk, J. A., Jr. 1971. The effects of suspended and deposited sediments on estuarine organisms, literature summary and research needs. Natural Resources Institute of the University of Maryland, Chesapeake Biological Laboratory, Solomons. Maryland. Contribution No. 443.

Simmons, E. G. 1957. An ecological survey of the Laguna Madre, Texas. University of Texas. Publ. Inst. Mar. Sci. 4(2):156–200.

Singer, F. S. 1969. Federal interest in estuarine zone builds. Environmental Science and Technology, Vol. 3, No. 2. pp 124–131.

Wastler, T. A., and L. C. de Guerrero. 1968. National estuarine inventory, handbook of descriptors. U.S. Department of the Interior, FWPCA, Washington, D.C.

U.S. Army, Corps of Engineers. 1974. Shell Dredging in San Antonio Bay, Texas. U.S. Army Engineer District, Galveston, Tex.

U.S. Department of Commerce, NOAA National Marine Fisheries Service. Current Fishery Statistics #5600, Fisheries of the United States, 1970. March 1971.

———. Current Fisheries Statistics #6124, Texas Landings, Annual Summary 1972. December 1973.

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1970. National Estuary Study, 1970. Volume 1–8, USGPO Washington, D.C.

Woodhouse. 1972. Marsh building with dredge spoil in North Carolina. North Carolina State University, Agricultural Experimental Station Bulletin 445.

NUTRIENTS

NUTRIENT LOADING IN THE NATION'S ESTUARIES

MICHAEL A. CHAMP
The American University
Washington, D.C.

ABSTRACT

An evaluation is made of the current status of nutrient loading in the nation's estuaries. Special consideration is given to sources and transport of nutrients and their impact on estuarine ecosystems. Critical problems and trends in nutrient loading are reviewed at the national level and for six major estuaries: Cook Inlet, Columbia River Estuary, San Francisco Bay, Galveston Bay, Pamlico Sound and Chesapeake Bay.

INTRODUCTION

Estuaries and their transition zones comprise 27,000,000 acres in the United States (Congress, 1970) and are annually responsible for more than 65 percent of America's fish and shellfish harvest (Smith, Massmann and Swartz, 1966). An estuary is a unique zone in coastal environments in which fresh water from rivers mixes with salt water from the ocean. It is a complex interacting system in delicate balance among the physical, chemical, and biological forces present at any particular time.

An estuary is a nutrient storehouse; marshes and wetlands are constantly flushed of decomposing plant material by tides. These nutrients are transported into the estuary and support a substantial production of biomass. A Georgia salt marsh for example contains enough nutrient reserve to permit optimum ecosystem functioning for 500 years without renewal (Clark, 1974). The enriched soils of estuaries are often several feet thick and are held together by extensive plant root systems. This natural ageless phenomenon can continue as long as the system is not modified by the impact of human activities. "The National Estuary Study" (1970) reports that all of the nation's estuaries have been modified: 23 percent severely, 50 percent moderately and 27 percent slightly. One of the major impacts has been increased nutrient loading.

Nitrogen, phosphorus and organic carbon are the major components of nutrient loading; their transition is cyclic, resulting in effects which are cumulative and compounded (Woodwell, 1970). A major result of nutrient overenrichment is eutrophication which is the normal environmental aging process. Eutrophication is the buildup of rapidly cycled organic carbon. Early signs are excessive growth by phytoplankton or vascular plants, and a reduction in species diversity. Nutrient loading is a relative state in which low and high levels produce undesirable conditions: high levels stimulate eutrophication while low levels limit productivity. The optimum nutrient load is a mid level in which the estuarine system reaches stability in both productivity and diversity. The optimum nutrient loading will vary with each estuary due to the natural accumulative capacity of each system. In all cases, the limiting nutrient controls the total potential development.

The health of an ecosystem is directly proportional to the species diversity of that system over an extended period of time. A healthy system exhibits many species of phytoplankton, each of which has a particular dominance period followed by its return to background levels, with other species blooming at their selected times when environmental conditions dictate. This natural cycle permits many different algal species to coexist and compete against one another while the entire system remains in careful balance. Under natural conditions, these blooms will occur regularly, each with an associated assemblage of zooplankton, invertebrates and fish larvae within the estuary. Many species prey on selected plankton forms and have evolved mechanisms of timing stages of embryonic development to follow specific plankton blooms. It is this type of mechanism that characterizes a healthy aquatic ecosystem and permits it to function with a high rate of productivity year after year. Excessive nutrient loading supports the bloom of one or more species which are particularly favored and/or tolerant of the added nutrients. Those species which succeed under these conditions are usually not preferred components of food webs, and total fisheries productions are reduced. The result is an unbalanced system, low in species diversity due simply to the selective fertilization of undesirable phytoplankton.

NUTRIENT SOURCES AND TRANSPORT

Municipal Sewage and Industrial Waste Discharges

The major contributors of nutrient sources are municipal sewage and industrial waste discharges, urban runoff, agricultural and forestry practices. In the coastal zone, most nutrients are terrigenous and are transported toward the ocean with river flow. In some estuarine zones, it is even possible for nutrients to be transported up river by floodtide (Ketchum, 1969). Therefore, an area of an estuary cannot be considered immune to a nutrient source located below it.

The flushing of nutrients from an estuary is a function of the volume and flow rate of the water source in addition to the physical topography of the water basin. If the freshwater source is of great magnitude, as in the case of the Columbia River in Washington, the residence time of water mass may be very short, meaning that nutrients do not have enough time to exert their effects upon the system. If, on the other hand, the freshwater flow rate is slow (Pamlico River Estuary), the flushing action is reduced and the system is unable to rapidly export nutrients, therefore allowing them time to exert more influence on the system. For this reason, estuaries differ greatly in their tolerances of nutrient loading.

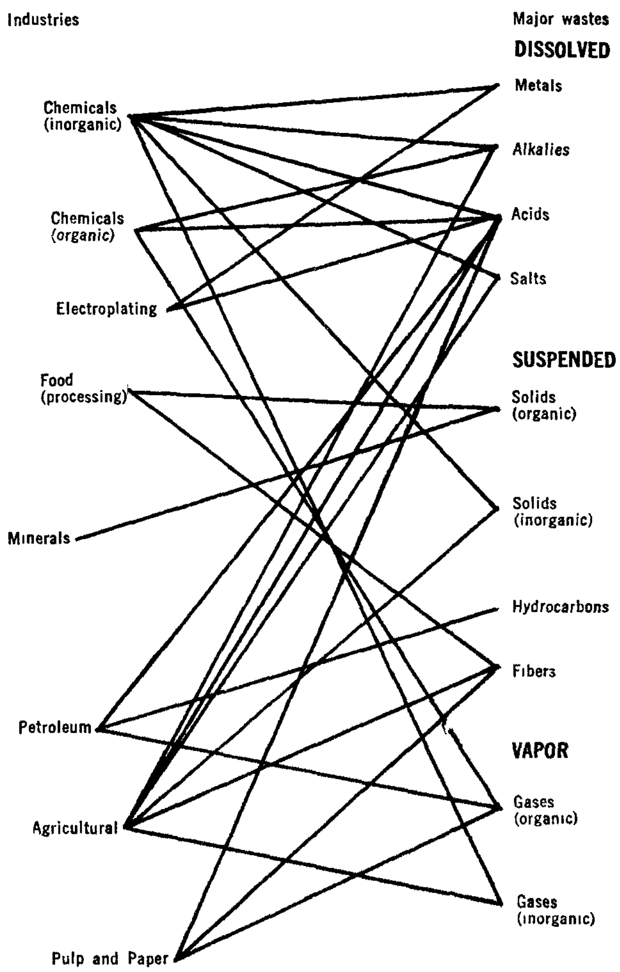
Thousands of municipalities dump sewage treated to various degrees into inland waterways flowing towards the sea. A great number of inland coastal cities were founded on rivers for a variety of reasons, but among them was the availability of municipal and industrial waste disposal into the waterways. This practice has continued today. Even though the cities have grown to tremendous sizes, these rivers are expected to transport greatly expanded volumes of waste downstream to be rendered innocuous by natural processes, even though the average annual riverflows remain approximately the same. Municipal sewage has its origins in plant and animal wastes; therefore, it is an enriched mixture of nitrogen, phosphorus and carbon compounds which provide the essentials necessary for plant growth. This growth (primary production) is consumed in turn by microorganisms, protozoa, rotifers, zooplankton, crustaceans and so on up the food chain, stimulating species diversity and stability in the system. Pollution of the stream by sewage treatment effluents and runoff from fertilized lawns has caused the State of Florida to place restrictions on recreational activities there, after seeing the harmful effects exemplified by a number of fish kills between 1970 and 1973.

Unregulated construction in urban areas increases the amount of sediment and nutrient transport into estuaries by freshwater runoff from the land. Simple construction like paving significantly increases the sediment loading. Dredging activities, bridge-building and resort land developments tend to resuspend the sediments containing nutrients, organic particles, trace elements, and toxic substances in estuaries.

Public Law 92-500 requires that point source dischargers (industries, municipal treatment plants, feedlots, and other discrete sources) must obtain permits requiring that such discharges meet all applicable requirements relating to effluent limitations as regulated by the Environmental Protection Agency. This effort to regulate what enters the nation's waters represents an attempt on the part of the government to not only limit nutrient input but also the thousands of other chemicals discharged daily with little if any treatment. States which desire to administer the national permit program may submit complete program descriptions to the Administrator for approval with the stipulation that all individual permits are subject to EPA review, and annually the states must submit reports to EPA that inventory all point sources of pollution and assess existing and anticipated water quality. This National Pollution Discharge Elimination System (NPDES) provides EPA with the authority to enforce the effluent limitations and allows private citizens or groups to levy judicial process against any polluter in violation of an effluent limitation or administrative order.

Industrial and commercial wastes provide a further nutrient source to estuaries. Industry has been accredited with contributing over 60 percent of all U.S. water pollution (Nobile and Deedy, 1972). The principal industrial offenders are by category: paper, organic chemicals, petroleum and steel. Much of the conventional technology used in municipal waste water treatment is used also to treat industrial wastes. Existing data suggest that about half the total volume of waste water treated by municipal plants is of industrial origin. The current trend appears to be toward more joint use of treatment plants by industry and municipalities. It is also difficult to generalize on treatment of industrial waste waters because the sources are highly diverse. Industrial waste waters generally are less amenable to conventional waste treatment because they contain substances such as trace metals and chemical compounds that resist biological degradation. Also, to reduce discharges, industry has increased its reuse of water, partly to reduce the costs of pollution abatement and stay within federal regulations pertaining to discharges. Today, industry probably reuses an average of three gallons of water for every new gallon it takes in.

Table 1.—INDUSTRIAL SOURCES OF NUTRIENT LOADING



Modified from Nobile and Deedy (1972).

Most industrial discharges contain high oxygen-demand wastes or toxic materials; however, a large portion of industrial discharges contain some form of available nutrients. Most contain some form of carbon (inorganic or organic). Then there are special industries which produce some form of nitrogen or phosphorus either as an intermediate byproduct or a waste product (i.e., fertilizer manufacturing or phosphate mining, cattle feed lot operations). In farming operations, the fertilizer is applied to increase production and a portion leaches out and is carried away in runoff. The major industries and their major wastes are given in Table 1.

Another important industrial waste as a source of nutrients is the food processing industry. Most of these discharges are processing wastes and are discharged into rivers from the canneries. However, commercial fishery industries have a unique waste that is discharged directly into the estuary; for instance: one third of a salmon's weight is considered to be waste and Alaska salmon canneries annually dump more than 100 million pounds of this waste into estuaries. Some of this fish is used as mink food but the vast majority is dumped into coastal waters. The decomposing fish waste contributes to the nutrient loading and greatly influences species diversity and can increase selected species populations. In Alamitos Bay, Calif., very polluted bottom areas are found which are surrounded by a thick sediment of fish scales containing unnatural populations of red annelid worms (*Capitella capitata*) in concentrations as high as 6,000 per square meter. In 1963 it was reported that several Texas harbors were receiving shrimp and crab wastes, raising the phosphorus concentration from 0.049 mg/L to 0.143 mg/L (Odum, et. al., 1974). Such dumping not only represents an additional nutrient source but it enters in such forms as protein and fat at irregular intervals. The abundance of nutrients favors organisms which expend less metabolic energy and gives advantage to forms which can use organic breakdown products at the early stages of their decomposition cycle. For instance, species capable of utilizing ammonia as a nitrogen source are usually tolerant to high levels and survive better than those organisms requiring it oxidized to nitrate.

Pulp and paper mills have long been known for their pollution effects in rivers. The waste produced by their processes exerts an immediate oxygen demand upon the water their effluent enters. This is caused by the chemical demand for oxygen made by the SO_2 which depletes the dissolved oxygen present in the water. Studies of the York River, Va., indicate that sulfate wastes inhibit oysters from efficiently metabolizing carbohydrates. The volume of water filtered by the oysters was also reduced but increased as they were removed from the waste water. (Odum, et. al., 1974)

Urban Runoff

Vitale and Sprey (1974) have reported that between 40 and 80 percent of the total annual BOD and COD entering receiving waters from a city is caused by sources other than the treatment plant. They also report that 94 to 99 percent of the total BOD and COD load from a single storm event is contributed by sewer overflows, storm sewers, runoff and bypasses, and that the periodic loads from storm events exert a demand which is 40 to 200 times greater than that of the normal dry weather effluent from the sewage treatment plant. In their study they found that the storm water annual contribution of nutrients (nitrogen and phosphorus) appears to be generally less than 10 percent; however, storm water nutrients dominate all other sources during a storm event.

ESTUARINE NUTRIENT CYCLES

A better understanding of the cycling of nutrients in estuaries would greatly contribute to man's ability to increase the yield of coastal fisheries. Already estuaries are considered among the most productive aquatic areas in the world and their importance continues to grow with the world's growing populations.

Estuarine ecosystems differ from freshwater and marine ecosystems by their relatively high concentrations of nutrients. These nutrients enter the estuary from river nutrient loading and the decay of marsh vegetation and are trapped by physical, chemical and biological processes. The large quantities of nutrients trapped in the estuary promote a high rate of plant production. This plant biomass is very important because the animals in an estuary are directly or indirectly dependent upon plant material as an energy source. Plant tissues are composed of the following principal elements in descending order by weight: oxygen, carbon, hydrogen, potassium, sodium, calcium, sulfur, chlorine, phosphorus, and magnesium. Certain necessary trace elements include silicon, iron, manganese, and zinc. Much current literature indicates that in coastal waterways, nitrogen and phosphorus compounds have been reported to be the limiting factors for plant growth.

Nitrogenous Compounds

Nitrogen represents the fourth most abundant element by weight present in plant tissues and one of the two generally considered to be limiting in aquatic production. Clark (1974) reports that in coastal waters the amount of available nitrate is generally believed to be the nutrient factor that controls the abundance of plants. Municipal sewage disposal into rivers and estuaries is the major contributor of nitrogen compounds in the estuarine systems. Nitrogen naturally occurs in these forms: ammonium ion-NH_4^+, ammonia-NH_3, nitrite-NO_2^-, the nitrate ion-$NO_3^=$, molecular nitrogen-N_2, and complex organic nitrogen complexes. A simplified estuarine nitrogen cycle is given in Figure 1, which has been modified from Odum, 1971.

In the atmosphere, most of the nitrogen present is in the form of N_2 with lesser amounts of ammonia, and oxides of nitrogen derived from the combustion of fossil fuels. Atmospheric ammonia originates from a number of sources including air pollution, photochemical reactions of the stratosphere, and the decay of plant and animal byproducts. Rainfall acts to rinse the air, bringing this vast array of nitrogeneous products into aquatic systems. Only a few algal and bacterial species are able to utilize molecular nitrogen (N_2) for their nitrogen requirements. Ammonia is oxidized into nitrites (NO_2^-) by nitrifying bacteria, which is further converted to nitrate ($NO_3^=$) using the reaction as an energy source and making the product more available to plants. Most plants use ammonia, nitrate, or nitrite in the production of proteins and nitrogeneous nucleic acid components. This is an important interconversion of inorganic nitrogen to organic nitrogen. Animals, being unable to make this interconversion, are entirely dependent on plants. In decomposition, biological processes convert organic nitrogen to ammonia, nitrite, and nitrate for recycling. The refractory organic forms are resistant to decomposition and may remain for years in the system (Williams, 1971).

Photosynthesis assimilates inorganic and organic nutrients, most of which are present in excessive amounts. However, nitrogen naturally occurs in micromolar concentrations which can be completely assimilated from the water mass by phytoplankton of a given area. The major unnatural sources of nitrogen in an estuary are: municipal and industrial wastes, fertilizers from agricultural and forestry practices, and urban runoff. In estuaries where nitrogen is limiting, these wastes accelerate eutrophication. EPA criteria (1973) recommended prevention of any nutrient discharge causing enrichment leading to any major change in the natural levels of flora. However, there are no EPA standards regarding nutrient loading for "maximum acceptable concentrations" of nitrogen and its compounds (Proposed Criteria for Water Quality, EPA, 1973).

Phosphorus Compounds

Nitrogen and phosphorus represent the two elements generally found to be limiting in natural systems; however, nitrogen is generally considered to be the more important of the two. Ryther and Dunstan (1971) suggest that since phosphate is normally present in concentrations twice that of nitrogen in the coastal marine environment, nitrogen must be the critical limiting factor. The "maximum acceptable concentration" for phosphorus is placed

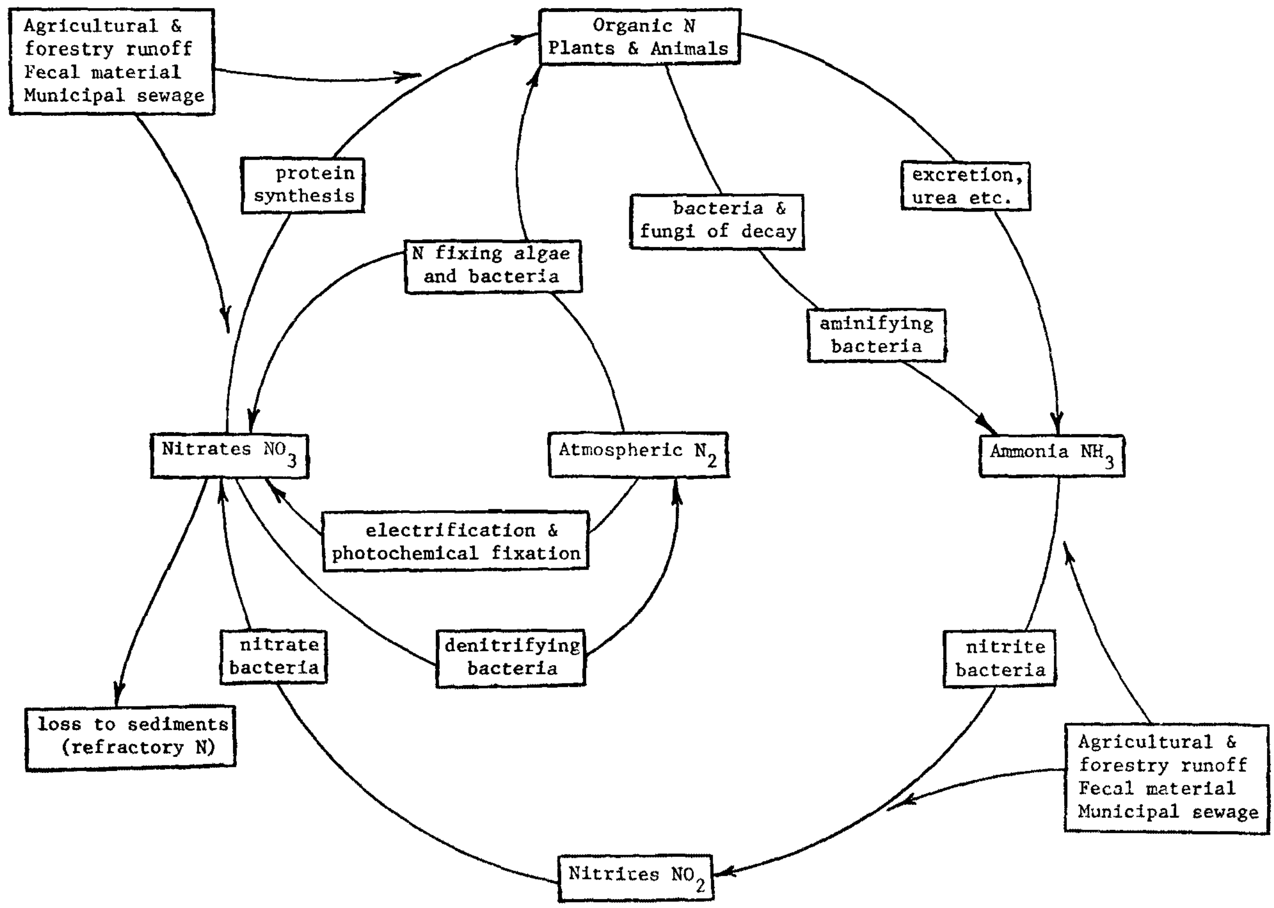


FIGURE 1.—The estuarine nitrogen cycle (modified from Odum, 1971).

as 100 mg/L with no "minimum risk threshold" value given (EPA, 1973).

Phosphorus exists in a great number of forms, the most prevalent of which is the phosphate group PO_4. A simplified estuarine phosphate cycle is given in Figure 2, which has been modified from Odum, 1971.

The slightly soluble inorganic phosphorus of the earth's crust is an unlimited reservoir which slowly leaches into aquatic systems through the weathering of rock. These soluble orthophosphates are quickly assimilated by plants and transformed into particulate organic phosphorus. Dissolved inorganic phosphorus compounds are released into solution by excretion or decomposition and are transformed into particulate organic phosphorus, or through degradation are converted back to inorganic orthophosphates. As in nitrogeneous forms, some of the organic products result in refractory compounds, unavailable for biological use and become part of the sediments.

Manmade detergents contain phosphates similar to those produced by living organisms. If phosphates in detergents are replaced by nitriloacetic acid (NTA), a nitrogen compound as is, the current trend in industry, the net effect could be the acceleration of eutrophication (Ryther and Dunstan, 1971). These authors also estimate that 25–50 percent of the total land-derived phosphate comes from detergents. The amount of nutrient exchange between sediments and the water column is dependent on the exposed surface area between the two media and not on the amount of nutrient material present. Low oxygen concentrations cause the release of phosphorus from the sediment. Several studies have found that under natural conditions an equilibrium is established between the phosphate concentration of the sediment and the water (Lee and Plumb, 1974). However, if these sediment nutrient reservoirs are covered by silt, or sand, no such interchange can take place. One study showed no phosphorus was released 0.54 cm below the surface of the bottom (Lee and Plumb, 1974).

Unlike many pollutants, phosphorus appears harmless by itself, but in combination with nitrogen,

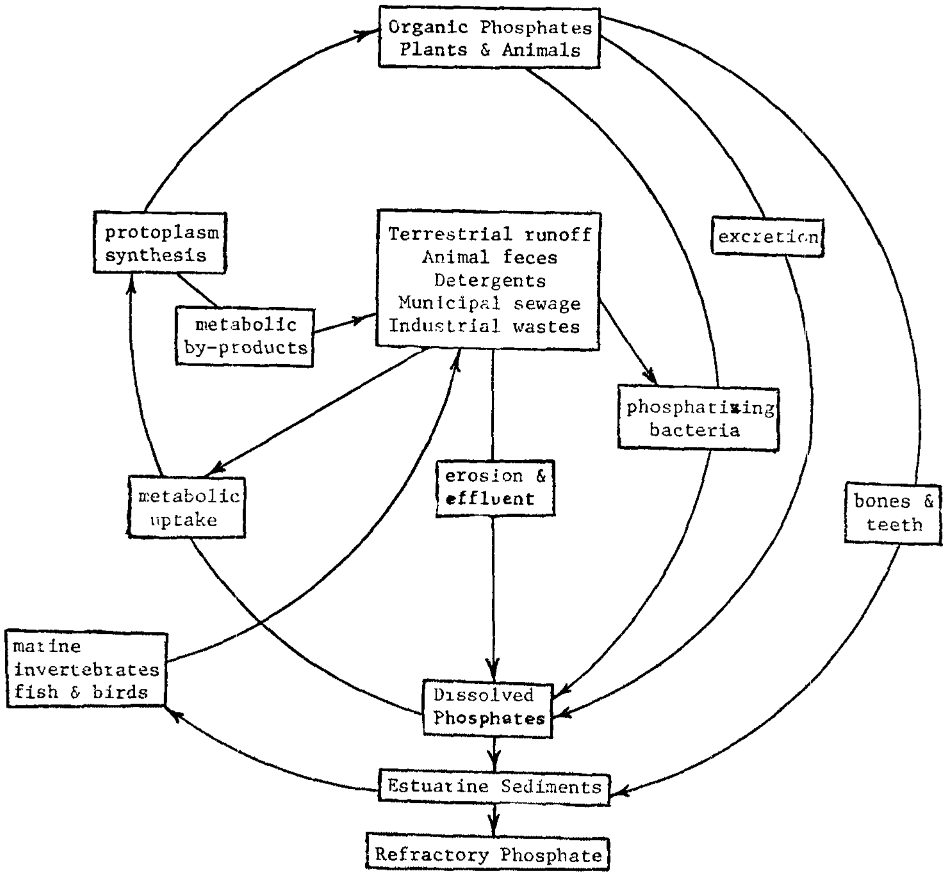


FIGURE 2.—The estuarine phosphorus cycle (modified from Odum, 1971).

it can change the whole biota (Redfield, et. al., 1963). Samples of water enriched with phosphate alone show no greater growth than control samples, while nitrogen-enriched cultures have shown tenfold growth in several cases (Ryther and Dunstan, 1971).

Carbon Compounds

The sources for most inorganic and organic carbon compounds in estuaries are terrestrial runoff, municipal and industrial discharges into rivers, and photosynthetic carbon fixation. A simplified carbon cycle for estuaries is given in Figure 3, which has been modified from Wangersky, 1972. Inorganic carbon is converted into organic carbon by photosynthesis. Organic carbon can be separated into particulate organic carbon (POC) and dissolved organic carbon (DOC) fractions by bacterial decomposition. Either of these can be associated with the sediments, the POC by settling, the DOC by adsorbing onto larger aggregations and settling to the bottom. Organic carbon is important as a nutrient because of the interconversion to inorganic carbon.

Since algal tissue contains between 35 and 50 percent organic carbon by weight, it merits classification as a major nutrient. In many cases, organic carbon may be directly correlated with nitrate distribution in a body of water. Carbon fixation rates are often stimulated by the addition of nitrogen or phosphate compounds as in the case of eutrophication. Organic carbon does represent an area of concern, but many authors believe that the reservoir of inorganic carbon compounds is in such excess that the rapidly cycling organic carbon is usually not a limiting factor under natural conditions.

Mineral and Trace Elements

In the late 1800's Dittmar studied 77 seawater samples and found chlorine, sodium, magnesium, boron, potassium, calcium, sulfur, sulfate, carbonate, bicarbonate and strontium represent from 99.7–99.9 percent of the total dissolved material. (Corcoran and Alexander, 1964.) The 0.2 percent remaining included the principal plant nutrients: nitrogen, phosphorus, and silicon, in addition to iron, copper,

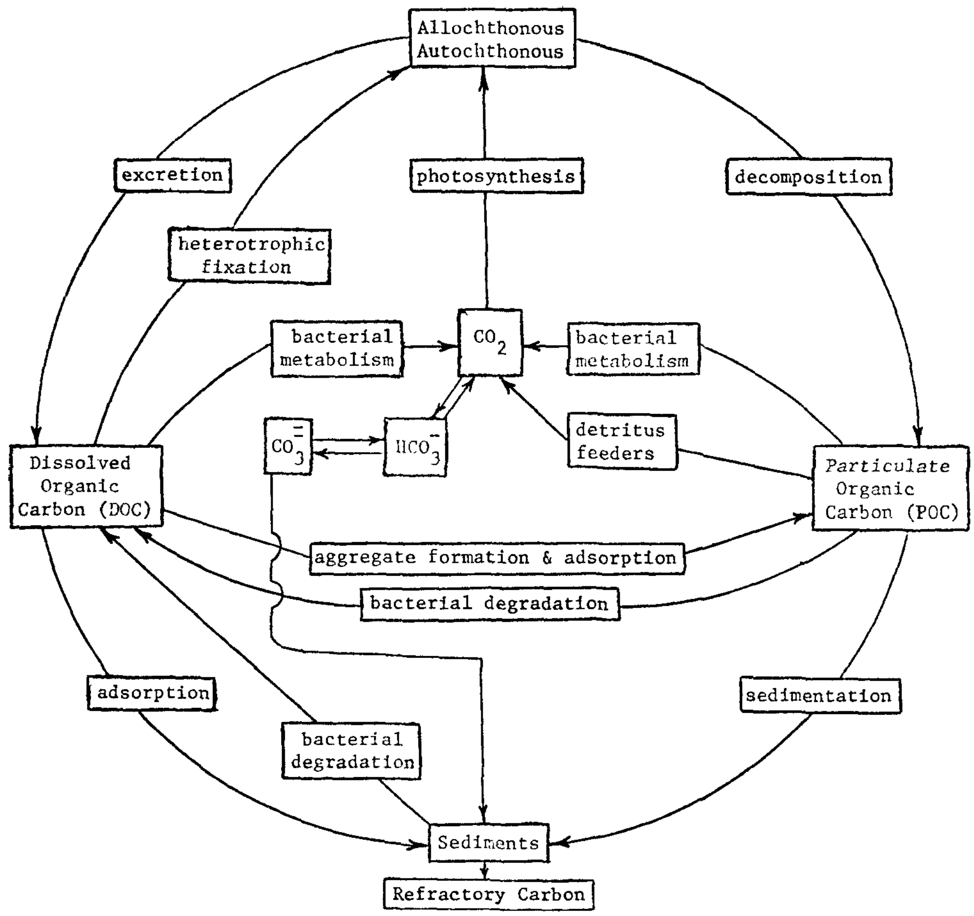


FIGURE 3.—The estuarine carbon cycle (modified from Wangersky, 1972).

›balt, and manganese. Iron, because of its role in emoglobin, catalases, and cytochromes is an es- ›ntial element in life processes. Iron in the form f ferric hydroxide (rust) has been postulated by ›olberg (1952 and 1954) to have a scavenger role ı the accumulation of trace elements, allowing hytoplankton to concentrate them along with their ormal uptake of iron. Copper, another essential lement, is found in hemoglobin, cytochromes, and emocyanins, as well as being necessary in the tabilization of the chloroplast. It aids in oyster and arnacle attachment, formation of octopus melanin, nd the hardening of exoskeletons and egg encase- ›ents. However, its toxicity at high concentrations › evidenced by its use in antifouling paints.

The trace elements exist in all three phases: water, ediment, and the biota. Using zinc as an example, n the water column it can be in an ionic state or a omplexed form with many other molecules. While . part of the estuarine sediment, it can be dissolved in interstitial water, ionically bound to charged clay and organic surfaces, entrapped within iron and manganese precipitates in addition to lattice and organic complexes. In the biotic phase, zinc is associated with an organism: bound to mucous membranes, enzymes, contained in cellular protoplasm or within the digestive system. This permits biological cycling as it passes up the food chain from the plankton through the carnivorous fish, and possibly returning to the sediments.

The concentrations of trace elements present in the estuary prevent them from being limiting factors for photosynthesis. Dittmar's hypothesis includes a general statement that the concentrations of these elements vary little in relation to each other in sea water. Trace elements can be toxic at concentrations above background levels (Doudoroff and Katz, 1961). EPA has set up a table listing "maximum acceptable concentrations" (Clark, 1974; EPA, 1973) for various substances; see Table 2.

Table 2.—Maximum acceptable concentrations for indicated substances. U.S. Environmental Protection Agency, 1973

Substance	Concentrations (mg/l)
Aluminum	1.5
Arsenic	0.05
Copper	0.05
Boron	N.A. adequate data not available
Fluorides	1.5
Iron	0.3
Lead	0.05
Manganese	0.1
Mercury	0.001
Nickel	0.1
Phosphorus	0.0001

The values represent the "maximum allowable concentrations" of toxic substances as established by EPA following a National Academy of Sciences Review in 1973.

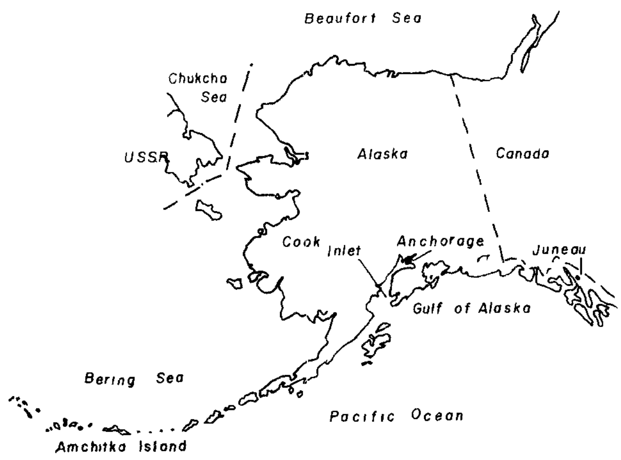


FIGURE 4.—Cook Inlet and Alaska (from "National Estuary Study," 1970).

NUTRIENT LOADING IN SIX MAJOR U.S. ESTUARIES

Cook Inlet, Alaska

Cook Inlet (see Figure 4) in the south central area of the state, exhibits a 30-foot tidal range, a rapid flow rate, and a large natural suspended sediment load. The estuary has an estimated 400–500 miles of tidal shoreline (1 percent of Alaska).

In Cook Inlet there are four major sources of nutrient loading: (1) municipal sewage discharges, (2) fish processing waste discharges, (3) salmon spawning wastes, and (4) turbid outwash—outflow from glaciers. Anchorage borders the inlet and discharges the sewage of nearly one-half of the state's population. The depth and flow rate of the estuary greatly reduces the impact of this nutrient load. However, with the discovery of oil, the Anchorage area will experience tremendous population growth. In 1963, oil was discovered at Middle Ground Shoal in Cook Inlet; in less than two years oil production exceeded 1,000 barrels per day per well ("National Estuary Study," 1970). Along the shores of Cook Inlet numerous fishing villages (Seldovia, Anchor Point and Homer) base their economies on chinook, pink and red salmon, king crabs and shrimp. It is a common practice for canneries to dispose of 20 percent by weight of salmon back into the inlet, producing unnaturally high nitrogen concentrations in small areas. Murphy et. al. (1972) concluded that there is some pollution near the Chester Creek and Cairn Point Outfalls, but as a whole, Cook Inlet is not polluted due to the high degree of turbulence, flow rate, and sediment transport. They further suggest that 200 million gallons per day of untreated domestic waste could be pumped into the inlet without causing an undesirable situation.

In Alaska many fishing villages are located on small finger bays. The villagers utilize individual cesspools and septic tanks for sewage disposal, which seep nutrients into the coastal waterways (Department of Health and Welfare, 1967). In many small villages waste materials are stored frozen during the colder months and dumped onto intertidal beaches to be washed away. These practices of waste disposal permit contaminants to enter the ground waters, infecting wells and becoming a hazard to public health.

Brickell and Goering (1970), investigating the concentration of nitrogen in a pink salmon spawning stream (Sashin Creek, and its associated estuary, Little Port Walter on Baranot Island in southeastern Alaska), found that dissolved organic nitrogen ranged from 0.006 mg/L to 0.018 mg/L following spawning, indicating a tremendous nutrient loading from the decay of adult fish.

In the future, the anticipated population growth in Alaska will overload the current estuarine waste disposal methods and greatly impact these waters. Continued nutrient loading through human waste, commercial fisheries' waste, and industrial discharges will alter the natural equilibrium of these estuaries, especially during the warmer months.

Columbia River Estuary

The Columbia River Estuary has a high velocity flow rate. It is ranked seventh in total length (1,324 miles) and second in flow volume (behind the Mississippi) of any river in the United States. The yearly mean discharge has been calculated to be 170,000 cubic feet per second, with a watershed of

259,000 square miles. The elevation of the river drops from 2,650 feet to sea level, generating an enormous velocity and producing a large effluent plume into the Pacific (see Figure 5).

The Columbia River has significant impact on the adjacent Pacific coastal zone. During 1966 and 1967 the annual chemical input to the Pacific was estimated to be 10^8 moles of phosphate, 2.6×10^9 moles of nitrate, and 2.2×10^{11} moles of total carbon dioxide (Pruter and Alverson, 1972). Due to the high velocity and short retention time within the estuary, these levels of nutrients do not have enough time to produce adverse conditions. It has been reported that: "With the exception of slime growths (*Sphaerotilus natans*) in the lower river, the biological populations of the river are diverse and balanced, the opposite of eutrophic conditions. Although nitrate and phosphorus levels exceed desirable levels (particularly during high runoff periods), there are none of the usual symptoms of excess productivity such as noticeable variations in dissolved oxygen saturation. There are no trends to suggest increasing eutrophication" (EPA; National Water Quality Inventory, 1974). The slime growths mentioned were found to be associated with pulp and paper mill wastes and became a problem to the fishermen by fouling their nets and also to those using the river for recreation. By the summer of 1972, practically all of the slime growth had been eliminated following a program of more extensive effluent treatment by the paper plants. The recommendation made was that all pulp and paper mills should at least have mechanically cleaned primary

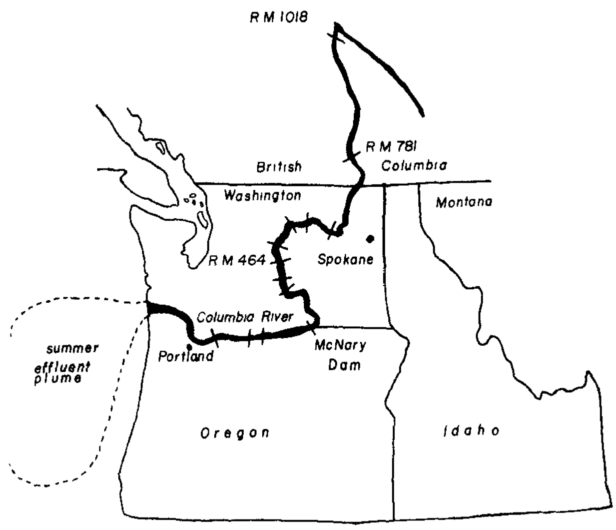


FIGURE 5.—The Columbia River showing summer effluent plume and dam locations (modified from EPA, National Water Quality Inventory, 1974).

Table 3.—Columbia River: Distribution of point waste discharges by source (1972-73)

Waste source	Flow *m.g./d.	BOD lb./day	Phosphorus lb./day	Nitrates lb./day
Municipalities	113.6	145,132	5,800	16,372
(Portland)	(71.1)	(66,962)	(3,102)	(9,340)
Pulp and paper	395.1	606,211	993	706
Chemicals	85.3	7,418	107	463
Aluminum reduction	91.3	4,300	493	415
Washington public power	1,710.0	—	—	—
AEC Hanford Works	289.5	—	1	—
Food processing	47.2	4,033	39	8
Other	36.0	1,634	75	95
Total	2,768.0	768,728	7,508	18,059

* Million gallons per day.
Modified from National Water Quality Inventory; 1974.

waste treatment facilities to reduce the release of paper fibers into the river.

Nutrient enrichment can be divided into controllable point discharges and generally uncontrolable non-point discharges coming from the normal land runoff. The point discharges come from a variety of sources on the river including municipal dumping, pulp and paper mills, food processing plants, grain washing plants, and so forth. Each of these makes contributions to the Columbia through industrial discharges. A point waste discharge for the Columbia River is given in Table 3. These point discharges are generally minor in their influence on the water but twice they have been involved in pollution problems in the lower river. Fortunately, the volume and velocity of the Columbia River have been great enough to maintain a quality that rarely drops below the very high standards set by the States of Oregon and Washington. While the quality of water in the Columbia remains generally high, some of her tributaries experience nutrient levels higher than state standards.

Sufficient amounts of all nutrients are present to support a diverse and abundant biota. During most of the year, nitrates are present in concentrations far greater than the 0.3 mg/L limit set for the usual formation of algae blooms (EPA; National Water Quality Inventory, 1974). In fall and winter nitrate median concentrations range from 0.3 to greater than 0.4 mg/L from McNary Dam (RM330) to the mouth; in spring, the median exceed 0.3 mg/L from Longview (RM68) to the mouth. Concentrations at McNary Dam exceed 0.8 mg/L in 15 percent of the readings; however, the effect is very slight. During the summer months when conditions are optimum for algal growth, nitrate concentrations fall well below the 0.3 mg/L value.

Phosphorus concentrations show a similar annual trend. From McNary Dam to the mouth, during the fall and winter, the median phosphorus value exceeds the 0.05 mg/L value set as the limit. During the warmer summer months, the median value is consistently below the limit value except in the lower 60 miles. It appears that total phosphorus concentrations can be correlated to river flow. Low flow years experience lower values (1967–1969), while higher flows (1970–1972) produce higher median concentrations. Fortunately, the Columbia River's nutrient levels are sufficient, with the vast majority of nitrates and phosphates coming from natural non-point sources. Phosphorus comes from soil-bound materials and is runoff dependent. "In 1972, 6 percent of the annual loading of the Columbia occurred from point sources discharging directly into the Columbia, 65 percent was carried to the Columbia by its major tributaries, and 29 percent was accounted for by other mechanisms—among them minor tributaries, direct runoff, and sedimentation" (EPA, National Water Quality Inventory, 1974).

Therefore, the Columbia River receives vast amounts of nitrogen and phosphorus principally from land runoff, but natural conditions have not permitted eutrophic conditions to occur. Point sources contribute large amounts of nutrients but the rate and volume of river flow is enough to disperse these substances during the algal growth season. It appears that some of the tributaries are experiencing increased eutrophication. The Columbia River has been sampled for 82 years and now has 89 monitoring stations along its length, which should enable recognition of potential problems.

San Francisco Bay

San Francisco Bay represents the oceanic outlet for the Sacramento River, San Joaquin River, and many lesser rivers that drain the Central Valley of California into the Delta (see Figure 6). Its history is unusual; in about 1850 the bay complex was estimated to be 700 square miles but by 1960 extensive diking and filling had reduced the area by 38 percent to 435 square miles. In addition, the bay area boasts a population in excess of five million, which discharges industrial and municipal wastes into the rivers and bay. This population represents a fourfold increase over census figures of 1930.

In 1969, municipal and industrial wastewater discharges were estimated at approximately 600 million gallons per day and this figure is forecast to increase to over 2,100 million gallons per day by the year 2020 (Kaiser Engineers, 1969). These figures do not include industrial use of water for cooling purposes. Natural runoff has increased due to increased urban development.

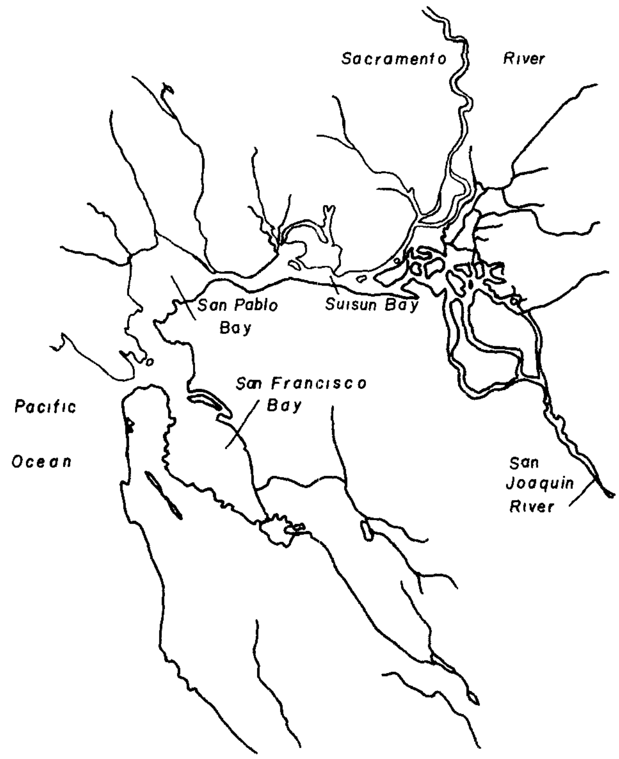


FIGURE 6.—San Francisco Bay (from Kaiser Engineers, Final Report to State of California, 1969).

In San Francisco Bay, nutrient overenrichment is the major problem. The rivers entering the bay are rich in nitrogen, phosphorus and carbon from point sources (municipal and industrial) and non-point sources (natural and agricultural) from the California Central Valley. Low velocity riverflows produce a residence time for the northern reach of San Francisco Bay estimated at 100 days according to the California State Water Resources Control Board in 1971. This time period permits extensive nutrient cycling and high rates of carbon assimilation. "Recent studies have indicated that nitrogen and phosphorus concentrations were from 10 to 100 times greater in the Delta than those reported for substantial growths of algae" (Kaiser Engineers, 1969). Reported concentrations of total nitrogen ranged from 0.2 to 2.5 mg/L with the higher values found at the San Joaquin River near Stockton, an agricultural area. An unusual feature of the bay is that nitrogen and phosphorus are at too high levels for them to be limiting eutrophic conditions. A California State Water Resources Control Board Report (Kaiser Engineers, 1969) states that in the Suisun Bay (see Figure 6) during periods of maximum phytoplankton concentration, no more than 17 percent of available nitrogen was being utilized.

The report further states that the possibility that phosphorus could be the limiting nutrient is even less credible. Data from 1961–1964 computes that municipal and industrial sources contribute 53 tons per day of total nitrogen and 42 tons per day of total phosphates (Pearson, Storrs and Selleck, 1969).

Phytoplankton blooms occur frequently. In general, algal populations found in the bay are 1/10 to 1/100 of those found in the delta region; however, densities of greater than 4 million cells per liter have been observed below Dumbarton Bridge. Blooms occur almost every summer. Typical summer plankton counts in the delta area range from 3 million cells per liter in the Sacramento River to greater than 30 million cells per liter in the San Joaquin River which normally exhibits much higher values than the other inflowing rivers (Kaiser Engineers, 1969). Therefore, nutrient enrichment and eutrophication are a major water quality problem for the bay-delta system. The increasing volume of wastes expected in the future, coupled with the reduced freshwater flow caused by the development of the Central Valley Project and the State Water project influenced Kaiser Engineers (1969) to project: "Within the preceeding context, it is believed that the bay-delta system has no assimilative capacity for wastes above the quantities now being discharged. Eutrophication of the system, particularly in the delta and south bay, is well advanced. Increasing waste loads and the decreasing availability of flushing water from the Sacramento and San Joaquin Rivers will inevitably accelerate the eutrophication of the system."

In the Final Report for the California State Water Resources Control Board, comparison was made between San Francisco Bay and Lake Erie. The Report states many differences between the two bodies of water: size, salinity, Erie's 920 day residence time vs. the bay's 100 day period, et cetera . . . but the mean soluble phosphate content is 10 times that of Lake Erie's and the bay's average nitrate concentration is usually three times higher than Erie. Furthermore, the median coliform bacteria content of San Francisco Bay, which is an indicator of the presence of domestic wastes, is from 5 to 250 times that which is reported for Lake Erie.

Galveston Bay, Texas

The Galveston Bay Estuary is made up of about 1,022,000 acres including 383,400 acres of water, 230,000 acres of rice farms and cattle ranges, and 190,000 acres of urban and industrial areas; see Figure 7 ("National Estuary Study," 1970).

The estuary exchanges water with the Gulf of

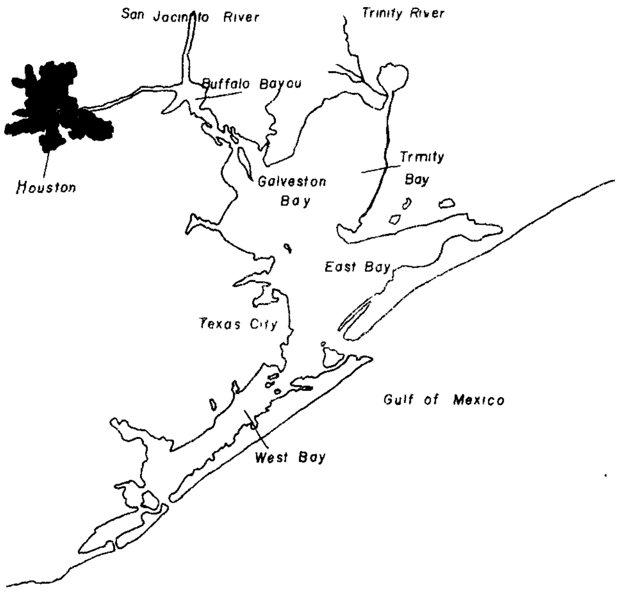


FIGURE 7.—Galveston Bay, Tex. (from EPA Proceedings in the Matter of Pollution of the Navigable Waters of Galveston Bay and its Tributaries, 1971).

Mexico in three places: Bolivar Pass, San Luis Pass and Rollover Pass. In 1914 the Houston ship channel was constructed, making Houston a major seaport with entry from the Gulf of Mexico. The major direct effect has been oil pollution from ship traffic and from the development of petrochemical industries along the Houston ship channel. The indirect effect has been the tremendous urban development and other industrial growth in the entire area. These have produced major chemical and biological changes in Galveston Bay.

Under the Texas Water Quality Act of 1967, permits are issued to municipalities and industries regulating disposal into Texas estuaries. By 1971, the Environmental Protection Agency had granted 141 municipal and domestic sewage permits and 136 industrial permits. The total permitted discharge of waste effluent to Galveston Bay and tributaries was 779 million gallons per day: 583,000 pounds suspended solids; 270,000 pounds BOD, and 1,657,000 pounds COD. The 136 industrial waste discharges were allowed to add 563 million gallons per day in total effluent, most of which enters into the Houston ship channel. The remaining 215 million gallons represented effluent from the 141 municipal and domestic waste sources. These sources contribute high levels of coliform bacteria which have closed many of the shellfish areas within Galveston Bay. Of the 277 permits mentioned above, the waste treatment needs and status of 189 of them were not listed, and an additional 40 provided either inadequate or no treatment at all. Only 22 were listed as being in compliance with permit requirements (EPA Galveston Bay Conference, 1971).

Major nutrient alterations have occurred frequently in the recent history of Galveston Bay. Wallisville Dam, located on the Trinity River four miles above its entrance into the bay, will eliminate "20,000 acres of brackish ponds, sloughs, marshes, and bottomland, nearly all of which biologists of the U.S. Fish and Wildlife service regard as prime shrimp and finfish nursery grounds with an annual productive capacity of not less than $300 an acre and probably more" (Carter, 1970). This marshland loss will substantially alter the nutrient input of Trinity Bay which is part of the Galveston Bay complex. The nutrients contributed by the Trinity River support the tidal marshes, the estuary and Galveston Bay. The 0.5 feet tidal fluctuation contributes additional nutrients from the tidal marshes to the estuary. McCullough and Champ (1973) reported that 255 miles or half of the entire length of the Trinity River was impacted by municipal and industrial waste discharges from the Fort Worth-Dallas area before organic carbon concentrations returned to background levels. Also, the authors calculated that the Trinity River exports an estimated 3.52×10^4 metric tons/year of total organic carbon into Trinity Bay, utilizing data from the 1972-1973 study period.

Several other human activities have a potential for increasing the impact of nutrient loading in Galveston Bay:

1. Silting in at the new bridge at San Luis Pass, a process that is increasing the water mass retention time.
2. Increased dredging activities that include $2,807,000 in 1970 in the polluted Houston ship channel, which was necessary for navigation.
3. Escalation in recreational construction of bay homes and bay front properties by diking marshes and dredging activities. "In sum, Galveston Bay is providing a classic case history of an estuary that can be rescued from its troubles only by determined and imaginative effort—the solutions to the bay's problems seem to lie in large scale research, ambitious programs of pollution control plus tough enforcement and a close watch on the outfalls" (Carter, 1970).

Pamlico Sound

The Pamlico Sound and adjacent Albermarle and Currituck Sounds represent a drowned North Carolina coastal plain separated from the Atlantic Ocean by the Outer Banks (see Figure 8).

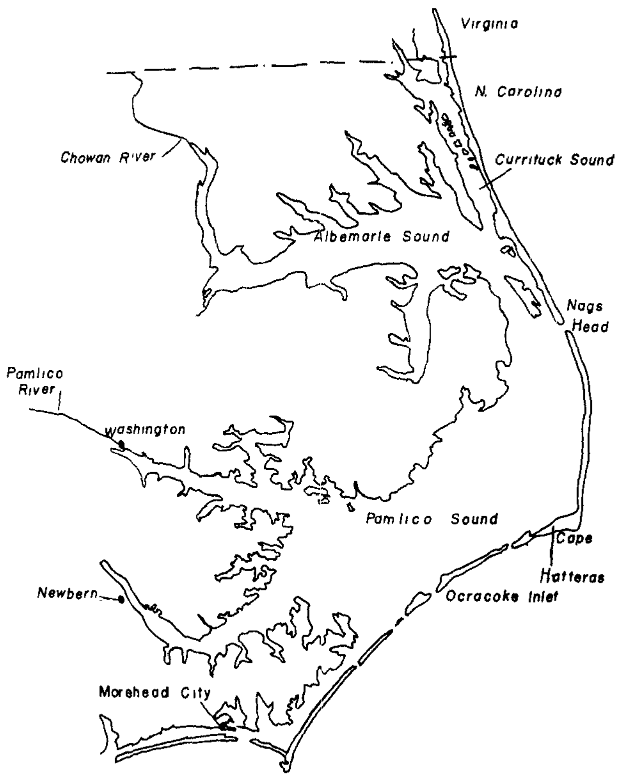


FIGURE 8.—Pamlico Sound (from "National Estuary Study," 1970.)

This entire complex makes up the second largest estuarine area in the eastern United States with Chesapeake Bay being first (Schoenbaum, 1972).

Currituck Sound	102,400 acres
Albemarle Sound	302,000 acres
Pamlico Sound	1,088,000 acres
TOTAL	1,492,000 acres
Chesapeake Bay	2,816,000 acres

Exceeded only by Alaska and Louisiana, North Carolina contains an estimated 2,200,000 acres of estuarine area (Rice, 1968). Shallow water characterizes these estuaries with a maximum depth of 7 feet in Currituck Sound and 20 feet in Pamlico Sound, but lessens to a few inches in many of the numerous shoal areas. In Washington, N.C., the Tar River becomes the Pamlico River flowing east to the Pamlico Sound (see Figure 8). An important feature is the slow riverflow allowing longer residence time and consequently a much slower flushing rate. Lunar tides are negligible due to the Outer Banks, and the extreme shallowness allows wind mixing of the water producing turbid conditions during most times. (Copeland and Hobbie, 1972).

Copeland and Hobbie (1972) have reported that nitrogen appears to be the nutrient limiting eutrophication in the Pamlico River Estuary. The soils of this region are unusually high in natural phosphorus, allowing large amounts to leach into the waterways. Natural deposits are high enough to make mining (for use in fertilizers) profitable by the Texas Gulf Sulphur Company (TGSCo) which contributes quantities into the Tar River. This additional phosphorus enters the water column and becomes part of the sediment, particularly near the TGSCo effluent pipes. Under conditions of low oxygen, significant amounts of this phosphorus are released from the sediment to the overlying water mass. Copeland and Hobbie (1972) have reported that:

> When the total unfiltered phosphorus data were summarized for the upper, middle and lower river, it became obvious that there had been a general increase in the concentration of phosphorus in the upper river over three years of sampling (67–69). In spite of the scatter of values and seasonal changes, there was a tripling in the phosphorus concentration in the upper river . . . the middle river was greatly affected by the concentration of phosphorus entering from Texas Gulf Sulfur . . . the lower section . . . also seems to be strongly affected by Texas Gulf Sulfur's activities . . . while it is difficult to say whether or not the amount of phosphorus reaching Pamlico Sound is increasing, most of the time only low levels reach the Sound.

Yentsch (unpublished data; NAS, 1969) has postulated 2.8 μg of phosphate per liter as the approximate upper limit for unpolluted coastal waters. This value is exceeded most of the time in the Pamlico area but eutrophic conditions do not exist because "it appears that nitrogen is limiting in this estuary and that the polluting effects of the Texas Gulf Sulphur phosphate are slight at this time." (Copeland and Hobbie, 1972). Other required micronutrients appear to be abundant. Experiments were conducted adding phosphorus to the water but increased photosynthesis did not occur. Added nitrogen produced significant increases in carbon assimilation.

In summary, phosphorus by itself is relatively harmless in the Pamlico Estuary area but if nitrogenous compounds become available to the system, excessive eutrophication could occur.

Chesapeake Bay

The Chesapeake Bay represents the largest estuarine area in the eastern United States (2,816,000 acres), having major freshwater flow from the Susquehanna River, Potomac River, Rappahannock River, and the James River along her western shore ("National Estuary Study," 1970); see Figure 9. The Potomac River itself drains 14,670 square

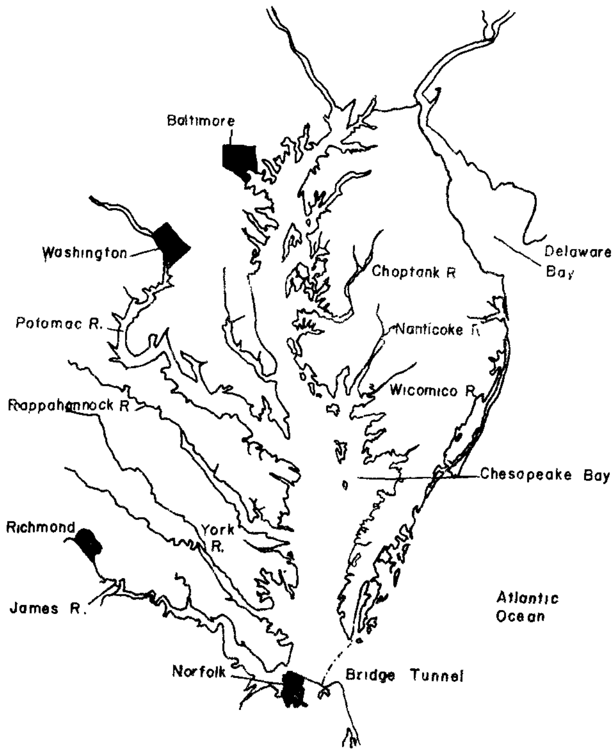


FIGURE 9.—Chesapeake Bay (from "National Estuary Study," 1970).

miles and extends 100 miles southeast from Washington, D.C., to the bay (Jaworski et al., 1971). Major cities contributing to the bay or her tributaries include Baltimore, Md., (pop. 905,759), Washington, D.C., (756,510), Richmond, Va., (249,430) and Norfolk, Va., (307,951). These urban areas contribute to the nutrient load through municipal and industrial wastes, land silt runoff, and wastes contributed by the estimated 110 million tons of cargo annually shipped through the bay ("National Estuary Study," 1970). The Susquehanna River contributes 600,000 tons of terrigeneous silt to the Chesapeake each year, but this volume seems insignificant to the estimated 2.5 million tons originating in the smaller Potomac Basin. Nearly half of the economically important oyster beds located in the upper bay have been destroyed or moved lower in the bay due to this massive sedimentation. Cities and suburban areas are presently adding uncontrolled quantities of silt into Chesapeake Bay ("National Estuary Study," 1970).

Regarding nutrient enrichment in Chesapeake Bay, there are two considerations: (1) the predominant influence of three principal watersheds on the nutrient balance of the bay—the Susquehanna, the Potomac, and the James; and (2) the seasonal nature of nutrient enrichment, whereby the majority of nutrients transported are via nontidal discharges (Guide and Villa, 1972). There is a relationship between river discharge and nutrient loadings, especially NO_2 and NO_3 as nitrogen. High NO_2 and NO_3 as nitrogen loadings are indicative of land runoff as contrasted to TKN as nitrogen loadings which are attributable mainly to treatment plant discharges. Conversely, total phosphorus as PO_4 is more difficult to characterize since it tends to absorb to particles and sediments. During low flow phosphorus is retained in bottom deposits in the stream channel and is unavailable due to sedimentation. The greatest impact of these nutrient loadings occurs during periods of low flow (and high temperature) during which high retention times result in algal blooms. Guide and Villa (1972) have by regression extrapolation over a 15-month study period (Nov. 1969-May 1970) calculated the primary source of nutrients entering Chesapeake Bay as follows:

Tributary Watershed	Loadings (Lbs/Day) as % T PO_4 as PO_4	Pi	TKN as N	NO_2 + NO_3 as N	NH_3 as N	TOC
Susquehanna River	49	54	60	66	71	51
Potomac River	33	27	23	25	15	27
James River	12	13	10	6	11	12
Rappahannock River	2	2	2	1	1	3
Pamunkey River	2	2	2	1	1	4
Mattaponi River	1	1	1	<1	<1	2
Chickahominy River	1	1	1	<1	<1	1

Clark, Guide, and Pheiffer (1974) have developed the following conclusions regarding the nutrient loading in the Susquehanna River:

1. Runoff from agricultural land (42 percent of the study area) accounted for 75–85 percent of the nonpoint source phosphorus contribution, 60–70 percent of the TKN contribution, and more than 90 percent of the nitrate nitrogen contribution from all nonpoint sources.
2. Runoff from forested land (53 percent of the study area) accounted for 10–15 percent of the non-point source phosphorus load, 25–30 percent of the TKN load, and about 5 percent of the nitrate nitrogen load from all non-point sources.
3. Phosphorus is considerably more manageable than nitrogen in the lower Susquehanna River Basin during all flow conditions.
4. In order to protect the biological integrity of the upper Chesapeake Bay, a sizeable reduction (70–90 percent) in the existing point source contribution of phosphorus must be realized.
5. The effectiveness of nitrogen control at point sources is questionable unless attention is given towards reducing the existing load from agricultural runoff.

Guide and Villa (1972) have also reported the existence of a direct relationship between total and inorganic phosphorus concentrations as PO_4 and river discharge. They found that higher than normal flow resulted in total and inorganic phosphorus surges from the upper Susquehanna River Basin.

Jaworski et al., (1971) report that 325 million gallons per day of wastewater is discharged from municipal treatment facilities which serve the Washington area. Schubel (1972) adds that this present sewage discharge contains more than six metric tons of phosphorus and 10 metric tons of nitrogen per day with these values expected to double in the next 30 years. During periods of low river flow (75 m^3/sec.) these inputs drastically alter the nutrient load of the Potomac, increasing the concentration of phosphorus by about 180 μg/liter (Carpenter, et. al., 1969). Total nitrogen in the river varies seasonally but generally appears highest from January to March. Total phosphorus reaches its highest values during the late fall and early winter. Agricultural drainage and sewage in the Potomac produce adverse phosphate conditions above Washington, D.C. Measurements made in 1965–1966 showed that nitrate concentrations in the river above Washington were 100–150 μg at./liter during periods of high river flow, and phosphate concentrations were 5 μg at./liter (Carpenter, et. al., 1969). This loading in summer and fall produces large algal populations of blue-green algae *Microcystis aeruginosa* which are present from the metropolitan area as far downstream as Maryland Point (40 river miles). Comparison of chlorophyll *a* concentrations for 1965–1966 to 1969–1970 for Smith's Point (River Mile 0) and Indian Head (River Mile 75 from the mouth of Chesapeake Bay) indicate that algal populations have not only increased in density in later years but have become more persistent over the annual cycle (Jaworski, et. al., 1971).

Organic carbon studies in the Patuxent River, Md., have found that the concentrations of dissolved organic carbon (DOC) were higher than particulate organic carbon (POC). The DOC to POC ratio was 1.7:1 for the 18 river miles studied (Hill, 1973). An analysis of variance indicated that DOC varied significantly with salinity while POC varied significantly only at low and high salinities. Both DOC and POC concentrations decreased down river (Hill and Champ in manuscript).

Thus far, Chesapeake Bay itself has been able to avoid the problems associated with nutrient loading leading to eutrophic conditions which are present in many tributaries (e.g. Potomac River, Patuxent River and Black River). In the main body of the upper bay nutrient levels and phytoplankton production are high, but the grazing rate is also high, thereby preventing an undesirable buildup of algae. Nutrient levels are probably near the upper limit for healthy conditions in the bay. The discharge of improperly treated sewage and municipal wastes constitutes the most serious immediate threat to the Chesapeake Bay estuarine system (Schubel, 1972).

CRITICAL PROBLEMS AND RECOMMENDATIONS

Current U.S. Trends in Nutrient Loading

The current trend in expansion, development and population growth of coastal cities will greatly accelerate man's impact on the Nation's estuaries. Nutrient loading is increasing in general with some harmful results. The 1974 National Water Quality Inventory stated that the "chemical and physical measurements taken in 22 waterways show that the pollutants receiving the most widespread controls (including bacteria and oxygen demand) greatly improved in the last five years." It continued to report that "nitrogen and phosphorus, the nutrients most frequently associated with eutrophication, showed worsening trends." The overall effect of these opposite trends is not completely understood; however, if the present increased use of chlorine as a disinfectant is considered, lower bacteria counts and BOD levels could be explained even though nutrient loading has increased. Phosphorus levels were high enough to exceed suggested levels in up to 57 percent of the reaches studied. In addition, "82 percent of the reaches showed increased levels of phosphorus from 1968–1972 over the previous five years . . . with nitrogen exceeding reference levels in one quarter of the reaches measured, and increased in up to 76 percent of the reaches." Table 4 presents the percent of the reaches exceeding reference levels and the percent change from 1963 to 1972.

Table 4.—Major waterways: Reference level violations, 1963-72

Parameter	Reference level and source	Percent of reaches exceeding reference levels		
		1963–72	68–72	Change
Suspended solids	80 mg/l aquatic life	26	14	−12
Turbidity	50 JU aquatic life	28	28	0
Ammonia	0.89 mg/l aquatic life	16	6	−10
Nitrate (as N)	0.9 mg/l nutrient	12	24	+12
Nitrite plus nitrate	0.9 mg/l nutrient	18	26	+8
Total Phosphorus	0.1 mg/l nutrient	34	57	+23
Total Phosphate	0.3 mg/l nutrient	30	41	+11
Dissolved Phosphate	0.3 mg/l nutrient	11	22	+11
Chlorides	250 mg/l water supply	12	9	−3
Sulfates	250 mg/l water supply	12	12	0

Modified from National Water Quality Inventory; 1974.

The National Water Quality Inventory (1974) represents a landmark work in the study of the United States continental waterways because it was a cooperative effort by the states in association with the Environmental Protection Agency. The report studied the 10 longest rivers in the country; the 10 rivers with the highest streamflow volume; and the rivers or harbors where the 10 largest urban areas are located.

In 1972, the National Pollution Discharge Elimination System (NPDES) Act was passed requiring permits for discharging from a point source into the nation's waters. These permits specify the amounts of pollutants that each discharge point is allowed. By March 1974, about 41,000 permit applications had already come in with an expected 34,000 still to be filed.

Municipal sewage contributes large amounts of nutrients to the river or estuary depending upon the treatment it receives. Primary treatment removes the particulate matter from the raw sewage thereby removing 20–35 percent of the biological oxygen demand (BOD). Tertiary waste treatment, using the effluent from the secondary process, involves nutrient removal (nitrogen and phosphorus) and can reduce BOD effluent concentrations significantly below secondary treatment. Table 5 lists the number of municipal discharges by treatment level and by state.

Agricultural sources are more difficult to study. Most farms are not considered to be point sources and are not required to have permits, but large feedlots, fish hatcheries, and return flows from irrigated fields must have permits. Most operations of this type are found in the west and midwest with about 6,500 permit applications expected under the National Pollution Discharge Elimination System (NPDES).

Increased nutrient loading represents a potential hazard to the nation's estuaries which may have a profound effect on a type of American way of life. Many communities bordering the estuaries depend upon the estuarine ecosystem for their economic and cultural livelihood. In tidewater Virginia, for example, fishing and oystering have been community pursuits for well over a century and they could easily be eliminated, impacting economic and social structures. Socially, the estuaries annually provide recreation for millions in the form of swimming, boating and fishing. In North Carolina, the annual

Table 5.—Municipal discharges by state (From EPA National Water Quality Inventory, 1974)

State	Number of municipal facilities by treatment level							Number of facilities by population served			
	Total	Primary	Adequate secondary	Inadequate secondary	Unclassified secondary*	Tertiary	None	Less than 1,000	1,000 to 9,999	10,000 to 100,000	Greater than 100,000
Alabama	261	32	65	42	101	0	21	96	137	27	1
Alaska	38	8	0	1	25	0	4	31	4	2	1
Arizona	119	3	7	13	75	1	20	51	54	11	3
Arkansas	211	18	5	29	157	0	2	71	118	21	1
California	659	119	69	62	375	11	23	196	300	140	23
Colorado	233	11	15	16	168	7	16	119	86	24	4
Connecticut	180	39	11	7	84	6	33	83	44	45	3
Delaware	25	5	8	8	2	0	2	8	15	1	1
District of Columbia	1	0	0	1	0	0	0	0	0	0	1
Florida	582	40	173	147	189	14	19	261	240	78	3
Georgia	474	64	207	114	62	2	25	264	173	33	4
Hawaii	39	5	9	3	15	0	7	11	22	6	0
Idaho	129	17	16	42	37	0	17	67	53	9	0
Illinois	828	71	183	230	287	31	26	313	416	92	7
Indiana	741	43	37	80	355	104	122	450	241	44	6
Iowa	639	27	23	122	350	0	117	421	195	22	1
Kansas	632	98	13	67	442	0	12	405	192	33	2
Kentucky	284	25	6	5	238	3	7	96	166	20	2
Louisiana	188	11	1	2	159	0	15	42	111	33	2
Maine	68	15	4	3	24	0	22	27	34	7	0
Maryland	304	28	61	57	141	0	17	195	88	19	2
Massachusetts	153	37	0	0	77	0	39	56	56	33	8
Michigan	482	108	59	58	132	13	112	184	245	48	5
Minnesota	520	53	15	92	311	15	34	295	195	27	3
Mississippi	312	7	4	11	277	0	13	170	114	27	1
Missouri	454	20	18	31	376	0	9	213	205	30	6
Montana	163	24	2	2	127	2	6	109	46	8	0
Nebraska	496	41	4	24	385	7	35	374	109	10	3
Nevada	39	3	7	2	24	1	2	14	21	1	3
New Hampshire	45	18	0	2	23	0	2	10	26	9	0
New Jersey	339	84	20	33	193	4	5	73	176	80	10
New Mexico	82	1	8	27	45	0	1	27	39	14	2
New York	747	472	34	66	135	16	24	312	329	86	20
North Carolina	1,156	114	150	166	634	33	59	901	200	53	2
North Dakota	256	15	3	11	216	0	11	194	54	8	0
Ohio	1,033	89	219	123	298	132	172	576	344	101	12
Oklahoma	385	12	76	157	137	0	3	199	155	28	3
Oregon	249	42	39	54	91	2	21	117	102	28	2
Pennsylvania	1,877	164	429	263	494	253	274	1,225	518	121	13
Rhode Island	27	8	1	7	2	2	7	11	6	8	2
South Carolina	1,416	113	37	93	1,067	82	24	1,202	188	25	1
South Dakota	227	19	93	74	26	2	13	169	50	8	0
Tennessee	265	17	60	42	134	6	6	102	133	26	4
Texas	911	73	172	490	171	1	4	239	530	123	19
Utah	89	14	23	21	17	1	13	42	79	16	2
Vermont	79	34	1	4	31	0	9	34	41	4	0
Virginia	956	99	54	90	673	22	18	733	184	31	8
Washington	363	95	22	39	182	2	23	202	120	37	4
West Virginia	578	149	6	10	385	5	23	472	94	12	0
Wisconsin	562	84	101	195	132	14	36	326	197	36	3
Wyoming	85	9	0	2	70	1	3	52	29	4	0
Guam	1	0	0	0	1	0	0	1	0	0	0
Puerto Rico	82	25	5	47	1	0	4	6	66	9	1
Virgin Islands	1	1	0	0	0	0	0	0	1	0	0
Total	21,065	2,723	2,575	3,287	10,153	795	1,532	11,852	7,291	1,718	204

* Data insufficient to classify further.

marine sport fishing value was estimated at 9 million dollars in 1960, with marine commercial fisheries valued at 3.6 million dollars. Estuarine dependent oceanic fish were valued at 2.5 million with waterfowl hunting valued at 0.2 million dollars. Therefore, the annual primary economic value of fish and wildlife resources of the North Carolina estuarine areas were in excess of $15 million in 1960 (National Estuarine Study, 1970). In 1966 in Chesapeake Bay $30 million dollars worth of fish and shellfish were harvested, half of this oysters. The 20 million pounds of oyster meat harvested in 1966 dosen't compare well with the 177 million pounds harvested in 1880 Oyster harvesting could evidently be prohibitec in some areas if pollution and eutrophication are allowed to continue. Swimming has been banned in some rivers, for instance in the Potomac River, where up to 5 million gallons of untreated raw sewage per day are currently being discharged due to treatment plant overloads.

Nutrient loading in some estuaries has accelerated eutrophication, altering the biota and reducing species diversity. The species considered to have economic value generally do not thrive in eutrophic conditions. Perhaps the most significant alterations in the biology of eutrophic estuaries would be the reduction in embryonic and juvenile survival rates and the reduction of alternative food webs. Oysters, clams, lobsters crabs and many species of fish have been placed in stressing environments. The resulting biota is composed of large populations of polycheate worms, trash fish, and echinoderms. In tropical waters, sewage dumping accelerates algae production which drastically alters the production of coral reefs. On the west coast, sewage disposal stimulates large populations of sea urchins, which over-graze the giant kelp beds, eliminating nursery areas for larval and juvenile forms, habitats for fish, sea otters, and numerous invertebrates. These alterations are at the interacting ecosystem level and cause irreversible damage.

With world food production today at a premium, the 4.06 billion pounds of U.S. estuarine commercial fish and shellfish (1967) are a very important source of protein. Several investigators have reviewed the potential for controlled cultural eutrophication as a new source for man's food (Sawyer, 1970). The philosophy is that added nutrients increase phytoplankton biomass, which could be channeled into food chains specifically for the production of commercially important fish or shellfish (aquaculture). This could serve a twofold purpose: first, it could use treated sewage as a nutrient source, and secondly, it could produce a vast industry if developed. The statistics compiled for 1969 by the National Marine Fisheries Service of the National Oceanic and Atmospheric Administration indicate that the Gulf of Mexico Fisheries contributed $152 million, or about 30 percent of the total U.S. fisheries production ($518.5 million). In 1970 the gulf shrimp fisheries alone were estimated to be worth $108 million.

A smooth system doesn't exist whereby federal agencies administer to state agencies, which control local operations, with one federal group as the lead organization responsible for coordination of estuarine programs. Instead, a free lance theory of operation exists which can break down interagency cooperation. Federal "maximum acceptable permissible concentrations" exist in many cases but these need to be evaluated as standards for water quality and as methodology incorporating both accuracy and simplicity. EPA and other governmental groups are on the right track in coordinating activities and defining critical values, national zones and areas of study. However, a total cooperative program will be required to reverse the national trend. An integrated systems approach will enable a better qualification and quantification of estuarine dynamics, eliminating problems associated with interpreting individual parameters. For enforcement policy to be effective, it must be uniform, and those at fault must be given an economic incentive for corrective action. If fines are not enough, stiffer measures must be taken to develop cooperation.

A nationwide monitoring system using standardized methodology is needed which could be state and federally supported and staffed. This allows for progressive trends to be realized and would be beneficial in discovering problem areas. Phosphates, largely coming from households, represent an easy source for action but certainly that is not enough. Nitrogenous compounds, generally considered to be the limiting nutrient in coastal areas, need to be strictly monitored. New technology in municipal sewage treatment has increased the efficiency of phosphate removal; however, there must be a greater effort to investigate the impact of specific nutrients on specific estuaries. Fertilizers could be made less deleterious simply by increasing the efficiency of their uptake.

Nutrient loading in the nation's estuaries exists as a problem between good management (cooperative policy and decision) and enforcement of regulations.

RECOMMENDATIONS

1. *Formation of a National Estuarine Coordinating Board.* The Board would consist of representatives from the various state and federal agencies. The Board would be responsible for approving management programs and directing the enforcement of policies and enactments. The Board would be responsible for reviewing every estuarine proposed project prior to submission to Congress for funding, similar to the Board of Engineers for River and Harbors for civil works projects. The Board would be responsible for coordinating estuarine monitoring surveys and evaluating national trends. The Board could be housed in the Office of Coastal Zone Management of NOAA.

2. *Development of a national policy* on coastal land use with regard to construction of recreational homes

and beach houses, et cetera, modeled after the Currituck County Plan in North Carolina. This plan concentrates housing and populations in small areas which enables better sewage treatment and reduces the human impact on the system.

3. *Formation of a Nationwide Estuarine Monitoring System* in which the many regional programs would be coordinated and manned by federal and state authorities using standardized techniques. The data could be stored in EPA STORET System with a system of quality control instigated.

4. *Designation of natural* undisturbed estuarine areas as biospheres to be preserved and protected for research and long term studies

5. *Seasonal and long term studies* evaluating the impact of the addition of specific nutrients to specific estuarine ecosystems to determine the limiting nutrient.

REFERENCES

Alaska Division of Public Health. 1967. Water supply and waste disposal in the Gateway Borough. Published by the Branch of Environmental Health. Juneau.

Brickell, D. C. and J. J. Goering. 1970. Chemical effects of salmon decomposition on aquatic ecosystems. In International Symposium on Water Pollution Control in Cold Climates. Edited by R. S. Murphy and D. Nyguist. U.S. GPO Stock No. 5501-02028. pp. 125–138.

California State Water Resources Control Board. 1971. A comprehensive study of San Francisco Bay. Final Report, Publication No 42.

Carpenter, J. H., D. W Pritchard, and R. C. Whaley. 1969 Observations of eutrophication and nutrient cycles in some coastal plain estuaries. In Eutrophication: causes, consequences and correctives. National Academy of Sciences, Washington, D.C. pp. 210–224.

Carter, L. J. 1970. Galveston Bay: test case of an estuary in crisis. Science, Vol. 167, No. 3921. pp. 1102–1108.

Clark, John. 1974. Coastal ecosystems: ecological considerations for management of the coastal zone. The Conservation Foundation. Washington, D.C

Clark, Leo J., D. K. Donnelly, and Orterio Villa, Jr. 1973. Nutrient enrichment and control requirements in the Upper Chesapeake Bay. EPA-903/9-73-002-a.

Clark, L. J., Victor Guide, and T. H. Pfeiffer. 1974. Nutrient transport and accountability in the Lower Susquehanna River Basin. US-EPA-903/9-74-014. Technical Report 60.

Copeland, B. J. and J. E. Hobbie. 1972. Phosphorus and eutrophication in the Pamlico River Estuary, N.C. Water Resources Institute of the Univ of N.C Report No. 65.

Corcoran, E. F and J. E. Alexander. 1964. The distribution of certain trace elements in tropical sea water and their biological significance. Bull. of Marine Science of the Gulf and Caribbean. Vol. 14, No. 4, pp 594–602.

Doudoroff, P. and M. Katz. 1961. Critical review literature on the toxicity of industrial wastes toxic components to fish. Sewage and Industrial Wastes. 22:1432.

Eppley, R. W, A. F. Carlucci, et al. 1972. Evidence for eutrophication in the sea near southern California coastal sewage outfalls California Mar. Res. Comm., CalCOFI Rept., 16:74–83.

Goldberg, Edward D. 1952. Iron assimilation by marine diatoms. Biological Bulletin. Vol. 102, No. 3. pp. 243–248.

Goldberg, Edward D. 1954. Marine geochemistry 1. Chemical scavengers of the sea. Journal of Geology, Vol. 62, No. 3. 1954. pp 249–265

Guide, Victor, and Orterio Villa, Jr. 1972. Chesapeake Bay nutrient input study Technical Report 47. US-EPA Region III.

Hill, J. M. 1973. Distribution and diurnal cycle of dissolved and particulate organic carbon in the Patuxent River, Md. MS thesis. The American University. Washington, D.C.

Hill, John M., and Michael A. Champ. (In manuscript.) Distribution and diurnal cycle of dissolved and particulate organic carbon in the Patuxent River Estuary, Md.

Jaworski, N. A, D. W. Lear, Jr., and O. Villa, Jr. 1971. Nutrient management in the Potomac Estuary. Technical Report 45. Environmental Protection Agency.

Kaiser Engineers. 1969. Final report to the State of California-San Francisco Bay-Delta water quality program

Ketchum, B. H. 1969. Eutrophication of estuaries. In Eutrophication: causes, consequences, and correctives. 1971. National Academy of Sciences. Washington, D.C. pp. 197–209.

Lee, G. F., and R. H. Plumb. 1974. Literature review on research study for the development of dredged material disposal criteria. NTIS AD-780 755/5GA.

McCullough, J. M., Jr., and Michael A. Champ. 1973. Limnology-aquatic elements in ecological survey data for environmental considerations on the Trinity River and tributaries, Texas A report for U.S Army Corps of Engineers. Contract No. DACW63-73-C-0016. pp. 91–229.

Murphy, R. S, R. F Carson, D. Nyquist, and R. Britch. 1972. Effects of waste discharges into a silt-laden estuary—A case study of Cook Inlet, Alaska. Institute of Water Resources, University of Alaska. Publication No. IWR 26.

Noble, Philip, and John Deedy. (Editors.) 1972. The complete ecology fact book Doubleday and Co, Inc., Garden City, N.Y.

Odum, E. P. 1971. Fundamentals of ecology. Third edition. W. B. Saunders Co., Philadelphia, Pa.

Odum, H. T., B J. Copeland, and E. A. McMahan. 1974. Coastal ecological systems of the United States. The Conservation Foundation. Washington, D.C. Vol. 1-4.

Pearsons, E. A., P. N. Storrs, and R. E. Selleck. 1969. Final report. A comprehensive study of San Francisco Bay. Vol. 3. Waste dischargers and loading. SERL Report No. 67-3. Berkeley: Sanitary Engineering Research Lab., University of Calif.

Pruter, A. T., and D. L. Alverson (ed.) 1972. The Columbia River estuary and adjacent ocean waters. U. of Seattle press.

Redfield, A. C., B. H. Ketchum, and F. A. Richards. 1963. The influence of organisms on the composition of seawater. In Hill, M. N. (ed.) The Sea, Interscience, N.Y. Vol. 2.

Rice. Estuarine lands of North Carolina: Legal aspects of ownership, use and control, 46 N C.L. Rev. 779 (1968).

Ryther, J. H. and W. M. Dunstan. 1971. Nitrogen, phosphorus and eutrophication in the coastal marine environment. Science. Vol. 171. pp. 1008–1013.

Sawyer, C. N. 1970. ABCs of cultural eutrophication and its control. Part 1—cultural changes Presented at meeting of Psychological Society of America, Indiana University. Published in the Proceedings. pp. 278–281.

Schoenbaum. 1972. Public rights and coastal zone management. 51 N.C.L. Rev. 1.

Schubel, J. R. 1972. The physical and chemical conditions of Chesapeake Bay; an evaluation. Chesapeake Bay Institute, The Johns Hopkins University. Special Report No. 21.

Smith, R. F. 1966. In R. F. Smith, A. H. Swartz, and W. H. Massmann (ed.) A symposium on estuarine fisheries. Amer. Fish. Soc. Spec. Publ No. 3. pp. vii–viii.

U.S. Department of the Interior, Fish and Wildlife Service. 1970. National estuary study. U.S. Government Printing Office. Volumes 1–7.

U.S. Department of the Interior. 1970. The national estuarine pollution study Report of the Secretary of the Interior to the U.S. Congress. 91st Congress, Document No. 91-58. U.S. Government Printing Office.

U.S. Environmental Protection Agency. 1971. Conference in the matter of pollution of the navigable waters of Galveston Bay and its tributaries, Texas. (3 vols.) Houston, Tex

U.S. Environmental Protection Agency. 1973. Water quality criteria. 1972. National Academy of Sciences Committee on Water Quality Criteria Report. Washington, D.C. EPA-R3-73-033.

U.S. Environmental Protection Agency. 1974. National water quality inventory. Vol. 1. Report to Congress, Office of Water Planning and Standards. Washington, D.C. EPA-440/9-74-001.

Vitale, Anne M. and Pierre M. Sprey. 1974. Total urban water pollution loads: the impact of storm water. NTIS TB-231730.

Wangersky, P. J. 1972. The cycle of organic carbon in seawater. From a lecture given to the Societe Vaudoise des Sciences *Naturelles* on April 26, 1972. Chima 26 Nr. 11-559-564.

Williams, P. H. 1971. The distribution and cycling of organic matter in the ocean. Chapter 7. In Organic compounds in aquatic environments (Samuel D. Faust and Joseph W. Hunter, eds.). Mariel Dekker, Inc., N.Y. pp. 145–163.

Woodwell, G. M. 1970. Effects of pollution on the structure and physiology of ecosystems. Science. 108. p. 429.

Yentsch, C. S, unpublished data. Ketchum, B. H. 1969. Eutrophication of estuaries. In Eutrophication: causes, consequences, correctives. National Academy of Sciences, Washington, D.C. pp. 197–209.

ACKNOWLEDGEMENTS

Sincere appreciation is extended to William J. Rue, Jr., without whose valuable assistance this manuscript could not have been compiled. A. R. Armstrong, Roland F. Smith, and Paul R. Becker are to be thanked for their critical review. Rosie Valigra's efforts in editing and typing the final manuscript are also greatly appreciated.

EFFECTS AND CONTROL OF NUTRIENTS IN ESTUARINE ECOSYSTEMS

JOHN E. HOBBIE
B. J. COPELAND
North Carolina State University
Raleigh, North Carolina

ABSTRACT

Almost all nutrients entering estuaries come via streams, with smaller amounts from precipitation and the ocean. Oversupplies of nutrients are transported to estuaries from land-use activities, sewage disposal, industry, agricultural wastes, urban runoff and mining. Increased nutrients cause algal blooms, which lead to more subtle estuarine ecological problems.

Many processes affect nutrient concentrations during transportation and after they reach the estuary. Absorption, dilution, coagulation, and sedimentation decrease nutrient concentrations in estuarine waters. Since an equilibrium is established between water and sediment, nutrients are also released to the water from sediment storages. Biological activities influence nutrient cycling and concentration.

Several control mechanisms are discussed. The potentially most successful and least harmful means of controlling nutrient inputs to estuaries is to control them at their source. After nutrients reach estuaries, there is little possibility for effective reduction in nutrient concentrations.

Suggestions for research to develop new and more effective means to control nutrient inputs to estuaries are made. These include denitrification, land-use practices, natural filters, treatment innovations, and new ways to assess ecosystem response. Finally, management mechanisms are suggested to influence nutrient inputs and to minimize effects.

INTRODUCTION

The Problem

In all aquatic systems, nutrients are important raw materials supporting a basic biological activity, primary production. Estuaries, being open-ended and subject to tidal flushing, are highly dependent upon a continuous import of nutrients to maintain their productivity. Under circumstances of an oversupply of nutrients, however, the normal rate of primary productivity is altered and changes in structure and function of the ecosystem result.

The most obvious symptom of increased nutrient input is the often-cited bloom of certain types of algae. This is usually manifested by the rapid growth of the few species capable of rapid utilization of the incoming nutrients. The result is the competitive exclusion of many species present under more normal conditions. When these imbalances in the primary producers occur, entire food chains may also be altered and the secondary production prized by man may decrease.

Algal blooms may also lead to more subtle changes in the ecosystem. Decomposition of the dying and sinking bloom organisms results in low oxygen conditions, especially in areas of slow flushing, which lead to fish kills and destruction of benthic populations. Some algae prominent in blooms (e.g., some blue green algae) are little utilized by consumer organisms; these may also clog gills of animals. Shading occurs in bloom conditions and the photosynthetic activity of bottom plants is affected (e.g., several instances have been reported of grass flats being replaced by phytoplankton in cases of high nutrient input).

Estuarine waters are a mixture of sea and fresh water. As seawater contains large amounts of a mixture of salts, most of the salts necessary for plant growth, such as potassium and sodium, will be plentiful. Also, there will be no lack of the trace elements, such as molybdenum or cobalt, that often limit photosynthesis in oligotrophic lakes (Goldman, 1972). Two nutrients that are low in concentration in both sea and fresh water, nitrogen and phosphorus, have been shown to control productivity in estuaries. Consequently, we will consider only phosphorus and nitrogen in the following pages.

Objectives

1) To identify the sources and characteristics of nutrients entering the estuaries of the U.S.;

2) To characterize the transport mechanisms for nutrients entering estuaries;

3) To summarize the impact and fate of nutrients in the estuarine ecosystem, both physical and biological;

4) To identify control mechanisms and evaluate them in terms of estuarine management; and

5) To recommend future programs of control and management.

SOURCES OF NUTRIENTS

Estuaries receive nutrients in both dissolved and particulate forms. Almost all of these nutrients enter the estuary in streams and rivers; a small amount also comes from precipitation and from the ocean. These relative proportions will be different in different reaches of an estuary so that at the mouth, for instance, most of the nutrients may have come from seawater (a large volume offsets the small concentrations). In this dependence on outside sources of nutrients, estuaries resemble lakes and rivers. All these systems contrast with forests or crop lands where some nutrients are constantly supplied from breakdown of the parent rocks and from the soils.

In forests and grasslands undisturbed by man, the soils and vegetation combine to conserve the nutrients in the watershed and allow only small amounts to leave in the streams. One example of this comes from a New Hampshire forest where more nitrogen and phosphorous entered the watershed in the rainfall than left by streams (Table 1, Table 2). Hobbie and Likens (1973) mentioned that while only 21 g P/ha left the watershed, some 1900 g P/ha were contained in the annual leaf-fall alone.

Table 1.—Inputs and outputs from the Hubbard Brook Experimental Forest* *(from Deevey 1972, Table 2)*

	Weighted av. conc 1963/1969 (mg liter^{-1})	Average all undisturbed watersheds 1963/1969 (kg ha^{-1}yr^{-1})	
		Input	Output
Ca^{2+}	0.21	2.6	11.8
Mg^{2+}	0.06	0.7	2.9
Na^{+}	0.12	1.5	6.9
K^{+}	0.09	1.1	1.7
Cl^{-}	0 42	5.2	4.9
SO_4^{2-}	3 1	38.3	48.6
NH_4^{+}	0.22	2.7	0.4
NO_3^{-}	1.31	16.3	8.7
SiO_2	<0.1	**	35.1
Al^{3+}	—	**	1.8
HCO_3^{-}	0	**	14.6

* Sample data from Likens et al. (1971).

** *Not measured but very small.*

Table 2.—Input of phosphorus in precipitation and output in streams from watersheds 2 (deforested) and 6 from 1 June 1968 to May 31, 1969 (in g P ha^{-1}yr^{-1}). *The output is given as the sum of the total dissolved phosphorus (TDP) plus fine* particulate phosphorus (FPP) and as large particulate phosphorus (LPP) which is the sum of the phosphorus in inorganic particles plus that in organic particles > 1 mm *(from Hobbie and Likens, 1973, Table 3)*

	W-2	W-6
Input	99*	108*
Output		
TDP + FPP	20	9
LPP	183	12
Net gain or loss	*−104*	*+87*

* Estimated on the basis of precipitation analyses during 1971–1972, when the weighted concentration was 8 ug P liter^{-1}.

When the forests are cut, then the nutrient loss increases. For phosphorus, this loss doubled for the dissolved P in Hubbard Brook but increased fifteenfold for the P in particulate matter (Table 2). The nitrogen also increased drastically (36-fold) in Hubbard Brook after the forest was cut (Borman et al. 1974), mostly as dissolved nitrate. It is true of soils in general that phosphorus is strongly attached to soil particles and is lost from soils mainly by erosion of the particles themselves. In contrast, nitrate nitrogen is soluble in the soil water and is lost by percolation.

Much of the nutrients entering the freshwater streams and rivers of the U.S. come from sewage and agricultural wastes. The nutrients in sewage arise from human wastes, detergents, street runoff, and industrial wastes. There are a number of detailed studies of the amounts contributed by each source; an idea of the magnitude of the problem may be gained from the summary of Vollenweider (1968) for average conditions in central Europe (Table 3) and from Jaworski, Lear and Villa (1972) for the Potomac estuary (Table 4). The actual concentrations of nutrients in a given river will vary according to such factors as volume of flow, number of cities, amount of forest, and type of agriculture. High concentrations of nutrients are added by point sources, such as domestic sewage and industrial wastes (domestic sewage contains 1 to 4 g P/person/day and 5 to 15 g N (Vollenweider, 1968)). The concentrations of nutrients from nonpoint sources, such as farms and forests, is low but the total amount added will often equal or exceed that from point sources (Table 3). Thus, Vollenweider states that a lightly fertilized pine forest may receive 2 kg P/ha and 26 kg N/ha each year while heavily fertilized farmland may receive 37 kg P and 340 kg N. Between 10 and 25 percent of the nitrogen and 1 and 5 percent of the phosphorus will enter the streams from this fertilized land.

Table 3.—Amounts of nitrogen and phosphorus (kg/ha/yr) in runoff from an average area (from Vollenweider 1968). The range for farmlands and meadows and grassland reflects differing amounts of fertilizer reaching the streams

Sources	N	P
	kg/ha/yr	
Sewage		
Human wastes	6.6	0.8
Detergents	—	0.4
Street runoff	0.7	0.1
Industrial wastes	0.7	0.1
	8.0	1.4
Agricultural and Forest Runoff		
Arable land	2.3–5.8	0.1–0.5
Meadows and grasslands	4.3–13.3	0.1–0.5
Forests	1.0	0.1
	8.6–20.1	0.3–1.1
Total	16.6–28.1	1.7–2.5

Table 4.—Summary of nutrient sources, upper and middle reaches of the Potomac estuary (from Jaworski et al. 1972, Table 3)

	Land runoff (kg day^{-1})	Wastewater discharges (kg day^{-1})	Air-water interface (kg day^{-1})
Low-flow conditions (Potomac River discharge at Washington, D.C. = 33.98 m^{3}sec^{-1})			
Carbon	77,100	72,600*	431,000**
Nitrogen	3,040	27,200	726***
Phosphorus	454	10,900	0
Median-flow conditions (Potomac River discharge at Washington, D.C. = 184.06 m^{3}sec^{-1})			
Carbon	159,000	72,600	431,000
Nitrogen	18,100	27,200	726
Phosphorus	2,400	10,900	0

* Of the 72,600 kg day^{-1}, 27,200 kg day^{-1} are discharged as inorganic carbon.

** The potential CO_2 obtainable from the atmosphere was determined by using only 0.1% of the transfer rate of 0.8 mg cm^{-2} min^{-1} as indicated by Riley and Skirrow (1965).

*** Based on a nitrogen fixation rate of five lb acre^{-1} yr^{-1} as reported by Hutchinson (1957).

Seawater is also a source of nutrients in estuaries. It is usually considered that the reverse is true, and little thought is given to input from the ocean. As will be discussed later, however, a number of processes in estuaries will concentrate nutrients from water so even the nutrient-poor ocean water may lose some P and N to estuaries. In one estuary in Scotland, the Ythan, 70 percent of the P and 30 percent of the N that flow into the estuary were marine in origin (Leach, 1971) but the distribution of the P and N retained was not measured.

TRANSPORT OF NUTRIENTS

After the nutrients enter streams and rivers, some fraction may be changed by various processes before they finally reach the estuary. One process is the absorption by plants and bacteria; another is the absorption by sediments. The total quantity absorbed is difficult to quantify and it is also possible that some of the absorbed material eventually reaches the estuary (e.g., by washout during exceptionally high discharge). In the Upper Potomac Basin (Jaworski, Villa and Hetling, 1969), 38 percent of the phosphorus entering the surface waters is retained in the channel. The high nutrients in the water and the rich sediments will cause a dramatic increase in the aquatic plants (Fig. 1).

Another factor causing loss of nutrients in streams is adsorption onto particulate matter. Jaworski et al., (1972) states that more than 20 percent of the reduction of phosphates measured during peak flows could be attributed to adsorption followed by sedimentation of the particulate.

Nitrogen in land runoff enters the rivers and streams mostly as nitrates; however, the nitrogen from wastewater enters mostly as ammonia. This nitrogen is taken up by algae and other plants, is deposited on the bottom (as organic nitrogen after death of algae and plants), and is oxidized to nitrite and nitrate by nitrifying bacteria. In the Potomac

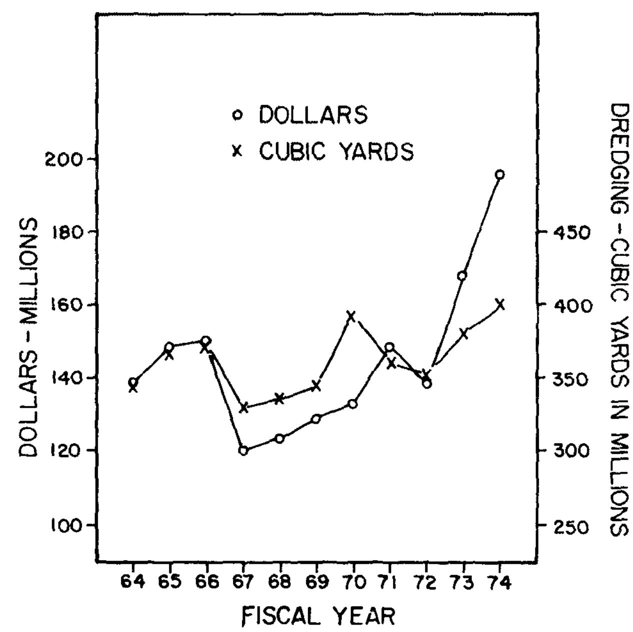


FIGURE 1.—Phosphorus, nitrogen, and organic carbon in the upper Potomac River from 1913–1970. The top line gives plant nuisances (from Jaworski, Lear, and Villa, 1972, Fig. 7).

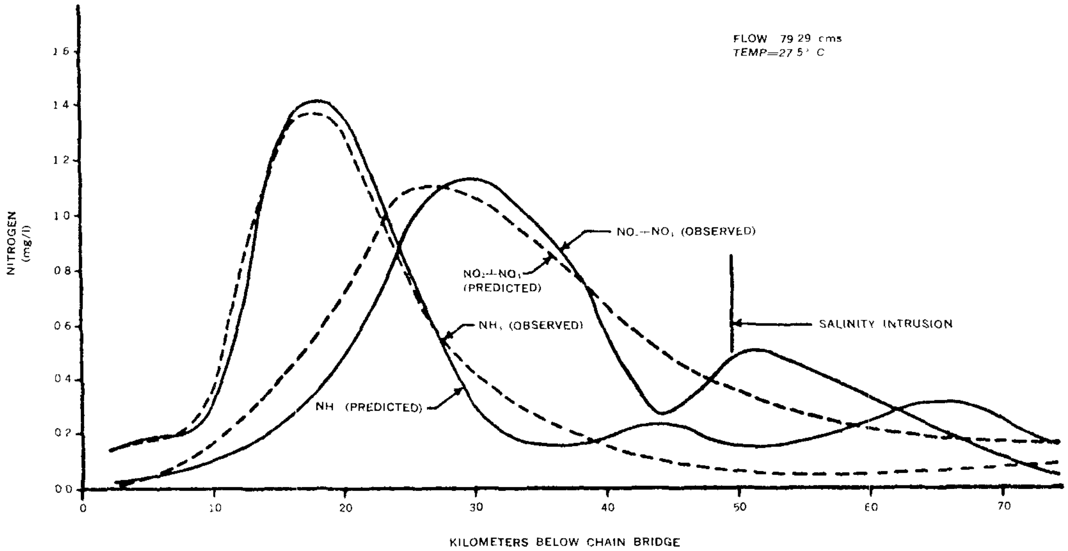


FIGURE 2.—The average and predicted concentrations of ammonia and nitrite plus nitrate in the Potomac River on August 17–22, 1968. The brackish water begins at about 50 km (from Jaworski et al., 1972, Fig. 12).

River the nitrification is the dominant reaction and most of the nitrogen is changed to nitrate (Fig. 2).

In some rivers that traverse coastal plains, such as the Chowan River in Virginia and North Carolina, the flood plain of the river is often flooded and the swampy ground resembles a giant sponge. Tremendous amounts of water flow in and out of these swamp soils as the water level in the river rises and falls due to flow and wind effects. The change in water level in the soils is easily measured 1 km from the river. The effect of this exchange of water on the concentration of nutrients is unknown but soils and peats do act as ion exchange columns and there are undoubtedly many changes occurring.

PROCESSES AFFECTING NUTRIENT CONCENTRATION IN ESTUARIES

A number of distinct processes change the concentrations of nutrients in estuaries. Most of these are acting simultaneously in most cases, but sometimes one process predominates. Thus, although the processes are described below in isolation, we do not mean to imply that only one process is occurring.

Physical and Chemical Processes

DILUTION

The circulation of estuaries causes a continual inflow of seawater and continual mixing with fresh water. If this were the predominant mechanism changing the concentration of the nutrients, then their concentrations would decrease in direct proportion to the increase in salt concentration. (The assumption that the ocean water has a lower concentration of nutrients than the fresh water is almost always valid.)

One estuary where dilution is important is Charlotte Harbor, on the west coast of Florida. Here, water from the Peace River, one of three rivers emptying into the estuary, contains 0.6 mg P/liter. This phosphate comes from phosphate mines and so there are no accompanying high amounts of nitrogen. Therefore, there are no algal blooms and the phosphate remains in the water (Alberts et al., 1970). As seen in Figure 3, the decrease in P concentration closely follows the ideal dilution curve indicating that neither biological nor chemical processes are important.

ADSORPTION AND COMPLEXING

Some of the nutrients entering estuaries are attached to particulate materials in the rivers. This is particularly true for phosphate and, to a lesser extent, ammonium. Most of the research has been carried out on phosphate.

When phosphorus is added to stirred suspensions of estuarine sediment, half of the phosphorus is adsorbed to the particulate matter within 15 seconds or so (Pomeroy, Smith and Grant, 1965). Much of the particulate matter is clay and silt and the adsorption properties of clay are well known. Evidence exists that some of this phosphorus may

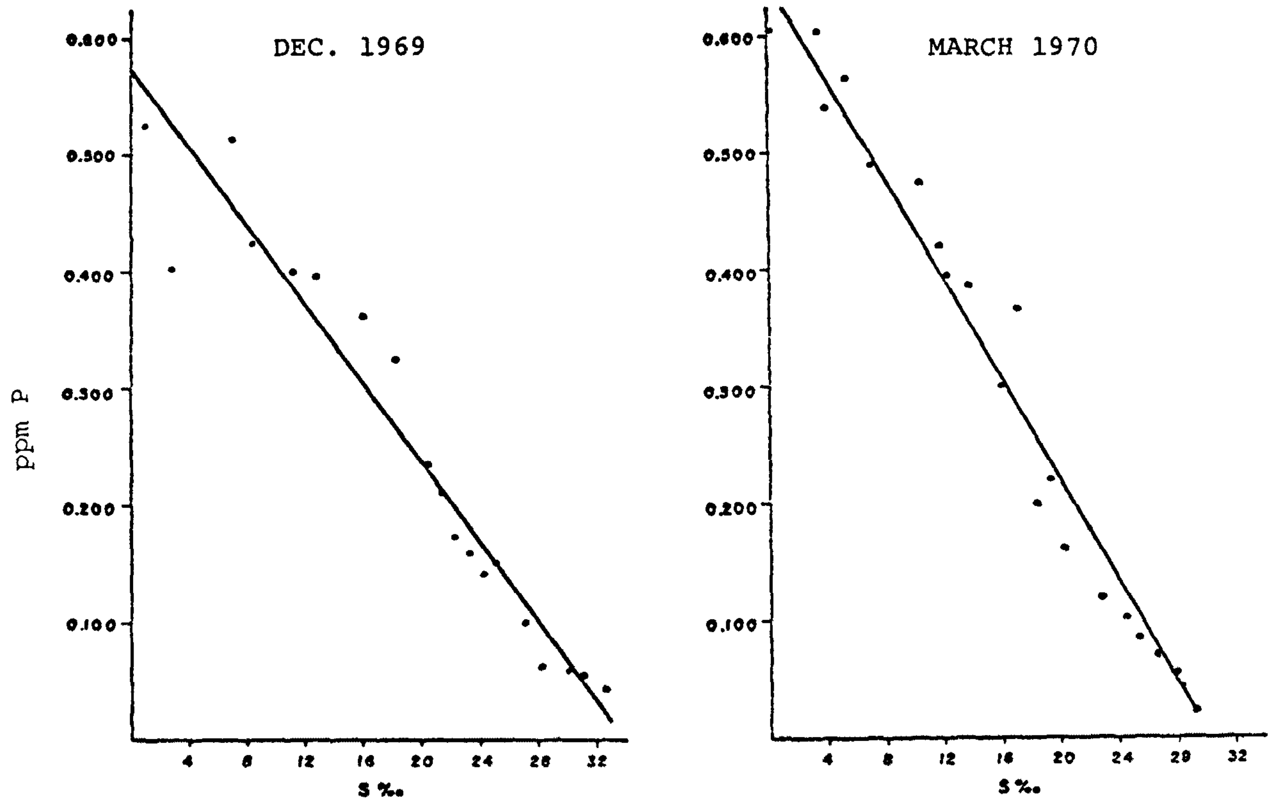


FIGURE 3.—Phosphorus concentrations and salinity in Charlotte Harbor, Fla. An ideal dilution curve is given as a solid line while actual measurements are plotted as dots (from Alberts et al, 1970).

be released or displaced by competing ions, such as chloride or sulfate, when the particulate matter reaches brackish water (Upchurch, Edzwald and O'Melia, 1974).

There also appears to be a good correlation between the amount of phosphorus and the amount of extractable (with oxalate) iron in estuarine sediments; this leads to the hypothesis that phosphorus can also be bound to particulate matter as a part of a phosphorus-iron-solids complex (Upchurch et al., 1974).

COAGULATION AND SEDIMENTATION

When the nutrient-rich river water reaches the upper parts of the estuary, the current slows as the river broadens. As a result, there is a rapid sedimentation of particulate matter and also of the phosphorus complex mentioned above. This sediment is very phosphorus rich (Fig. 4, the sediments above the 7 mile sample).

Some of the particulate matter is colloidal (i.e., small particles with a large surface area per unit mass). Typically, these colloidal particles are clays with an electrical charge. In fresh waters, the particles are kept from aggregating by repulsive forces, but when the particles move into brackish water the ions affect the particles and flocs are formed. The size and settling velocity of these flocs may be several orders of magnitude larger than those of the individual particles (see Edzwald, Upchurch and

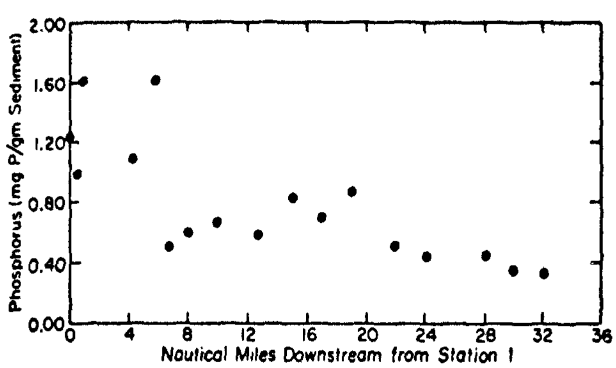


FIGURE 4.—The amount of phosphorus extracted from sediments by acid treatment (available phosphorus) as a function of distance downstream from the freshwater end of the Pamlico River Estuary (from Upchurch et al., 1974, Fig. 2).

O'Melia (1974) for a detailed description). In the Pamlico Estuary (Fig. 4), the decrease in P in the downstream sediments is possibly caused by coagulation and release of some of the phosphorus when the salinity of the water increased.

Although coagulation undoubtedly occurs in estuaries, it is a process that is easy to demonstrate in the laboratory and difficult to study in the field. In natural waters, organic colloids are present in addition to the clay colloids as well as some mixtures of the two. In addition, the adsorption sites on the clays in nature may be filled with a variety of ions both organic and inorganic. Thus, Button (1969) found that natural particulate material did not absorb small molecular weight organic compounds. Finally, other processes may be acting that obscure the coagulation effects. In the study shown in Figure 4, for example, large populations of clams are present in the upper parts of the river that may be just as effective in removing the particulate matter from suspension as the coagulation process.

No matter what the exact mechanism may be, the amount of nutrients deposited in the sediments of an estuary is high. For example, in upper Chesapeake Bay, Carpenter, Prichard and Whaley (1969) measured a loss of some 45 ug-at of nitrate nitrogen/liter (610 ug NO_3-N) during the late spring and summer or 450 mg-at/m² at the mean water depth of 10 m. They calculated that the annual sedimentation rate of 1 mm per year would add 500 mg-at/m² of nitrogen to the sediments. Thus, the loss of nitrogen was accounted for by the sedimentation (the authors regard the close agreement as fortuitous, however, as the sedimentation rate cannot be determined very precisely).

Equilibrium Between Sediments and Water

Not only do particulate matter and estuarine sediments remove phosphorus from solution, but they also release phosphorus back to the water. Thus, Pomeroy et al., (1965) showed that surface sediments acted as a giant buffer or reservoir for phosphates (Table 5). When the phosphorus in the water was less than about 0.9 ug-at/liter (28 ug P/liter), then phosphorus was released from the sediments to the water. Higher concentrations were absorbed by the sediments. Thus, these particular sediments were in equilibrium with water containing 0.7 to 0.9 ug-at P/liter.

This equilibrium level is somewhat higher than other values for fresh water but this will depend upon the type of sediments, previous history, pH, et cetera. It should be noted that recent studies by Lean (1973) and others show that the exchange of phosphorus between the soluble and particulate forms is really quite complex. Low-molecular weight phosphorus compounds and colloidal phosphorus may be involved as well as the particulate and dissolved inorganic fractions.

Table 5.—*Influence of suspended sediments on estuarine water of varying phosphate content. Final phosphate values are mean ± one standard error of the mean. Phosphate in μmoles/liter, 5 March 1964 (from Pomeroy et al. 1965, Table 1)*

Initial PO_4^{3-} of water	Final PO_4^{3-} of water	PO_4^{3-} in sediment ($\mu g\ PO_4^{3-}$/g dry sediment)	n
0	0.72 ± 0.03	−1 0	7
0.5	0.73 ± 0.02	−0.4	4
1.0	0.90 ± 0.07	+0.6	8
2.5	0.89 ± 0.05	+7.6	8
4 3	0.87 ± 0.002	+11.0	8
8.4	1.61 ± 0.22	+30 9	3

While it is likely that many of the same reactions and processes are occurring with nitrogen compounds, these interactions of nitrogen and sediment have never been investigated in detail. One reason for this is the great difficulty in techniques; there is, for example, no radioisotope of nitrogen and use of the stable isotope ^{15}N requires elaborate instrumentation and a mass spectrometer. Another reason is that phosphorus is much more important in the eutrophication of fresh waters and much of the research has centered on lakes.

The Estuarine Nutrient Trap

There is always some upstream movement of seawater or diluted seawater in estuaries; otherwise there could be no salty water in the upstream areas. In certain estuaries with a high freshwater runoff, a shear zone is maintained for long periods with fresh water or low salinity water on top moving downstream and more saline water on the bottom moving upstream. If nutrients are moving vertically from the top to the bottom layers, by sinking or migration of the organisms, then the bottom waters will be enriched with nutrients that otherwise would be lost from the estuary. Also, the bottom waters will be enriched because of decomposition of organic particulate matter in the surface sediments. The theory of this nutrient trap is given in detail by Redfield, Ketchum and Richards (1963).

A good example of this countercirculation comes from the Gulf of Venezuela (Fig. 5). The seawater, containing about 0.5 ug-at P/liter, moves into the shallow waters of the gulf. As it does so, it accumulates phosphorus (up to 1.0 ug-at P/liter). An

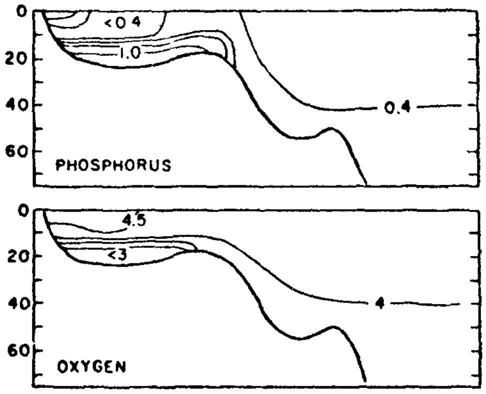


FIGURE 5.—The distribution of total phosphorus and oxygen in a section along the axis of the Gulf of Venezuela (the depth is in meters). From Redfield et al., 1963, Fig. 11

example of this type of circulation producing a sediment trap comes from upper Chesapeake Bay (Schubel, 1968). Sediments were kept in suspension in this part of the bay by tidal currents that mix the water column twice each tidal cycle and also transport the turbid matter upstream in the bottom waters.

Although the nutrient trap certainly exists in estuaries, its importance for the annual nutrient budget has not yet been proven. Thus, in Long Island Sound, Riley and Conover (1956) and Harris (1959) measured accumulations of phosphorus and nitrogen in the summer but also found comparable losses during the winter. In estuaries at Sapelo Island, Ga., Pomeroy et al., (1972) found no nutrient trap operating.

Biological Processes

BIODEPOSITION

A number of biological processes are also removing particulate matter and its associated nutrients from solution. This biodeposition may even be more important than the physical-chemical processes already discussed. Van Straatan and Kuenen (1958) found that dense populations of molluscs filtered clay from the water and produced pellets and flakes which then behaved like sand grains. Organic detritus also trapped clay particles and the resulting flocs settled faster than those formed by coagulation. In a more quantitative study, Lund (1957) calculated that oysters filtered and deposited eight times the volume of sediment deposited by gravity alone. In fact, the deposited material was enough to completely cover the oysters in 36 days.

From tables given in Chestnut (1974), the biodeposition rate of the oyster is around 1.5 g dry wt/individual/week. If the amount of suspended solids is 5 mg/liter, this represents a minimum of 300 liters of water filtered per week. Jorgenson (1952) gives a rate of 10 to 15 liters per day per animal which would be a slower rate than the 300 liter value. Certainly, a tremendous amount of water is processed by an oyster bed; when this oyster filtering is added to the activity of other filter feeders, it is enough filtering activity to process the whole of the volume of an estuary in a matter of days or a few weeks.

The large rooted plants of estuaries also act as traps for the sediments, both by catching fine sediments (Van Straatan and Kuenen, 1958) and by providing protection (e.g., mangroves) so that the sedimentation rate is increased in the calm water. Various invertebrates and even diatom algae also secrete mucus or slimes that trap sediments.

The net result is that estuaries in general and marshes in particular act as giant filters to remove particulate materials from the water. The vegetation of the marshes also stabilizes the sediment and thus reduces the turbidity (Odum, 1970). The importance of these processes is illustrated by the rapid siltation that took place in many harbors in southeastern England when the marshes were first diked and filled (Gosslink, Odum, and Pope, 1974). In the U.S., Port Tobacco on the Potomac is now landlocked but received large sailing vessels during colonial times (D. Flemer, personal communication).

UPTAKE BY ORGANISMS

There are four main types of photosynthetic organisms in estuaries, rooted plants, attached algae, phytoplankton algae and sediment algae. The most obvious plants are the marsh grasses and rushes (e.g., *Spartina* and *Juncus*). These plants take up nutrients only from the sediments (Broome, 1973) so are not in active competition with other primary producers for nutrients. As noted, their presence creates conditions favoring sedimentation and biodeposition (e.g., the mussels in salt marshes). These plants also tie up a tremendous quantity of nutrients. For example, the annual production of organic matter in a Georgia *Spartina* marsh is 1600 g/m^2 (Cooper, 1974). Assuming that 44 percent of this is C and a C:N:P ratio of 125:2:0.3 for *Spartina* (Thayer, 1974) gives 11.3 g N and 1.7 g P/m^2. Even more is tied up in roots and rhizomes.

In some areas, submerged eelgrass (*Zostera*) is an important primary producer. Williams (1973) estimates that eelgrass may supply as much as 64 percent of the total production of phytoplankton, *Spartina*, and eelgrass in the shallow estuaries near Beaufort, N.C. This may be 350 g C/m²/yr and other plants in the eelgrass beds (*Halodule* and *Ectocarpus*) may produce another 300 g C.

Attached algae are not important generally in estuaries because the soft substratum and the tidal flooding of the marshes do not offer a suitable habitat. Permanently submerged plants, on the other hand, accumulate a thick layer of attached algae (reds and browns) as they grow. Measurements of the primary productivity of these algae show a photosynthesis rate equal to that of the *Zostera* (P. Penhale, personal communication).

Microscopic algae also live in the upper layers of the mud. When these are extensive mud flats, such as in the Georgia salt marshes, the primary production may be as high as 420 g C/m²/yr (see summary by Cooper, 1974).

Phytoplankton algae are not abundant in many estuaries (Table 6) because of rapid flushing and high turbidity. Yet, they may be the most important food for zooplankton and invertebrate larvae (Odum, 1970). In very large estuaries, such as Chesapeake Bay, there is adequate time for the algae to develop and primary production may reach several hundred g C/m²/yr (Flemer, 1970).

The well-known efficiency of algae in taking up nutrients from even very nutrient-poor waters, means that they will be an agent for removing nutrients from the water of the estuary. This can come from death and sinking to the sediments, from the filtering action of benthic worms and molluscs, from being eaten and carried away by migrating fish, or from washout from the estuary when strong tides are present.

Green plants are not the only organisms removing nutrients as bacteria are also important. The only quantification of this comes from the work of Thayer (1974) who pointed out that the *Spartina* has low amounts of N and P relative to the C (see ratio above) while bacteria need a C:N:P ratio of 200:10:1 for their growth. Thus, bacteria decomposing the *Spartina* must get the additional N and P they need from the surrounding water. Thayer (1974) also showed that the bacteria out-competed the algae for these nutrients and suggested that the bacterial immobilization of nutrients might be a major cause of the extremely low levels of nutrients found near Beaufort, N.C.

Table 6.—Organic carbon production (g C/m²/year) in salt marshes and adjacent estuaries at Sapelo Island, Ga., and near Beaufort, N.C. (from Cooper, 1974; Williams, 1973)

	Georgia salt marsh	Beaufort shallow estuary
Salt marsh	700	256
Submerged plants	--	650
Attached micro algae	--	350
Mud algae	420	—
Phytoplankton	--	66

NUTRIENT CYCLING

Once nutrients reach the estuary and either are transported to the sediments or are taken up by the biota, they can cycle through various compartments before being locked into the sediments or flushed out of the estuary. For example, *Spartina* is tall near the creek banks where fresh sediments are continually deposited but short farther from the creek. Broome (1973) traced this effect to deficiencies of N in the sediments away from the creeks. Once the nutrients are taken up into the plant, part is used for growth, part is excreted or otherwise lost from the plants, and part is eventually released during decomposition. Some of the complex of reactions occurring in a *Zostera* bed are given in Figure 6 where 166 mg P/m²/day are absorbed from the sediments and 62 mg P excreted into the water.

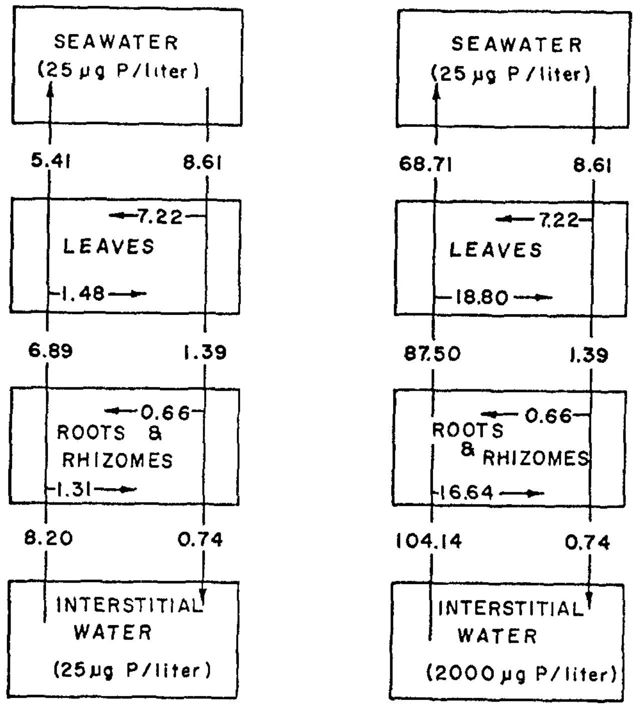


FIGURE 6.—Calculated daily phosphorus flux through 1 g dry wt. of eelgrass. Left: uniform dissolved reactive phosphorus concentration in water. Right: phosphate gradient similar to the natural environment. Units are ug P/g plant-day (from McRoy et al., 1972, Fig. 7).

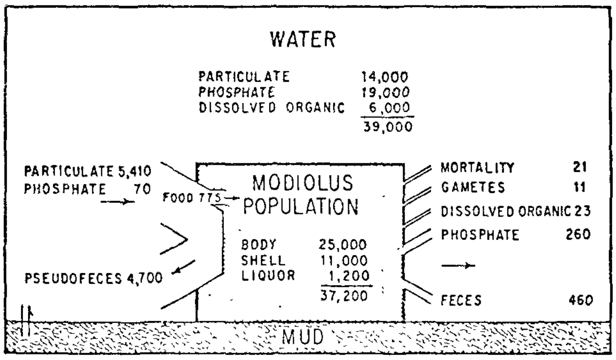


FIGURE 7.—Diagram of phosphorus flow through the mussel population. Values for the water and the mussel population are ug P/m² day. The flux rates of phosphorus in food and pseudofeces are calculated values necessary to balance the other, measured flux rates.

Table 7.—Some contributions to the net increase or decrease of inorganc nitrogen that occurred within the Pamlico River Estuary

Increase (metric tons N day⁻¹)	Decrease (metric tons N day⁻¹)
February 1972 net increase of 6.91 metric tons N (day⁻¹)[a]	
1. Sediment release—0.52	1. N assimilation—6.68
2. Rainfall —0.11	
0.63	6.68
August 1972. net increase of 0.10 metric tons N (day⁻¹)[a]	
1. Sediment release—3.43	1. N assimilation—231.65
2. Rainfall —0.71	
4.14	231.65

[a] Calculated from inputs minus output.

Algae and bacteria also excrete phosphorus (Kuenzler, 1971). The phosphorus budget for a salt marsh mussel (Kuenzler, 1961) illustrates that the large amount of P cycling through the animals is about equal to the quantities moving into the plants (Fig. 7).

Nitrogen also cycles in the estuary. The general pattern is for nitrate to enter the estuary (see Fig. 2) and be rapidly removed from solution. Ammonia is continually being formed (by decomposition processes and NO_3 reduction) and taken up so its concentration does not change very much. Organic nitrogen excretion and decomposition products are also continually cycled through the sediments and water. In the Pamlico River Estuary, for example, Harrison (1974) found that urea was recycled every 1.4 days in the summer and every 200 days during the winter His budget for N in this estuary (Table 7) indicates that during a winter month the N assimilated during photosynthesis was balanced by the N (mostly NO_3) left in the estuary as the water flowed through (here, this is given as a net increase of 6.91 tons). The budget is badly out of balance during the summer, however, and it is likely that ammonia recycling in the water column and coming from the sediment made up the discrepancy of 227.5 tons/day. Similar recycling in the upper waters was measured by Carpenter et al., (1969) in Chesapeake Bay. Thus, the observed photosynthesis rate would result in a recycling of N and P every 1 to 4 days. Because of the large number of zooplankton present, they thought that the algae were being controlled by grazing.

It is reasonable that marshes are nutrient sinks as they usually accumulate organic matter which, in turn, contains nutrients. The actual evidence for this is divided, however. Byron (personal communication) found a 40 percent reduction in nitrogen leaving a salt marsh compared with the amount entering on the flood. In contrast, Heinle et al., (1974) found that the net annual flow of N, P and C was from the marsh to the estuary while the chlorophyll pattern was the reverse. Marshall (1970) reported that marshes treated with sewage retained large quantities of N and P.

Finally, nitrogen may be lost from the estuaries, and particularly from the marshes, by denitrification. This is an anaerobic bacterial process that requires NO_3 and energy in the form of organic molecules. Both denitrification, and the opposite process, nitrogen fixation, are occurring in estuaries but their importance, judging from only a little data, is likely small.

Estuarine Responses to Nutrient Additions

In a review of the literature on estuaries that receive sewage wastes, Weiss and Wilkes (1974) concluded that hydrographic conditions, particularly the rate of flushing, was the most important factor determining the response of the ecosystem. An estuary with rapid flushing can handle tremendous amounts of added nutrients as long as they are quickly transported away and quickly diluted with low nutrient ocean water.

MORICHES BAY AND GREAT SOUTH BAY, LONG ISLAND, N. Y.

The first example, from Ryther (1954) and Ryther and Dunstan (1971), describes two connected embayments, Moriches Bay and Great South Bay. Duck farms around Moriches Bay formerly fed

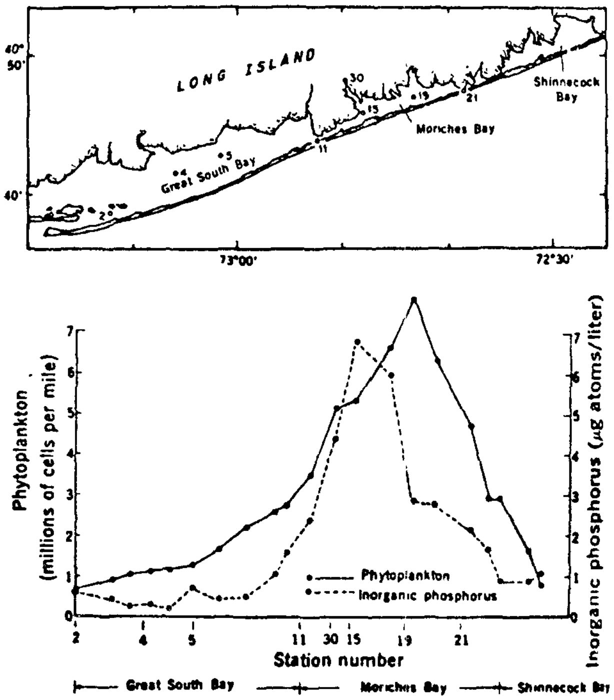


FIGURE 8.—The distribution of phytoplankton and inorganic phosphorus in Great South Bay, Moriches Bay, and Shinnecock Bay, Long Island, in the summer of 1952. Station numbers on the map (above) correspond to station numbers on the abscissa of the figure (right) (from Ryther and Dunstan, 1971, Fig. 1).

wastes into the bay. These nutrients reached Great South Bay which has a retention time of one month. This bay formerly had good stocks of fish and shellfish but the fishery began to decline in the early 1940's as the duck population increased. At the peak of the algal blooms, their numbers declined on either side of the Moriches Bay peak (Fig. 8).

Laboratory and field tests showed that the algae were actually limited by the low nitrogen which was used up almost as soon as it entered the estuary. The damage to the oysters came from a shift of phytoplankton from a mixed group of species dominated by diatoms to two small forms, *Nannochloris* and *Stichococcus*. Although oysters will eat these forms, these algae are nutritionally inadequate. Another factor adversely affecting the oysters was the large production of Serpulid worms which were able to overrun the oyster beds and competitively exclude the oysters.

PAMLICO RIVER ESTUARY, N. C.

A second example comes from the Pamlico River Estuary in North Carolina (Hobbie, 1974). The cities on the Tar River, the main influence, are relatively small but a great deal of nutrients enter the Tar from agricultural runoff, presumably from heavily fertilized tobacco, potato, corn, and soybean fields. The total phosphorus entering the estuary ranges from 2.4 to 6.3 ug-at P/liter (74 to 195 ug P/liter) while the reactive P ranges from 0.4 to 4.1 ug-at P/liter (12.4 to 127 ug P/liter). There is always adequate phosphorus in the estuary and also enough ammonia. There are tremendous blooms of dinoflagellates (esp. *Peridinium triquetrum*) in the middle reaches of the estuary (Fig. 9) in the winter months (January until April) whose occurrence is apparently triggered by the winter influx of nitrate nitrogen into the estuary (Fig. 10). It should be noted that any chlorophyll concentration above 15 is an algal bloom.

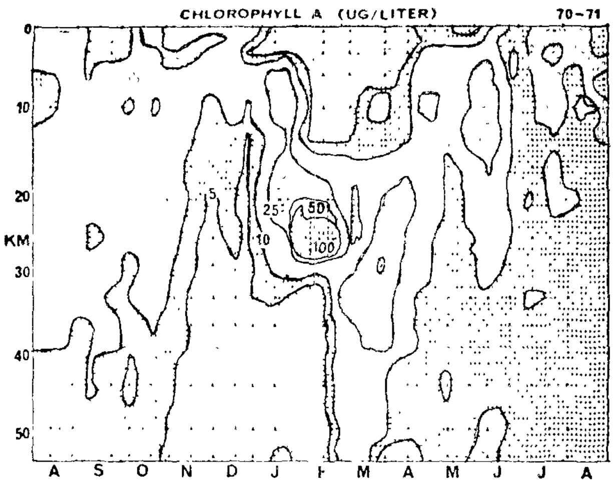


FIGURE 9.—Chorophyll *a* (ug/liter) in the Pamlico River Estuary for 1970–71. Distance is in km from Washington, N.C. (from Hobbie, 1974, Fig. 55).

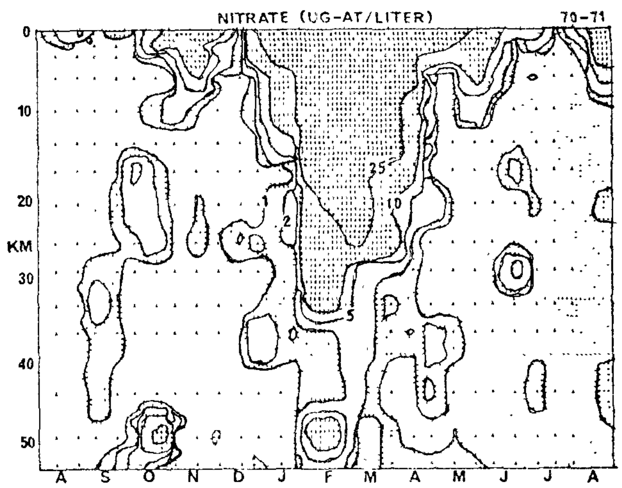


FIGURE 10.—Nitrate (ug-at N/liter) in the Pamlico River Estuary for 1970–71 (from Hobbie, 1974, Fig. 38).

The ecological effect of these blooms is slight so far. The estuary still harbors a commercial blue crab and shrimp industry and the benthic biota is diverse. The one well-documented result of the rich conditions is that areas of low oxygen bottom water do develop now and then during calm periods of the summer. These only last for a few weeks but do kill all the bottom fauna in the central part of the estuary each year (Tenore, 1972). Another minor effect is the apparent increase in filamentous algae. In summary, this estuary has reached a high level of production but the species are unchanged. The only effect is an indirect one by way of the sediment and their increased oxygen uptake during periods of low flow and calm conditions.

CONCLUDING STATEMENT

In these two examples it may be seen that the flushing of the estuary plays a central role in allowing the effects of high levels of added nutrients to be expressed. In both cases, the nutrient levels were greatly above the levels that would have ruined any lake. From these findings, and from the experiments that successfully added sewage to salt marshes with little detrimental effects, we conclude that estuaries can handle large quantities of nutrients. They do this by removing most of the nutrients to the sediments (by sedimentation, coagulation, biodeposition, et cetera) where they serve to enrich salt marshes. In addition, three characteristics of estuaries (rapid flushing, dilution with low nutrient seawater, and quite a lot of turbidity) help prevent dense algal blooms from developing.

When the capacity of estuaries to handle nutrients is exceeded, algal blooms can result that seriously degrade the water quality. Moriches Bay has been mentioned and Back River, a tributary of Chesapeake Bay that receives Baltimore's sewage, is another example (Carpenter, Pritchard and Whaley, 1969). Where conditions are suitable, rooted plants may also reach nuisance amounts as was seen for the water chestnut in the 1920's and the water milfoil in 1958, both in Chesapeake Bay (Jaworski et al., 1972).

As noted, nutrients by themselves can adversely affect estuaries by supporting algal blooms and the deoxygenation that can accompany eutrophication. Perhaps of more importance are the organic matter, heavy metals, and pesticides that often enter estuaries along with the nutrients.

CONTROL MECHANISMS

Control at the Source

The potentially most successful and least harmful means of control of nutrient inputs to estuaries is to control the nutrients at their sources. Obviously, some sources of nutrients are more easily identified than others. Technology is available to institute control mechanisms for most point sources, but in some cases the costs are beyond social desires. In cases of *non-point sources* of nutrient pollution the technology for control has not become feasible. In these situations, effective nutrient control is possible through changes in land use, cultural practices, environmental manipulations, economics, and other management schemes.

SEWAGE TREATMENT

Since nitrogen and phosphorus concentrations in domestic sewage are rather high, sewage effluent constitutes an important source of nutrient materials (Table 3). Recent developments in technology, however, have made it economically possible to control the nutrient emissions from sewage treatment plants. In most instances, however, these technologies have not been utilized and large nutrient inputs are still occurring via sewage treatment plants.

Through the utilization of treatment technology and the enforcement of regulations, nutrient inputs from sewage treatment facilities can be controlled. Indiscriminate, blanket regulations, however, can be unnecessarily expensive when complete control is not needed. Thus, nutrient control at the sewage plant should be done on a case by case basis and be dictated by the location of the treatment facilities and the nature of receiving waters. For example, very high degrees of treatment and stringent regulations may be necessary in very sensitive and delicately balanced, protected systems. In contrast, less stringent treatment regulations are required in large, open, rapidly-flushed systems or in areas such as marshes where there are already storages of organic matter and nutrients.

FERTILIZATION AND AGRICULTURAL PRACTICES

About one-third to one-half of the food and fiber production in the U.S. is attributed to the use of fertilizers in agricultural practices. Thus, the application of fertilizer to farmland is a necessity if we are to maintain the level of food production at present levels. Studies have shown, however, that

10 to 25 percent of the nitrogen fertilizer applied to cultivated crops leaves the field in drainage water. Thus, crop fertilization is a source of nutrients capable of flowing into estuaries. Heavy applications of fertilizers are applied to cultivated crops particularly in the coastal plains of the Gulf of Mexico and southeastern Atlantic areas.

Since the rate of food and fiber production in the U.S. must be maintained, application of less fertilizer is not likely in the near future. Possibilities of control at this source of nutrient inputs lie in the areas of agricultural practices and technological breakthroughs. One possibility is the utilization of cover crops during the non-cropping seasons to help hold the fertilizer in the soil layers. Other possibilities include timing and rates of fertilizer applications, repeated small applications and development of new crops. Of high potential for control of nutrient transport is the control of water drainage from fields by catchment basins, with re-percolation back into the fields between plowings. The very recent development of chemicals to control nitrifying bacteria, to prevent conversion of ammonia to nitrate, offers great hope for reducing nitrogen loss from fields. These chemicals help maintain the nitrogen in the form of ammonia (which has much greater potential for remaining in the soil than nitrate), and therefore allow reduced application rates of nitrogen fertilizer.

Animal production techniques are changing from small producers with several types of animals on pastures to intense production of one species in feedlots. Confinement has allowed increased and more economical production, but has also resulted in point sources of nutrient materials to surface waters. Although, because of convenience and economics, these materials are disposed of in liquid systems, land disposal is considered to be another feasible method of terminal disposal. In either situation, however, there is the potential for nutrient percolation to ground water and surface water runoff.

It is unlikely that conventional sewage treatment facilities will be utilized for animal waste systems within the near future. Therefore, the most likely means of immediate control of this nutrient source is in disposal practices. Some feasible alternatives include deep well injection, controlled land application, or recycling through newly-devised feed preparation systems. This area of activity, however, probably presents one of the more serious disposal problems facing present day technology.

Where large metropolitan areas are adjacent to coastal waters the practice of the suburban dweller "keeping up with the neighbors" and over-fertilizing his lawn presents a real nutrient input problem. With very little means of disposing of suburban runoff, the ultimate fate of that water is usually the adjacent surface waters. The main control mechanism available at the present time is to cycle these materials through municipal treatment plants.

Industrial Waste Treatment

Industrial wastes represent another large source of nutrients to surface waters and constitute another area where treatment technology is available for control. Advanced industrial waste treatment technology has been developed for the control of nutrient materials in most industrial wastes. The problem has been in instituting complete and proper waste control facilities in existing industrial complexes.

The runoff of nutrient materials from the surface areas of industrial complexes presents a separate problem in the control of nutrient sources. Mechanisms need to be developed for channeling this runoff through treatment or filtering systems to reduce nutrient inputs and drainage.

Runoff

One of the sources hardest to control is the runoff of materials from watersheds. This represents a very diffuse and highly variable source of nutrient materials but is, nevertheless, extremely important. The main possibilities of controlling nutrients from runoff involve watershed management.

Erosion control can prevent a large source of nutrients entering surface waters from watersheds. Carefully controlled forestry practices, reforestation, protection of uncovered areas, road maintenance, controlled drainage, vegetated filter strips, and contour plowing are management techniques currently available for erosion control.

Large areas of urbanized watersheds represent a tremendous source of nutrients and other materials. Catchment basins and storm drainage mechanisms are the best possibilities for control here.

Ground Water

Ground water as a source of nutrients for estuaries is not very well understood. Drainage of nutrient materials from septic tanks into ground water has been documented in several situations, particularly on the Barrier Islands along the U.S. seashore. Shallow ground water tends to percolate toward the inside of Barrier Island shores, thus, leaking into estuaries and sounds. The best means of control under these situations is the central collection of waste waters and channeling through waste treatment facilities on a regional basis.

A problem that must be dealt with is the physical manipulations that allow alterations in ground water drainage patterns. For example, dredging deep channels in estuarine systems may enable groundwater percolation to bring in a new source of materials from outside the estuarine system. Considerable research must be conducted on this problem before the impact is understood or control legislation can be enacted.

Control of Transport Mechanisms

Control of nutrient inputs through manipulation of transport processes offers scant possibilities. There are some subtle changes that may be enacted in various physical processes. By and large, however, these may have little beneficial effect on the receiving system downstream because detrimental side effects may be greater than any benefit from nutrient control (e.g., reduction of vital freshwater inputs).

Stream Flow

Once nutrient materials reach the streams flowing into estuaries, institutional controls offer little benefit. Considerable evidence exists concerning decrease in nutrient concentrations downstream from sources due to deposition, biological cycling, and so forth, but additional control of nutrient inflows is not now technologically feasible.

Utilization of reservoirs on streams may offer some control benefits. Selective release of downstream water through reservoir dam structures can be used to regulate nutrient concentrations downstream.

Channelization

The increase in channelization of natural streams in recent years for the purposes of increased drainage and agricultural activities has changed normal stream flow mechanisms. Creating faster flowing streams has minimized the natural loss of nutrients as water meanders downstream. Channelization also allows the water to move downstream rapidly, thus avoiding the natural cleansing action by swamp soils around these streams where water normally percolates (see Transport of Nutrients).

Controlled transport of nutrients can be maintained if channelization procedures are closely regulated. For example, construction of low dikes or diversions to assure normal percolation can be beneficial. Considerable research needs to be done on this phenomenon before control mechanisms can be a significant factor on nutrient inputs into coastal systems.

Denitrification

Denitrification offers the best possibilities for the control of nitrogen during transport. Considerable reduction of nitrogen can be achieved if conditions are properly maintained over a time period. Holding drainage water from agricultural lands, for example, could be maintained so that favorable conditions could exist for denitrification (considerable research is underway in this area and still more needs to be done). The use of small reservoirs and low level dikes in some stream situations could be utilized in denitrification. Sewage holding ponds have long been utilized to achieve reductions in nitrogen concentrations in effluents. This technique has also been used for some industrial waste.

Within the Estuary

Control mechanisms for nutrient reduction within estuarine systems probably offer the least possibilities of effective reduction in nutrient concentrations. The worst problems include detrimental side effects, high costs, and interference with normal cycling procedures within the ecosystems. A few innovations, however, are worth looking into on a pilot study basis.

Selective Harvesting

Since certain organisms (e.g., species of algae during blooms) take up large amounts of nutrients, selective harvesting of these species serves as a means of removing the nutrients from the system. This technique, however, offers little hope for effectively removing nutrient materials from estuarine waters since the cost and engineering of such harvesting systems would be large. Natural means of doing this have been tried in several cases by culturing species of algae-utilizing fish, Manatee harvesting underwater grasses in Florida, culturing species of clams and oysters, and so forth. Estuaries are large dynamic systems, making this kind of control mechanism very difficult. Physical means, such as filtering algae and clipping higher plants, are expensive and ineffective.

DIVERSIONS

Creating canals to divert nutrient-laden water around estuarine systems is an unlikely means of control because of obvious side effects. There are several examples in the U.S. coastal area where large regional sewage interceptors are diverting large amounts of waste waters around estuaries for offshore disposal. These are expensive and, in some cases, deprive estuaries of the much-needed freshwater input and its flushing action.

ZONING

Estuaries in each state might be zoned so that some receive added nutrient input while others are protected. This means of control, however, assumes that decisions can be made concerning which estuaries receive added nutrients and which do not. Considerable research will be required before zoning can become a viable option.

IMPOUNDING

Construction of impoundments at the heads of estuaries offer some possibility for selective control of nutrient inputs into the large estuarine expanse. Impoundments offer the advantage of trapping water, allowing time for denitrification and deposition of phosphorus materials into the sediments, and selected withdrawal of water from the impounded area. This type of control, however, has serious side effects in that the normal flushing activity of freshwater inputs would be altered, possibly leading to severe changes in the estuarine system.

REGENERATION OF MARSHES

Marshes adjacent to estuaries are known to select nutrient materials from estuarine waters flushing over the marsh areas. The marsh system, with its grasses, algae and accumulated organic muds, acts as a filtering system to reduce nutrient content of the surrounding water. This, indeed, is one of the more beneficial roles of marshes as part of the estuarine system (i.e., maintaining the balance of nutrients and organic materials in estuarine waters).

The technology for regeneration of marshes has been worked out. Thus, it is possible to plant marsh grasses and generate new marsh area around estuarine shores. This may serve as an important means of controlling nutrients in estuarine waters and of creating desirable nursery habitat as well.

RECOMMENDED FUTURE PROGRAMS

Research Needs

DENITRIFICATION

Since nitrogen seems to be a major nutrient factor in estuarine ecosystems and it is difficult to control at point sources, denitrification offers many opportunities for the reduction of nitrogen compounds entering estuarine systems. The biological and physical aspects of denitrification processes are fairly well understood, but the conditions of natural systems necessary to control the processes are less well known. Utilization of sewage holding ponds has offered significant promise in aiding the denitrification process. These techniques have been expanded to include the waste from animal feed lots and industrial sources. The diffuse and harder-to-identify sources of nitrogen from agricultural practices, runoff, and ground water are places where denitrification processes offer considerable promise for imposing controls.

Experiments and pilot studies need to be conducted to determine natural conditions whereby denitrification can be initiated. For example, we need to know the length of time water running off and through cultivated fields needs to be impounded before denitrification is significant. Some work is being conducted now in North Carolina, Oregon and California on drainage water from fertilized fields.

NITRIFICATION

Since ammonia nitrogen has greater potential than nitrate for binding with soils and remaining on the fields, prevention of its conversion to nitrate (nitrification) could provide considerable promise for control of nitrogen loss. Chemical procedures to reduce nitrification, capable of widespread and effective use in agriculture, have been recently developed. Still unknown, however, are application procedures, timing of application, rates of application, economic returns, environmental impact of the added chemicals and cultural acceptance. If this process can be developed and utilized there can be tremendous reductions in nitrogen losses from fields through both prevention of nitrate formation and from reduction in fertilizer amounts needed to maintain productivity.

FORESTRY TECHNIQUES

Recent work has verified that nutrient materials in water running off deforested areas is higher than water coming from similar forested areas. It is not known, however, how much vegetation needs to remain on the forest floor to hold the nutrient materials against runoff nor is it known what mechanisms are at work in adding the nutrients to runoff water. For example, decaying tree stumps on the forest land could aid in percolation of water into the soil, thus averting nutrient escapement from the forest lands. Well-vegetated filter strips adjacent to surface streams might help control the loss of nutrients from the watershed. These kinds of research activities could lead to considerable reduction in the amount of nutrient materials washing from the large expanses of forested areas, particularly in the southeastern section of the U.S.

Farming Activities

More research is needed to determine the optimum rates and timing of fertilizer applications to various crops. Although it is well understood that the use of fertilizer is necessary to maintain the production of food and fiber at the present level in the United States, it is possible that additional research could reveal means of preventing fertilizer loss from these crops. The use of certain types of cover crops during the non-cropping season might benefit the control of nutrient escapement. Controls of water tables, drainage procedures and harvesting activities need to be investigated.

The treatment and disposal of waste from animal feed lot activities need to be researched. It is already known that lagoons and oxidation ponds are very helpful in the reduction of nutrient concentrations and effluents, but the land disposal of these wastes still raises problems and the necessity for additional treatment is not known. Considerable interest has been recently generated for the recycling of wastes from feed lots back into the feed cycle and utilization of valuable nutrients as growth additives.

Research needs to be conducted on the ways and means whereby large areas of forested land are converted to agricultural lands by drainage and soil conditioning. Very little is known about optimizing the drainage patterns, density of drainage ditches, and vegetation belts around fields to reduce nutrient loss.

Natural Filters

The use of natural filters for decreasing nutrient loading in estuarine systems offers some possibilities, but research is needed before these can become a practical reality. Although regeneration of marshes is presently feasible, the positioning and physical arrangements of such systems need to be investigated before much practical judgement can be made. Utilization of attached algae and rooted plants in incoming streams and peripheries of estuaries for taking up nutrients might be a possibility if the biology and harvesting problems can be worked out. If harvesting techniques for algae could be developed, the use of certain species could be feasible for the removal of large amounts of nutrients from estuarine waters.

Treatment Innovations

Although technology for the removal of nutrient materials from sewage and industrial waste has been developed, the costs and hardware needed for this treatment level are often prohibitive. Thus, additional research needs to be conducted to find ways to reduce these costs and to provide means whereby siting benefits can be used.

New treatment technology needs to be developed for handling animal waste and drainage from agricultural areas. Deep well injection and land disposal of these wastes are presently being utilized without complete knowledge of the fate and changes in nutrient components of the waste.

Disposal of domestic and industrial waste into deep ocean waters is a popular remedy. Before this becomes more widespread and waste water criteria established, we need to know more about what kind of treatment is needed and the fate of these materials in the near ocean waters. Further, various innovations concerning the type of disposal conduits and outlets need to be investigated and realistic distances from shore for disposal need to be known.

Ecosystem Response

In spite of the recent emphasis on the fate of nutrients in estuarine waters, we still lack considerable knowledge about the response of whole ecosystems to nutrient additions. We can predict certain algal blooms under certain conditions of nutrient inputs, but we fall dismally short of predicting the response of food chains and other ecosystem components to nutrient inputs. Can we, for example, under certain conditions of additional nutrient inputs expect larger fish yields in estuarine systems?

Since nutrient input controls make little sense unless the impact on the estuarine ecosystem is known to be detrimental, we need to develop better knowledge and predictability of these inputs on various kinds of estuarine systems. More work needs to be done in the development of ecosystem modeling as it relates to nutrient flows and the use of microcosms for testing various practical theories.

Management Mechanisms

Point Sources

Although it is the aim of the Environmental Protection Agency to eventually control inputs at all point sources, it is necessary to initiate a management scheme to make this a reality. These management mechanisms may include the selection and mixing of different kinds of materials, particularly regulating nutrients into other selected inputs. For example, in certain instances auxilliary input of nutrient materials may be beneficial in establishing additional opportunities for selected harvesting, food production or ecosystem planning.

Some benefit may be obtained in regard to point sources of nutrient materials by the physical placement of the input mechanisms. For example, controlled point source release of nutrient materials in estuarine channels or into marsh systems may be a viable management technique.

Runoff

Management means to control the nutrient inputs from runoff involves a complicated and well devised management plan. A factor complicating management of watersheds for controlled runoff is the fact that most watersheds are owned by private citizens outside the jurisdiction of the water manager.

Nutrients from runoff are largely attached to or incorporated in particulate materials. Various mechanisms are available to control the removal of particulate matter, but programs of implementation and regulation need to be developed. For example, silt screens could be used in construction activities to capture particulate runoff and prevent it from entering surface waters.

Transport of sediments from the surrounding watershed to streams entering estuaries offers great potential for control. The sediment transport could be minimized by management techniques involving improved road maintenance practices, stabilization of uncovered land areas, and drainage of excess water through filter strips.

Development of vegetated filter strips adjacent to streams and estuarine shores would minimize the transport of nutrient materials into the surface waters. Changes in forestry and agricultural practices by private land owners can be a means of controlling runoff and possibly improving the economic return for the land owner.

Estuarine Modifications

In the management of estuaries, it may become desirable to modify inputs and components to maximize utilization of materials and productivity. If these action programs are to be instituted they should be identified as an example of a class of action and studied before and after the change so that we can obtain guidelines for future operations of this type. For example, the diversion of nutrient-laden input water over and through large, natural filtering systems in estuaries may be a viable possibility in estuarine management.

Recently the use of systems analysis and simulations have been effective in assessing management needs. Although it is necessary for the system as a whole to be managed to avoid detrimental side effects and to maximize system yield, simulations of component parts may be a powerful tool for achieving the goal. In managing estuaries in regard to the desirability of modifications, it is important that the scientific approach be combined with economic analyses to achieve some management optimization.

Land Use Planning

By examining the environmental characteristics of an area, land use planning can be delineated and used as a guide for locating various use categories. Most urban areas have adopted zoning ordinances and have developed procedures for exerting some control over their patterns of development, but outside the confines of these municipalities little has been done in terms of developing realistic planning. To make land use planning a reality in coastal systems, one must be able to combine and optimize the environmental needs with the economic needs.

Since the technology exists for controlling nutrient inputs at point sources, management of point source inputs is a matter of economics and enforcement. But, the non-point sources present a more difficult problem. Land use planning offers the greatest potential for controlling these non-point sources. Drawbacks include lack of knowledge in instituting a planned program and development of public trust.

Estuaries as Ecosystems

Any plans for the successful development, management and regulation of estuaries of the United States must be consistent with the ecological and economic principles by which such systems operate, with and without man. Unlike normal land problems, estuaries are moving, dynamic systems influenced by inputs from every direction. For example, many maps from regional planning programs show their boundaries lying across bays and estuaries as if they were a piece of real estate. This is unworkable because any planning and management done on one side of the bay may be negated if something contrary is done on the other side of the bay. Any new legislation enabling planning and management schemes must allow authority over units of circulation if the management is to be scientifically sound. Until estuarine systems are recognized and planned as whole ecosystems, any management mechanisms brought to bear will be doomed to failure.

REFERENCES

Alberts, J., R. Harriss, H. Mattraw, and A. Hanke. 1970. Studies on the geochemistry and hydrography of the Charlotte Harbor Estuary, Florida. Progress Report No. 2. Mote Marine Laboratory, Sarasota and Placida, Fla.

Bormann, F. H., G. E. Likens, T. G. Siccama, R. S. Pierce, and J. S. Eaton. 1974. The export of nutrients and recovery of stable conditions following deforestration at Hubbard Brook. Ecol. Monogr. 44:255–277.

Broome, S. W. 1973 An investigation of propagation and the mineral nutrition of *Spartina alterniflora*. Unpublished Ph D. Thesis, Dept. of Soil Sciences, North Carolina State University.

Button, D. K. 1969. Effect of clay on the availability of dilute organic nutrients to steady-state heterotrophic populations. Limnol. Oceanogr. 14:95–100.

Carpenter, J. H., D. W. Pritchard, and R. C. Whaley. 1969. Observations on the eutrophication and nutrient cycles in some coastal plain estuaries, p 210–221. In Anonymous (ed), Eutrophication: Causes, Consequences, and Correctives. National Academy of Sciences, Washington, D.C.

Chestnut, A. F. 1974. Oyster reefs, p 171–203. In H T. Odum, B J. Copeland, and E. A McMahan (eds). Coastal Ecological Systems of the United States, v. II. The Conservation Foundation, Washington, D.C.

Cooper, A. W. 1974 Salt marshes, p. 55–98 In H. T. Odum, B J. Copeland, and E. A. McMahan (eds). Coastal Ecological Systems of the United States, v. II The Conservation Foundation, Washington, D C.

Deevey, E. S. 1972 Biogeochemistry of lakes: major substances, p. 14–20 In G. E. Likens (ed). Nutrients and Eutrophication. Special Symposia, v. I. American Society of Limnol. Oceanogr., Inc.

Edzwald, J. K, J B. Upchurch, and C. R. O'Melia 1974. Coagulation in estuaries Environm. Sci. Tech. 8:58–63.

Flemer, D. A. 1970. Primary production in Chesapeake Bay. Ches. Sci. 11:117–129.

Goldman, C. R. 1972. The role of minor nutrients in limiting the productivity of aquatic ecosystems, p. 21–33. In G. E. Likens (ed), Nutrients and Eutrophication. Special Symposia, v. I. American Society of Limnol. Oceanogr., Inc.

Gosselink, J. G., E. P. Odum, and R. M. Pope. 1974. The value of the tidal marsh. Publ. No. LSU-SG-74-03 of the Center for Wetland Resources, Louisiana State University, Baton Rouge, La.

Harris, E. 1959. The nitrogen cycle in Long Island Sound. Bulletin Bingham Oceanographic Collection 17:31–65.

Harrison, W. G. 1974. Nitrogen budget of a North Carolina estuary. Unpublished Ph.D. Thesis. Dept. of Zoology, North Carolina State University, Raleigh, N.C.

Heinle, D. R., D. A. Flemer, J. J. Ustach, and R. R. Murtagh. 1974. Contribution of tidal wetlands to estuarine food chains. Tech. Report No., NRI. No. 74-157, University of Maryland, Center for Environmental and Estuarine Studies, Chesapeake Biological Lab., Solomons, Md.

Hobbie, J. E., and G. E. Likens. 1973. Output of phosphorus, dissolved organic carbon, and fine particulate carbon from Hubbard Brook watersheds Limnol. Oceanogr. 18:734–742.

Jaworski, N. A., E. W. Lear, Jr., and O. Villa. 1972. Nutrient management in the Potomac Estuary, p. 246–273. In G. E. Likens (ed), Nutrients and Eutrophication. Special Symposia, v. I. American Society of Limnol. Oceanogr., Inc.

Jaworski, N. A., O. Villa, Jr., and L. J. Hetling. 1969. Nutrients in the Potomac River Basin. Tech. Report No. 9 to WPCA, Chesapeake Technical Support Laboratory.

Jorgensen, C. B. 1952. On the relationship between water transport and food requirements in some marine filter feeding invertebrates. Biol. Bull. 103:356–363.

Kuenzler, E. J. 1961. Phosphorus budget of a mussel population. Limnol. Oceanogr. 6:400–415.

Kuenzler, E. J. 1971. Aspects of phosphorus cycling in brackish waters In A. de la Cruz and I. L Brisbin (eds), Towards a Relevant Ecology. University of Georgia Press, Athens.

Leach, J. H. 1971. Hydrology of the Ythan Estuary with reference to distribution of major nutrients and detritus J. Mar. Biol. Assoc. U. K., 51:137–157.

Lean, D. R. S 1973. Movements of phosphorus between its biologically important forms in lake water. J. Fish. Res. Bd. Can. 30:1525–1536

Lund, E. J. 1957. Self-silting by the oyster and its significance for sedimentation geology. Publ Inst Mar. Sci. (Texas) 4(2):320–327.

McRoy, E. P, R. J. Barsdate, and M. Nebert. 1972. Phosphorus cycling in an eelgrass (*Zostera marina* L.) ecosystem. Limnol. Oceanogr. 17:58–67.

Marshall, D. E. 1970. Characteristics of *Spartina* marsh which is receiving treated municipal wastes, p. 317–358. In H. T. Odum and A. F. Chestnut (eds), Studies of Marine Estuarine Ecosystems Developing with Treated Sewage Wastes. U. N C. Institute of Marine Science Annual Report to NSF, Sea Grant Project Division, Chapel Hill, N.C.

Odum, W. E. 1970. Insidious alteration of the estuarine environment. Trans. Amer. Fish. Soc. 99:836–847.

Pomeroy, L. R., L. R. Sheuton, R. D. H. Jones, and R. J. Reimold. 1972. Nutrient flux in estuaries, p. 274–291. In G. E. Likens (ed), Nutrients and Eutrophication. Special Symposia v. 1. The Amer. Soc. Limnol. and Oceanogr., Inc.

Pomeroy, L. R., E. E. Smith, and C. M. Grant. 1965. The exchange of phosphate between estuarine water and sediments. Limnol. Oceanogr. 10:167–172

Redfield, A. C., B. H. Ketchum, and F. A. Richards. 1963. The influence of organisms on the composition of sea-water, p. 26–77. In M. N. Hill. The Sea, v. II. Interscience Publishers, New York, London, Sydney.

Riley, G. A., and A. S. Conover. 1956. Oceanography of Long Island Sound 1952–1954. III. Chemical Oceanography. Bulletin Bingham Oceanographic Collection 15:47–61.

Ryther, J. H. 1954. The ecology of phytoplankton blooms in Moriches Bay and Great South Bay Long Island, N.Y. Biol. Bull. 106:198–209.

Ryther, J. H. and W. M. Dunstan. 1971. Nitrogen, phosphorus and eutrophication in the coastal marine environment. Science 171:1008–1013.

Schubel, J. R. 1968. Turbidity maximum of the northern Chesapeake Bay. Science 161:1013–1015.

Tenore, K. R. 1972. Macrobenthos of the Pamlico River Estuary, North Carolina Ecol. Monogr. 42:51–69.

Upchurch, J. B., J. K. Edzwald, and C. R. O'Melia. 1974. Phosphates in the sediments of the Pamlico Estuary, North Carolina. Environm. Sci. Tech. 8:56–58.

Thayer, G. W. 1974. Identity and regulation of nutrients limiting phytoplankton production in the shallow estuaries near Beaufort, N.C. Oecologia 14:75–92.

Van Straatan, L. M. J. U., and P. H. Kuenen. 1958. Tidal action as a cause of clay accumulation. J. Sediment. Petrol. 28:406–413.

Vollenweider, R. A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Tech. Report DAS/CSI/68-27 to the Organization for Economic Cooperation and Development. Paris.

Weiss, C. M. and F. G. Wilkes. 1974. Estuarine ecosystems that receive sewage wastes, p. 71–110. In H. T. Odum, B. J. Copeland, and E. A. McMahan (eds), Coastal Ecological Systems of the United States, vol. 3. The Conservation Foundation, Washington, D.C.

Williams, R. B. 1973. Nutrient levels and primary productivity in the estuary, p. 58–89. In R. H. Chabreck (ed), Proceedings of the Coastal Marsh and Estuary Management Symposium. Div. of Cont. Ed., Louisiana State University, Baton Rouge.

ESTUARINE WASTEWATER MANAGEMENT: DESIGN CONCEPTS AND CONSIDERATIONS

ERMAN A. PEARSON, S.D.
University of California
Berkeley, California

ABSTRACT

The design of estuarine wastewater management systems should consider the cost and effectiveness of specific pollutant removal (treatment), and the cost and efficacy of wastewater transport to and dispersion in areas of high dilution capacity, and of minimal ecological significance. A representative example cost analyses for a city of one million persons (wastewater flow of ~ 4.4 m^3/sec) indicates that the incremental cost of upgrading treatment from secondary to advanced (tertiary) level is adequate to build and operate a land interceptor-transport system about 124 kilometers ($\sim$77 miles) in length. Similarly, for a coastal city (Pacific Coast conditions) the same incremental cost for upgrading treatment would build and operate (break-even basis) a deep water outfall-diffuser system about 28.6 kilometers ($\sim$17.2 miles) in length. If long-term protection of estuarine resources is to be achieved, all technical and economically feasible steps should be taken to transport *adequately treated wastewaters out of estuarine systems, to the open coast* in well engineered transport and high-dilution capacity outfall dispersion systems.

INTRODUCTION

Increasing concern about environmental quality coupled with limited factual information about waste discharge effects and a general ignorance of conventional wastewater treatment systems, contribute to increasing confusion in the development of estuarine and coastal wastewater management systems. Although this paper is concerned with estuarine wastewater management systems, it will be pointed out that one cannot rationally separate the estuarine problem from the broader question of coastal wastewater management. Unfortunately, all too often these two problems are treated separately, even by some evolving regulatory policies. If this continues, it will result in substantial if not gross damage to our estuarine resources.

There appears to be a general belief among the public, conservationists, and even some scientists and regulatory agencies that all wastewater treatment systems accomplish the same or similar objectives. Wastewater treatment is conceived as uniformly good, depending only upon the level or cost of treatment (i.e., the higher the cost the better); therefore, the higher the level of treatment for a given discharge location, the better the results. Unfortunately, generalizations of this type may lead to wastewater system designs that are inappropriate for the particular situation both technically and economically. In some cases, such systems could produce drastic effects on the local ecosystem.

The estuaries and coastal regions of the United States are the ultimate recipients of the major portion of conservative (non-decayable) pollutants discharged to inland lakes and rivers directly connected to the sea. In addition, a substantial additional load of both conservative and non-conservative pollutants is discharged directly to the estuaries from municipalities and industries located on the immediate estuarine periphery. Obviously, conservative pollutants as well as some of the non-conservative (decayable) pollutants will reach the coastal area in a relatively short time. Considering the estuary's location in the wastewater recipient-transport structure, in the interest of long-term protection of the estuarine system, it would appear prudent to reduce the locally generated waste load as much as is economically feasible by either wastewater treatment or *removal from the estuarine system.*

Unfortunately, the subject of estuarine and coastal wastewater disposal has not received as much attention as that of inland disposal practices. Consequently, the advantages and disadvantages of traditional inland wastewater treatment and disposal applied to the estuarine/marine systems have not been elucidated clearly. Of the total effort expended on estuarine problems, most has been devoted to studying the physical-hydraulic/exchange aspects of the problem, rather than the biological and chemical effects on the local ecosystem.

THE PROBLEM—WHAT AND WHERE TO DISCHARGE?

The nature of the estuarine wastewater management problem depends upon the regulatory agency position, the characteristics of wastewater discharges, and of the estuary itself, and the particular beneficial uses that are to be protected. Regulatory requirements always affect wastewater management; however, in the estuarine system these may play a special role in eliminating treatment-disposal options that may have both economic and ecological benefits. For example, if the minimum degree of wastewater treatment required, regardless of location of the discharge, is secondary treatment (such as current federal policy), then the option of using the incremental cost between primary and secondary treatment to transport the waste water to the open coast for submarine outfall-diffuser discharge (following primary treatment) is not available.

Problem Types

The types of estuarine pollution problems encountered range from those found in inland lakes and rivers to those that may be associated with nearshore, shallow, coastal waters. The geometry and characteristics of the estuarine system and the wastewater discharge will determine the type of pollution problem. In estuarine systems as elsewhere, the effects of pollutants can be highly variable; nonetheless, they can be lumped into several general categories that describe roughly the general spectrum of problems and effects.

MICROBIAL/PUBLIC HEALTH

One of the oldest parameters of wastewater pollutants is the coliform group of bacteria. These organisms are used as presumptive indicators of the presence of pathogens. Concentration levels of coliform organisms (MPN/100 ml—most probable number of coliform bacteria) are established to protect the waters for water contact sports, shellfish growing and harvesting, aesthetic enjoyment, and so forth.

ORGANIC ENRICHMENT/OXYGEN DEPLETION

The classic oxygen demand parameter of wastewaters is its biochemical oxygen demand (BOD), the removal of which has been the principal objective of secondary treatment processes. The addition of organic matter or BOD exceeding the natural capability of respiration, synthesis, and reaeration processes (assimilative capacity) of the receiving waters may result in substantial depletion of the dissolved oxygen content of the water. Such depletion may adversely affect its suitability for maintaining a balanced biota, sport or game fish having some of the highest dissolved oxygen requirements.

SUSPENDED SOLIDS/WATER CLARITY

The second major municipal wastewater constituent that is removed in substantial degree (65–90 percent) by primary and secondary wastewater treatment processes is that of suspended solids. However, in most estuarine systems the amount of suspended solids contributed by wastewater discharges is a very small fraction (<1.0 percent) of the total suspended solids contributed by river inflow, surface runoff and resuspension of bottom sediments. Similar, but somewhat less extreme relationships exist for the organic (volatile) fraction of the suspended solids.

ACUTE TOXICITY/BIOTIC STRESS

A relatively new "lumper" parameter of the acutely toxic substances (toxic metals, organics, ammonia, et cetera) present in wastewaters, the fish bioassay for determination of the median tolerance limit (TL_{50}) is being used to an increasing degree in assessing potential toxic stresses from wastewater discharges. One of the major concerns about adverse stresses on the biota of estuarine systems is that of acute toxicity and increasingly stringent requirements are being imposed both on the concentration in the wastewater discharges and in the receiving waters.[1,2,3]

FLOATABLES/AESTHETIC ENJOYMENT

The amount of particulates of identifiable wastewater origin and slick forming materials (oil and grease) constitute one of the most significant characteristics of public wastewater discharges for which there is no adequate quantitative method for assessment. Nonetheless, in terms of potential adverse and obvious effects on the receiving waters, these materials must be given increasing attention. Fortunately, the oil and grease fraction of the floatables can be quantitated crudely, and control levels established to minimize the physical appearance of surface films or slicks.

NUTRIENTS/EXCESSIVE ENRICHMENT

Quantitation and control of the discharge of the various nutrient forms, nitrogen, phosphorus and others, is possible in those estuarine situations where adequate information is available to show that specific nutrient species are in fact, controlling the level of phytoplankton in the receiving waters. Unfortunately, adequate information is rarely available to show clearly that a particular nutrient (or several nutrient species) is actually responsible for the existence of excessive plankton concentrations or excessive pulses (blooms) in the concentration of particular algal species. Generally, practical control of the discharge of particular nutrients is based upon the presumption that it will help to keep the concentration of plankton in the receiving waters within acceptable limits.

EXOTIC POLLUTANTS/SPECIAL EFFECTS

On occasion, exotic or special pollutants may give rise to unusual problems which fall in a separate category. An example might be that of identifiable chlorinated hydrocarbon compounds in public wastewater systems.[4] Such problems may require special methods for their solution ranging from extensive source control efforts[5] to the application of special treatment systems.

Treatment/Discharge Location Considerations

INSTITUTIONAL/REGIONAL

Most estuaries have a substantial number of discrete public (municipal) and private (industrial) wastewater management organizations located around their periphery. The number and type of these organizations depends upon the historical development of the area as well as upon local wastewater regulatory policies and practices. For example, in the San Francisco Bay area there are currently (1974) over 100 different political or administrative institutions, each involved with its own particular wastewater management problem. It should be obvious that the development of a coordinated or regional wastewater management program will require a tremendous effort to satisfy the legitimate technical, economic and political interests of each organization. Nonetheless, the development of a coordinated and appropriate regional wastewater management plan is essential for the prime reason of economy, to say nothing of ancillary benefits, not the least of which is adequate protection of the local ecosystem.

HOW MUCH TREATMENT AND WHY?

The critical problem in estuarine waste management after resolution of the political-institutional problem, is what level of wastewater treatment is required and where should the treated effluent be discharged? Historically, the general trend in wastewater management has been to invest heavily in treatment processes—frequently as much as can be financed, and to pay little attention to the location and type of dispersal system. This general and significant neglect has been and still is being abetted by those who believe that the diluting or assimilating characteristics of the receiving water should not be considered in the design process. Regardless of one's philosophy on this question, the hard facts are that the treated effluent must be discharged to and diluted with the receiving water. The faster that this dilution can be accomplished, or the greater the immediate dilution of the effluent with the receiving water the lower the concentration of pollutants in the receiving water environment. Consequently, for any level of pollutants in the treated effluent, the greater the dilution the lower the concentration, and the effect on the local ecosystem is reduced proportionately.

In the past, the choice of the level of wastewater treatment has been somewhat arbitrarily made between the minimal, or primary (mechanical removal of suspended and settleable solids) and secondary (biological) treatment. However, with the advent of PL 62-500 and EPA's definition of the minimum acceptable wastewater treatment regardless of location as secondary,[6] the apparent treatment choices will be between secondary and advanced waste treatment (tertiary). Thus the fundamental question remains, is it preferable to provide advanced waste treatment and discharge the highly treated effluent directly to the estuary with little or no concern for the discharge location or initial dilution; or, is it preferable to employ a lesser degree of treatment (i.e., secondary which is cheaper with lower levels of pollutant removal), and transport the effluent to a distant area, such as the open coast, where high dilutions (at least 100 to 1) are available. The latter, equal-cost alternative, would use the incremental cost between advanced and secondary treatment to transport the effluent seaward, preferably to the open coast, where greater volumes of diluting water are available.

Unfortunately, an attitude appears to be developing in favor of continuously increasing the degree (and cost) of wastewater treatment with least consideration to the location of the ultimate discharge, the degree of initial and subsequent dilution of the waste water, or to the decay rate of the pollutants in the receiving water. This trend appears to be supported by many of the consulting engineers and scientists involved with the design of wastewater management systems. If the foregoing concept becomes accepted and practiced widely, it will discourage any economic or ecologic incentive to use the incremental cost between various levels of treatment to transport the lesser treated effluent to a disposal site with maximum diluting capabilities and the least adverse effect on the local ecology.

If one is concerned about pollutant concentrations in the environment and their effects, one must give serious consideration to determining waste discharge locations where the residual pollutant concentration will have minimal ecological (including human) impact. To accomplish this, it should be obvious that quantitative information must be available on pollutant mass emission rates and concentrations, on the efficacy of pollutant removal processes, and on the physical, chemical, and biological characteristics of alternative disposal sites. The practical facts are that such information is not generally available to permit rational assessment of alternative treatment and dilution combinations. However, this lack of such information in no way justifies the absence of rational qualitative assessment of the consequences and quantitative assessment of the costs of the various alternatives.

Dilution Realities

The available dilution of wastewaters within an estuary depends upon the size of the estuary, the amount of advective (river) inflow, tidal exchange, the quantity of wastewater, and the discharge location. For most estuaries located in urbanized areas, the available dilution ranges from approximately the ratio of river inflow to wastewater flow at the head end of the estuary, to a maximum of from 30-50 to 1 for a well designed diffuser discharge at the seaward end of the estuary. Obviously, these numbers will vary depending upon runoff, river flow, tidal exchange, and waste flow. However, in general, the available dilution for wastewaters discharged within the estuarine systems is markedly less than is often implied. For example, if all estimated 1,990 municipal and industrial wastewaters generated around the periphery of San Francisco Bay were collected and discharged to the central bay in front of the Golden Gate, the average dilution of the wastewaters would be in the order of only 30 to 40:1. And, it must be noted that San Francisco Bay is a large estuary with appreciable river inflow and tidal exchange.

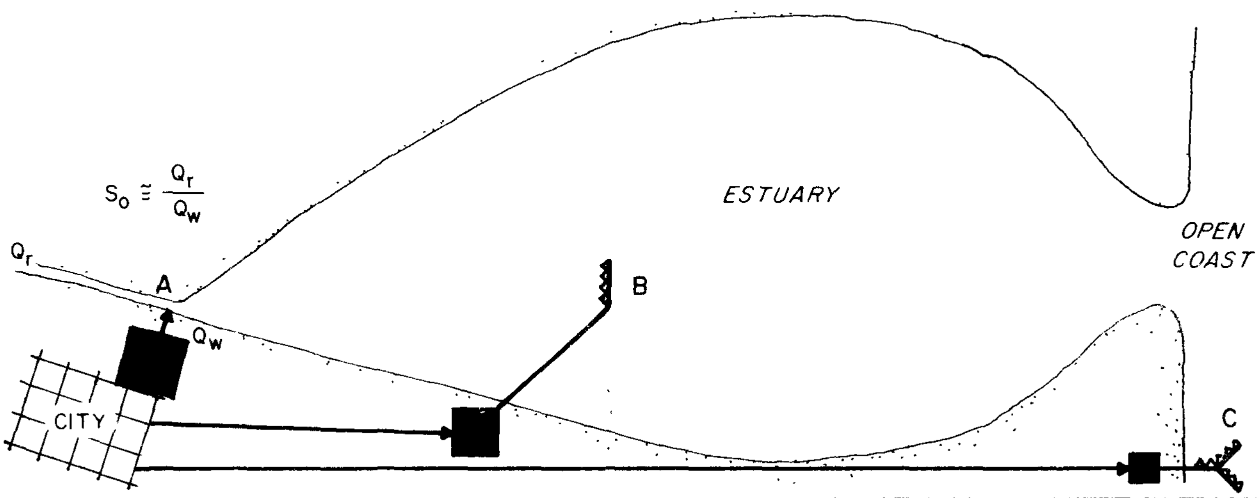
In contrast, wastewater disposal systems located along open coasts (such as the California coast adjacent to San Francisco Bay) can be designed to achieve immediate dilutions of the wastewater with ocean water in the order of 150:1 or more for waste flows up to at least 1.5×10^6 m^3/day (~400 mgd). While these dilutions may appear to be on the favorable side, it is difficult to envision any likely disposal area along the major U.S. coastlines where well-designed submarine outfalls could not achieve average initial dilutions of 100:1 or more.

It is helpful to put the effect of treatment or pollutant removal in terms of equivalent dilution; that is, the reduction of pollutant concentrations in the effluent stream. Conventional secondary treatment plants affect, as an average, about 90 percent of the pollutants for which they are designed (essentially BOD and suspended solids). Thus, about 10 percent remains as residual pollutant concentration in the effluent. Such treatment efficiency is equivalent to a dilution of ~10:1, if the diluting water has negligible concentrations of that pollutant. Similarly, advanced waste treatment processes may achieve at best an average removal of about 98 percent, leaving about 2 percent of the original pollutant in the effluent. This is equivalent, on a pollutant concentration basis, of an average dilution of only 50, assuming of course that the dilution water is essentially free of the pollutant.

The foregoing examples do not consider the efficiency of disinfection processes for bacterial removal. Disinfection efficiency is a combined function of disinfectant dosage and contact time and to be effective must achieve levels equal to or greater than, 99.99 percent removal which is equivalent to a physical dilution of about 10,000:1 with bacteria free water. Obviously, the latter physical dilution is not a likely possibility.

Example of Alternative Analysis

To illustrate most effectively some of the logical treatment/transport-discharge alternatives that should be considered in designing estuarine waste management systems, a simplified example will be considered. Figure 1 shows a typical estuary connected to the open coast with a major city located at its head. The city has several obvious choices with respect to the disposal of its wastewater. One choice, designated as discharge location A, would entail a high degree of treatment—say advanced waste treatment (average of 98 percent pollutant removal)—to meet discharge or effluent requirements. A second alternative, designated as discharge location B, would entail modified secondary treatment with an average pollutant removal of about



1	DISCHARGE LOCATION	A	B	C
2	INITIAL WASTE DILUTION, S_0 (MIN. RIVER FLOW)	10	30	150
3	POLLUTANT CONCENTRATION NEAR SOURCE (AT DIFFUSER) (NO TREATMENT)	$\sim \frac{C_0}{10}$	$\sim \frac{C_0}{30}$	$\sim \frac{C_0}{150}$
4	TREATMENT (ASSUME) PERCENT REMOVAL OF POLLUTANT	98	90	85
5	POLLUTANT CONCENTRATION NEAR SOURCE IN RECEIVING WATER	$\sim \frac{C_0}{500}$	$\sim \frac{C_0}{300}$	$\sim \frac{C_0}{1000}$

FIGURE 1.—Idealized estuarine-coastal disposal alternatives

90 percent. The third alternative discharge. location C, would have the current EPA minimum secondary treatment with an average of 85 percent removal of pollutants. Alternatives B and C obviously entail significant transport and submarine outfall dispersion systems compared to that required at discharge location A. To make these alternatives economically competitive, the incremental cost between the levels of treatment required at the B and C locations and that required at location A will finance construction and operation of the interceptor sewer and submarine outfall diffuser system on a break-even basis.

The basic questions to be answered are:

1. What are the average residual pollutant concentrations in the receiving waters right at the discharge location? Presumably, from an environmental point of view, the system producing the lowest pollutant concentration in the receiving waters would be the preferred solution.
2. On an equal cost basis, how long an interceptor sewer and submarine outfall can be built for discharge locations B and C with the incremental savings in treatment costs ($A > $B > $C)?
3. What advantages may be associated with each alternative?

POLLUTANT CONCENTRATIONS

To answer the first question outlined above, a simple tabular computation analysis is presented in Figure 1. While the dilution values reported in Figure 1 are hypothetical, nonetheless, the values are typical of those found in real estuaries. Obviously, these values must be estimated for each particular estuary. The crux of the analysis is to illustrate the need to compare the trade-off in costs and consequences of pollutant removal with transport and disposal in areas of high dilution potential—with the goal of achieving reduced levels of pollutant concentrations and effects in the estuary.

Line 2 in the table shows the average physical dilution of the wastewater with the receiving water at each of the three discharge locations. At location

A, a dilution, So, of 10:1 assumed, that is, the ratio of the river flow Q and wastewater flow, Q_w (Qr/Qw) is about 10:1. At point A the only dilution available for the wastewater is the advective river flow: there is no dilution at the head end of the estuary due to tidal exchange. At location B, line 2, the average dilution, So, is assumed to be about 30:1, a typical value encountered in estuaries. At location C, the average initial dilution, So, is assumed to be 150:1 which is an easily attainable value with a well designed outfall-dispersion system in open coastal waters.

Line 3 in the table reports the pollutant concentrations in the mixed wastewater-receiving water right at the discharge location. The pollutant concentration is simply the reciprocal of the dilution; that is Co/10 at A, Co/30 at B, and Co/150 at C, where Co is the pollutant concentration in the untreated waste water. This computation assumes that the pollutant concentration in the diluting water is negligible.

Line 4 introduces the effect of the different treatment levels in reducing the pollutant concentration in the discharged waste and correspondingly in the receiving water. As mentioned previously, it is assumed that the highest level of treatment is provided at location A with an average pollutant removal efficiency of 98 percent. A lower degree of treatment with an average pollutant removal of 90 percent is provided for location B. At location C a still lower level of treatment is provided; however, this is assumed to be equivalent to the "EPA defined secondary treatment," the currently specified minimum level of acceptable treatment, providing an average of 85 percent removal of pollutants.

Line 5, the crux of the table, shows the calculated concentration of pollutants in the receiving water resulting from the combined effect of pollutant removal by treatment and the dilution of the treated effluent with the receiving water. The pollutant concentration at location A of Co/500 is the result of the product of the physical dilution, So, of 10:1 and the equivalent dilution of 50:1 due to the pollutant removal (98 percent) by treatment (2 percent remaining), which gives Co/10 × 1/50 = Co/500. The values of Co/300 at B and Co/1000 at location C are found in the same way.

It should be noted that alternate C, the coastal outfall discharge, produces a pollutant concentration at the diffuser equal to one-half (Co/1000 vs Co/500) that produced by alternate A, advanced wastewater treatment with discharge at the head of the estuary. Thus, discharge at point C should be the preferred solution to minimize ecological effects. The reported concentrations relate to all pollutants that are removed by treatment at the percentages cited for each level of treatment, namely, 98, 90, and 85 percent respectively.

Two questions logically might be asked concerning the efficacy of the several alternatives.

1. Which alternative is preferred relative to possible effects of pollutants that are either unknown or are removed to a lesser degree than the pollutant removals stated for each process?

2. Although alternate C apparently produces the lowest pollutant concentration, it also has the highest pollutant mass emission rate to the environment. If the pollutants are concentrated or magnified in the biota, will not alternate C be the poorest solution rather than the preferred solution?

Both of the foregoing questions need serious consideration. With respect to question 1, and considering our imperfect knowledge about pollutants and their effects, one should be concerned about both possibilities. Inspection of the table in Figure 1 reveals that in both cases, alternate C is the preferred solution, because the total apparent dilution is less dependent on the "equivalent treatment dilution" and depends in major degree on the physical dilution to produce the lowest pollutant concentrations. For example, if all treatment processes failed or suffered serious loss in removal efficiency, such as has been known to happen, alternate C would produce a pollutant concentration in the receiving water of Co/150 compared to Co/10 for alternate A—more than a order of magnitude lower pollutant concentration which is not insignificant in terms of possible effects on the local ecosystem. Moreover, in an era of labor strikes and chemical shortages, the possibility of major impact on process performance from this standpoint alone must be considered.

With reference to question 2, it must be remembered that pollutant effects are a function of both the pollutant mass emission rate (i.e., kgms/day), and pollutant concentration for a given exposure or contact time. However, the direct effect of pollutants on any aspect of the environment is primarily concentration dependent for a given exposure time. This is true for both conservative and non-conservative pollutants, including those materials that may be concentrated (magnified) in the biota. The rate at which any effect is demonstrated by any transport mechanism known to the writer is concentration dependent: that is, the higher the pollutant concentration the more rapid its accumulation or effect on the biological system. Consequently, any wastewater management system that produces the lowest pollutant concentration in the environment at the discharge point will have the least effect on the local ecosystem

No mention has been made of the effect of pollutant decay rates on the preferred discharge location. For pollutants such as BOD where a significant decay rate exists, it should be obvious that for the "within the estuary" discharge locations (A and B), oxygen demand will be exerted and in some cases may impose significant oxygen depression in at least part of the estuary. Thus, some of the estuary's pollution assimilative capacity will be utilized. However, for the discharge location on the open coast, C, the oxygen demand imposed with an initial dilution of 150:1 is generally non-detectable in terms of the dissolved oxygen level of the coastal water.

Several other significant advantages are associated with coastal wastewater discharge, alternative C. First, by removing the locally generated wastewater load from the estuary, one preserves the capacity of the estuary to handle the ever increasing quantity of pollutants generated upstream in the drainage basins tributary to the estuary. These pollutants are included in the incoming river flow and there are no economically feasible methods for their removal once they reach the head of the estuary. Second, it is likely that the coastal region will have an area available for wastewater discharge that will be less important and sensitive from the standpoint of the local ecosystem than the estuarine region. Third, some nutrients such as nitrogen may need to be removed from the wastewater discharge to control excessive enrichment of the estuary. Coastal waters are generally deficient in nutrients, nitrogen in particular, so there would be no reason for their removal. In fact, the nitrogen sources may be valuable for the controlled enrichment of coastal waters. This is a practical example of a pollutant in one situation which might become a valuable resource at another location.

TREATMENT/TRANSPORT—DISPOSAL TRADE-OFFS

To answer question 2, how large a transport/disposal system can be constructed and operated for the incremental cost between the alternative plans, it is necessary to deal specifically with the cost functions for treatment, interceptor and outfall sewer construction. It should be obvious that the incremental cost saving between two levels of treatment can be considered as available for wastewater transport (interceptor sewer) and submarine outfall/diffuser construction and operation. Thus, we can compare one system with a high level of treatment and discharge with maximum dilution close to the source of waste generation, to an alternate system with a lower level of treatment (also lower cost) but transport and disposal to an area of high dilution capability. Obviously, a rational comparison of alternatives entails quantitative comparison of both sites with respect to dilution capabilities and ecological characteristics.

It must be recognized that a rational comparison of alternative treatment levels and disposal sites unfortunately is not often made. We simply lack definitive environmental data on dilution capabilities and ecological characteristics of the alternative disposal sites, as well as on pollutant parameters and treatment process removal characteristics. The latter is especially true for the evolving pollutant parameters such as floatables, acute toxicity, and enrichment. However, the lack of this data should not preclude the simple economic comparison of treatment-transport alternatives, an example of which follows. To evaluate properly the role and economic justification of the optimum combination of wastewater treatment-transport, and the appropriate dilution-dispersion system, it is necessary first to consider the current unit costs of each component.

TREATMENT

Table 1 presents a summary tabulation of the 1973 California total unit costs for several levels of treatment and four sizes of treatment plants ranging from a capacity of 1 million gallons per day (1 mgd) or the flow from about 10,000 persons, to a 1,000 mgd plant which would handle the wastewater flows from about 10 million persons. The unit costs are ex-

Table 1.—Estimated 1973 unit costs[a] of wastewater treatment *Capital, operation and maintenance in $/million gallons ($/mg)

Treatment system	Plant design flow			
	1 mgd 3 780 m³/day	10 mgd 37,800 m³/day	100 mgd 378,000 m³/day	1000 mgd 3.78×10^6 m³/day
Primary	280	125	70	55
Intermediate (Chemical, filtration, chlorination)	490	280	140	100
Secondary (Act. Sludge, filtration, chlorination)	490	280	140	100
Advanced				
a) (Chemical, filtration act. carbon chlorination)	910	430	245	175
b) (Act. Sludge, chemical, filtration, act. carbon, chlorination)	980	475	265	200

[a] Costs: a) include disposal of waste residuals.
b) Treatment capital costs based upon 20 year life, i = 5%.

pressed in dollars per million gallons ($/mg) and include all costs: capital (based upon 20 year life and 5 percent interest), operation, and maintenance.

TRANSPORT

The cost of the transport system, principally that of the interceptor sewer depends primarily upon the surface and subsurface conditions along the pipeline route. Pumping, if required to overcome the friction loss for the pipeline system, constitutes a small fraction (< 10–15 percent) of the total cost for a system of reasonable size (10 to 200 mgd). Table 2 presents estimated 1973 California construction costs for dry-trench construction of interceptor sewers of suitable size to handle the three example flow rates considered.

OUTFALL

The costs of submarine outfall diffuser systems vary considerably because of differences in construction (surf, et cetera) and bottom conditions. Also, the cost of the inshore-surf section is high where the outfall must be buried for protection of the pipe. The average cost of outfalls depends upon the length of the outfall and fraction of inshore to offshore lengths. For outfalls in excess of one mile in length and for construction to terminal depths of 25 to 60 meters, Table 3 presents the best estimate of 1973 construction costs based upon actual costs of outfalls constructed along the Pacific coast during the past 20 years. Essentially all of these outfalls have been designed to provide average dilutions of the waste water with the coastal waters of at least 100:1. Actual performance of the built systems generally results in average dilutions higher than the design objective.

BREAK-EVEN INTERCEPTOR-OUTFALL LENGTH

If one considers the incremental treatment cost between advanced waste treatment, alternate B (see Table 1) and secondary treatment, assuming that to be the minimum treatment level allowed, one can compute the length of interceptor or outfall that can be built for this incremental annual cost. Table 4 presents a summary computation of these pipeline lengths based upon the cost data cited in Tables 1, 2 and 3. The table shows the computed interceptor and outfall lengths that can be built for the incremental treatment costs between advanced waste-water treatment, alternate B, for three wastewater flow rates, 1 mgd, and 100 mgd.

Table 2.—Estimated 1973 unit construction costs*—interceptor sewers

Design flow		Sewer size		Construction cost	
mgd	m³/day	inches	centimeters	$/foot	$/meter
1	3,780	10	25.4	18.00	60
10	37,800	36	91.5	63.00	206
100	378,000	96	245	205.00	672

* Dry Trench Construction.
EPA Index = 200.

Table 3.—Estimated 1973 unit construction costs*—submarine outfalls

Design flow		Sewer size		Construction cost	
mgd	m³/day	Inches	Centimeters	$/Foot	$/Meter
1	3,780	6	15	100	330
10	37,800	24	61	425	1,395
100	378,000	76	194	830	2,720

* California construction practice.
EPA Index = 200.

It is of particular interest to note the considerable lengths of interceptor and outfall sewers that can be built for a wastewater flow of 100 mgd (equivalent to a city of about one million persons). About 77 miles of interceptor or about 18 miles of submarine coastal outfall can be built and operated for the incremental cost between secondary and advanced treatment, alternate B. Obviously, the total incremental treatment cost would not be used to build only interceptor sewers or submarine outfalls (unless the city was located directly on the open coast). A realistic, break-even solution would permit the construction of a 100 mgd secondary treatment plant with about 38 miles (77/2) of land interceptor and about 8 miles (17.8/2) of submarine outfall discharging at C on the open coast for the same cost as an advanced wastewater treatment plant (alternate B) discharging at location A at the head of the estuary. As noted previously, these pipeline lengths neglect the cost of pumping to overcome the friction loss during transport (i.e., assumed gravity flow). However, if such pumping were required due to the topography, it should be included in the trade-off analysis, but it would reduce the pipe lengths that can be built by less than 10 percent. Obviously, if suitable open coast disposal sites were available closer to the wastewater source (or a shorter outfall would suffice), then the coastal alternative (location C) would be more economical than treatment and discharge at location A.

The data presented in Table 4 indicate that waste-

Table 4.—Lengths of interceptor sewer or submarine outfall that can be constructed for incremental cost between secondary treatment and advanced waste treatment, alternate b†

Flow	Incremental unit cost secondary to AWT Alt b		Total annual incremental cost sec vs AWT Alt b.	Equivalent interceptor length*			Equivalent outfall length**		
mgd	\$/mg	\$/m³	\$	Unit cost \$/Mile-yr	Miles	Km	Unit cost \$/Mile	Miles	Km.
1	490	0.13	179,000	5,230	34.2	55	30,800	5.8	9.3
10	195	0.053	712,000	18,200	39.1	63	131,000	5.4	8.7
100	125	0.033	4,560,000	59,400	76.7	124	256,000	17.8	28.6

† See Table 1 for process description
* Based upon useful life of 50 yrs, i = 5%, Friction losses (pumping) and O&M not incl.
** Based upon useful life of 40 yrs, i = 5%, Friction losses (pumping) and O&M not incl.

waters can be transported great distances on either land or in the sea for the cost of upgrading the level of wastewater treatment. Certainly, there is adequate evidence to indicate that in planning an estuarine wastewater management system, a reasonable extensive investigation of alternative disposal sites, both within the estuary and on the open coast, is warranted before decisions are reached to provide very high degrees of wastewater treatment with disposal to the local environment. It should be noted that the preceding analysis is based upon a comparison of secondary and advanced wastewater treatment. Where regulations do not require secondary treatment as a minimum, a similar comparison can be made for the incremental cost between primary and secondary treatment. Surprisingly, the incremental cost between primary and secondary treatment is of similar magnitude as that between secondary and advanced treatment used in the example computation; hence, similar transport distances would be obtained.

Ancillary Considerations

Several additional aspects of the open coast disposal alternative should be mentioned. First, it has shown that it is economically possible to transport about 100 mgd of wastewaters over 70 miles at the same cost as upgrading treatment from secondary to advanced (or from primary to secondary treatment). From an environmental or ecological point of view, it would appear highly logical to expect that, within a distance of that magnitude from the wastewater source, one could find a wastewater discharge location with high dilution capabilities and of lower ecological significance than discharge at or near the head of an estuarine system.

Yet a valid argument can be made against coastal waste disposal. *In the long term we cannot afford* to waste the freshwater sewage to the sea; it should be reclaimed. In many places, such as California, this may well be true. If wastewaters are ever to be reclaimed for beneficial reuse, including public water supply, more pollutants must be disposed of than at present. *Moreover, the major pollutant to be removed* to permit continued reuse is salt. Where is a better sink for salt and other non-reclaimables, after suitable terminal treatment, than the sea? Nowhere in the writer's judgement—at least for those cities *located in the coastal zone.*

Moreover, in the short term, one of the major adjuncts for wastewater reclamation is the existence of a marine outfall not only to handle the treated non-reclaimable substances compatible with the sea, but *to provide an effective, economic alternate disposal system* for the wastewater when it is not possible to reclaim it all (i.e., seasonal and demand variations, failsafe provisions, and so forth).

CONCLUSIONS

Rational analysis of estuarine wastewater management requires: (1) consideration of the efficacy of several levels of treatment with respect to pollutant removals and costs; (2) the consequences and costs of transporting adequately treated wastewaters to disposal sites with high diluting capabilities and/or low levels of significance in the local ecosystem; (3) and the effects of the resulting pollutant concentrations in the receiving water environment. The absence of adequate data on pollutants, their removal or effects, or on the characteristics of the local ecosystem, should in no way preclude the straightforward comparison of alternate treatment/transport/disposal systems on an economic and pollutant concentration basis such as presented herein.

Adequate conceptual design of wastewater management systems requires consideration of the incremental costs between several possible levels of wastewater treatment for assessment of the transport distances that the wastewater can be conveyed to a disposal site with high diluting capacity and/or a lesser level of significance in the local ecosystem. An example computation shows that for a 100 mgd (378,000 m^3/day) plant the incremental cost between secondary (including filtration) and advanced waste treatment, an interceptor sewer 38 miles (61 km) long and a coastal submarine outfall ~9 miles (~14 km) in length can be constructed at 1973 California prices.

As has been shown, in many situations the coastal outfall alternative not only provides the lowest waste concentrations, but also may well be the most economic. Moreover, the coastal alternative is highly superior to the high treatment-estuary disposal alternative for unknown pollutants or pollutants only partially removed by the conventional treatment processes (i.e., some toxic substances).

In general, a number of specific advantages can be claimed for open-coast, treatment-disposal alternatives as compared to higher treatment level and disposal within the estuary. These can be summarized as follows:

1. Produces the lowest concentrations of pollutants in the receiving waters for conventional levels of treatment.

2. Discharge location likely can be in area of lesser significance in the local ecosystem.

3. Reduces pollutant stresses on the estuarine ecosystem resulting from locally generated wastewater, thereby allowing capacity for the inevitable increasing pollutant stress associated with incoming river flow and drainage basin pollutant contributions.

4. Because of the high terminal dilutions, greater protection is provided for the local ecosystem from:

   a) Unknown pollutants or those not removed by treatment.
   b) Treatment process malfunction or failure (strikes, et cetera).

5. Provides maximum economy and flexibility to deal with:

   a) Identification and control of new pollutants.
   b) Major improvements in treatment technology.
   c) Future development of engineered wastewater reclamation.

In short, if long-term protection of our estuarine resources is to be provided, all technical and economically feasible steps should be taken wherever possible to transport adequately treated wastes out of the estuarine system to the open coast in well engineered, high dilution capacity outfall dispersion systems.

RECOMMENDATIONS

The federal government in cooperation with the states should sponsor large scale field investigations of all significant estuaries and adjacent coastal waters. The focus of these studies should be twofold:

1. Development of quantitative descriptions of the estuarine ecosystems to permit realistic assessment of the characteristics of the flora and fauna, its general condition or "health" and the general level of sensitivity and biological significance of the various portions of the estuary and adjacent coastal waters.

2. To identify, insofar as possible, the significant effects of pollutants on the estuarine ecosystem—at least to the degree of categorizing what appears to be the critical pollutant problems and parameters associated therewith.

REFERENCES

1. Pearson, E. A., P. N. Storrs, and R. E. Selleck. 1970. Final Report, A Comprehensive Study of San Francisco Bay. Vol. 8, Univ. of California Sanitary Engineering Research Laboratory Report No. 67-5. Berkeley.

2. Kaiser Engineers Consortium. 1969. Final Report, San Francisco Bay Delta Water Quality Management Program. California Water Resources Control Board, Sacramento, Calif.

3. State Water Resources Control Board. 1972. Water Quality Control Plan, Ocean Waters of California, Sacramento, Calif.

4. Burnett, Robin. 1971. DDT Residues: Distribution of Concentrations in Emerita analoga (Stimpson) along Coastal California Science: (174):606–608.

5. Parkhurst, J. D. 1971. The Control of Pesticide Emissions from Municipal Discharges, Report at hearing before State Water Resources Control Board, Los Angeles, Calif.

6. U.S. Environmental Protection Agency. 1973. Office of Water Programs Operations. Washington, D.C.

POLLUTION PROBLEMS IN THE ESTUARIES OF ALASKA

DONALD W. HOOD
JOHN J. GOERING
University of Alaska
Fairbanks, Alaska

ABSTRACT

The Alaskan marine coastal systems are classified into 13 categories which represent nearly all systems found in the 48 contiguous states with the exception of tropical systems and those heavily stressed by petrochemical and other complex industrial pollutants. Alaska is the only state that has ice-stressed coastal systems. It also has 54 percent of the United States coastline and 53 percent of its tidal shoreline.

The scope of Alaskan coastal pollution problems at present and in the future are examined. Minor problems associated with wastes from municipalities and activities of the petroleum, timber, pulp and paper, and the fishing industries are presently evident. Increased petroleum production and the associated transport of oil products through Alaskan coastal systems poses a future large scale pollution risk

An evaluation of previous Alaskan coastal pollution abatement programs and trends is given. Because Alaska has such unique coastal systems it is concluded that any future coastal pollution control program will succeed only if based on sound environmental data rather than on adaptations of standards uniformly administered throughout the 48 contiguous states. Emphasized through the paper is the need for better environmental understanding of Alaska's coastal systems upon which decisions can be wisely made that will protect them, and at the same time utilize them for waste disposal and extraction of the resources needed to benefit man.

INTRODUCTION

Alaska, with its total population of about 350,000 people is very sparsely populated. Centered around Anchorage is a population of 150,000 which constitutes by far the largest population center; Fairbanks is second with about 40,000, and Juneau third with about 20,000. The remaining population is composed of small villages and towns, mostly located on the coast. Most of the villages are native and still adhere to native customs and practices.

Most Alaskans live on the state's coast, a coast that extends from the rain forest of southeast Alaska to the arctic tundra (Fig. 1). The gradation from temperate to arctic, which encompasses a very broad geographical range in latitude and longitude, includes all types of coastal systems found in the contiguous 48 states with the exception of tropical systems and those stressed by petrochemical and other complex industrial pollutants. Alaska is the only state that has ice-stressed coastal systems. There are four types: glacial fiords, turbid outwash fiords, sea ice systems and ice-stressed coasts. The first two types occur in southeast and southcentral Alaska and the last two types are arctic (Fig. 1 and Tables 1 and 2).

The small population of Alaska, although concentrated on the coast, has had a very limited influence on the natural systems of the 76,100 km of Alaskan tidal shoreline. But, Alaska is presently experiencing rapid economic growth primarily from development of the natural resources (e.g., petroleum, timber and fish) near its coast and certain coastal systems are therefore already stressed by man's activities.

Classification of Alaskan Marine Coastal Systems

Alaska's coastal systems are very diverse (Fig. 1, Tables 1 and 2) because its coastline extends over a very broad geographical range. The general coastline of Alaska is 10,680 km long (McRoy and Goering, 1974), 54 percent of the total (19,924 km) coastline of the United States (Pederson, 1965). The tidal shoreline, which includes islands, inlets, and all shoreline to the head of tidewater, is much longer and reflects the intricacy of coastal Alaska. This distance is estimated to be 76,100 km in Alaska and 142,610 km in the United States. Alaska, then has 53 percent of the total United States tidal shoreline. The tidal shoreline is greatest in southeast Alaska (63 percent), where the coast is a maze of fiords, islands, bays, and rocks, and is minimal in

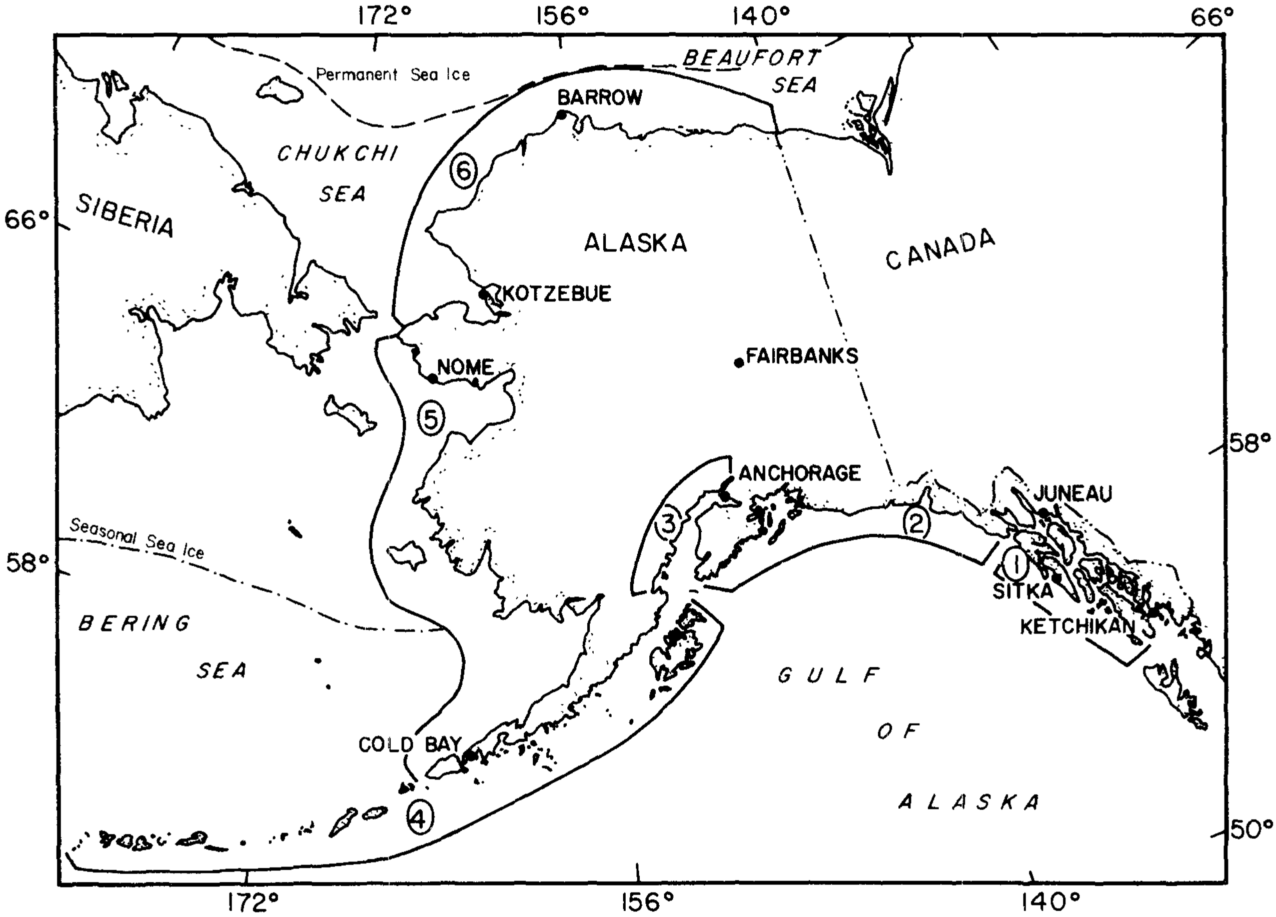


FIGURE 1.—Map of Alaska. Numerals refer to regions described in Table 2.

the arctic (2 percent), existing as a series of lagoons and barrier beaches (Table 2).

Because the four ice-stressed systems are unique to Alaska their characteristics will be briefly described.

GLACIAL AND TURBID FIORDS

The major indentations of the southeast Alaskan coastline are fiord-type estuaries. Glacial and turbid outwash fiord refers to inlets which owe their distinctive physiography to the action of glacial ice on mountainous coastal regions. These inlets are usually narrow, straight, have deep water and receive their major freshwater runoff from active glacial sources. Those fiords with active glaciers in the intertidal zone are referred to as glacial fiords. In these, most of the glacial-melt water (i.e., the major estuarine freshwater source) passes directly into the marine environment. Fiords whose glaciers terminate on land, so that the melt water reaches tide water via a freshwater river system, are termed "turbid outwash fiords." In contrast to the clear water environment of the glacial fiord, in the turbid outwash fiord large quantities of glacially-ground sediments are transported into the inlets by glacial-melt water from the sediment deposits between glacier and fiord. These sediments restrict light passage as well as influence the inlet geochemistry.

Table 1.—Types of coastal systems in Alaska

1. Glacial fiord
2. Turbid (terrestrial outwash) fiord
3. Rocky sea front and intertidal rocks
4. High velocity tidal channel
5. Neutral embayment and associated shore waters
6. Medium salinity estuary
7. Sheltered and stratified estuary
8. Oligohaline river system
9. Sedimentary river delta
10. Marshes
11. High energy beach
12. Ice-stressed beach
13. Sea ice system

Table 2.—Distribution of Alaskan coastal systems by regions (See Fig. 1)

Region	Estimated km of tidal shoreline	Percent of Alaskan shoreline	Coastal types (See table 1)
1. Southeast Alaska	48,270	68	all but 12 and 13
2. Pacific Coast, Cape Spencer to Cape Elizabeth	10,460	14	all but 12 and 13
3. Cook Inlet	800	1	4, 5 and 8
4. Kodiak Island, Alaska Peninsula and Aleutian Islands	12,070	16	3, 4, 5, 6, 7, 10 and 11
5. Bristol Bay to Bering Strait	2,900	4	3, 4, 5, 6, 7, 10, 11 and 12
6. Arctic, Bering Strait to Canadian Border	1,600	2	8, 9, 10, 11, 12 and 13

Commonly, fiords contain an entrance sill, which restricts the free exchange of waters within with those outside (Pritchard, 1952). However, all inlets in southeast Alaska do not have such sills and the amount of circulation restriction, a feature which is very important in pollutant assimilative capacity, varies from inlet to inlet. Most have entrance sill depths which allow continuous contact with the exterior source waters so that a slow circulation prevents the basin from stagnating. Where shallow sills penetrate the low salinity outflowing upper layer, exchange of deep basin water is inhibited and stagnation is theoretically possible. No fiords in southern Alaska, uninfluenced by man, show stagnation to the degree that extensive oxygen depletion occurs. The circulation in Skan Bay, Unalaska Island, one of the Aleutian Islands, however, is restricted to the extent that complete oxygen depletion occurs naturally once every year (Goering and Boisseau, personal correspondence). Stagnation as a consequence of restricted circulation also occurs in areas of limited freshwater inflow. Inflow is strongly seasonal with a pronounced primary freshwater input maximum during the period of May through July. The major energy sources within the fiords are the total freshwater inflow and the effects of tides, with the latter usually predominating.

Sea Ice System

Sea ice is a coastal system unique to Alaska. The ice itself is a type of beach with associated fauna and flora. Seals and walrus breed on the ice; diatoms and other algae grow on its undersurface; numerous species of birds feed near it; Eskimos depend on it for food and travel.

Ice is the major feature of the Arctic Ocean and northern Bering Sea in winter. Seawater in this system freezes to an average thickness of 2 to 3 m. This thickness varies locally with the severity of the winter. Losses due to surface melting are replenished by accumulation of new ice on the undersurface. The southern boundary of the sea ice varies from year to year. This limit is frequently near the Pribilof Islands (59° N., Fig. 1). The summer boundary of the polar ice is between 10 and 100 miles off the Alaskan arctic coast. During August and September the Arctic Sea adjacent to Alaska has the least ice. Advancement of the sea ice begins in late September and October but the north flowing current through Bering Strait tends to keep the southern Chukchi Sea open longer. Ice closes Bering Strait by the end of October. In late October and November Norton Sound freezes and the sea ice progresses south to its maximum in midwinter. Breakup begins in mid-April. Open water does not extend into the Chukchi Sea until June.

Ice on the sea is not one continuous mass, nor is it flat and uniform. Winds, currents, and other stresses produce openings, hummocks, and ridges in the ice. The surface topography generally reflects the undersurface topography. Polynyas and leads, a result of stresses acting on the ice, are present at all seasons.

The boundary of ice and water may take a variety of forms depending upon the given freezing and melting conditions. In the open sea, only sea ice formed by the freezing of seawater is important. However, near the coast, and in particular near river mouths, floating river ice is introduced into the oceans.

Ice-Stressed Coast

This system is characterized by ice formed by the freezing of the arctic seas. Ice along a shore has profound effects on the fauna and flora of the coast in that it eliminates most organisms from the littoral zones of the sea.

The ice-stressed littoral system reaches a maximum intensity on the northernmost coast of Alaska, from Point Barrow east, where ice is present from September through July and in extreme years may be periodically onshore all summer. The effects of ice on coastal systems diminish with the decreasing latitude along the Chukchi and Bering Sea coasts. The southern extent of the ice-stressed system varies with the intensity of winter; it can extend as far south as Izembek Lagoon near the tip of the Alaska Peninsula (55° N., Fig. 1). In these lower latitudes the ice effects are much less than in the Arctic. On the arctic coast the pressure on sea ice from wind stress and currents is transferred to the fast ice on shore and causes scouring. Ice cover on the open Bering Sea never extends as far south as the Aleutian Islands.

Although the stress of ice influences long portions of the Alaskan shoreline (approximately 4,500 km), most studies have been limited to the region near the Naval Arctic Research Laboratory at Point Barrow. For other regions only inferences can be made based on the Point Barrow work. The best studied ice-stressed coasts are those of the arctic Soviet Union (Zenkevitch, 1963). They appear to be comparable to Alaskan coastal systems.

SCOPE OF ALASKAN COASTAL POLLUTION PROBLEMS PRESENT AND FUTURE

Alaska's extensive coastline and corresponding coastal estuarine systems are one of the state's most important resources. Estuaries are as beneficial to man as forests, lakes and rivers. They are very productive biologically as well as versatile in usefulness. A vast variety of finfish and shellfish spend all or part of their life cycle in estuaries. These serve as nurseries, as spawning and feeding grounds, and as passageways between the open sea and the spawning areas of freshwater streams. Most of the commercial seafoods harvested in Alaska are associated with coastal estuarine systems (Table 3).

These systems also provide habitat for numerous species of sea birds and marine mammals. They act as buffers against the ravages of violent storms and provide the harbors and transportation routes for commerce, and are the best potential sites for certain industrial plants. Also, Alaskan coastal waters offer a wide variety of recreational opportunities for fishermen, boaters, hunters, and wildlife observers. It is thus very clear that Alaska's coastal systems are very rich in renewable and non-renewable resources—distinctive, aquatic systems which man cannot afford to use carelessly or destructively. We must obtain a keen knowledge of how these systems function naturally before the stresses that they can accept without significant change can be assessed. Procuring information as to how these systems function naturally is the greatest challenge to wise management of their use. Without this knowledge for management decisions, failure is inevitable.

Because of the state's great diversity, baseline data on many systems is not available. Therefore, the present water quality standards which are based on the best information available, or taken from other states and areas, have many weaknesses which must be corrected as better information is obtained.

Table 3.—Alaskan commercial species of finfish and shellfish which are nurtured in estuarine environments

Group	Common name	Scientific name
1. Finfish		
Salmon	coho (silver) salmon	Oncorhynchus kisutch
	pink (humpback)	Oncorhynchus gorbuscha
	chum (dog) salmon	Oncorhynchus keta
	king (chinook) salmon	Oncorhynchus tshawytscha
	sockeye (red) salmon	Oncorhynchus nerka
Trout	rainbow trout (steelhead)	Salmo gairdneri
	arctic char (dolly varden)	Salvelinus malma
Halibut	Pacific halibut	Hippoglossus stenolepis
Herring	Pacific herring	Clupea harengus pallasi
Smelt	capelin	Mallotus villosus
Cod	ling cod	Ophiodon elongatus
Rockfish	redsnapper (yelloweye rockfish)	Sebastes ruberrimus
Whiting	shee fish	Stenodus leucichthys
2. Shellfish		
Crabs	king crab	Paralithodes camtschatica
	tanner (snow) crab	Chionoecetes bairdi
	tanner (snow) crab	Chionoecetes opilio
	dungeness crab	Cancer magister
Shrimp	pink shrimp	Pandalus borealis
	side-stripe shrimp	Pandalopis dispar
	coon-stripe shrimp	Pandalus hypsinotus
	humpback shrimp	Pandalus goniurus
	spot shrimp	Pandalus platyceros
Scallop	weathervane sea scallop	Patinopecten caurinus
Clams	razor clam	Siliqua patula
	goe-duck	Panope generosa

Environmental baseline research is the only mechanism that can supply the required information needed to upgrade and establish realistic marine water quality standards. Once realistic water quality standards are established then research to develop more appropriate methods of waste treatment and pollution abatement can begin. Without realistic standards, the government requirement for industrial and municipal installation of treatment facilities is environmentally pointless, morally irresponsible, and fiscally absurd.

Marine coastal pollution in Alaska is then caught in a dilemma. On the one hand are the extremely complex coastal ecosystems of widely diverse nature that are sufficiently different from those of other regions that the same criteria for water quality do not apply, and on the other the strong commitment on the part of the government to impose standards, usually the same as for the rest of the United States even though there is little evidence for their applicability. To exemplify this point, there seems to be very little reason to set effluent standards in Alaska to help meet a dissolved oxygen concentration in the environment, as may be necessary elsewhere, since Alaskan waters are unusually rich in dissolved oxygen. In one test case in Silver Bay a discharge of 112 metric tons/day of 5-day BOD under less than ideal discharge conditions led to only a few violations of the state water quality standard for dissolved oxygen (6 mg/l), and this was associated with low oxygen water input resulting from coastal upwelling. It would seem advisable to put the intellectual resources available to bear on problems other than BOD discharge. Likewise, does it make sense to impose the same temperature effluent standards in Alaska; most ecosystems would benefit from higher temperatures, as in Florida or Texas where the systems are thermally stressed under natural conditions.

To protect Alaska's renewable resources it will be necessary to develop environmental standards especially directed toward local situations. In such considerations full regard to the investigation of the ocean's capacity for waste assimilation and dispersion should be given while being explicit about the nature of the waste discharged and its effects on the dominant ecosystems present.

The future marine pollution problems in Alaska will be well managed, poorly managed, or managed not at all, depending on how well the responsibilities of the oceanographic scientific community are carried out in the next few years and what kind of management plan is developed. There will unquestionably be large offshore oil developments on the continental shelves of the Gulf of Alaska, Beaufort Sea offshore of the Prudhoe oil field, the Chukchi Sea, Norton Sound, Bristol Bay, North Pacific south of the Alaska Peninsula, and the Bering Sea. These continental shelves represent 74 percent of the U.S. total. With these developments must come a proliferation of docks, harbors and transportation corridors to move the product to market. Much of the gas will be liquified before transport out of Alaska thus providing enormous quantities of heat, which under proper institutional arrangements, can probably be economically utilized to enhance renewable resource production.

Some plants will be built to utilize oil and gas within Alaska, particularly nitrogen based fertilizer plants and some types of petrochemical plants.

Alaska is an underdeveloped mineral rich resource area. Large reserves of copper, tin, molybdenum, platinum, iron, antimony and coal are yet undeveloped. Only gold and some copper has been processed until now, largely because of lack of transportation and the world economic picture. Soon this will change with the imminent world need for these raw materials. The metal beneficiation mills that will result will bring new sets of pollution problems to the state.

The timber stands in Alaska are about the same as Washington, Oregon, and Idaho combined, yet the harvest is small compared to these three states. With the shortages in wood and wood products now facing the nation and the world a greater harvest of this raw material in Alaska is inevitable. With the increased harvest will come numerous new paper, wood pulp, and wood mills with their associated pollution problems. In addition, the increased cutting will affect water quality, land erosion, and stream habitation.

Marine food production, historically Alaska's most important product, will continue to expand and Alaska will long remain as one of the world's greatest fisheries' centers. Pending the adoption of the 200-mile economic zone or some similar coastal state jurisdictional arrangement, the continental shelf of the Bering Sea, perhaps the most valuable fishery in the world, will fall under Alaska's jurisdiction. In addition, aquaculture should thrive in Alaska, especially in the coastal fiords which offer promising opportunities for marine food production without expenditure of conventional energy.

For Alaska to be a supplier of marine foods and at the same time of such materials as petroleum, lumber and associated products, places an extremely heavy burden on those investigating environmental effects to determine what stress the system can take without significant damage, and provide for means to control those stresses found to be incompatible with desirable uses of the marine environment. Government, science, and private enterprise must face these problems together realistically and with forthright determination to make this possible.

ALASKAN COASTAL POLLUTION BY TYPES OF EFFLUENTS

Petroleum Industry

Significant pollution of Alaska's coastal systems by oil has not yet occurred. Pollution by oil could, however, become a problem as soon as large amounts of it are tankered from Alaska to other areas. This is slated to begin after completion of the Trans-Alaska pipeline, about three years from now. When oil is handled, there is a spill risk, even under the best control and intentions. We must develop a data bank of its effects so that cleanup and control may be systematic and effective.

In the development of the vast petroleum reserves located in the state the danger of oil pollution must

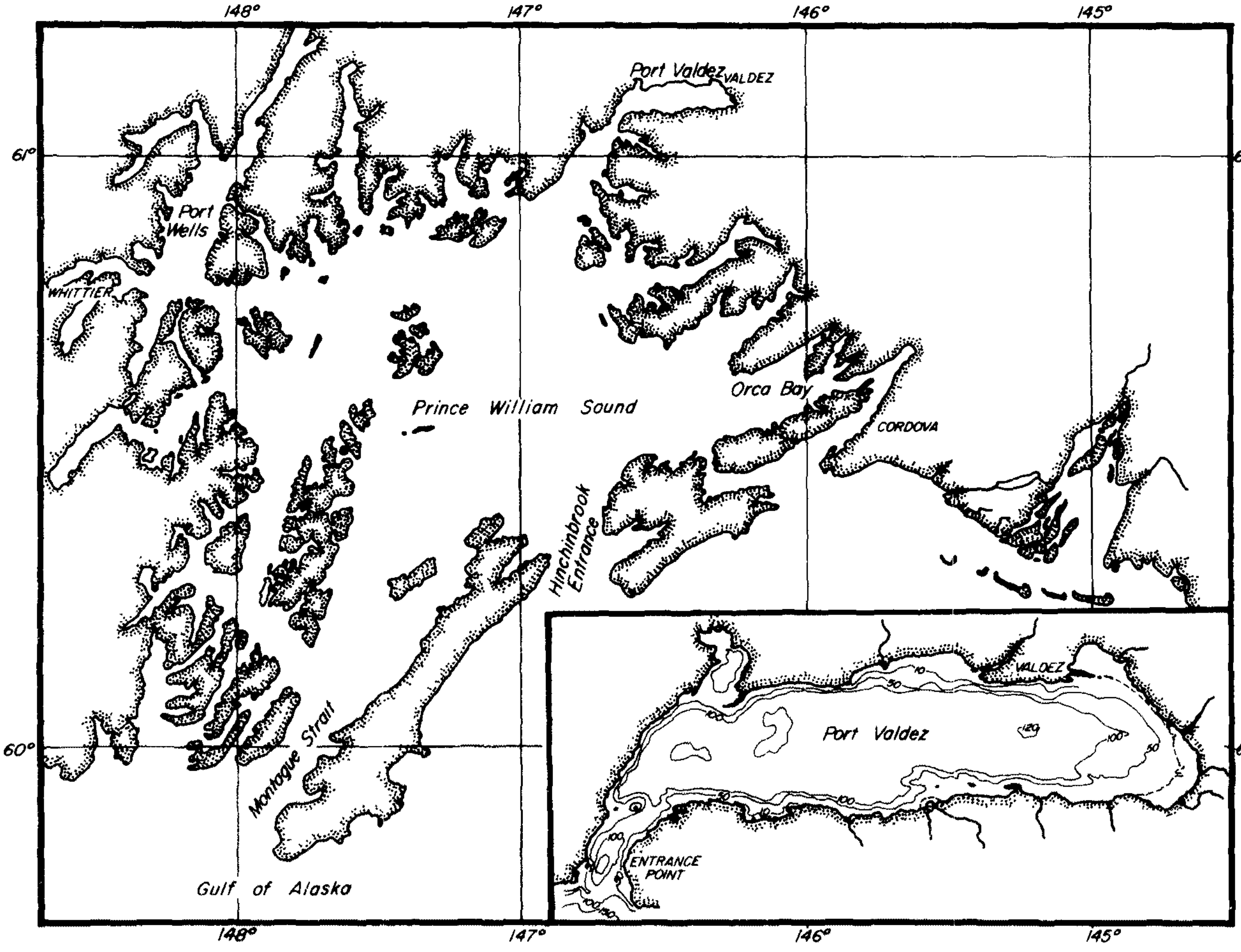


FIGURE 2.—Prince William Sound.

be foreseen and forestalled. The most immediate problems appear to surround the 800-mile Trans-Alaska pipeline which is to bring oil from the oil-rich North Slope to the ice-free tanker terminal in Port Valdez in southcentral Alaska. The coastal systems in region 2 (Fig. 1) are particularly vulnerable, especially Port Valdez, Valdez Arm, and other systems located in Prince William Sound (Fig. 2).

Prince William Sound is one of the largest tidal estuarine systems on the North American continent not yet influenced by urban development. It is comparable in size to Puget Sound yet has only a permanent population of about 5,000. The sound is an area of rich biological resources and scenic splendor. Important runs of silver, pink, and chum salmon enter the sound each summer to spawn in its numerous freshwater systems. Large stocks of king and dungeness crabs, a variety of clams and scallops, as well as commercially important pelagic fish reside there. Large numbers of marine mammals and sea birds are associated with the rich marine fauna.

When the Trans-Alaska pipeline is completed the tanker traffic in Prince William Sound and along the southeast Alaska coast will almost certainly lead to sporadic oil pollution. Chief risk areas are near the loading terminal in Port Valdez; but with sensible organization for treating them, such oil spills as occur need not cause environmental degradation.

Oil tankers returning from the west coast under ballast to load at Port Valdez will not be able to discharge dirty ballast water at sea. They will unload it into a ballast treatment plant where the oil content will be reduced to less than 8 ppm before release into the port. Thus Port Valdez will suffer planned chronic pollution of a low level. The Alyeska Pipeline Company, responsible for operation of the pipeline and terminal, commissioned a study of the hydrography, geology, and biology of the port by the Institute of Marine Science of the University of Alaska to predict the impact of this chronic pollution. The report (Hood et al., 1973) provides information which has been used in the design of the treatment plant and effluent dispersion system to minimize the impact of this oil on Port Valdez waters. The extreme care used to investigate the pollution impact that the treatment plant might have, and to design the outfall in such a way to minimize effects, should be a model for all future industrial and urban developments in the sound.

A study to quantitatively define the magnitude of oil pollution in Alaska's Cook Inlet has been described by Kinney et al., (1969). Physical dissipation and biodegradation rates were determined and combined with estimates of hydrocarbon input rates to assess the extent of oil pollution in the inlet.

The authors report that as of the date of their report, accidental spills and effluents contribute from 10,000 to 17,000 barrels of oil per year or about 0.03 percent of the total produced and handled. The most recent spill and discharge analyses show that the 0.03 percent figure is now about 0.01 percent and will further decline as NPDES discharge permits go into effect between 1975 and 1977. When oil is added to the surface the slick is dissipated rapidly by the inlet's large tidal turbulence. This turbulence and its geometry also tend to keep spilled oil out in the inlet away from beaches, with the exception of Kalgin Island. Tidal and river-driven flushing reduces components in the inlet by 90 percent in about 10 months. Evaporation effectively removes hydrocarbon components smaller than C_{12} within eight hours and the amounts of $C_{10} - C_{25}$ hydrocarbons in Cook Inlet waters and sediments are below 0.02 μg/liter.

A microflora of hydrocarbon oxidizing organisms (about 10^3/liter) exists and functions as an inoculum and suggests the persistence of transient, possibly naturally occurring, hydrocarbons. Biodegradation of oil in the inlet is complete in one to two months. Thus biodegradation is more important than physical flushing in removing hydrocarbon pollutants from this body of water.

Many questions concerning the influence of oil on marine biota remain unanswered. The lack of this information generally results in panic when oil is spilled, although oil seeps occur naturally in coastal waters of Alaska, particularly in southeast Alaska near Yakataga, Malaspina, Icy Bay, and Yakutat (Rosenberg, 1972). The fate of oil once it reaches Alaska's coastal system needs to be assessed. Biodegradation will occur; but just how fast in the various systems isn't precisely known. Interaction of oil with silt and glacial silt will occur, but where does the silt deposit, what effects do oil-laden silt have on the benthic community and what rates of degradation may be expected? Arbitrary controls of oil pollution other than cleanup of spills should not be attempted without more knowledge of the fate and effect of oil on the marine ecosystems involved. Caution should be used when chemicals are used to clean up oil because they may, in cold water, as has been often found in warmer waters, have more detrimental effects to marine organisms than allowing natural processes to degrade the oil left after physical cleanup. It is obvious that the State of Alaska and the U.S. Government must obtain detailed knowledge of the interaction of oil and the marine environment under Alaskan conditions to avoid panic and tragedy in the event of major accidental oil pollution incidents.

Timber Industry

Among Alaska's most important industries now and in the future are those involved with forest harvest and processing. Approximately 60 individual logging companies operate within southeast Alaska (State of Alaska, 1971). They supply timber to two large pulp mills and about 20 smaller saw mills. In 1970, they harvested 560 million board feet of timber, most of which was hemlock (*Tsuga heterophylla*). Much of this timber was taken from Baranof, Kruzof, and Prince of Wales Islands. About 2.6 square km of water was used for handling and storing logs. Since some of the logging companies move their cutting sites each year, a large area of water has been used for log handling and storage in southeast Alaska. Coastal pollution problems originating from the timber industry are already apparent in southeast Alaska. Logging practices have influenced the water resources, particularly small streams in the logging areas and estuaries utilized for log storage in log rafts. The absence of roads and the distance between logging areas and processing mills have resulted in the extensive use of salt water for storage and transportation of logs. Wood-boring organisms, such as teredos, inhabit southeast Alaskan marine waters, so logs are generally stored in intertidal areas of shallow bays. These areas are chosen for extended log storage because grounding at low tide and the relatively low salinities minimize infestation by wood-boring organisms. Protection from strong winds is another factor considered when choosing storage areas.

During the log dumping and rafting processes, bark is knocked off the logs and sinks to the bottom, often in substantial amounts. This accumulation can greatly increase oxygen demand, resulting in the depletion of benthic organisms, and also can cover the bottom to the extent that repopulation by benthic forms is prevented (Pease, 1974). Organic compounds leached from logs when stored in water, in addition to exerting an oxygen demand, add color-producing substances to the water, and some leachates (e.g. Douglas fir leachates) are acutely toxic to marine and freshwater fish (Schaumburg, 1973). Steel bands and cables which are used in the rafting process also often accumulate on the bottom.

The exact effects of water-based log handling in southeast Alaska need to be better assessed before restrictions or alternative methods of storage are imposed. In general, any method which reduces the accumulation of debris and log leachates in the shallow storage areas would appear to be beneficial.

Pulp and Paper Industry

The processing of timber by pulp mills has also seriously affected water quality in certain southeast Alaskan bays. A rather serious degradation of water quality due to inadequately treated wastes from pulp mills in Ward Cove and Silver Bay has been documented by the Federal Water Quality Administration (1970). The Alaska Lumber and Pulp Company located in Silver Bay and the Ketchikan Pulp Company in Ward Cove both operate magnesium based sulphite process pulp mills which produce a dissolving pulp for the rayon industry. Both plants have relied upon chemical recovery and screening to remove wastes and both discharge into the marine environment from outfalls without the benefit of dispersers. This treatment has been shown to be insufficient to comply with Federal or Alaska Water Quality Standards. Sulphite waste liquor concentrations known to exceed the level toxic to phytoplankton and salmon food organisms have been found throughout Ward Cove and Silver Bay. The waste liquor discharges containing a high 5-day BOD coupled with the release of solid materials, plus the inability of the waters in these systems to effectively disperse the pollutants, combine to reduce the dissolved oxygen at some times during the year. In the summer, coastal upwelling occurs, resulting in low oxygen containing waters being transported into the inlets. This event, coupled with oxygen depletion resulting from the waste load, causes the dissolved oxygen to fall below 6 mg/liter, the minimum level allowed by the Alaska Water Quality Standards. The permit requirements now being imposed are based on a discharge level for 5-day BOD per ton of product produced with no regard for environmental effects. It is not clear at this time, in the case of the Alaska Pulp Mill at Silver Bay, whether reduction of the 5-day BOD discharge level to the proposed best practical level will effectively improve the dissolved oxygen situation in Silver Bay, since it appears that the largest contributor to the low oxygen values is natural circulation and similar processes dominating this system. More consideration needs to be given to other components of the waste, and their distribution in the bay, to provide a sound environmental disposal system.

Fishing Industry

Alaska ranks as one of the leading states in the tonnage of seafood landed and processed (fourth in 1972, U.S. Dept. of Commerce, 1973). In 1972 there were 131 salmon, 72 shellfish and 50 miscellaneous fish processing plants operating along the coast of Alaska. The wastes from this industry have already brought on serious degradation of water quality and impeded the various other important and economic uses of that water. The main areas of environmental degradation are in regions where several processors are concentrated, where currents carry wastes onshore, or where water circulation is restricted and stagnation ensues.

A large percentage of the shellfish and finfish processing in Alaska is done at Kodiak. In 1972, 113,268,000 pounds of fish were landed there; only six other U.S. fishing ports had larger landings. In Kodiak, the shrimp and crab industries are faced with a complex problem. The wastes which are left after the extraction of meat for freezing or canning, the majority of the body weight (mainly entrails and chitinous skeletons), always have been dumped into Chiniak Bay beside the processing plants. This practice has created serious environmental problems, e.g., accumulation of organic debris resulting in near bottom anoxia, release of toxic hydrogen sulphide from anoxic sediments, and elevated concentrations of potentially toxic inorganic nutrients such as ammonium. The lowered oxygen concentrations have undoubtedly affected the natural flora and fauna of the bay.

Iliuliuk Bay, Unalaska Island is a site of increasing seafood processing. It has been speculated that the amount of processing on or near Unalaska will surpass that on Kodiak in the next few years. Large concentrations of ammonium and depletions in oxygen have already been observed in Iliuliuk Bay (Brickell and Goering, 1970), and the decomposition of seafood processing wastes, which are emptied into the bay rather continuously, appears to be responsible for the observed changes in the nitrogen and oxygen chemistry. An examination of the ammonium concentration at stations off the mouth of the bay suggests that ammonium originating in Iliuliuk Bay influences the nitrogen economy of the surrounding ocean. However, high concentrations of ammonium, organic nitrogen, and oxygen depletion are not restricted to waters receiving waste from seafood processing plants. They can occur naturally, as evidenced by the natural phenomenon of salmon carcass decomposition which results in oxygen depletion and elevated concentrations of ammonium and other nitrogen compounds, closely simulating the industrial situation (Brickell and Goering, 1970).

Municipal Wastes

Disposal of untreated municipal wastes in the sea surrounding Alaska is common to coastal cities and villages. Household waste is the dominant component with minor contributions from small industries. Larger industries dispose of their wastes separately. The cheapest means of disposal is often used, i.e., untreated municipal wastewater is released into the open sea. In most instances this appears to have not seriously stressed the marine environment. Only in embayments with restricted circulation have minor adverse effects been documented.

Disposal of sewage into seawater affects the physical and chemical nature of coastal waters. The specific gravity of the waste products in relation to the density of seawater will determine whether the material disperses into water masses, settles to the bottom, or floats to the surface. These materials will also affect light penetration, poison plants and animals, destroy bottom habitat by settling, and destroy valuable recreation sites by floating to surfaces and washing onto beaches. More serious are the primary and secondary consequences of the chemical and biological oxidation of the organic matter. Biodegradable organic matter discharged into the sea is oxidized by microorganisms. The initial oxidation is accomplished by organisms entering with the effluent, and after dilution with seawater marine bacteria are probably the major oxidizers. The bactericidal properties of seawater are well documented (Ketchum et al., 1949). In the oxidation process, the dissolved oxygen in seawater is utilized as the electron acceptor, and when the rate of removal is greater than the rate of supply by diffusion and the photosynthetic activity of plants, the oxygen is depleted. Anoxic microorganisms begin to stabilize the remaining organic matter using the nitrate ion first, and when it is depleted, the sulfate ion, as the electron acceptors. During the latter process, noxious hydrogen sulfide is produced. The reduced compounds (e.g. hydrogen sulfide) are in reality also an oxygen debt which has to be paid before oxygen can again accumulate. In all of the biodegradation reactions carbon dioxide, ammonium, and phosphate are released into the water, and become available for organic synthesis in algal growth. Baalsrud (1967) showed that when a mixture of seawater and sewage, having a certain oxygen demand, was stored in the dark an oxidative breakdown occurred, thereby reducing the oxygen demand. However, when the mixture was inoculated with a few algae and placed in the light, algal growth gave rise to organic matter with an oxygen demand much greater than that originally found in the sewage. His experiments clearly demonstrate that the organic matter formed as a result of eutrophication potentially represents a much greater organic load than that added directly with sewage. Therefore, it appears necessary to clearly understand the secondary as well as the primary effects of sewage addition to seawater.

Cook Inlet receives untreated municipal sewage from all of the Anchorage populace, the largest metropolitan area in Alaska. The 30-foot tidal range of Cook Inlet is common knowledge. However, less known are its other characteristics, such as extreme turbulence, horizontal velocities of flow, suspended sediment loads, natural biological productivity, the effects of freshwater inflows, temperature, and wind stresses. Because of heavy sediment loads in summer and treacherous ice flows in winter, the upper inlet has not been extensively used for commercial or recreational purposes. Because of these negative properties, little concern has, until recently, been given to its capacity to assimilate man's wastes. Its strong currents and mixing, however, make it much more suitable for waste disposal than most other Alaskan systems.

In Alaska only isolated cases of water quality decline, resulting from municipal sewage discharge into the sea, have been documented. Physical, chemical and biological data indicate that some minor pollution of Cook Inlet waters near the Chester Creek and Cairn Point outfalls results from domestic sewage, but the water mass as a whole has not been adversely affected by it. Because of its extensive turbulence and heavy sediment loads, large quantities of domestic waste, as much as 7.6×10^6 m^3/day, can be discharged into the inlet without causing serious water degradation (Murphy et al., 1972). Thus a population of two to three million people could safely dispose of their domestic waste water into the inlet.

In Ketchikan, Alaska, domestic sewage disposal consists of septic tanks and drain fields, cesspools and seepage pits, or piping raw sewage into the tidewaters of Tongass Narrows (State of Alaska, 1967). Most of the sewage is believed eventually to reach salt water either by surface or underground drainage or by direct piping to points near water's edge on shore. The raw sewage outfalls are responsible for the large numbers of coliform bacteria found in the adjacent waters of Tongass Narrows, particularly Bar Harbor. The eutrophication of the waterfront area by nutrients resulting from the sewage has not been studied. Studies have indicated, however, that state bacteriological water quality standards are exceeded in many areas along the Ketchikan waterfront. Fecal solids and shredded toilet paper, which are potential health hazards as well as aesthetically offensive, are often observed along the shoreline and floating within Bar Harbor, near Bar Point and alongside the Dock, Mission, and Mill Street area. The stratification of the low density discharged sewage near the sea surface, slow nearshore tidal currents with net northward movement in Tongass Narrows, and an onshore wind component all tend to concentrate Ketchikan sewage discharges in the surface waters of the waterfront area, and to move it slowly northward past the city.

In other areas of Alaska, particularly where restricted flow of seawater is inherent or little has been done to utilize the assimilative capacity of the ocean for waste oxidation, isolated cases of water quality decline have resulted. Often, as in the case at Iliukiuk Bay, Unalaska Island, and Kodiak Island, the combined effects of fishing industry wastes and municipal sewage wastes, have resulted in low oxygen water. Low oxygen water is not, however, a very serious problem in Alaska because the environmental conditions generally prevailing lead to very high surface water concentrations of dissolved oxygen. The concentration of dissolved oxygen seems more controlled by the oceanography of the continental shelf than by locally imposed influences.

EVALUATION OF PREVIOUS PROGRAMS AND DISCUSSION OF TRENDS

Until recently, waste disposal in Alaska was done by the least expensive way. Industries and municipalities have generally discharged their primary wastes into streams, rivers, or estuaries without even the benefit of deep water outfall disperser systems. Little control of effluent quality or quantity was administered until the advent of the pulp mills in southeast Alaska and petrochemical plants in Cook Inlet.

The first modern waste disposal system in Alaska was that of the Collier Carbon and Chemical Company liquid ammonia and urea fertilizer plant located north of Kenai on the east banks of Cook Inlet. The company, after careful examination of the waters of Cook Inlet, including circulation, ammonium and nitrate cycling, and biological population assays, designed a discharge system which utilizes jet diffusers and the turbulence of the inlet to lower the concentration of the fertilizer ammonium well below harmful levels within about 10 feet of the discharge pipe. This system has operated according to design since 1969 with no evidence of harm to the environment.

Municipalities are presently facing the requirements for secondary sewage treatment before discharge into the environment. Studies conducted in connection with municipal effluents released into Cook Inlet from the city of Anchorage give no evidence that secondary treatment is necessary or even desired environmentally (Murphy et al., 1972); likewise there appears to be no reason to demand this level of treatment of other municipalities who discharge into the coastal waters of Alaska. Each situation and location should be examined to assess the capacity of the receiving waters to assimilate the planned discharge. The decision concerning secondary waste treatment plant requirements should rest on those findings. To systematically force most coastal Alaskan cities to construct secondary treatment plants when the environmental capacity to assimilate municipal waste is enormous, is not in the best public interest.

Many plants which process the fisheries products of the State of Alaska are also being forced to comply with the secondary treatment effluent requirements. In the past, these plants have discharged untreated wastes, often representing up to 75 percent of the catch by weight, into the water immediately adjacent to the plant, and have depended upon tides and scavenging organisms to keep the solid residues at a low enough level to avoid offensive surface exposure. Requirements now dictate that solids be removed and processed in some other manner. At Kodiak, the major Alaskan fishing port, many of these solid wastes are processed commercially and converted to an animal feed marketed on the west coast of the United States. The water soluble portion of the fish wastes also has considerable value for protein feed supplements, but such processing plants have not yet been constructed in Alaska. To treat these water soluble wastes by a secondary sewage treatment process appears unadvisable for two major reasons. First, the protein in the water has high food value; and second, discharge of untreated waste through outfalls designed to keep concentration levels compatible with the environment would at least return some of the energy to the system from which it was derived, thus yielding some environmental advantage. This process could in most cases be accomplished at a lower cost.

The recent trend in Alaska, because of enforcement by government regulatory agencies to adopt effluent standards uniformly administered throughout the country with no regard to environmental quality, can only lead to devastation of Alaska's renewable resources. We must understand the ecosystems involved well enough to assess possible damage resulting from the stress of added effluents. Discharge of any amount of wastes that might result in damage to an ecosystem is foolhardy. Likewise, it is ludicrous to impose restrictions on waste discharges if it can be clearly established that the system can easily handle the loading involved without damage. If the environment itself is the real concern, as it should be, then industries must develop and install effluent discharge systems that are compatible with the environmental situation in which they find themselves rather than being forced to meet some general specified waste or water quality standard. A scientifically alert and flexible attitude toward Alaska's effluent practices is badly needed as we begin developing the state's resources. A much better understanding of the oceanography of Alaskan coastal systems should be the first priority followed by a management plan responsive to environmental needs and not political expediency.

RESULTS WHICH OFFER DIRECT USE IN ALASKAN ESTUARINE MANAGEMENT

Throughout this paper we have attempted to point out the uniqueness of the Alaskan environment and emphasize the need for better environmental understanding upon which decisions can be wisely made that will protect it, and at the same time utilize it for waste disposal and extraction of the resources needed to benefit man. The concept of trade-offs becomes important in environmental management and, in general, is a viable philosophy to be used in Alaska.

To comply with a recent NPDES permit, to become effective January 1, 1977, a urea plant at Kenai will need to spend $1,500,000 in capital improvements and consume 500,000,000 BTU's of energy per day to reduce its present ammonia effluent (about 3500 kg/day) to meet the best practical technology for ammonia effluents. Documentation has shown that the ammonia currently released by this plant is not harmful and is probably beneficial to the biota of Cook Inlet, and the revised scheme would put the ammonia into the atmosphere where the environmental hazards are much greater. The expenditure of energy and capital investments for what appears to be of questionable value environmentally, cannot be justified. Even if there was a slight environmental advantage, the justification for using large capital and amounts of energy for marginal environmental improvement is probably of negative social benefit. Other cases in Alaska could be indicated, particularly where heated effluents are concerned, in which large expenditures of both money and energy are being imposed without realizing any apparent environmental benefits.

In today's modern world social benefit must weigh heavily on decisions to utilize energy to reduce effluent concentrations unless environmental benefits can be conclusively demonstrated as a result of this energy consumption. Most effluents of the chemical industry are waste materials to that industry. They could, however, be a feed stock of considerable value to the bioengineering industry. Alaska, with its great potential for aquaculture (Kelley and Hood, 1973), should turn its attention to using these wastes for enhancement of food or marine product producing systems. Some institutional barriers will need changing for such a system to be developed, but it seems of such importance in helping meet some of man's future needs that it should be thoroughly explored and activated as soon as possible. Perhaps a more rational approach, other than imposing strict effluent standards in Alaska, would be a requirement for converting waste materials into useful feed stocks for bioengineering projects including aquaculture. Would this not be an enlightened attitude directed toward solving mankind's ever increasing needs for food supplies?

REFERENCES

Baalsrud, K. 1967. Influence of nutrient concentration on primary production. In: T. A. Olsen and F. F. Burgess (eds), Pollution and Marine Ecology. Interscience Publishers, New York: p. 159–169.

Brickell, D. C. and J. J. Goering. 1970. Chemical effects of salmon decomposition on aquatic ecosystems. In: R. S. Murphy and D. Nyquist (eds), International Symposium on Water Pollution Control in Cold Climates. U.S. Government Printing Office, Washington, D.C.: p. 125–138.

Federal Water Quality Administration, Alaska Operations Office, Northwest Region. 1970. Effects of pulp mill wastes on receiving waters at Ward Cove, Alaska.

Hood, D. W., W. E. Shiels and E. J. Kelley (eds). 1973. Environmental Studies of Port Valdez. Institute of Marine Science, University of Alaska. Occasional Publication No. 3.

Kelley, E. J. and D. W. Hood (eds). 1973. Aquaculture in Alaska Workshop: Sitka, Alaska April 10–13, 1972. Institute of Marine Science. Public Information Bull. 73-1, University of Alaska.

Ketchum, B. H., C. L. Carey, and M. Briggs. 1949. Preliminary studies on the viability and dispersal of coliform bacteria in the sea. In: Limnological aspects of water supply and waste disposal. American Association for Advancement of Science, Washington, D.C.

Kinney, P. J., D. K. Button and D. M. Schell. 1969. Kinetics of dissipation and biodegradation of crude oil in Alaska's Cook Inlet. Present at the Joint Conference on Prevention and Control of Oil Spills: American Petroleum Institute; Federal Water Pollution Control Administration, December 14–17, 1969, New York, N.Y.

McRoy, C. P. and J. J. Goering. 1974. Coastal Ecosystems of Alaska. In: H. T. Odum, B. J. Copeland and E. A. McMahan (eds), Coastal Ecological Systems of the United States. The Conservation Foundation, Washington, D.C. 1:124–131.

Murphy, R. S., R. F. Carlson, D. Nyquist and R. Britch. 1972. Effect of waste discharges into a silt-laden estuary: A case study of Cook Inlet, Alaska. Institute of Water Resources, University of Alaska. Report AO, IWR 26.

Pease, B. C. 1974. Effects of log dumping and rafting on the marine environment of Southeast Alaska. USDA Forest Service General Technical Report PNW-22.

Pederson, L. R. 1965. United States. 1. Area and boundaries. In: Encyclopedia Americana. Americana Corp., New York 27: 473–475.

Pritchard, D. W. 1952. Estuarine hydrography. In: H. Landsberg (ed), Advances in Geophysics Academic Press, New York 1:243–280.

Rosenberg, D. H. 1972. Oil and gas seeps of the Northern Gulf of Alaska. In: D. H. Rosenberg (ed), A Review of the Oceanography and Renewable Resources of the Northern Gulf of Alaska. Institute of Marine Science, University of Alaska, Report No. R72-23: p 143–148.

Schaumburg, Frank D. 1973. The influence of log handling on water quality. Office Res. Monitor, EPA, Washington, D.C.

State of Alaska, Department of Environmental Conservation, Water Quality Control Section. 1971. Inventory of water dependent log handling and storage facilities in Alaska.

State of Alaska, Department of Health and Welfare, Division of Public Health. 1967. Water supply and waste disposal in the Gateway Borough.

United States Deparment of Commerce, National Oceanic and Atmospheric Administration, National Fisheries Service. 1973. Fisheries of the United States, 1972.

Zenkevitch, L. 1963. Biology of the Seas of the U.S.S.R. John Wiley and Sons, New York.

ENVIRONMENTAL STATUS OF HAWAIIAN ESTUARIES

STEPHEN V. SMITH
University of Hawaii
Kaneohe, Hawaii

ABSTRACT

Hawaiian estuaries are small but numerous, and they are of importance to the State of Hawaii. With a few exceptions, detailed environmental information about these estuaries is lacking. Circulation in the estuaries is sluggish. Many of the estuaries fail to meet water quality standards set by state law; this failure represents the combined effects of unrealistic standards governing excessive discharges. The major human stresses imposed on the estuaries are the introduction of nutrients, freshwater, and sediments. More research directed at the estuaries as total systems is needed.

INTRODUCTION

In simplest terms, an estuary is an area in which fresh and salt waters come together.* This mixing of waters has led to the development of a rich and productive coastal zone ecosystem, with an influence that extends far beyond the physiographic boundaries of the estuary. This biotic importance of estuaries, together with their widespread use for commercial and recreational purposes, mandates that a better understanding of estuarine ecosystems be available for the intelligent management and preservation of such a valuable resource.

Some Hawaiian estuaries contain beautiful quiet-water coral reef assemblages unlike any biotic community found elsewhere in the United States (Smith et al., 1973). The estuaries are breeding and spawning grounds for a variety of commercially valuable fishes (Miller, 1973; Watson and Leis, 1974). Several species of seabirds, listed as rare and endangered, inhabit the nearshore environment (Berger, in Armstrong, 1973). The estuaries are popular areas for fishing, boating, swimming, and camping. One estuary (Kaneohe Bay) also serves as the site for ongoing research by both the state and the federal governments. It is in the interest of ecology, economy, recreation, and scientific research that this report has been prepared.

According to the report by Cox and Gordon (1970), approximately 50 features in the state may be broadly classified as estuarine systems. Figure 1 is an index map of the Hawaiian Islands, and Figures 2 through 6 show each of the Hawaiian Islands which have significant estuaries. The locations of these features are noted. Most Hawaiian estuaries are small, with water areas well under 1 km². Existing charts for most of these features are not sufficient to show significant bathymetric or other detail. The larger estuaries and other embayments are illustrated in the atlas by Grace (1974). Even the two largest estuaries are small in comparison with their North American (or other continental) counterparts. These estuaries are important, nonetheless. Because these features are small, they are particularly vulnerable when subjected even to relatively minor environmental insults.

The total estuarine area of the state is estimated here to be about 100 km². It is impossible to judge accurately the coastal area outside the estuaries but within the legally defined estuarine zone; however, some limits can be imposed. If the mean width of the estuarine zone is 50 meters (surely an overestimate for most of the Hawaiian coastline), then only another 100 km² of estuarine zone are added to the 100 km² estimated for the true estuaries, bringing the total Hawaiian estuarine zone to less than 200 km².

This figure is probably satisfactory within the legal limits of the estuarine zone, but it is deceptive in terms of the importance of the Hawaiian coastal zone. Because the State of Hawaii as a whole is a small watershed in comparison with the North American continent, the zone of freshwater influence about the Hawaiian Islands is small in comparison with the zone of such influence off North America. In relative terms, however, the zone vulnerable to impact from activities on land may not be greatly different from Hawaii to the mainland of North

* "... the term 'estuarine zones' means an environmental system consisting of an estuary and those transitional areas which are consistently influenced or affected by water from an estuary such as, but not limited to, salt marshes, coastal and intertidal bays, harbors, lagoons, inshore waters, and channels, and the term 'estuary' means all or part of the mouth of a navigable or interstate river or stream or other body of water having unimpaired natural connection with open sea and within which the sea water is measureably diluted with fresh water derived from land drainage." (P.L. 89-753)

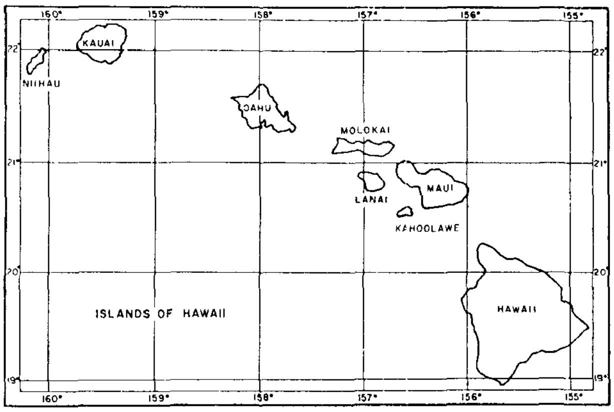


FIGURE 1.—The main islands of the Hawaiian chain. Of these, Niihau, Lanai, and Kahoolawe lack significant estuaries.

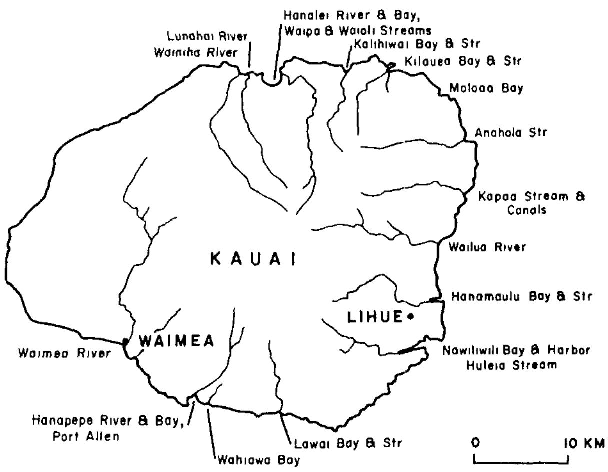


FIGURE 2.—Kauai Island, estuaries.

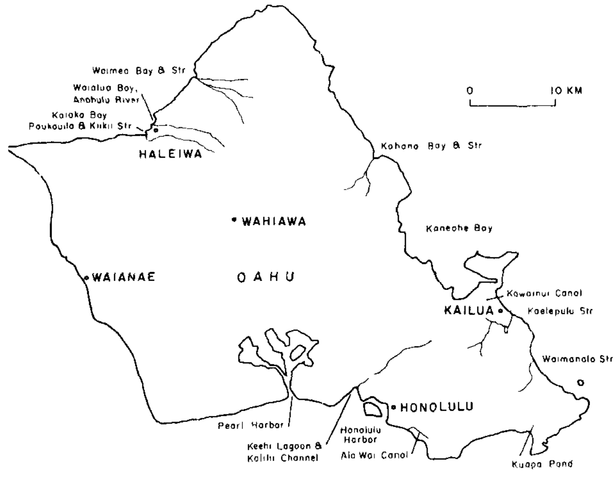


FIGURE 3.—Oahu Island, estuaries.

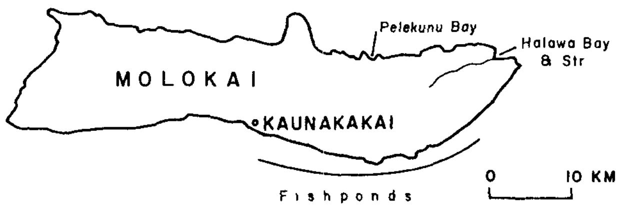


FIGURE 4.—Molokai Island, estuaries.

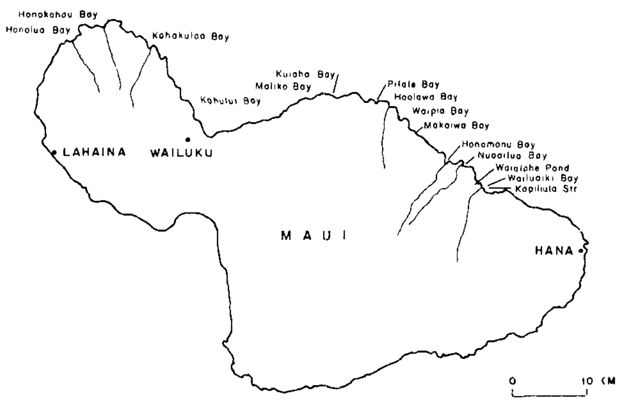


FIGURE 5.—Maui Island, estuaries.

America. Indeed, the large bights which scallop most of the Hawaiian Islands (Figures 2-6) are already the subjects of concern to local environmental scientists and should be the subject of another report such as this one.

Table 1 helps to put the scale of Hawaiian estuaries into proper perspective. The ratio of estuarine area to the state's land area is only about half the equivalent ratio for the total United States. However, the ratio of tidal shoreline length to total land area is an order of magnitude larger for Hawaii than for the rest of the nation. That is, there is a close spatial relationship between the land of the state and the coastline.

The distribution of population is also instructive. The recent Atlas of Hawaii (Armstrong, 1973) reveals that about one-third of the state's population lives immediately adjacent to one of the major estuaries in the state. Both culture and climate have acted to enhance the utilization of estuaries and the coastal zone by the people of Hawaii, so that even those persons who do not live near the water are likely to frequent it.

There are also small embayments in the state (e.g., Hanauma Bay, Oahu; Honaunau and Kealakekua Bays, Hawaii) which are renowned for their beautiful reefs. These bays are subject to insufficient freshwater inflow to qualify as estuaries, but nevertheless could be devastated with a relatively small degree of thoughtless activity. The summaries of the biology

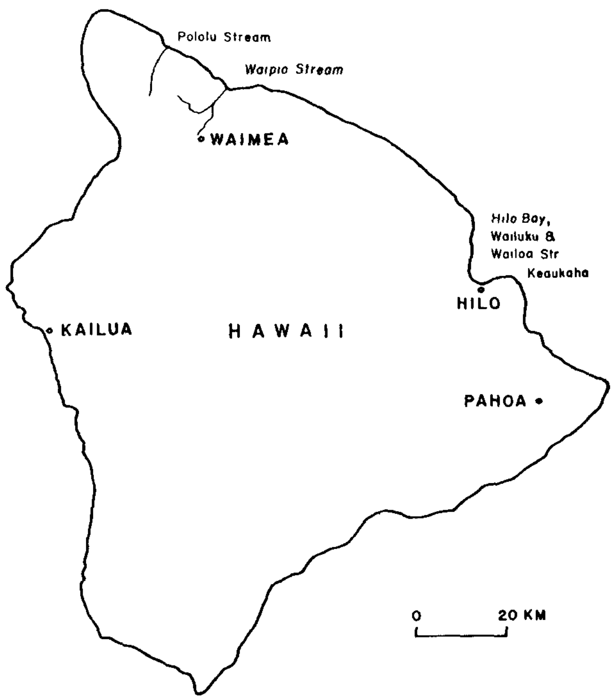


FIGURE 6.—Hawaii Island, estuaries.

Table 1.—*Comparison of Hawaiian estuarine dimensions with the scale of estuaries found in the remainder of the U.S.*

	U.S. exclusive of Hawaii	Hawaii
Total area (km^2)	9,350,000	16,700
Estuarine area (km^2)	117,000	100
Tidal shoreline (km)	136,000	1,700
Estuarine area/total area	0.013	0.006
Tidal shoreline/total area	0.015	0.10

of Kealakekua and Honaunau Bays (Doty, 1968a and b) are particularly instructive in this regard.

Kaneohe Bay is the largest well-defined embayment in the state. This embayment on the northeastern coastline of the island of Oahu (Figure 3) occupies an area of about 50 km^2, less than half of which is truly estuarine in character. Pearl Harbor, Oahu (Figure 3), with a water area of about 20 km^2, is the second largest estuary in the state and may be considered a classical estuary throughout its extent. These two estuaries are also the most widely studied Hawaiian estuarine systems, although even they are insufficiently known. Other large Hawaiian estuaries include the Keehi Lagoon/Honolulu Harbor complex, Oahu (Figure 3); Nawiliwili Harbor, Kauai (Figure 2); and Hilo Harbor, Hawaii (Figure 6). Some data on water quality and circulation are available for these last three systems, but virtually no biological information, other than hearsay and very limited biological observations, is available for these estuaries.

Because of the general lack of adequate information, an attempt to document the environmental status of the Hawaiian estuarine zone has proven to be a frustrating undertaking. Some aspects of this problem for the state as a whole have been recently summarized by Cox and Gordon (1970). That report dealt with estuarine water quality, a subject for which there is a great deal of information. Even that data base is, for the most part. insufficient for establishing trends through time. The circulation patterns of several Hawaiian estuaries have also been described, although these data have not been so recently summarized as has water quality. Quantitative information about the biological status of most Hawaiian estuaries is almost totally lacking. The biology of only two of the larger Hawaiian estuaries (Kaneohe Bay and Pearl Harbor) has been examined in any detail; some fragmented information about a few other estuaries is available. Much of the information which has been collected is difficult to locate because it is buried in private or government files. It would be well worth the expense to retrieve this information. There are numerous studies of particular Hawaiian nearshore regions aside from estuaries. As discussed above, the degree of terrestrial freshwater influence on these regions is so small that they do not qualify as part of the estuarine zone, although even these areas may be subject to damage, potentially or presently, by human activities along the Hawaiian coastline.

ESTUARINE CIRCULATION

Knowledge of the circulation of an estuary is of particular importance in assessing environmental integrity, because the characteristics of water circulation determine the residence time of pollutants in the system, or portions thereof, and hence determine the possible damage those pollutants may do to the system. There is limited information describing some aspects of circulation in numerous Hawaiian estuaries.

The most comprehensive survey to date on this subject is that of Laevastu et al., (1964), dealing with the general currents of Hawaiian inshore waters. Much of that information, plus some additional observations, is reported in the recent Marine Atlas of Hawaii (Grace, 1974). Detailed circulation studies of a few Hawaiian estuaries are available (e.g., Bathen's 1968 description of Kaneohe Bay; and Buske's 1974 description of Pearl Harbor). Most available studies of Hawaiian estuarine circulation are far less comprehensive than the ones cited above, involving current measurements at only a few localities within any particular estuary and under a narrow range of oceanographic conditions.

Tidal ranges are relatively small in Hawaii (about 1 meter), and river input into estuaries is generally small. Except during periods of heavy runoff, the larger estuaries are not strongly stratified. Largely lacking the energy sources of tidal flushing and major river flow, the circulation of the estuaries is strongly related to wind patterns (e.g., Buske, 1974), to wave-driven flow into the estuarine areas (Bathen, 1968), and to tidal and wind-driven ocean currents sweeping by, outside of the estuaries (Wyrtki et al., 1967).

Despite their small size, Hawaiian estuaries generally flush rather slowly, chiefly because water movement depends, to a large extent, on the least effective of the previously-mentioned energy sources. Buske (1974) has estimated that some of the water in Pearl Harbor may have a residence time of more than four days. Dr. J. Caperon (Hawaii Institute of Marine Biology, personal communication) has suggested that water may reside in the more enclosed parts of Kaneohe Bay for several weeks. These relatively long residence times for estuarine waters and their included pollutants have obvious implications for the biota of Hawaiian estuaries and emphasize the importance of intelligent, informed estuary management.

WATER QUALITY

Water quality is surely the best-documented general environmental parameter of Hawaiian estuaries. The fact is undoubtedly true because water quality standards can be objectively spelled out, routinely measured, and thus easily legislated. Table 2 gives the state's definitions for the three coastal water classes; from best to worst, these are AA, A, and B. Cox and Gordon (1970) have summarized the water quality of Hawaiian estuaries relative to those standards, and a modified version of their summary is presented as Table 3. Several important aspects of water quality emerge from these data.

Most of the waters supposed to be pristine (AA) are considered by Cox and Gordon (1970) to be so. Kaneohe Bay is probably the most conspicuous exception to this generality. It is obvious from the data presented by Cox and Gordon that as soon as some deterioration of water quality is permitted or occurs (to class A or B), there is little chance that even these lower standards will be met. Over half the estuaries assesed by Cox and Gordon

Table 2.—Water quality standards pertinent to Hawaiian estuaries. From Cox and Gordon (1970)

	Class of water		
	AA	A	B
Substance			
A. BASIC			
1 Settleable materials forming objectionable deposits	0	0	0
2 Floating debris, oil, scum, etc.	0	0	0
3. Substances producing objectionable color, odor, taste or turbidity	0	0	0
4. Materials, including radionuclides, in concentrations or combinations which are toxic or produce undesirable physiological responses in human, fish and other animal life and plants	0	0	0
5. Substances, conditions, or combinations producing undesirable aquatic life	0	0	0
6. Soil from controllable accelerated erosion	0	0	0
B. SPECIFIC			
1. Microbiological			
A. Coliform bacteria (/100 ml)			
Median	≤ 70	1000	
Upper decile	≤	2400	
Maximum	≤ 230		
B. Fecal coliforms			
30-day mean	≤ 200	400	
30-day upper decile	≤ 400	1000	
2. pH			
Departure from natural	≤ 0.5	0.5	0.5
Maximum except from natural causes	≤ 8.5	8.5	8.5
Minimum except from natural causes	> 8.0	7.0	7.0
(except fresh tidal water)	≥ 7.0		
3. Nutrients (mg/liter)			
Total phosphorus	≤ 0.020	0.025	0.030
Total nitrogen	< 0.10	0.15	0 20
4. Dissolved oxygen (mg/liter)			
(except from natural causes)	≥ 6.0	5 0	4.5
5. Total dissolved solids.			
TDS departure from natural (% of natural fluctuation)	10		
TDS (mg/liter)	≤ 28,000		
6. Temperature (°F)			
Departure from natural	≤ 1.5	1.5	1.5
7 Turbidity			
Secchi disk extinction coefficient, departure from normal (%)	≤ 5	10	20
8. Radionuclides			
(MPCn values by NBS)	≤ 1/30	1/30	1/30
(concentration)	≤ USPHS values for drinking water		
(concentration in harvested organisms)	≤ Federal Radiation Council recommended limits		

Table 3.—Summary of water quality relative to standards for coastal waters. Modified from Cox and Gordon (1970)

Class of water	Total* estuaries	Number probably meeting standards	Number probably not meeting standards	Number with insufficient data
AA	14	11	3	0
A	65	5	39	21
B	10	1	5	4
Total	89	17	47	25

* Estuaries with two or more classes of water quality receive multiple listing in this table.

apparently fail to meet the legislated water quality standards, and most of the violations involve class A waters. Most of the class B waters for which data are available fail to meet even these very permissive standards. Even though water quality has been cited as the best-known environmental aspect of the Hawaiian estuaries, with rare exception, the knowledge of water quality is also, in itself, insufficient to point to either trends of water quality change with time for a particular estuary or spatial trends within the estuary.

Some of the failure to meet legislated standards lies with the standards themselves; they are artificially imposed water quality limits with little allowance for natural variations within those limits. For example, some nearshore areas with natural freshwater seeps may locally exhibit salinities and nutrient levels outside the legislated limits (e.g., Honaunau Bay; Doty, 1968). Natural freshwater seepage may contain, for instance, many times as much phosphate as open ocean waters, which form the basis for legislation. Moreover, departures from legislated limits may not harm particular environments. In other instances these standards are probably too permissive for maintaining biological integrity. We must conclude that water quality standards are not adequate measures of estuarine biological integrity.

Table 4.—Summary of recurrent stresses, by island*

Development	Kauai	Oahu	Molokai	Maui	Hawaii	Total
Water	12***	6	0	8	3	29
Agricultural						
Sugar cane	12	5	0	2	3	22
Pineapple	1	3	0	4	0	8
Taro	4	1	0	1	1	7
Ranching	14	7	1	6	0	28
Miscellaneous	0	1	0	0	0	1
Industrial						
Sugar factory	1	1	0	0	1	3
Pineapple factory	1	1	0	1	0	3
Petroleum refinery	0	1	0	0	0	1
Thermal discharge	1	2	0	1	0	4
Quarry	1	0	0	0	0	1
Miscellaneous	1	5	0	1	1	8
Urban						
Sanitary sewage	2	8	0	1	1	12
Urban cesspools	9	11	0	2	1	23
Estuarine						
Commercial/military harbor	2	3	0	1	1	7
Small boat harbor	2	5	0	1	1	9
Sewage outfall	2	5	0	1	1	9
Fishing**	2	2	0	0	1	5
Recreational**	8	9	0	0	1	18
Number of Estuarine Systems	15	12	3	11	4	45

* Niihau, Lanai, and Kahoolawe do not have significant estuaries.

** Some fishing and recreational use occurs in most Hawaiian estuaries. The estuaries listed experience heavy use.

*** These numbers represent the number of estuaries subjected to each kind of development.

RESOURCE DEVELOPMENT RELATED TO HAWAIIAN ESTUARIES

Cox and Gordon (1970) summarized the resource development pertaining to Hawaiian estuaries. Their list, divided into various estuarine types within each estuarine system, is summarized here in terms of the 45 major estuarine systems within the state. The resource developments can be broadly divided into water, agricultural, industrial, urban, and estuary; and each of these divisions can in turn be subdivided.

Table 4 lists the divisions and subdivisions of resource development and their distribution. Water development, almost entirely in the form of irrigation or storage, appears to be the least disruptive use of the resources. It simply involves reduction of water flow into the estuaries, with consequent potential alteration of salinity and circulation patterns. Most of the estuaries in the state experience some water loss or diversion for irrigation.

A variety of agricultural developments is felt by estuaries of the state. Moreover, the open-coast, non-estuarine zones are subject to much the same developments. Ranching and sugar cane cultivation are the two most recurrent agricultural developments affecting Hawaiian estuaries, with most estuaries receiving materials from one or more of these.

Industrial developments are about as diverse as the agricultural activities but are much more localized. There are miscellaneous industrial developments, primarily on the island of Oahu. The three major discrete categories of insults from industry are thermal discharges, discharges from sugar factories, and discharges from pineapple factories. It should be emphasized that these three activities also exert profound influence on the open coastline. The major thermal effect is simply that of heating the receiving water. Discharges from sugar factories include sediment, bagasse and other cane trash, nutrients, soluble organics, and bacteria. The pineapple factory discharges include pineapple wastes and soluble organics.

Urban discharges affect most Hawaiian estuaries. Those areas with sanitary sewage disposal will nevertheless contribute trash, detergents, miscellaneous industrial pollutants, nutrients, and bacteria during any period of runoff (i.e., heavy rains). Those areas served with cesspools will contribute all of the above pollutants, at higher levels. Most urban areas, but particularly the multiplying housing developments less than 10 years old, are particularly susceptible to the erosion and runoff of large volumes of water and sediment.

The last category of resource development is that of the estuaries themselves. In terms of numbers of estuaries affected, various recreational uses prevail. These activities, as well as fishing, introduce miscellaneous boat sewage and trash into the waters. The uses of estuaries in the state for commercial/military harbors and small boat harbors contribute the same kind of wastes (but in larger amounts than recreational uses) plus oil, bilge discharges, industrial pollutants of various forms (including heavy metals), and disruptive activities from dredging. The stirring of the water column and sediment has been recently pointed out as almost certainly important (Evans et al., 1974), but it is not clear whether the net effect of this activity is beneficial or deliterious.

EFFECTS OF RESOURCE DEVELOPMENT ON HAWAIIAN ESTUARINE BIOTA

Available information is inadequate for providing an assessment of the biological status of most Hawaiian estuaries. Only Pearl Harbor and Kaneohe Bay have been studied in any detail. Hence an alternative approach for discussing the status of these communities is taken. The various resource developments listed in Table 4 lead to a relatively small variety of kinds of stresses (or stimuli) to which the environment is subjected. It is possible either to document or to speculate how the biotic communities could be expected to respond to these stimuli. The stresses considered here include salinity variation, sediment discharges, nutrient enrichment, and thermal enrichment. Insufficient data are available for tropical organisms to judge the damages from oil, heavy metal, or biocide pollution, but these and related stresses are judged from evidence elsewhere to be severely detrimental to marine life.

Hawaiian estuaries are subjected to two directions of salinity variation by human intervention. Use of stream water for irrigation lowers discharges into numerous Hawaiian estuaries, hence raises their salinities. Timbol (1972) studied the species distribution of Kahana estuary (Oahu) and determined the salinity tolerances of selected species. Over the salinity range examined (9 to 19‰ (parts per thousand), or 25 to 50 percent oceanic salinity) the number of species increases with increasing salinity. It is safe to assume that below 9‰, the species count increases with decreasing salinity as freshwater organisms became dominant. If the bulk of Hawaiian estuarine waters are considered to be more saline than 9‰, then lowering the discharges of stream water into the estuaries should cause an intrusion of marine organisms into the estuaries.

There is another, perhaps more devastating, salinity variation imposed upon some Hawaiian estuaries—that of high freshwater runoff. The effect has been well-documented in Kaneohe Bay, where changing patterns of land usage (including paving a substantial portion of the watershed and baring many acres of topsoil during the construction of housing) have resulted in tremendous flood discharge into that bay. Banner (1974) has demonstrated that such runoff creates a freshwater wedge on top of the more dense seawater. During a single storm in 1965, such a wedge killed marine organisms (most conspicuously corals) to a depth of almost two meters in some portions of the bay. Unpublished studies by Smith, Jokiel, Key, and Guinther (Hawaii Institute of Marine Biology) suggest that biotic microcosms typical of shallow water communities found in the bay can survive two or more days of salinities as low as 25‰ with little damage, but that salinities below 20‰ are immediately detrimental to most of the biota. Hence, such freshwater discharges lowering the salinity to near 0‰ can be expected to be immediately damaging to intertidal and immediate subtidal biota in the marine portions of the estuaries.

Sediment discharges into Hawaiian estuaries are a conspicuous parameter arising from numerous human activities. As described above, runoff from changing land use is a prominent feature along much of Hawaii's coastline. Many streams have been channelized in urban developments and are now more prone to flooding (Banner, 1974). That runoff tends to run red with Hawaiian soil. At least one industry—sugar milling—presently contributes substantial amounts of sediments (mostly to the open coast rather than to estuaries). Again, data from Kaneohe Bay are instructive. Roy (1970) estimated that 100 thousand tons of land-derived sediment per year are being deposited in that bay. Later estimates of the fraction of Kaneohe Bay sediments which are land-derived (Smith et al., 1973) indicate that Roy's figure may be low by a factor of two.

Such sediment inputs are deliterious to estuarine biota in a number of ways. They may directly smother corals and other organisms which live at the interface between the substratum and the waters of estuaries. They may contain material toxic or noxious to the biota. In the water they may block the light from those organisms which photosynthesize organic products. They may foul the feeding mechnisms of those organisms which filter food from the water. Organic material in the sediments may alter the food-web relationships of the community in question.

Another form of sediment input appears to be fading from the Hawaiian scene—the discharge of finely-milled cane trash (bagasse) from sugar mills. Grigg (1972) has demonstrated that even on open coastlines there may be tens of meters of accumulated bagasse on the sea floor offshore from these mills. Coral-reef communities subjected to such inputs have been completely demolished. This material is now finding use in the sugar industry as a valuable fuel (R. Webb, Hilo Coast Processing Company, personal communication), so this input should terminate. Grigg's data demonstrate that the material flushes from the open coasts within a few years after the bagasse input stops. As yet, the time required for community recovery is unknown. Biotic population of submerged lava flows is apparently measured in decades (Grigg and Maragos, 1973). The flushing and repopulation characteristics of an estuary may not be even that rapid.

Most Hawaiian estuaries are probably subjected to some nutrient enrichment. Of course, elevated nutrient levels are characteristic of most estuarine systems, and this is one reason (as previously mentioned) that even some unpolluted waters of the state may fail to meet the legislated water quality criteria. Nevertheless, it seems likely that Hawaiian estuaries may not naturally experience the levels of eutrophication which typify mainland estuarine systems. Caperon et al., (1971) have demonstrated that the southern end of Kaneohe Bay is a highly eutrophic system which is apparently not limited by nutrient levels in the water, and Krasnick (1973) has shown that this eutrophication has increased the primary productivity of that bay over the past decade. A bulbous green alga which may be found as small fist-sized masses on most Pacific coral reefs, has grown to gargantuan size (some masses being a meter or more across) in Kaneohe Bay, apparently in response to this eutrophication (Banner, 1974; Soegiarto, 1972; Smith et al., 1973). There is evidence (Banner, 1974; Maragos, 1972) that this alga has severely damaged the coral community of the bay and has also otherwise altered the community structure of the reefs. The growth of the alga is likely to represent the combined effects of high nutrients and low grazing pressures by fishes or other reef herbivores.

Pearl Harbor is another estuary which has been subjected to high nutrient inputs. Apparently phytoplankton blooms ("red tides") are occurring with increasing frequency and over an increasing portion of that harbor. (Evans et al., 1974).

Some Hawaiian waters are subjected to thermal enrichment. Until recent studies by Jokiel et al., (1974) and Jokiel and Coles (1974) it had been assumed that Hawaii, with its largely tropical biota in a subtropical setting would probably not be greatly damaged by thermal enrichment. That does not seem to be the case. Summertime ambient temperatures are about 27°C, and that temperature is about the optimum temperature for corals and, apparently, for other biota found on Hawaiian reefs. These organisms may be able to tolerate an enrichment of 1 or 2°C above ambient, but further temperature elevations are detrimental. Even open water reefs have been damaged by thermal enrichment (Jokiel and Coles, 1974), albeit very locally.

Table 5 lists the various resource developments, the number of estuaries subjected to each, and the likely stresses from each. The column sums provide an index of the relative importance of the various stresses on Hawaiian biota. Nutrient enrichment, decreased salinity, and sediments are by far the most recurrent stresses imposed upon the estuarine communities. Inputs of biocides and heavy metals are also important. Only 45 estuarine systems were used in the construction of Table 4, hence Table 5; yet all of the above insults appear over 45 times in Table 5. This situation addresses the fact that the estuaries are for the most part subjected to multiple stresses—a consideration which will probably make the job of removing insults all the more difficult.

Table 6 summarizes the expected biotic responses to five major stresses. It is clear that more experimental data are sorely needed to verify most of these responses in tropical communities. Equally needed is an improved data base describing the Hawaiian estuaries. In particular, there appears to be a lack of foresight in obtaining baseline data before any projected environmental alteration—whether that alteration is predicted to be good, bad, or benign—or to combine that data with post-alteration descriptions, in order to describe the biotic responses to that alteration.

NEEDS FOR ENVIRONMENTAL MANAGEMENT OF HAWAIIAN ESTUARINE SYSTEMS

Table 5 suggests that nutrients may be the primary stressing parameter imposed upon Hawaiian estuaries. Virtually every human activity appears to have the potential of delivering nutrients to these estuaries. Thus, any regulation to lower discharges appears likely to improve the nutrient status of Hawaiian nearshore waters. Various considerations suggest that a change from uncontrolled nutrient input to controlled input may be as satisfactory as

Table 5.—Stresses imposed by various resource developments.

	No. of estuaries	Decreased salinity	Increased salinity	Sediment	Bagasse	Nutrients	Thermal	Oil	Metals	Biocides
Water	29		×							
Agriculture										
Sugar cane	22	×		×		×				×
Pineapple	8	×		×		×				×
Taro	7	×		×		×				×
Ranching	28	×		×		×				
Miscellaneous	1	×		×		×				×
Industry										
Sugar	3	×		×	×	×				
Pineapple	3	×				×				
Petroleum	1							×		
Thermal	4						×			
Quarry	1			×						
Miscellaneous	8	×		×		×				
Urban										
Sanitary sewage	12	×		×		×			×	×
Cesspool	23	×		×		×			×	×
Estuaries										
Commercial/military harbor	7					×		×	×	
Small boats	9					×		×	×	
Sewage	9	×				×			×	
Fishing	5					×				
Recreational	18					×				
Total		124	29	113	3	163	4	17	60	73

no input—or perhaps more satisfactory. Without going into these considerations, suffice it to point out that the uncontrolled discharge of nutrient-laden water into Hawaiian estuaries must be slowed if these environments are to be preserved and maintained. Improved sewage treatment facilities are a major move in the direction of controlling this nutrient flow. The State of Hawaii is moving toward this goal. Discharges of treated or untreated sewage into the estuaries must stop. Indeed, federal and local agencies are working towards this goal; the 15,000 m^3/day of sewage presently being discharged into Kaneohe Bay is scheduled to be diverted by the end of 1977. Runoff from agricultural regions may be more difficult to control, but it should be minimized. Dumping of material from ships is a debatable practice at sea; in harbors, it should not be allowed.

Slowing the freshwater and nutrient inputs into the estuaries should simultaneously stop much of the sediment input. Hence that input need not be discussed as a separate topic.

Finally, more data are needed. The water quality data, which are collected routinely, are certainly vital, but they do not substitute for an adequate knowledge of the organisms themselves. Because biotic data are more difficult to gather, the techniques for gathering and reporting these data should be increasingly researched and developed. Some sort of local data bank for central storage of these data is also needed; with adequate funding, the Hawaii Coastal Zone Data Bank (University of Hawaii) could serve that function. Increased funding is necessary to demonstrate quantitatively the biotic responses to various environmental stresses. Such work should include both field observation and laboratory experimentation. The biotic experimental and observational work cannot be expected to yield

Table 6.—Likely effects of major stresses on estuarine biota.

Nutrient Enrichment

Eutrophication, algal blooms (benthic and planktonic), oxygen stress, alteration of community structure through food-web modification or competitive pressures, buildup of organic material in sediment.

Lowered Salinity

Abrupt destruction of marine communities.

Sedimentation

Smothering, light blockage, blockage of feeding mechanisms, introduction of adsorbed toxicants.

Biocides

Possible abrupt destruction of marine communities or portions thereof. Buildup in marine organisms, with possible long-term effects on these organisms or on man.

Heavy Metals

Similar to biocide effects.

short-term results. Because of the great disparity in the longevities of organisms in any community, the total community responses to external stimuli take years. Therefore, the necessary field or laboratory observation times must be of similar magnitude. Particular attention needs to be paid to low stress levels as they affect total communities. The day of assessing environmental insults from lethal bioassays over periods of days on a few arbitrarily chosen organisms should be over. For the most part, Hawaiian estuaries, or any other ones for that matter, are not subjected to that kind of stress regime. Yet Hawaiian estuaries are obviously changing in response to human perturbations. A new look is necessary to learn why.

It is certainly desirable that EPA fund a portion of the much-needed research, but other federal, state, and local governmental agencies, and private industries should fund environmental research as it pertains to the effects of their activities on the estuarine environment. Much of this funding could be handled in terms of some kind of "blind trust" and be administered by an appropriate agency, so that the funding agencies or industries could not be questioned about their influence on the research.

Multidisciplinary, total-system research and monitoring must be encouraged and amply funded. It is the lack of efforts such as these which makes realistic assessment of the total environment not entirely satisfactory. Research by the Hawaii Environmental Simulation Laboratory (University of Hawaii) is a step in the right direction. Their work is also not entirely satisfactory; it concentrates primarily on terrestrial considerations (hence inputs to estuaries) without adequate consideration of effects on receiving waters and their biota. Nevertheless, that kind of study carries the needed potential for interaction between research units and governmental planning agencies. That kind of effort needs expansion to include the marine environment.

The small size of both the Hawaiian estuaries and the watershed draining into them makes these systems particularly tractable to total-system description and analysis. It is therefore appropriate that Hawaii be the site for concentrated efforts to describe and improve the environmental status of estuaries.

REFERENCES

Armstrong, R. W. (ed.). 1973. Atlas of Hawaii. Univ. Hawaii Press.

Banner, A. H. 1974. Kaneohe Bay, Hawaii: urban pollution and a coral reef ecosystem. In: Proc. Second Int. Coral Reef Symp. V. 2, p. 685–702.

Bathen, K. H. 1968. A descriptive study of the physical oceanography of Kaneohe Bay, Oahu, Hawaii. Univ. Hawaii, Hawaii Inst. Marine Biol. Tech. Report 14.

Berger, A. J. 1973. In: R. W. Armstrong (ed), Atlas of Hawaii. Univ. Hawaii Press.

Buske, N. L. 1974. Tides, runoff and currents. Section 3.3. In: E. C. Evans, III et al., Pearl Harbor biological survey—final report. Naval Undersea Center TN1128, Hawaii Laboratory.

Caperon, J., A. S. Cattell and G. Krasnick. 1971. Phytoplankton kinetics in a subtropical estuary: eutrophication. Limn. Ocn. 16:599–607.

Cox, D. C. and L. C. Gordon. 1970. Estuarine pollution in the State of Hawaii. A statewide study on estuarine pollution in the State of Hawaii. Univ. Hawaii, Water Resources Research Center Tech. Report 31, V. 1.

Doty, M. S. 1968a. Biological and physical features of Kealakekua Bay, Hawaii. Univ. Hawaii, Hawaii Botanical Science Paper No. 8.

Doty, M. S. 1968b. The ecology of Honaunau Bay, Hawaii. Univ. Hawaii, Hawaii Botanical Science Paper No. 14.

Evans, E. C. III et al. 1974. Pearl Harbor biological survey—final report. Naval Undersea Center TN1128, Hawaii Laboratory.

Grace, J. M. (ed). 1974. Marine Atlas of Hawaii, Bays and Harbors. Sea Grant Misc. Report UNIHI-SEAGRANT-MR-74-01. Univ. Hawaii Press.

Grigg, R. W. 1972. Some ecological effects of discharged sugar mill wastes on marine life along the Hamakua Coast, Hawaii. In: Papers presented Jan. 1972 to May 1972. Water Resources Seminar Series No. 2. Univ. Hawaii, Water Resources Research Center, pp. 27–45.

Grigg, R. W. and J. E. Maragos. 1973. Recolonization of hermatypic corals on submerged lava flows in Hawaii. Ecology 55:387–395.

Jokiel, P. L. and S. L. Coles. 1974. Effects of heated effluent on hermatypic corals at Kahe Point, Oahu. Pac. Sci. 28:1–18.

Jokiel, P. L., S. L. Coles, E. B. Guinther, G. S. Key, S. V. Smith and S. J. Townsley. 1974. Effects of thermal loading on Hawaiian reef corals. Final Report for EPA Grant #18050DDN.

Krasnick, G. J. 1973. Temporal and spatial variations in phytoplankton productivity and related factors in the surface waters of Kaneohe Bay, Oahu, Hawaii. M. S. Thesis, Univ. Hawaii.

Laevastu, T., D. E. Avery and D. C. Cox. 1964. Coastal currents and sewage disposal in the Hawaiian Islands. Univ. Hawaii, Hawaii Inst. Geophys. Report 64.

Maciolek, J. M. and R. E. Brock. 1974. Aquatic survey of the Kona Coast ponds, Hawaii Island. Univ. Hawaii, UNIHI-SEAGRANT-AR-74-04.

Maragos, J. E. 1972. A study of the ecology of Hawaiian reef corals. Ph.D. Thesis, Univ. Hawaii.

Miller, J. M. 1973. Nearshore distribution of Hawaiian marine fish larvae; effects of water quality turbidity and currents. Proc. Int. Symp. on Early Life History of Fish, Oben, Scotland.

Roy, K. J. 1970. Change in bathymetric configuration, Kaneohe Bay, Oahu, 1882–1969. Univ. Hawaii, Hawaii Inst. Geophys. Report 70-15.

Smith, S. V., K. E. Chave and D. T. O. Kam (in collaboration with others). 1973. Atlas of Kaneohe Bay: a reef ecosystem under stress. Univ. Hawaii, UNIHI-SEAGRANT-TR-72-01.

Soegiarto, A. 1972. The role of benthic algae in the carbonate budget of the modern reef complex, Kaneohe Bay. Ph.D. Thesis, Univ. Hawaii.

Timbol, A. S. 1972. Trophic ecology and macrofauna of Kahana Estuary, Oahu. Ph.D. Thesis, Univ. Hawaii.

Watson, W. and J. M. Leis. 1974. Ichthyoplankton of Kaneohe Bay, Hawaii. A one-year study of fish eggs and larvae. Univ. Hawaii, UNIHI-SEAGRANT-TR-75-01.

Wyrtki, K., J. B. Burks, R. C. Latham and W. Patzert. 1967. Oceanographic observation during 1965-1967 in the Hawaiian Archipelago. Univ. Hawaii, Hawaii Inst. Geophys. Report 67-15.

This paper is Contribution No. 470 of the Hawaii Institute of Marine Biology.

INDUSTRIALIZATION EFFECTS

THE EFFECTS OF INDUSTRIALIZATION ON THE ESTUARY

ROBERT B. BIGGS
University of Delaware
Newark, Delaware

ABSTRACT

Industrial dependence on the estuary is restricted to those industries which rely on the estuary for waterborne transportation, for process water, or for products derived from the estuarine waters or bottom sediments. Among these, crude oil handling, refineries and petrochemical plants, utilities, iron and steel production, paper manufacturing, and sand and gravel extraction are the more important industries. Channel dredging, spoil disposal, and a wide range of pollutants resulting from industrial discharge are described.

Responsible federal agencies seem to be approaching the problem of industrial pollution from the perspective of reducing impacts by adopting water quality standards. In the short term, that is the most expedient solution. In the longer term, though, we must assess the possibility of reducing impacts by relocating certain estuarine-dependent industrial centers to new, more environmentally acceptable sites.

INTRODUCTION

When the United States was still an agriculture based society, ports were developed to transport goods and products from the hinterland. Ports were generally located as far inland as possible and road-rail transport systems were developed in response to port location. As the country evolved into an industrialized society, these ports became the hubs of industrial activity. Industrialists took advantage of the fact that water transportation for the shipment of raw materials and products was cheap, the harbors contained abundant water for cooling and waste disposal, and a supply of workers was already available. Through the late 19th and early 20th centuries, industrial activity, the quantity and diversity of effluents, and the population all increased around these ports. Technology of ship construction developed so that drafts of larger ships grew beyond the water depths in most of these ports. Because major industries were located at the ports, large dredging programs were undertaken to deepen the channels. After the channels were deepened, new industries had to locate along them to receive or ship materials.

Throughout the development phase of the ports, occasional fish kills would occur and there was a general decline in commercial fishery production of our estuaries. Beginning in the mid-20th century, researchers studying estuarine processes began to document the biological importance of the estuary as a spawning and nursery ground for a significant part of the entire coastal area. Oceanographers learned that circulation of waters in estuaries is generally weak, and that they have a limited capacity to absorb pollutants.

We find ourselves in the present situation of having major industrial centers, dependent on water transportation, located on estuaries which are not deep enough to handle modern ships, are not large enough to assimilate wastes, and which are incredibly valuable as a biological-recreational natural resource.

When dealing with the effects of industrialization on the estuary, this paper will address those problems unique to estuarine areas which have arisen through increasing industrial activities in the estuarine environment, and will delineate individual industrial-estuarine pollution problems and discuss possible solution. More specifically, the report will examine pollution problems in estuaries, identify factors that actually pollute, investigate the effect of control on the estuarine environment as a whole including human activities, and describe the procedures, if possible, for gaining control of such factors. For the purposes of this report, the period from 1970 to the present will be emphasized.

This paper will not deal with pollution resulting directly from agricultural activity, from domestic sewage or from non-point source discharges such as storm runoff. Industrial effluents discharged into the freshwaters or the nation's air and carried to the estuary will not be considered.

INDUSTRIAL DEPENDENCE ON THE ESTUARY

Uses and Projections

For purposes of this study, industrial "dependence" on the estuary will be restricted to those industries which rely on the estuary for waterborne transportation, for process water, or for products derived from the estuarine waters or bottom sediments.

Waterborne transportation of bulk materials for the year 1971 is summarized in Table 1. Data are presented for coastal U.S. ports, excluding the Great Lakes.

Our basic industries (petroleum, coal and coke, iron and steel) are the principal users of our coastal waterways both for foreign and domestic commerce (sand and gravel are significant commodities in domestic commerce). The transportation of large quantities of these bulk commodities implies that related processing/refining/utilizing industries are also located on our coastal waterways. From the point of view of marine transportation, we have at least three candidate industrial complexes which are dependent on the estuary:

1. Crude oil handling, associated refineries, and petrochemical plants;
2. Iron, steel, and closely allied metal fabricating industries; and
3. Industries using coal, coke, asphalt, and tar either as an energy source or as a raw material.

An estimate of the kinds of industries dependent on large volumes of process and/or cooling water can be obtained by examining Table 2. Industries having major surface discharges have been categorized by the EPA. Three of these industries, the chemical, paper, and utilities industries represent 47 percent of the major industrial discharges to the surface waters of the United States. Some of these large water users are the same ones which utilize the estuary for transportation. These include the iron and steel (including metal fabricating) and petroleum and coal industries. The chemical industry (including inorganic acids and salts, organic fibers, plastics and pigments, and drugs, cosmetics and soaps), paper industry, and utilities industry have been added to the list.

Table 1.—Total waterborne commerce (Calendar, 1971). Coastal ports of the United States (millions of short tons).

	Foreign	Domestic
Total	506.5	242.9
Imports	333.8	—
Exports	172.7	—
Petroleum and Products	38.7%	44.0%
Coal and Coke	11.7%	14.9%
Iron Ore and Steel	12.5%	8.2%
Sand, Gravel and Stone	2.2%	12.1%
Grain	6.8%	2.0%
Chemicals	5.8%	5.2%
Logs and Lumber	3.8%	2.5%
All Others	18.5%	11.1%

Table 2.—Industrial discharges by industry group*

	Number of Permits
Chemical and Allied Products	522
Paper and Allied Products	407
Electric and Gas Utilities	392
Textiles	151
Fabricated Metal Products	149
Iron and Steel	142
Petroleum and Coal Products	136
All Others	902

* Source: National Water Quality Inventory, 1974

The third group of industries which are estuarine dependent are those which extract materials directly from the water or bottom of the estuary. Desalinization plants extract fresh water from estuaries while other industries extract bromine, magnesium, calcium, and sodium that is dissolved in the waters of the estuary. Sea shells (a source of calcium and lime), and sand and gravel, are taken in large quantities from the bottom of our nation's estuaries.

Industry Projections

Where data are available, projections for future requirements in each of the estuary dependent industries have been made. These projections are for the entire industry in each case, and do not necessarily indicate the pressure to locate new facilities on estuaries.

The industry profiles for petroleum refining, petrochemical manufacturing, and paper products have been developed by D. M. Bragg, associate research engineer, Industrial Economics Research Division, Texas A & M University and have been extracted here with the author's permission.

PETROLEUM REFINING

In the U.S. today, there are 247 petroleum refineries with an average daily capacity of 57,555 barrels. Three refineries have capacities of over 400,000 barrels per day each and four have over 300,000. Many of these refineries can be expanded but some cannot—either because of limitations of space or

Table 3.—Refineries planned but not constructed

Company	Location	Size (B/D)	Final Action Blocking Project
Shell Oil Co.	Delaware Bay, Del.	150,000	State Reacted by Legislature Passing Bill Forbidding Refineries in Coastal Area.
Fuels Desulfurization (1)	Riverhead, L.I.	200,000	City Council Opposed Project and Would Not Change Zoning.
Maine Clean Fuels (1)	South Portland, Me.	200,000	City Council Rejected Proposal.
Maine Clean Fuels (1)	Searsport, Me.	200,000	Maine Environmental Protection Board Rejected Proposal.
Georgia Refining Co. (1)	Brunswick, Ga.	200,000	Blocked Through Actions of Office of State Environmental Director.
Northeast Petroleum	Tiverton, R.I.	65,000	City Council Rejected Proposal.
Supermarine, Inc.	Hoboken, N.J.	100,000	Hoboken Project Withdrawn Under Pressure From Environmentalist Groups. Considering State Near Paulsboro, N.J.
Commerce Oil	Jamestown Island, R.I. Narragansett Bay	50,000	Opposed by Local Organizations and Contested in Court.
Steuart Petroleum (2)	Piney Point, Md.	100,000	Withdrawn Due to Pressure From Environmental Groups.
Olympic Oil Refineries, Inc.	Durham, N.H.	400,000	Withdrawn After Rejection by Local Referendum.

(1) Maine Clean Fuels and Georgia Refining Company and subsidiaries of Fuels Desulfurization and the refinery in question is the same in each case, so the capacity in B/D is not additive, but the incidents are independent and additive.

(2) Again being introduced.

Source: "Trends in Refinery Capacity and Utilization," Federal Energy Office, Washington, D.C., June, 1974.

because they are not well sited logistically to meet the increasing demand.

The gulf coast currently has 16 percent of the U.S. demand but has approximately 40 percent of the country's refining capacity. On the other hand, the east coast has 40 percent of the demand but only 12 percent of the refining capacity. Based on assessments of site availability and limitations arising from environmental pressures, it is now anticipated that a number of the new refineries, which otherwise would have been built in the east, will be constructed instead on the gulf coast. Table 3 lists a large number of announced or planned refinery projects which have been postponed or have doubtful promise. It is significant to note that all of the refinery sites listed in Table 3 are located along estuaries.

PETROCHEMICAL MANUFACTURING

Historically, petrochemical production has been closely tied to the output of natural gas liquids (NGL) produced in natural gas processing plants. In these plants natural gas, comprised of over 90 percent methane, is stripped of its butane, propane and part of its methane.

As a result of the decreasing supply and increasing price of NGL, the future expansion of olefin manufacturing facilities will be based almost exclusively on heavy oil feedstocks. Facilities using heavy oil feedstocks accounted for only 12 percent of all ethylene produced in 1970. This type of production will be up to 24 percent of the total by 1975; and by 1980, it is expected that just under 50 percent of all ethylene produced will be generated from heavy liquids. As a result, consumption of heavy liquids in the manufacture of olefins will rise from 130,000 barrels a day at present to 780,000 barrels a day by 1980. The heavy liquids, such as naptha and gas oil, are produced from petroleum. And, because of this, the locations of future petrochemical complexes will be even more closely linked to those of oil refineries than in the past.

The location of future expansion in the industry will be determined more by the availability of feedstocks than by any other factor. In view of the transition to heavy cracker feedstocks, potential feedstock availability will increasingly be determined by refinery location which, in turn, will be determined by crude oil supply. Therefore, the gulf coast would no longer continue to have a clear-cut locational advantage, and the advantages of freight savings on finished products should make the east coast a more attractive location. If the oil refining capacity of the east coast experiences large increases, then a strong likelihood exists that there would be a corresponding increase in basic petrochemical capacity in the region.

ELECTRIC POWER

Fossil and nuclear energy sources form the basis for almost all U.S. electric production. Presently designed systems generate large quantities of waste

Table 4.—Growth of summer peak electric demand 1974-1983 as projected by regional reliability councils April 1, 1974; contiguous United States

Year	MW	Annual Increase (%)
1974	364,244	—
1975	394,005	8.17
1976	427,995	8.63
1977	460,377	7.57
1978	494,848	7.49
1979	531,699	7.45
1980	570,798	7.35
1981	612,252	7.26
1982	656,793	7.27
1983	703,774	7.15

Source: Federal Power Commission, Bureau of Power Staff Report, June 24, 1974.

heat which must be removed from the plant site, either by cooling towers, cooling ponds, or once-through cooling with discharge into a body of water.

Demand for electrical energy, recently revised downward due to conservation practices resulting from the "energy crisis" are presented in Table 4.

A fossil fuel plant with once-through cooling requires about 600 gallons per minute (GPM) of cooling water for each megawatt (MW) of electricity produced. Nuclear plants require about 900 GPM of cooling water per MW of electricity. Some of the waste heat of fossil plants goes directly up the stack but nuclear plants dissipate almost all their waste heat through the cooling system. In both cases, the temperature of the discharged water would be 15°F higher than the intake water.

Environmentalists had initially been most concerned with thermal pollution of estuaries because of the large volumes of hot water discharged. It now appears that the major impact of once-through cooling is not thermal pollution of the discharged water but the killing of most or all of the organisms sucked up by the pumps and passed through the plant. Fortunately, the installation of cooling towers can reduce the quantity of water required to 1 to 3 percent of the volume needed for once-through cooling.

> The solutions to this critical problem are: (1) to locate power plants along the open coast where there is deep-water nearby for strategic placement of intake and outlet structures, and, (2) to reduce the volume of cooling water by requiring plants to use closed cycle systems which recirculate cooling waters, rather than the open cycle systems which continuously withdraw and discharge large volumes of water from the environment. (Clark and Brownell, "Electric Power Plants in the Coastal Zone," American Littoral Society Publication #7, 1973.)

Power generation facilities can be sited on the coast; they do not require docks, large labor forces, downstream or satellite industries and their product can be shipped over long distances at modest cost.

Paper Products

Demand for paper and paper products has increased about 3.5 percent per year. Capacity estimates for the 730 paper plants are presented in Table 5.

In addition to the basic fiber raw materials, water and limestone are used in paper making. The limestone can be acquired from either mines or oyster shells. Both sources are used quite extensively, depending upon the proximity of the source, the abundance of the material, and other factors.

There are two major papermaking processes, the sulfite and the kraft. The sulfite process, however, is a major water polluter and is gradually being phased out. Although the kraft process does not pollute water as does the sulfite method, it has an odor problem resulting from the sulphur used in manufacturing.

Large quantities of wastewater are discharged into rivers and streams. Pollutants are either stripped from the discharge or nullified by sufficient treatment. Solid wastes, such as bark and particulates, are burned.

Sand and Gravel Production

These products, used for fill, building, and paving amounted to 944 million tons in 1970. About 90 million tons were mined from the estuaries of the U.S. in that year. As land values increase in onshore areas and as industry recognizes that large quantities of sand and gravel occur offshore and in our estuaries there will be increasing pressure to utilize these materials.

Table 5.—United States paper and paperboard capacity, annual summary 1972-1976 (thousands of short tons)

Grades	1972	1973	1974	1975	1976
Total All Grades Paper and Paperboard	61,868	64,431	66,098	68,377	69,736
Total Paper	26,545	27,394	27,954	28,633	29,125
Total Paperboard	29,328	30,565	31,482	32,986	33,749
Total Construction Paper and Board and Other	5,995	6,472	6,662	6,776	6,862

Source: "1972-1975 Capacity Survey," American Paper Institute, New York, N.Y., May, 1974.

IRON AND STEEL MANUFACTURING

Since 1950, the demand for metals in the United States has tripled. By the year 2000 it is expected to triple again. Recent forecasts put crude steel requirements by the year 2000 at 293 million tons for the United States.

Total iron ore requirements for the United States should reach 156 million tons per year by the year 2000. As Table 6 shows, imports of foreign iron ore through east coast ports should attain an annual level of 37.8 million tons by the same year, nearly one-fourth of United States consumption. It seems as though there will be increased reliance on foreign ore, shipped by water to U.S. ports, and presumably, processed there.

ENVIRONMENTAL EFFECTS OF INDUSTRIALIZATION OF THE ESTUARY

The environmental effects of industrialization include physical modifications of the estuary, the introduction of substances toxic or harmful to aquatic organisms, and the introduction of materials hazardous to human health or which impact aesthetic values.

Physical Modification of the Estuary

Our ports are located at or near the heads of estuaries and channels need to be dredged and maintained to serve these ports. The size of ships serving U.S. ports projected to the year 2000 is presented in Table 7. Note particularly the draft of the vessels.

The maximum channel depth of any U.S. harbor is 45 feet. It is quite clear that a large amount of dredging must be accomplished or the docking facilities must be moved out of the upper reaches of our estuaries. Investment in existing harbors is quite large (Table 8) and will serve as a deterrent to moving the facilities.

Of the total investment for these U.S. harbors, a significant portion is expended for dredging and related spoil disposal activities.

> The Corps of Engineers, in fulfilling its mission in the development and maintenance of these (navigable) waterways, is responsible for the dredging of large volumes of sediment each year. Annual quantities are currently averaging about 300,000,000 cubic yards of maintenance dredging operations and about 80,000,000 cubic yards in new work dredging operations with the total annual cost now exceeding $150,000,000. (Boyd et al. Corps. Tech. Rpt. H-72-8).

Table 6.—Tonnage of iron ore imports to North Atlantic by origin and destination (millions of short tons)

Destination	1970	1980	1990	2000
Baltimore	9.2	14.8	17.3	20.3
Delaware River	12.5	14.1	16.6	17.5
Total	21.7	28.9	33.9	37.8

Source: "Interim Report—Atlantic Coast Deep Water Port Facilities Study," U.S. Army Corps of Engineers, Philadelphia, Pa., June, 1973.

Table 7.—Projected vessel characteristics 1970 to 2000

	1970	1980	1990	2000
Freighters				
Maximum DWT in world fleet	25,500	33,500	43,500	50,000
Length (feet)	850	930	1,010	1,050
Beam (feet)	108	117	127	132
Depth (feet)	74	80	85	88
Draft (feet)	36	39	40	40
Average DWT in world fleet	8,168	8,853	9,043	9,350
Bulk Carriers				
Maximum DWT in world fleet	105,000	185,000	317,000	400,000
Length (feet)	870	1,040	1,230	1,325
Beam (feet)	125	152	183	198
Depth (feet)	71	84	99	106
Draft (feet)	48	57	66	71
Average DWT in world fleet	14,750	18,750	23,575	27,350
Tankers				
Maximum DWT in world fleet	300,000	760,000	1,000,000	1,000,000
Length (feet)	1,135	1,460	1,570	1,570
Beam (feet)	186	252	276	276
Depth (feet)	94	129	142	142
Draft (feet)	72	98	104	104
Average DWT in world fleet	39,825	76,225	94,325	94,325

Source: *Science and Environment*, Vol. 1, Panel Reports of the Commission on Marine Science, Engineering and Resources

Table 8.—Summary of federal investments in coastal harbors, 1824-1966 (in thousands of dollars)

	Construction Expenditures	Maintenance Expenditures	Total Expenditures	Non-Federal Cost[1]
Depth: 30 feet and over				
Atlantic coast	420,910	406,275	827,085	29,624
Gulf coast	181,593	122,596	304,189	29,844
Pacific coast	127,684	128,363	256,047	38,227
Subtotal	731,519	657,314	1,388,833	97,695
Related Investments[2]				
Atlantic coast	23,147	5,665	28,812	2,579
Gulf coast	12,065	6,387	18,452	3,609
Pacific coast	32,483	23,723	56,206	14,215
Subtotal	79,402	49,958	129,360	20,479

[1] Monetary value of local contribution identified in project authorization documents

[2] Additional federal construction items required to sustain functional utility of projects, but not incorporated in basic project.

Source: *Science and Environment*, Vol. 1.

The most obvious environmental effect of dredging is the destruction of bottom-dwelling organisms and habitat. All other factors being equal, the same kinds of organisms will repopulate the new bottom so long as the substrate is the same as that of the original bottom. If the material being dredged contains silt or clay, a "plume" of turbid water will drift down current from the dredging operation. In extreme cases, the turbid water can cause clogging of the gills or filtering apparatus of marine organisms and/or smothering of bottom living organisms under a blanket of deposited materials.

Other potentially serious effects of dredging include changes in water circulation patterns (tidal exchange, flushing rate, stratification, et cetera).

Effects of Disposal of Dredged Material

If the material dredged for the channel consists mostly of sand and/or gravel it is usually referred to as "fill" and is suitable as a core for a breakwater or an artificial island. On the other hand, if the material is silt or clay it is referred to as "spoil" and is a problem to dispose of without potential environmental effects.

The worst possible environmental conditions for spoil disposal would probably be similar to those encountered in a dredging operation in northern Chesapeake Bay. The material to be spoiled was all silt and clay, was hydraulically dredged, and was dumped on a submerged disposal area. Even though the end of the discharge pipe was directed downward, a large plume of suspended sediment moved down current from the discharge point. The disposal area did not contain the deposited sediment within its limits. The spoil apparently spread as a semi-liquid across the relatively flat bottom, covering a larger area than outlined as the disposal site. The character of semi-liquid silt and clay is such that maximum slopes measured are 1:100 (on a flat bottom, a pile of spoil built to a height of 1 ft. will spread at least 100 ft. horizontally in all directions) and average slopes are 1:500.

Biological effects observed in the Chesapeake disposal operation were not severe. The bottom dwelling organisms in the spoil receiving area were wiped out but new populations quickly reinvaded the spoil. It was found that some seasons of the year have less potential for damage both because organisms are less active and/or migrate from the region. If silt and clay are anticipated in the dredging operation, then methods of dredging and sites and seasons of disposal should be chosen to minimize biological effects. As a generalization, silt and clay are less likely to be encountered at port locations on the shelf than at locations inside the estuary. Estuarine silts also have a higher probability of being polluted with materials transported from the upper estuary.

Effects of Construction of Breakwaters or Islands

These structures remove from productivity the bottom environment beneath them. However, riprap or other protective materials surrounding islands and breakwaters create new habitat for marine organisms. So long as these structures are not built on ecologically "rich" bottom, the new habitat created probably represents a neutral or beneficial effect on the biota.

Breakwaters and artificial islands undoubtedly cause changes in the current and wave patterns in nearby areas. These structures can disperse or focus wave energy on nearby coasts, or by changing current velocities, can cause erosion or deposition of sediments with associated effects on bottom living organisms. Breakwater and island design must consider the ecological effects of altered current or wave patterns.

HEAT

Table 9 illustrates the use of cooling water by U.S. industry.

One of the major reasons why temperature is so biologically important is that the rates of chemical reactions are temperature-dependent. Since biological processes are ultimately controlled by the rates of enzyme-regulated reactions, it is not surprising that digestion, circulation, respiration, and reproduc-

Table 9.—Use of cooling water by U.S. industry

Industry	Cooling Water Intake (billions of gallons)	Percent of Total
Electric power	40,680	81.3
Primary metals	3,387	6.8
Chemical and allied products	3,120	6.2
Petroleum and coal products	1,212	2.4
Paper and allied products	607	1.2
Food and kindred products	392	0.8
Machinery	164	.3
Rubber and plastics	128	.3
Transportation equipment	102	.2
All others	273	.5
Total	50,065	100.0

Source Federal Water Pollution Control Administration, "Industrial Waste Guide on Thermal Pollution," September 1968.

tion increase with rising temperature. In fact, it has been noted that in the vicinity of power plants which discharge heated effluents into temperate waters, many species will reproduce earlier in the spring and continue to produce larvae later into the fall than species in the ambient water. The use of cooling towers and cooling ponds, although more expensive, is replacing once-through cooling with discharge to the estuary.

An innovative concept has been the proposal to construct floating nuclear power plants. All of these plants would be uniform in construction (present ground based plants are custom made) providing less difficulty in licensing procedures, and, presumably, cost savings by production line construction techniques. The construction of a sea defense system (breakwater) to protect the plant from storms and ship collisions is very costly, though. Perhaps such plants, built at remote sites and placed in coastal lagoons using the barrier island as a natural breakwater and cold seawater as a cooling medium would be economically attractive and environmentally acceptable.

Addition of Substances Harmful to Estuarine Organisms

Oil spills in United States waters and documented by the Coast Guard are presented in Table 10. Bulk storage facilities account for almost twice as much spilled oil as the next highest contributor, offshore wells.

Major spills on water are difficult to control and can cause great environmental damage, especially if they reach beaches or marshes. The least harmful spill is one that never occurs. Terminal location and design should be such as to minimize the possibilities of a spill. The less handling that the crude oil receives, the less likely the chances of a spill. For instance, a transfer operation involving pumping from tankers to offshore tanks to lighters to refineries requires three handlings while pumping from tankers to pipelines to refineries involves only two.

Given that, sooner or later, a spill will occur during the operation of a terminal, then containment and recovery operations should begin immediately. Their success depends on the size of the spill, the availability of personnel and equipment, and wind and sea conditions. The closer that a terminal lies to shore, the more rapid must be the response to prevent contamination of coastal margins. In an environmental sense, then, there is greater risk of shoreline contamination if a port is located within an estuary or near the coast.

Organic wastes resulting from industrial processes

Table 10.—Polluting spills in U.S. waters—1970

Source	Incidents	Gallons Spilled (millions)	Percent of Total
Spills in excess of 10,000 gals.			
Bulk Storage Facilities	9	6.676	43.5
Offshore Wells	4	3.553	22.8
Pipelines	14	1.316	8.4
Barges	19	1.238	8.0
Transfer Operations	8	1.021	6.5
Dumping	1	.500	3.2
Industrial Accidents	5	.367	2.3

Source: U.S. Coast Guard.

include compounds that have a high biological oxygen demand (BOD), which cause a reduction in the levels of dissolved oxygen in the receiving waters. The food processing, textile, refining and petrochemical industries all contribute significant quantities of BOD to the environment. The 1974 National Water Quality Inventory showed a decrease in the BOD on 74 percent of the major waterways on which water quality trends have been measured. Industries most often control BOD of effluent waters by secondary sewage treatment. Such secondary treatment can reduce BOD levels by 80–90 percent but produce about 0.75 lbs. of sludge per pound of BOD reduction. A problem then involves disposal of the sludge. Significant progress is being made in the reduction of BOD, phenol and ammonia discharges from refineries.

Organic wastes from petrochemical, crude oil handling, and refinery effluents may be toxic to aquatic organisms.

Trace metal concentrations, first publicized by the levels of mercury in swordfish, have come under close scrutiny. The major industrial sources of these metals are chemical, metal refining and metal processing effluents. Toxicity levels of some of these metals to estuarine organisms are presented in Table 11. Trace metal levels may be low in effluents but quite toxic to organisms in receiving waters. They are difficult and expensive to remove.

Health Hazards

Industrial effluents are not major sources of most human pathogens regarded as health hazards. Depending on the particular area, though, industrial effluents may serve as the source of toxic concentrations of trace metals concentrated in organisms which are consumed by man.

Concentration by biological processes is a phenomenon which is readily demonstrable. It is through biological concentration that toxic metals find their

Table 11.—Toxicity levels of metals for several marine organisms (in ppm of dosage)

Metal	Organism Tested	Lethal Level	Time
Cadmium	Eastern Oyster	0.10	15 Weeks at 20°C
	Eastern Oyster	0.20	8 Weeks at 20°C
Chromium	Eastern Oyster	0.102	—
	Nereis sp.	2–10	2–3 Weeks
	Shore Crab	50.0	12 Days
	Small Shrimp	10–80	1 Week, 100%
Copper	Soft Shell Clam	0.50	3 Days at 10°C
	Soft Shell Clam	0.20	23 Days at 10°C
	Soft Shell Clam	0.20	8 Days at 20°C
	Soft Shell Clam	0.10	10 Days at 20°C
	Mussels	0.05	10 Days at 20°C
	Mussels	0.025	24 Days at 20°C
	Nereis sp.	1.5	2–3 Days
	Nereis sp.	0.5	4 Days
Mercury	Five Marine Phytoplankton	0.006	10 Days
Nickel	Eastern Oyster	0.121	—
Lead	Eastern Oyster	0.50	12 Weeks

way into the food web. As an example, let us look at phytoplankton, the root of the marine food web. One thousand pounds of phytoplankton support in the food web the following:

100 pounds of zooplankton or shellfish
50 pounds of small food fish (anchovies)
10 pounds of small carnivores
1 pound of carnivores harvested by man
(Council on Environmental Quality, 1971)

Each level in the food web results in the concentration of at least some of the heavy metals concentrated in the previous levels. In addition, at any point in this food web, biological concentration may occur by uptake directly from the surrounding water, thereby further enriching metal concentration levels. Table 12 illustrates the interim standards for acceptable concentrations of metals in shellfish compared with the average levels found in Atlantic coast organisms.

SUMMARY

The technology is available to curb most industrial water wastes. Much has been done, by treatment and by designing production processes that minimize waste. More efficient production processes save money and may improve product quality. Where improved production processes are not available or are not economically feasible, treatment processes usually exist. Their total estimated costs, as a percentage of gross sales, are well under 1 percent, although costs may be much higher for some industries.

Table 12.—United States Public Health Service 1968 interim standards for shellfish, in ppm of wet tissue weight. Numbers in parenthesis represent average levels in organisms from Atlantic Coast (after Pringle, 1969)

Metal	Eastern Oyster	Soft Shell Clam	Northern Quahaug
Zinc	1500.0	50.0	50.0
	(1428.0)	(17.0)	(20.6)
Copper	100.0	15.0	15.0
	(91.5)	(5.8)	(2.6)
Cadmium	0.2	0.2	0.2
	(3.1)	(0.27)	(0.19)
Lead	0.2	0.2	0.2
	(0.47)	(0.70)	(0.52)
Mercury	0.2	0.2	0.2
Cadmium, Lead, Chromium and Mercury Combined	2.0	—	—

Our major industries are easily identifiable and the effluents that they discharge are subject to close scrutiny. In 1968, though, 45 percent of the municipal waste treatment water came from industrial sources. These can prove very difficult to monitor, particularly in our older metropolitan areas. We are just now beginning to quantify and categorize the pollutant sources to the estuary.

The greatest difficulties still to be solved involve the effects of industrial activity on the biology of estuaries. Decision makers need answers to questions like "How much marsh can be filled without significantly affecting the estuary?" and "Where is the 'best' place to locate the next power plant and to dispose of 1,000,000 cubic yards of spoil?" The estuarine system including its organisms, is sufficiently variable in time and space that several years (3–5) are required to get adequate data on the major components of the area. Only in the last decade have we learned enough about estuarine organisms' nutritional and environmental requirements to allow the consideration of controlled environmental laboratories. Results will not come quickly from these labs, but they seem to be the real hope for understanding the effects of environmental perturbations.

By lacking a national policy, we are continuing to encourage industrial development in the estuaries, particularly those areas which are already stressed. Let's look at an example, the refining industry. As has been mentioned, refineries (at least east coast refineries) have been established at most of our ports. A number of new refineries have been proposed but abandoned, usually on environmental grounds. Clearly, the proposal to establish a refinery indicates that a market exists for the products. But if the refinery isn't built, where does the product come from? Existing refineries, located on stressed estuaries, expand to increase production. We need a strong national policy to help "noxious but necessary" industries to find new locations. Offshore industrial islands (out of state jurisdiction) whose effluents must meet water quality standards may be an alternative to continued development in ecologically stressed estuaries. Agencies of the federal government have been quite innovative and responsive in dealing with water quality problems. As an example, the EPA developed "Criteria for Determining the Acceptability of Dredged Spoil Disposal to the Nation's Waters " The criteria are strict, and a number of dredging projects, particularly estuarine projects, could not pass the EPA criteria. The Corps of Engineers was responsive to the EPA criteria and launched a 5-year, $30 million "program of research . . to develop the widest possible choice of technically satisfactory, environmentally compatible, and economically feasible disposal practices."

Inherent in the above case of cooperation is that dredging of channels to the ports located at the head of the estuary will continue indefinitely. The question that has been posed seems to be "How can we reduce the impact of industrial pollution in our estuaries by adopting water quality standards and/or allotments?" Federal policy seems to be responsive to that most important question.

I submit that there is another, longer-term but equally important question that may not have yet been asked and certainly has not yet been answered. It is "How can we reduce the impact of industrial pollution in our estuaries by assisting industrial centers dependent on water transportation, located on estuaries which are not deep enough to handle modern ships, are not large enough to assimilate wastes, and which are incredibly valuable as a biological-recreational natural resource, to find new, more environmentally acceptable sites?"

Regional groups must initiate work on the identification of the areas, in an environmental sense, that can better accept the industrial wastes now discharged into our estuaries. The National Coastal Zone Management Act (16 USC, Sec. 145-1464) may serve as an excellent vehicle to achieve this long-term objective.

REFERENCES

API 1972–1975 Capacity Survey. 1974. American Paper Institute, New York, N.Y.

Bartsch, Perry. 1974. The Pulp and Paper Industry. American Paper Industry: pp. 24–25.

Federal Power Commission. 1974. Bulk Power Load and Supply Information for 1974–1983. Bureau of Power Staff Report, Washington, D.C.

Federal Power Commission. 1974. Bulk Power Load and Supply Projections for 1984–1993. Bureau of Power Staff Report, Washington, D.C.

Annual Review—Developments in the Iron and Steel Industry. 1974. Iron and Steel Engineer, Vol. 51, No. 1: pp. D1–48.

Federal Energy Office. 1974. Trends in Refinery Capacity and Utilization, Washington, D.C.

Gross, M. G. 1970. Analysis of dredged wastes, flyash, and waste chemicals—New York Metropolitan Region (Stony Brook: Marine Science Research Center, SUNY), technical report no. 7.

Hedgpeth, J. W., and Gonor, J. J. 1969. Aspects of the potential effect of thermal alteration on marine and estuarine benthos. Biological Aspects of Thermal Pollution, edited by P. A. Krenkel and F. L. Parker (Nashville: Vanderbilt University Press), pp. 80–118.

IDOE. 1972. Baseline studies of pollutants in the marine environment and research recommendations. The IDOE Baseline Conference, May 24–26, 1972 (New York: IDOE Baseline Conference).

Ketchum, B. H. 1969. Eutrophication of estuaries. Eutrophication: Causes, Consequences, Correctives (Washington, D.C.: National Academy of Sciences), pp. 197–209.

Livingstone, D. A. 1963. Chemical composition of rivers and lakes. Washington, D.C.: U.S. Geological Survey, prof. paper 440G.

McAleer, J. B., Wicker, C. F., and Johnston, J. R. 1965. Design of channels for navigation. Evaluation of Present State of Knowledge of Factors Affecting Tidal Hydraulics and Related Phenomena (Vicksburg, Miss.: U.S. Army Engineer Committee on Tidal Hydraulics) report no. 3.

MacCutcheon, E. 1972. Traffic and transport needs at the land-sea interface. Coastal Zone Management: Multiple Use With Conservation, edited by J. P. Brahtz (New York: John Wiley and Sons), pp. 105–148.

Miller, G. W., Garaghty, J. J., and Collins, R. S. 1962. Water Atlas of the United States (Port Washington, N.Y.: Water Information Center, Inc.)

Moss, J. E. 1971. Petroleum—the problem. Impingement of Man on the Oceans, edited by D. W. Hood (New York: Wiley-Interscience), pp. 381–419.

Odum, H. T. 1963. Productivity measurements in Texas turtle grass and the effects of dredging on intercoastal channel. Publications of the Institute of Marine Science (Texas), 9:48–58.

Pearce, J. B. 1969. The effects of waste disposal in the New York Bight—interim report for 1 January 1970.

Reynolds, W. W. 1972. Investing in primary petrochemicals. Chemical Engineering Progress, Vol. 68, No. 9, pp. 29–35.

SCEP. 1970. Man's Impact on the Global Environment (Cambridge, Mass.: MIT Press).

Simmons, H. B. 1965. Channel depth as a factor in estuarine sedimentation. (Vicksburg, Miss.: U.S. Army Engineer Committee on Tidal Hydraulics), technical bulletin no. 8.

Simmons, H. B., and Herrmann, F. A. 1969. Some effects of man-made changes in the hydraulic, salinity, and shoaling regimens of estuaries. Proc. GSA Symposium on Estuaries (in preparation).

Simmons, H. B., Harrison, J., and Huval, C. J. 1971. Predicting construction effects by tidal modeling (Vicksburg, Miss.: U.S. Engineer Waterways Experiment Station), miscellaneous paper H-71-6.

Sisselman, Robert. 1973. Iron Ore in the United States: A Profile of Major Mining, Processing Facilities. Mining Engineer, Vol. 25, No. 9, pp. 45–65.

Sykes, J. E., and Hall, J. R. 1970. Comparative distribution of molluscs in dredged and undredged portions of an estuary with a systematic list of species. Fishery Bulletin, 68:299–306.

Turekian, K. K. 1971. Rivers, tributaries, and estuaries. Impingement of Man on the Oceans, edited by D. W. Hood (New York: Wiley-Interscience), pp. 9–73.

U.S. Tariff Commission. 1968. Synthetic Organic Chemicals. U.S. Production and Sales (Washington, D.C.: U.S. Government Printing Office)

U.S. Department of Interior. 1970a. Mineral facts and problems (Washington, D.C.: U.S. Government Printing Office), Bureau of Mines bulletin 650.

Zitko, V., and Carson, W. V. 1970. The characterization of petroleum oils and their determination in the aquatic environment. Fisheries Research Board, Canada, technical report no. 217.

INDUSTRIAL WASTE POLLUTION AND GULF COAST ESTUARIES

ROY W. HANN, JR.
Texas A&M University
College Station, Texas

ABSTRACT

The status of gulf coast estuaries is explored with regard to degradation of water quality from a variety of sources and mechanisms, emphasizing industrial waste effluents. The typical features of gulf coast estuaries, particularly the limited tidal action, the presence of bays behind barrier islands, and in many cases, limited flushing, are outlined.

Environmental modification as differentiated from environmental pollution is presented and examples of the impact of each on Texas gulf coast estuaries is discussed. A hierarchy of water quality problems is presented and used to document the principal water quality problems in seven selected Texas estuaries. The causes of the degradation which lowers water quality in these seven estuaries are listed with emphasis on waste-generating industries.

The Houston ship channel is used as a case study to outline the potential solutions to each of the individual water quality problems. A plea is voiced for the consideration of novel or innovative solutions to water quality problems such as the concept of supplemental aeration which is proposed for the Houston ship channel.

INTRODUCTION

This presentation will explore the status of gulf coast estuaries with regard to degradation of water quality from a variety of sources and mechanisms with emphasis on the role of industrial waste effluents. Since the author's major work has centered on the gulf coast of Texas, the greatest attention will be directed at these estuaries as typical of the gulf coast area. A map of the Texas gulf coast is shown as Figure 1.

TYPICAL GULF COAST ESTUARIES

The major feature that differentiates gulf coast estuaries from those on the east and west coasts is the limited tidal range found along the gulf. This phenomenon is demonstrated in Figure 2 where it may be noted that the tidal pattern for several gulf coast estuaries follows a pattern from diurnal to semidiurnal with a range of only one to two feet.

The most significant gulf coast estuaries have large, shallow bays, separated from the Gulf of Mexico by barrier islands. These typically have one or more major rivers entering their landward ends which bring freshwater into the system. In the Texas gulf, the inflows to the major estuaries west of the Neches River are often small, leading to relatively slow flushings of the estuaries. For example, the upper Houston ship channel has an average flushing time of 38 days and a flushing time as great as 80 days over 10 percent of the time. The median flushing period for the ship channel above Morgan's Point is 30 days and that for Galveston Bay is 175 days.

This combination of limited tidal mixing and limited freshwater inflow creates a condition which is particularly susceptible to the buildup of pollutants and, consequently, to a significant impact of these pollutants in the water quality.

In the deeper estuaries or in dredged channels, gulf coast systems are partially stratified with lighter, less saline water overriding a more saline deeper layer. The degree of salinity difference varies from day to day as a function of freshwater inflow and turbulence generated by tides, wind, ship traffic, and other forces.

In the shallow bays and the deeper systems after extensive mixing, the salinity in the top and bottom layers is the same, creating what is defined as a homogeneous estuary. Evaluation of the impact of man's activities on estuaries requires a thorough understanding of the movement of water masses and pollutants in these systems.

ENVIRONMENTAL MODIFICATION

Gulf coast estuaries as they existed in the 19th century have been exposed to a wide range of environmental modification, as well as environmental

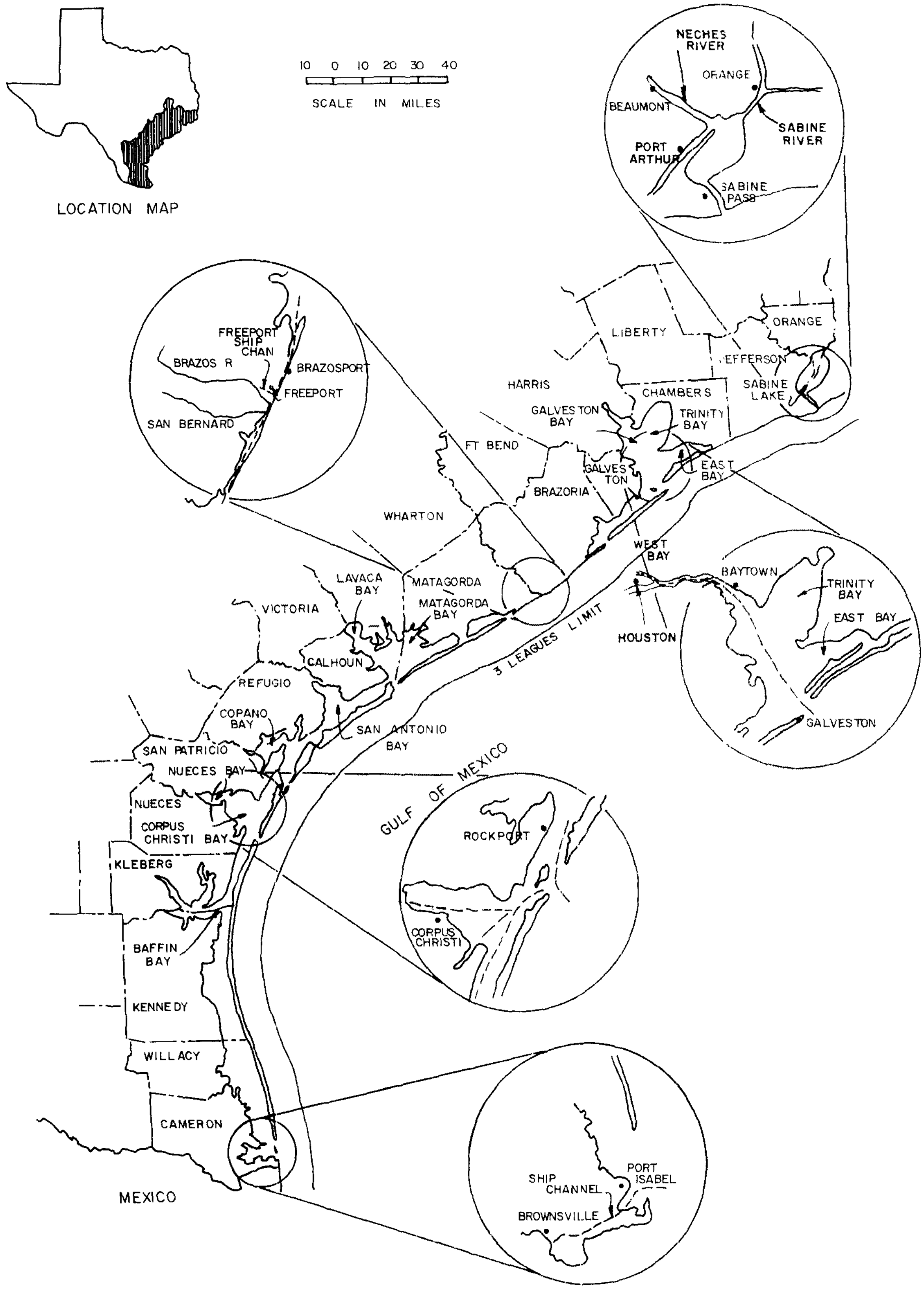


FIGURE 1.—Texas coastline.

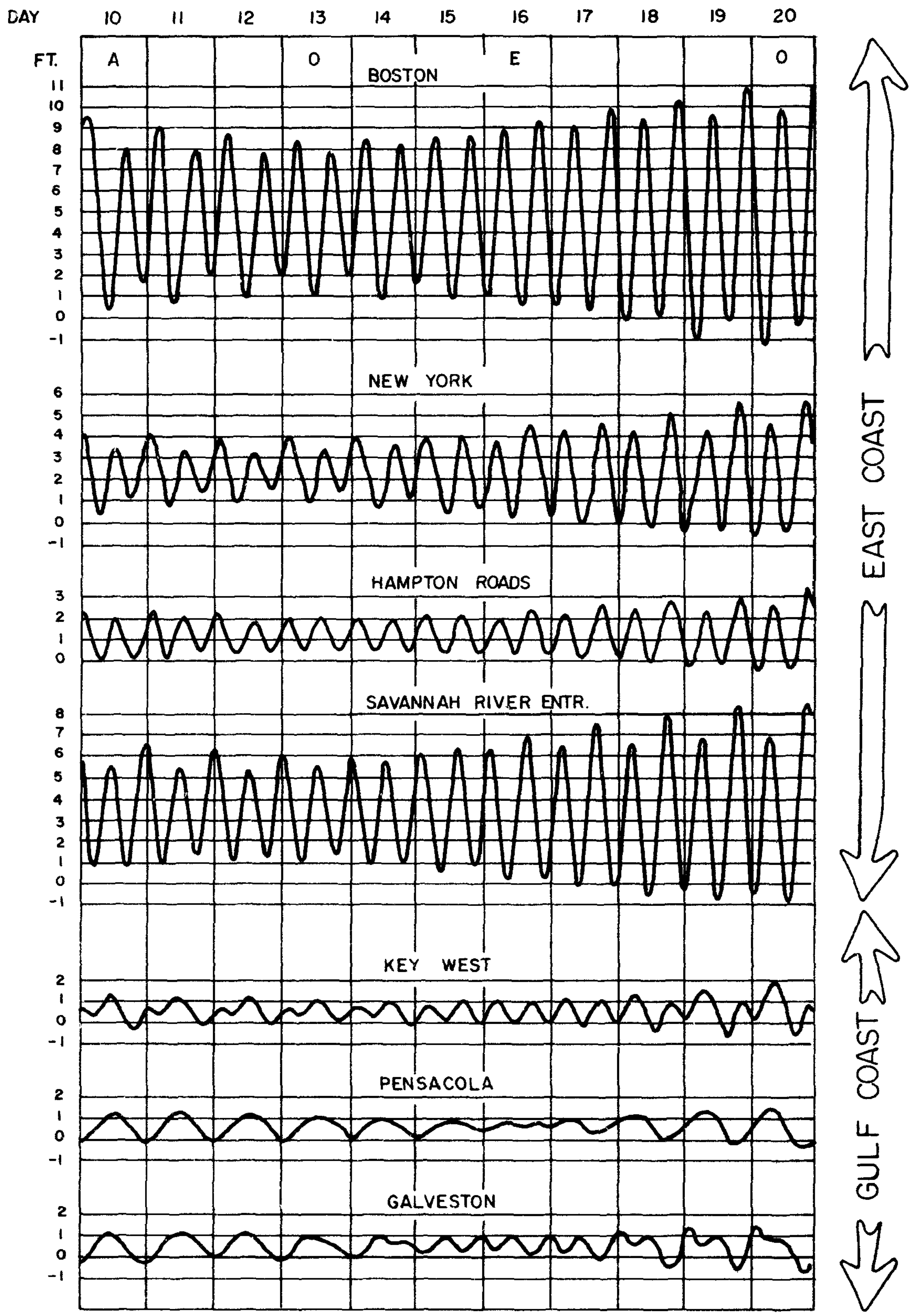


FIGURE 2.—Typical tide curves for the United States.

pollution. The environmental modification may be described in this context as changes in the physical, chemical and biological characteristics of a system as a result of engineered works and changes in land use. Environmental modification may result in both environmental costs and benefits.

In contrast, environmental pollution involves the direct and indirect discharge of pollutant materials as effluents from man's activities. Environmental pollution predominantly results in environmental costs or degradation with only occasional environmental benefits being demonstrated.

A list of the most important environmental modifications which affect gulf coast estuaries is shown in Table 1. The most significant of these in many estuaries has been the dredging of ship channels across shallow bay systems and river channels to higher, more protected land as much as 50 miles inland from the coastline.

These channels have changed estuarine flushing and circulation patterns and altered their salinity structure. The upstream modification of the river systems by reservoirs and other structures has also drastically altered the estuarine systems by affecting freshwater inflows, altering salinity structure, and reducing sediment and nutrient inflows.

These environmental modifications have wrought substantial and continual changes in these estuarine systems, generally making them more useful to man. They have also created the physical and economic climate in which cities, industry, and commerce have flourished and have brought the spectre of environmental pollution to our estuaries.

ENVIRONMENTAL POLLUTION

Environmental pollution is defined as the discharge of man's waste products into the environment. A convenient mechanism to consider environmental pollution is to follow an outline which may be called the "Hierarchy of Water Quality Problems" and assess the applicability of each parameter at it relates to the estuarine environment. This hierarchy is shown in Table 2. The ordering of the initial items generally conforms to the order in which water quality problems were perceived in

Table 1.—Environmental modifications affecting Texas estuaries.

1. Ship Channels
2. Upstream Water Resource Development
3. Water Withdrawals and Returns
4. Drainage of Marshlands
5. Urbanization
6. Sand, Gravel and Shell Dredging
7. Dikes, Jetties and other Structures

Table 2.—Hierarchy of water quality problems.

Pathogenic Bacteria and Related Coliform Indicating Organisms
Oxygen Demanding Organics and Resulting Oxygen Depletion
Inorganic Ions
Nutrients and Resulting Eutrophication
Sediments: Both Organic and Inorganic
Temperature Changes
Heavy Metals
Radionuclides
Pesticides and Herbicides
Refractory Organics
Oil Pollution
Hazardous Polluting Substances

freshwater streams. However, with our present technology, any parameter can be the dominant problem in any given estuary.

Table 3 examines the relative significance of each of these parameters in selected Texas gulf coast estuaries. For each estuary, the relative significance has been rated as H (highly significant, i.e. major problem), M (moderately significant), L (slightly significant), and Blank (no known problem). Additional categories are N for not known and P to

Table 3.—Hierarchy of water quality problems related to selected Texas estuaries

	Neches Ship Channel	Houston Ship Channel	Galveston Bay	Brazos River	Corpus Christi Ship Channel (Inner Harbor)	Corpus Christi Bay	Brownsville Ship Channel
Pathogens	L	H	H		N		
Oxygen Demanding Organics	H	H	L	L	M		L
Nutrients	M	M	L		L	L	
Sediments	M	M	L	M	L	L	
Temperature	L		H	L		L	
Heavy Metals	M	H	L	M	H	M	
Radionuclides		N					
Pesticides & Herbicides	L	L	L	L			
Refractory Organics	M	H	M	L	L		
Inorganic Ions				H			
Oil Pollution	L–P	M–P	P		M–P	P	P
Hazardous Polluting Substances	P	P	P	P	P	P	P

H—Major Problem
M—Moderate Problem
L—Slight Problem
Blank—no problem at this time
N—Not Known
P—Potential for Major Problem from Spill Situation

Table 4.—Pollution sources for selected Texas estuaries

	Neches Ship Channel	Houston Ship Channel	Galveston Bay	Brazos River	Corpus Christi Ship Channel (Inner Harbor)	Corpus Christi Bay	Brownsville Ship Channel
Domestic Sewage	L	H	L	H	L		
Urban Runoff	L	H	L		L		
Agricultural Runoff	L		L	L		L	
Petrochemical Industry	H	H	H	L	H	L	L
Petroleum Refining	H	H	M		H	L	
Pulp and Paper	H	H	L				
Mining	H		L				
Metal Processing	L	H	L	H	H	H	
Fertilizer		H	L				
Power Generation	H	L	H		L	L	
Dredging of Virgin Mtls.			M			M	
Maintenance Dredging	H	H	M	M	H	H	L
Marine Commerce	L–P	L–P	P	P	P	L–P	P

H—Major Waste Source
M—Moderate Waste Source
L—Minor Waste Source
Blank—No Significant Waste
P—Potential for Major Problem from Spill Situation

indicate a potential problem exists, but is not a chronic situation.

Table 4 carries the analysis further to identify the sources of the pollution by class in each estuary. Each of these estuaries, its individual problems and status will be discussed in following sections.

SELECTED TEXAS ESTUARIES

Seven Texas estuarine systems were selected for consideration in this presentation. The ones chosen span the Texas coast from the Neches estuary near the Louisiana border to Brownsville, the southernmost ship channel-estuary only a few miles from the Rio Grande River border with Mexico. The unique features of the individual estuaries and the role that industrial waste pollution plays in the overall water quality problem will be discussed.

The Neches Estuary

The Neches Estuary has its beginning at the confluent of the Neches and Sabine Rivers, some 20–30 miles inland from the Gulf of Mexico. This report is concerned with the lower 23 miles of the estuary (up to Beaumont, Tex.), which has been dredged for deep draft navigation. Saline water penetration above this point will in the future be prevented by a salt water barrier.

Since the city of Beaumont diverts its domestic sewage to Taylors Bayou which does not enter the Neches Estuary, very little domestic waste reaches this estuary. Similarly, urban runoff loads are not a major impact. Thus, for all practical purposes, the Neches Estuary pollution problems result solely from wastes discharged by the industries which line its banks. These include a pulp and paper plant, a sulphur mining operation, a metal processing plant, two fossil fuel electrical generation plants, and almost a dozen refinery and petrochemical plants and related shipping terminals.

The development of these industries during the 1950's and 1960's led to a grossly overloaded condition with regard to the water quality of the Neches River. A study carried out by the author in 1969 indicated that a freshwater inflow of over 5,000 cubic feet per second would have been necessary to achieve the stated water quality standard for dissolved oxygen of 3.0 mg/l. Consistent flows anywhere near this figure are not possible from the Neches River system, particularly as most if not all of the summer freshwater flow is diverted from the river for domestic use and irrigated farming.

An initially aggressive program to reduce the then-loading of 278,000 lbs. of BOD inflow per day was begun in 1970, but was delayed to investigate regional waste treatment. Since that time, the stream standards have been drastically lowered to require only 2.5 mg/l dissolved oxygen one foot below the water surface at a flow of 1000 cfs. These standards are questionable because roughly 25 percent of the time periods of flows below 1000 cfs are expected in the Neches and the one foot below the surface sampling location is not considered adequately representative.

The target waste loadings specified by the Texas Water Quality Board call for waste load reductions by 1977 to 20,400 lbs/day of ultimate oxygen demanding wastes above River Mile 11 and 26,187 lbs/day for the entire estuary. If these targets are achieved along with similar reduction of heavy metals and other contaminants, substantial improvement should be realized.

Further improvement could involve either further treatment, supplemental aeration, or diversion of the cooling water discharge from the Gulf States Power Generation Station to the upper estuary in order to assure a minimal flow throughout the estuary.

The Houston Ship Channel

The city of Houston has achieved the distinction of becoming the third largest port in the nation even though it is located some 50 miles from the coastline. Houston is connected to the Gulf of Mexico by a dredged deepwater channel across 25 miles of the otherwise shallow Galveston Bay and then, another 25 miles upstream from Morgan's Point, up what was once the lower reaches of the San Jacinto River and Buffalo Bayou to its terminus at the turning basin near downtown Houston.

This deep draft channel is the major lifeline of the city of Houston and it is along the upper 25 mile stretch of the channel that the major industries of the Houston industrial complex are located. The dominant industries, of course, are petroleum refining and petrochemical production, but others found along the channel include: pulp and paper, metal processing, fertilizer, power, cement, grain elevators, and manufacturers of offshore oil field structures. Warehouses and tank terminals also serve the area's marine commerce. By 1969, the waste loading from this industrial complex coupled with the domestic waste effluents and urban runoff reached, after treatment, the loading of over 500,000 lbs/day of ultimate oxygen demand. Almost all the other pollutants discussed earlier as part of the hierarchy of water quality problems were also discharged in large amounts. The BOD ultimate load overtaxed the allowable loading of 20–25,000 lbs/day as determined by mathematical modeling by a factor of between 20 and 25 to 1.

During this time the waters in the upper 16 miles of the channel were completely depleted of oxygen in every month of the year, black anaerobic sludges were building up on the bottom at the rate of 2–5 feet per year from sediment and organic waste discharge and the waters were so bacterially polluted that one gallon of ship channel turning basin water added to a 20,000 gallon swimming pool would cause it to be unacceptable from coliform bacteria count standards.

The industrial waste loadings to the channel have been reduced dramatically. Whereas in 1969, two-thirds of the loading excluding urban runoff was due to industry, now only one-third is industry related, according to Texas Water Quality Board figures.

The domestic waste of the city of Houston now is the major biodegradable organic pollutant load. In addition to heavy overloads by infiltration, the city still discharges large quantities of digested sludge into the channel.

During qeriods of high runoff from Houston, it is estimated that the urban runoff pollution loading equals or exceeds the domestic waste loading thus making it the dominant biodegradable pollution. The urban runoff also brings nutrients, sediments, and heavy metals into the channel.

The author has argued that specific pollutants such as heavy metals, unusual nutrient loads, oil and hazardous materials, and so forth must be reduced at each individual source and precautions taken to insure against major shock loads from spills and plant upsets. He has also argued that organic waste loading, being common to all polluters, is a problem susceptible to a novel cooperative solution. This Houston ship channel problem and the options for solution are discussed in greater depth in a later section.

Galveston Bay

Galveston Bay is the largest bay on the Texas gulf coast and considered to be most productive, both economically and ecologically. The bay is approximately 520 square miles in surface area. The major freshwater source is the Trinity River which drains central Texas, including the Dallas-Fort Worth area. Other sources include the San Jacinto River, Buffalo Bayou, Clear Creek, and other small creeks and bayous.

The bay is generally believed to be of good quality with the exception of coliform bacterial pollution and the unknown effect of refractory organics discharged by the Houston ship channel complex, and thermal discharges. The major pollution sources which impact on the bay and the major environmental modifications to the bay system are listed in Table 5. The solution to the pollution problems of this important bay is that of insuring that each of its inputs is of acceptable quality.

The impact of environmental modification will probably be of more importance to the bay in the future than environmental pollution.

Brazos River

The Brazos River differs from the other estuarine systems in that the river runs directly into the Gulf of Mexico without having a large bay at its mouth. The Brazos River has the largest drainage area in Texas and is partially controlled by upstream rivers. Flows range from near zero to major floods. Natural freshwater quality is affected by salt spring discharge and agricultural runoff. The major industrial discharges consist of saline waste streams from seawater processing, and petrochemical production wastes from several plants of a single company,

Table 5.—Environmental pollution and environmental modification of Galveston Bay

Significant Pollution Sources

1. Houston Ship Channel
2. Bayport Industrial Complex
3. Texas City Industrial Complex
4. Trinity River Inflow
5. Galveston Ship Channel and City of Galveston
6. Power Plant Discharges
7. Clear Lake Drainage Area

Significant Environmental Modification

1. Houston Ship Channel and Associated Dredge Spoil
2. Galveston, Texas City, Bayport and Cedar Bayou Channels and Associated Dredge Spoil
3. Upstream Water Resource Development on the Trinity River Including the Wallisville Reservoir
4. The Water Diversion from Tabbs Bay and the Houston Ship Channel as Part of the Cedar Bayou Power Generation Station
5. Upstream Water Resource Development on the San Jacinto River
6. Land Subsidence by Excessive Ground Water Production Centered Around the Upper Houston Ship Channel
7. Urban Development and Associated Runoff Characteristic Changes Around the Bay
8. Various Dikes, Jetties, Fish Passes and Other Structures

discharged a few miles above the river's mouth. The lower reaches of the river also suffer from domestic waste discharges from cities in the Freeport area.

Current plans for the construction of a superport off the Texas coast near Freeport will undoubtedly lead to increased industrial waste loading in the lower portion of the Brazos River.

Corpus Christi and the Corpus Christi Ship Channel

Corpus Christi Bay and its inland companion bay—Nueces Bay, form one of the larger bay systems on the Texas Coast. A ship channel has been dredged across Corpus Christi Bay to the city of Corpus Christi and thence alongside the city for a distance of 8.5 miles. It is this inner harbor which receives the heaviest industrial waste loading and which is included as a separate system for rating purposes. The quality in the inner ship channel is poor with regard to some parameters, but is substantially better than the major ship channels in eastern Texas mentioned previously. The channel is a useful study area to indicate how the Neches and Houston ship channels will behave when their quality improves.

The channel is subject to oil spills from a variety of commercial and industrial sources, and governmental entities have joined to form the most effective Oil Spill Control Cooperative on the Texas coast. This group has cleaned up almost 100 oil spills ranging from a few gallons to 13,000 gallons. This organization is serving as a model to potential groups elsewhere.

Brownsville

The port of Brownsville is a unique estuarine system in Texas. Unlike most other Texas ship channels, the Brownsville shipping channel was not dredged up an existing river. Dredging the Rio Grande would have had international implications as well as involving the sediment and other pollutants of the river. Thus, the channel is entirely manmade for commercial and industrial purposes. The channel is also blessed with good quality water and the governing authority, the port of Brownsville, is carefully programming development to insure maintenance of this quality. Only in Brownsville can one fish successfully in a ship channel turning basin.

TRENDS AND SOLUTIONS

The Houston ship channel is an excellent system to consider with regard to water quality management because the system receives almost all types of pollutants in significant amounts from nearly every class and type of polluter. The upper 25-mile segment of the Houston ship channel is shown in Figure 3. The system is also significant because classical solutions to water quality problems will not achieve required or desired water quality in this system. Thus, innovative techniques which go beyond traditional "dilution is the solution," "treatment at the source," and "classical complete treatment" must be developed.

These include new analysis techniques for exotic pollutants, novel advanced treatment methodology and in situ processes such as supplemental aeration to improve quality. A brief outline of ship channel problems and the appropriate solutions are shown in Table 6.

The problem of oxygen demanding wastes will be discussed in depth as it demonstrates several of the points to be made in this presentation. As mentioned previously, the Houston ship channel in 1969 was receiving a daily loading of over 500,000 lbs. of BOD_u per day. In layman's terms, this is roughly the equivalent of 500,000 lbs. of sugar per day. By 1973, the loading had been reduced to those shown in Figure 4. In 1969, about 60 percent of the problem was industrial wastes, 20 percent domestic wastes, and 20 percent urban runoff. By late 1973, the ratios were more like 45 percent urban runoff, 35 percent domestic wastes, and 20 percent industrial wastes during periods of urban runoff, and 65 percent domestic waste and 35 percent industrial waste during periods of no runoff.

Also plotted on Figure 4 is the value range for the assimilative capacity for oxygen demanding material

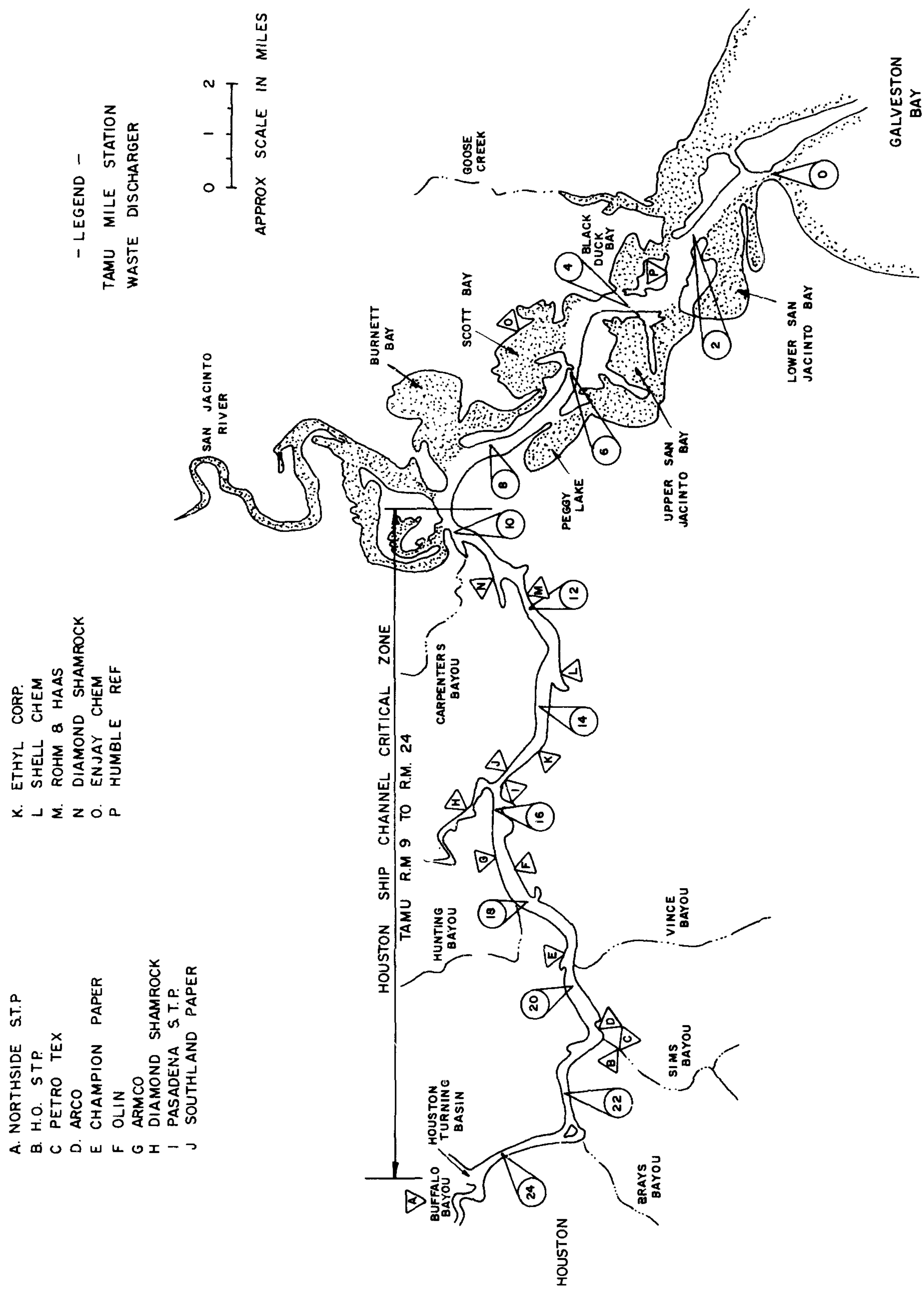


FIGURE 3.—Location of domestic and industrial discharges on the Houston ship channel.

Table 6.—Solution matrix, Houston Ship Channel problems

Problem	Solution
Pathogenic Organisms	Higher level domestic waste treatment, effluent chlorination reduction of sewer infiltration.
Oxygen Demanding Organics (Domestic)	Improved secondary waste treatment, advanced waste treatment and supplemental aeration.
Oxygen Demanding Organics (Urban Runoff)	Supplemental aeration.
Oxygen Demanding Organics	*Improved waste treatment and supplemental* aeration.
Nutrients	Advanced domestic and selective industrial waste treatment.
Sediments	Better sewage sludge handling and control of sediment from land and highway development.
Temperature	No major solution needed.
Heavy Metals (Industrial)	Process change and selective waste treatment.
Heavy Metals (Domestic)	Elimination of heavy metal discharges to the sewer system and waste treatment plant operation for heavy metal removal.
Heavy Metals (Urban Runoff)	
Refractory Organics	Better identification of pollutants—waste treatment with existing or new treatment processes—little known in some areas.
Oil Pollution	Better preventive action. Contingency planning equipment and training of industry and government personnel.
Hazardous Polluting Substances	Better preventive action. Contingency planning equipment and training of industry and government personnel.

for each month of the year based on federal-state water quality standards for the upper Houston ship channel.

The solution is obvious: namely, the load curve must be below the assimilative capacity curve. The traditional manner is to only reduce the waste loading; however, in this case, the residue waste loads from high level industrial and domestic treatment plus the urban runoff will still overload the system. The current reduced loadings still overload the channel by a ratio which varies from 6:1 without urban runoff to 10:1 during runoff periods. The channel still remains depleted of oxygen in its upper 10 miles during most of the year.

Occasional sitings of marine life in the channel after prolonged high inflow-cool temperature situations, do demonstrate a modest improvment in quality over that found five years ago, but this has been publicized out of proportion to the true situation.

The author has argued that an acceptable interim solution to the Houston ship channel oxygen balance is to increase the assimilative capacity of the system

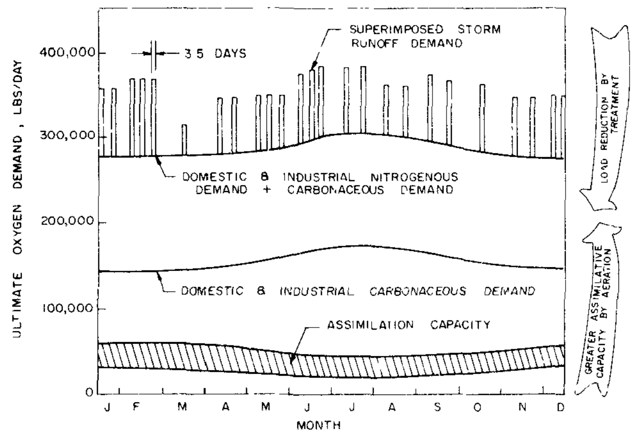


FIGURE 4.—Oxygen demand and assimilation capacity, Houston ship channel, mile 9 to 24 (1972 values).

with supplemental aeration which can be achieved at a very reasonable cost. In addition to its cost effectiveness in terms of social cost and energy efficiency, the proposed system also provides a reserve or fail-safe capacity for shock loads and/or future system loads by new discharges.

The concept is enthusiastically endorsed by the local Gulf Coast Waste Disposal Authority, the waste management entity with the authority to finance, build and operate the system, but acceptance of the concept has been slow on the federal level because of the resistance to novel or innovative solutions to achieve the desired end product of a cleaner environment.

Surely, more objective consideration can be given in the future—particularly, when it is realized on the national level that the goal of zero pollutant discharge is unachievable and that alternate technology which protects the environment must be sought.

SUMMARY AND CONCLUSIONS

The author has presented the unique factors concerning gulf coast estuaries which must be considered in managing these systems. Foremost are tide range, geometry inflow varieties, and density structure. These parameters make their behavior quite different from most east and west coast estuaries. Environmental modifications within and without the estuarine system which will continue to bring about change in the physical, chemical and biological characteristics of these estuaries in the absence of waste loadings are reviewed. They include ship channels, upstream water resource developments, water withdrawals and returns, drainage, urbanization, sand, gravel and shell dredging, and dikes, jetties, and other structures.

The classical hierarchy of water quality problems is examined to determine their applicability and importance in the gulf coastal zone in general and the Texas gulf coast in particular. Included are pathogenic organisms, oxygen-demanding organisms, inorganic ions, nutrients, sediments, temperature, oils and other floatables, heavy metals, radionuclides, pesticides and herbicides, refractory organics, and hazardous polluting substances.

For several of the Texas gulf coast estuaries, a matrix is presented which outlines the relative significance of these parameters in each system. This is followed by a matrix which summarizes the source of the pollutants in these selected Texas estuaries. Particular attention is given to industrial waste discharges, with oil refining and petrochemical, pulp and paper, mining and metal processing, fertilizer, and power plants predominating. Particular attention is given to the problems of the Houston ship channel as these display trends and make pertinent points.

Industrial wastes continue to be the dominant pollutant source in many gulf coast estuaries and a significant loading in others. Industrial attitudes toward pollution control still range from public spirited companies who lead the way in pollution control to those few bad actors who resist and avoid any major commitment toward pollution control until dragged to the courtroom.

Industry as a whole, however, has generally proved receptive to carrying its load when it has been effectively demonstrated that a problem really exists and that a true solution will be achieved by the steps they have been asked to carry out and the costs they are expected to bear. All too often, however, an individual industr·· has been asked to clean up when his counterparts have not. This is particularly evident in the Houston ship channel, where some industries have had effective treatment programs for almost a decade while some foot-dragging industries and the city of Houston have lagged far behind in cleaning up their effluents.

Even the most responsible industry personnel have doubts as to the need and economic justification of some of the requirements they are being asked to meet—particularly, toward the goal of zero pollution discharge.

It is validly argued that policy must be more closely tailored to individual situations and to the social costs and energy resource situations which exist today.

With these thoughts in mind, the following list of recommendations is formulated for consideration for the country as a whole and particularly, for consideration for gulf coast estuaries.

RECOMMENDATIONS

1. Programs to reduce industrial waste discharges should be continued. We still have a long way to go with some industrial discharges to achieve even basic levels of treatment.
2. Additional programs to characterize wastes and their impact should be carried out. There are still wastes that are not characterized and for which environmental impact is unknown.
3. Greater effort should be made to use appropriate parameters in assessing impact and developing management plans.
4. Equal effort should be placed on reducing domestic waste loadings with particular attention given to reducing the industrial wastes discharged into municipal systems.
5. Greater effort should be placed on the problem of urban runoff from cities whose runoff drains into estuaries. This must include erosion control to limit sediments.
6. It must be recognized that every estuary is different and should be evaluated for its unique situation, preferably using local scientists and engineers who understand the system.
7. Policy should permit innovative and unique solutions, i.e. different solutions are appropriate for different estuaries.
8. Solution choices must include consideration of social cost and energy efficiency. Policy must be upgraded to consider the realities of the times.
9. Failsafe systems are necessary to prevent a single plant breakdown from overpowering the effect of expensive control programs.
10. Realistic terms should be used to describe estuary quality or loading as compared to the allowable loadings based on quality standards. For example, claims of modest improvements in Houston ship channel quality, particularly, during high flow periods should not be allowed to hide the fact that the system is still overloaded by a ratio of 10:1.
11. Effective control programs for industrial wastes and domestic wastes should improve the quality of sediments and reduce pollution potential of dredged materials.
12. Enforcement activities to stimulate compliance by the few "bad actors" should be renewed.
13. Expanded activity to identify and control the danger from hazardous chemical substances shipped in marine commerce should be instigated including routine bioassay analysis of hazardous materials shipped in bulk.

14. The quest to determine the true cost of zero pollutant discharge and the accompanying ultimate disposal of residues should be pursued with the goal of achieving reasonable solution of our estuarine problems without generating a backlash which will stop us short of our goals.

15. More attention should be placed on the effect of environmental modification on estuarine ecology.

REFERENCES

"Waste Management in the Texas Coastal Zone," Environmental Engineering Division, Civil Engineering Department, Texas A&M University, prepared for the Office of the Governor, Division of Planning Coordination, The Coastal Resources Management Program, Interagency Council on Natural Resources, September 1972.

Tide Tables—High and Low Water Predictions—East Coast of North and South America Including Greenland, U.S. Department of Commerce, 1973.

"A Study of the Flushing Times of the Houston Ship Channel and Galveston Bay," Hann, R. W., Jr., Sparr, T. M., Sprague, C. R., Estuarine Systems Project Technical Report No. 12, May 1970.

"Neches Estuary Water Quality Study," Hann, R. W., Jr., Estuarine Systems Project Technical Report No. 14, October 1969.

"Waste Load Evaluation for Segment 601 of the Neches River Basin," Hann, R. W, Jr, prepared for the Texas Water Quality Board, Austin, Tex., May 1974.

"Waste Load Evaluation for the Houston Ship Channel," Hann, R. W, Jr., prepared for the Texas Water Quality Board, Austin, Tex., September 1974.

"Management of Industrial Waste Discharges in Complex Estuarine Systems—Second Annual Report," Hann, R. W., Jr., Estuarine Systems Project Technical Report No. 15, June 1970.

"Management of Industrial Waste Discharges in Complex Estuarine Systems—Third Annual Report," Hann, R. W, Jr., Estuarine Systems Project Technical Report No. 22, September 1971.

"The Case for Inchannel Aeration of the Houston Ship Channel," Hann, R. W., Jr., and Ball, John, presented at the Texas Meeting of the American Society of Civil Engineers, Austin, Tex., 1973

"Field and Analytical Studies of the Corpus Christi Ship Channel and Contiguous Waters," Hann, R. W., Jr., Withers, R. E., Jr., Burnett, N. C, Allison, R. C., and Nolley, B W., prepared for the Texas Water Quality Board, August 1973.

"Environmental Study of the Brownsville Ship Channel and Contiguous Waters," by Withers, R. E., Jr., Slowey, J. F., Garrett, R L., prepared for the Brownsville Navigation District, October 1974.

POWER PLANT EFFECTS

IMPACT OF WASTE HEAT DISCHARGED TO ESTUARIES WHEN CONSIDERING POWER PLANT SITING

J. W. BLAKE
United Engineers & Constructors, Inc.
Philadelphia, Pennsylvania

ABSTRACT

With present experience certain efficiencies can be brought to bear on evaluation of proposed power plant sites. These concern (1) ways and means of determining what data are really needed for thermal discharge impact evaluation, and (2) optimization of efforts to obtain such data.

Data relevance cannot be determined through comparison with a list of parameters which must always be studied at every site, but rather through a list of topics to be considered for possible study, i.e., questions to be asked (the answers to which determine the parameters which need study at the specific site under consideration).

Optimization of data acquisition could be greatly improved through addition of geographic indicators to all environmental data publications and indexing/storage systems, following the examples set by EPA STORET and NODC listings for water quality parameters. Such complete data availability will make possible better predictions of significance of impact, and therefore more realistic and consistent decisions on utilization of our environment.

INTRODUCTION

It is encouraging to see that progress is being made in some quarters toward devoting appropriate effort to evaluating the effects of thermal discharges on the estuarine environment. Now is the time to take advantage of the experience of the past few years, and move into more efficient protection of the environment and more productive utilization of scientist and engineer hours.

The power industry has now docketed some 200 nuclear generating stations, and each of these has required an environmental report—new ones of massive proportions (on the order of 1,500 pages to *summarize* studies). Similar, though generally less massive, environmental impact statements have been filed for new fossil-fueled generating stations.

Certainly in producing these documents considerable independent effort has been oriented toward obtaining data of much similarity. While it is certain that many have long wished for standardized descriptions of environments and environmental impacts, biologists and ecologists have been more modest, perhaps because of their familiarity with environmental complexities. Their wish has been for standardized programs for collection of the data necessary for such descriptions. In fact, that item which is of major concern in this paper is actually composed of two subtopics: first, the seeking of standardized criteria for the amount and kind of data required for any given site, and second, improvements in how such data are acquired.

These then are the two topics which will be addressed in this discussion: (1) ways and means of determining what data are needed for thermal discharge impact evaluation; (2) optimization of efforts to obtain such data.

DETERMINATION OF DATA NEEDS

Obviously, the first question—determination of data needs—has been addressed, consciously or subconsciously by every scientist, engineer, administrator, elected official, and voter confronted with a change in his or her environment. Each of us is either unfortunately vulnerable to bias, or fortunately able to perceive the true picture, due to our own experiences, training, and our career objectives. We may be highly motivated to:

(1) Preserve the environment in its pristine condition;

(2) Make possible most efficient utilization of the earth's resources; or

(3) Take advantage of every opportunity to gain further knowledge of the detailed interactions of all creatures in the complex ecosystems.

Of course, all of these sometimes diverse intermediate goals are expressed in terms of everyone's final goal of "Betterment of Mankind." Certainly within reasonable limits we should all be striving toward all the above three intermediate goals as well as the final one. But, before we rush to accomplish one and all, we must look to the aforementioned "reasonable limits" as we direct our efforts and resources toward achieving one of the goals, or better, toward some multiple use concept.

Thus, this paper will discuss means of determining the logical responsibility for environmental studies which should be assigned to the power industry, or indeed to any other industry wishing to utilize a portion of our environment.

It is important to note at the very beginning that aquatic ecological surveys and monitoring must be carried out to ensure that impacts of thermal power plants on aquatic communities do not exceed acceptable levels. To formulate these specific protective standards, an integrated overview approach must be set up to identify potential for significant effects upon important organisms at the earliest possible time. Similarly, such a scheme should quickly identify those areas in which limited or no effort is needed. As a step toward providing a framework for such an overview, this presentation will draw upon a draft version of American National Standards Institute's Standard No. N224 "Aquatic ecological surveys required for the siting, design, construction, and operation of thermal power plants." This standard has been drawn up by a committee composed of representatives of utilities, architectural and engineering firms, consultants, universities, private laboratories, and government agencies, including the Environmental Protection Agency, the Nuclear Regulatory Commission, the National Oceanic and Atmospheric Administration, and the Fish and Wildlife Service.

This ANSI draft standard has been constructed on the theory that while no one set of prescribed procedures will permit evaluation of all sites, a uniform set of questions can serve to rank parameters and permit concentration of efforts on those actually worthy of specific studies, for individual sites.

For example, the lower Mississippi River is, in terms of saline distribution, a fairly typical estuary, However, after only a brief investigation, one can see that the river itself has been channelized and confined by levees for many miles, so that it now resembles a smooth walled pipe characterized by high-speed, frequently unidirectional flow. The classical estuarine functions of providing habitats and nursery areas for aquatic organisms, have been fulfilled in this area by the bayous and onshore island/sandbars along the coastline of Louisiana and adjoining states. Thus there is a reversal in the more common rank of the estuary and coastline areas for utilization as sites for energy production. This is not to say that unlimited development should be allowed to take place along the river, but only that overall, the order of thoughtful utilization is somewhat different. Thus one may minimize the potential for a large scale study of possibly non-useful parameters, and find that a more directed study is really needed.

This paper is intended as an aid to, not a substitute for, professional judgement on a case-by-case basis. Designed to promote uniformity and efficiency, this guide will assist those not familiar with some of the complexities of the natural environment. Using it, the executive or engineer may better understand a specific environment's interrelationship with a steam electric generating station.

A survey of environmental regulations, the biological state-of-the-art, and recent power plant license review cases, suggests some general needs for aquatic ecological surveys. These basic needs (Table 1), briefly described in this section, should help shape the general philosophy of thermal impact surveys.

The first need is to recognize the limitations inherent in the current biological/ecological state-of-the-art. Aquatic ecology is not generally a predictive science. Determination of cause and effect relationships where natural variables cannot be controlled, make data analyses of plant-induced impacts difficult. This is not to imply that monitoring for impacts should not be attempted. Rather, it means that surveys should be designed on the basis of what can be accomplished with current sampling methods and statistical analyses in differentiating aquatic changes caused by various factors. A possible shortcut to site-by-site impact prediction based on specific field and/or literature data, is the use of national chemical or temperature tolerance criteria. However, such national criteria generally tend to overestimate impacts at many sites in order to be completely safe at the most sensitive. If using these criteria requires costly designs, then would it be more appropriate to derive specific data for that site through field or laboratory bioassays. Another approach may be to collect and review the thermal impact data at operat-

Table 1.—Factors to be considered in design of thermal impact studies

(1) Recognize predictive limitations imposed by ecological state-of-art
(2) Obtain ecological information appropriate to stage of project development
(3) Limit ecological effort to those impacts relevant to specific site-plant combination
(4) Concentrate initial efforts on most sensitive organisms, with later expansion only if necessary
(5) Incorporate good biometric techniques in design of surveys
(6) Recognize value of uniformity in design, conduct and analyses of ecological studies in so far as appropriate

ing power plants having similar site-plant configurations and interrelationships. In short, survey programs should be developed from a practical standpoint of what can be accomplished in the field.

A second need is to recognize the specific objectives with respect to schedules for planning, construction, and operating steam electric power plants. This includes examining aquatic ecological information appropriate to the stage of project development. Information supplied out of sequence is often unnecessary. Also, the considerations used in the environmental assessment should be integrated with design engineering to weigh design cost against potential environmental costs.

A third need is to develop aquatic ecological information based on impacts that are critical for a specific plant and site combination. General survey information is often useful. It appears, however, that time, effort, and money have been wasted by surveys that were too broad and general. A rational assessment of effects of power plants on aquatic ecological systems requires well-planned ecological surveys which can detect impacts. Massive data collections which fail in this objective or achieve the objective with excessive redundancy, represent wasted effort. Compliance with regulations, and a utility's own economic interest, are both served by critical survey designs which address specific problems related to specific plant and site situations.

A fourth need concerns the sequence and priority of surveys for potential aquatic impacts. Some regulatory agencies request aquatic ecological information for essentially all trophic levels. This seems to stem from the fact that all trophic levels are interrelated so an impact at one level may be felt throughout an ecological system. However, from a practical standpoint, impacts initiated at one level take time to be reflected in others and are not generally reflected to the same degree. Thus it is more efficient to concentrate surveys on biota which are most sensitive to plant construction and operation and can be expected to be the first to be affected. These first-order groups are more often called indicator organisms. An early focus on these would allow surveys to be expanded to other trophic levels only if unacceptable impacts on indicator organisms were detected.

A fifth need is to incorporate good biometric techniques in survey design so that, significant plant-induced impacts can be distinguished from natural stresses. The experimental approach to assessment of impacts in the field is often not possible because of lack of controls. The evaluation of data obtained from sampling can only yield estimates of population size and survival rates. Impact evaluation must rely largely on approximate evaluation methods based largely on observational studies. Such an approach is presented in a recent report by Eberhardt and Gilbert (1974).

A sixth need is for greater uniformity in design, conduct, and analysis of aquatic ecological surveys. The advantage in working toward uniformity is twofold. First, it will result in making the license review process more efficient, and secondly, it will allow comparison of data from one site to another. This comparison could result in the development of a body of information for examining the ecological trends in a region and for making better estimates of the possibility of power plant induced impacts. This could also lead to more efficient design of environmental surveys for future power stations, and better design of the power stations themselves. Complete uniformity of surveys is not desirable because of the uniqueness of each site-plant situation. However, special or unusual surveys that are proposed on the basis of uniqueness should be carefully evaluated to avoid unnecessary surveys based on arbitrary personal preference of investigators.

A series of matrices (for examples see Figures 1–3 and Table 2) has been proposed corresponding to a checklist of possible data needs, or questions to be asked of the environment. These are to determine relative significance of parameters which have a credible connection to the proposed construction and operations of a power plant. Each matrix represents a survey stage and specifies parameters to be considered, indicates the temporal distribution of the data collections, and the quality of data to be gathered. It should be noted that the survey matrices were developed as a tool to determine information needs, not necessarily study requirements, since the desired information may be available from alternate sources.

The sequential information-need phases can be functionally subdivided into as many of the following stages as are useful in the specific case under consideration (Figure 4). The Site Selection Phase can be divided into an Initial Evaluation Survey to select candidate sites from candidate regions and a Site Selection Survey to rank those candidate sites. The Preconstruction Phase can be divided into an Initial Plant Design Evaluation Survey to obtain data needed for preliminary engineering, a Baseline Survey to obtain data needed for the environmental report and impact prediction, and where site exploration may be expected to cause significant environmental impacts, a Site Exploration Monitoring Survey. The Preoperational Phase can be divided into Construction Monitoring Survey to monitor construction activities and, if warranted, to sample

Survey Stage	Currents & Other Water Circulation Patterns	Flushing Rate	Existing Temperature Patterns	Bathymetric Conditions & Contours	Bottom Sediments & Sediment Transport	Salinity	D.O. of Water and Sediments	Turbidity	Dissolved Solids	pH	Nutrients	Manmade Chemical Stresses
Initial Eval	1,A,I	1,A,I	1,A,I	1,A,I	1,A,I							
Site Select	2,A,II	2,A,II	2,A,II	2,A,II	2,A,II	++	++	++	++	++	++	++
Baseline	4,E,III	3,B,III	4,E,III	4,A,III	4,A,III	4,E,II	4,C,III	4,C,III	4,C,III	4,C,III	4,C,III	4,C,III
Site-Plant Design Eval	4,E,III	3,A,III	4,E,III	4,A,III	4,A,III	4,E,II						
Site Explor Monitoring					4,A,III	4,E,II	4,A,IV	4,E,III	4,A,IV	4,A,IV	4,A,IV	4,A,IV
Construc. Monitoring				4,A,III	4,A,III	4,E,II	4,B,IV	4,E,IV	4,B,IV	4,B,IV	4,B,IV	
Preoperation Survey	4,B,II	3,B,II	4,E,III	4,A,III	4,A,III	4,B,II	4,C,IV	4,C,IV	4,C,IV	4,C,IV	4,C,IV	4,C,III
Startup Monitoring	4,E,III	4,E,III	4,E,III		4,A,III	4,E,II	4,A,IV	4,E,IV	4,A,IV	4,A,IV	4,A,IV	4,E,III
Operation Monitoring	4,B,III	3,B,III	4,B,III	4,A,III	4,A,III	4,B,III	4,B,IV	4,B,IV	4,B,IV	4,B,IV	4,B,IV	

Figure 1.—Physical-chemical matrix.

for significant ecological changes; a Preoperation Survey to collect data necessary to provide baseline information for operational monitoring; and Startup Monitoring Survey to include any special studies needed to identify significant changes in the ecosystem caused by various activities occurring during start-up. The duration of the Operation Phase is determined by imposed environmental technical specifications, but greater detail would normally be obtained for the initial operating years of the plant as opposed to later years of operation, in order to determine operating effects of the plant and to compare them with those predicted in the environmental impact statement.

All these aquatic ecological surveys should be considered, but implemented only if appropriate and necessary. If implemented, they should be designed

Survey Stage	Periphyton	Phytoplankton	Zooplankton	Macroinvertebrates	Macrophytes	Fish	Any Organism Category If Used
Initial Evaluation	1	1	1	1	1	1	
Site Selection	2	2	2	2	2	2	
Baseline	3	3	3	3	3	3	
Site-Plant Design Evaluation	2	2	2	2	2	2	
Site Exploration Monitoring							3
Construction Monitoring							3
Preoperation Survey	3	3	3	3	3	3	
Startup Monitoring							3
Operation Monitoring							3

Figure 2.—Highest quality level of information collected.

Table 2.—Key to level of biotic survey information

QUALITY OF INFORMATION

1. qualitative from available existing sources
2. qualitative from field observations
3. quantitative from field studies with statistical precision adequate for impact evaluation

FREQUENCY OF INFORMATION COLLECTED*

A at least once by end of survey or annually if appropriate
B. quarterly
C. monthly
D. weekly
E. continuously
F. periodically**

GEOGRAPHICAL AREA STUDIED

I. regional
II. general site area
III. site impact area (for particular parameter)
IV. site impact area (particular parameter) plus control area

* While the key gives some guidance to the frequency of sampling, it does not provide guidance on best geographic spacing of sampling points. This is considered to be a site specific parameter best decided on a case by case basis.

** Periodically means sampling as often as a professional in charge of a survey considers necessary to identify a biotic change during the time it is likely to undergo the change.

	Ocean						Estuary						Lake						River					
Organism Groups	IS	PA	A	PR	S	SS	IS	PA	A	PR	A	SS	IS	PA	A	PR	S	SS	IS	PA	A	PR	S	SS
Periphyton																								
Phytoplankton																								
Zooplankton																								
Macroinvertebrates																								
Macrophytes																								
Fishes																								
Physical-Chemical	Refer to appropriate stage of Physical-Chemical Matrix 4.6																							

Figure 3.—Sample ecological matrix.

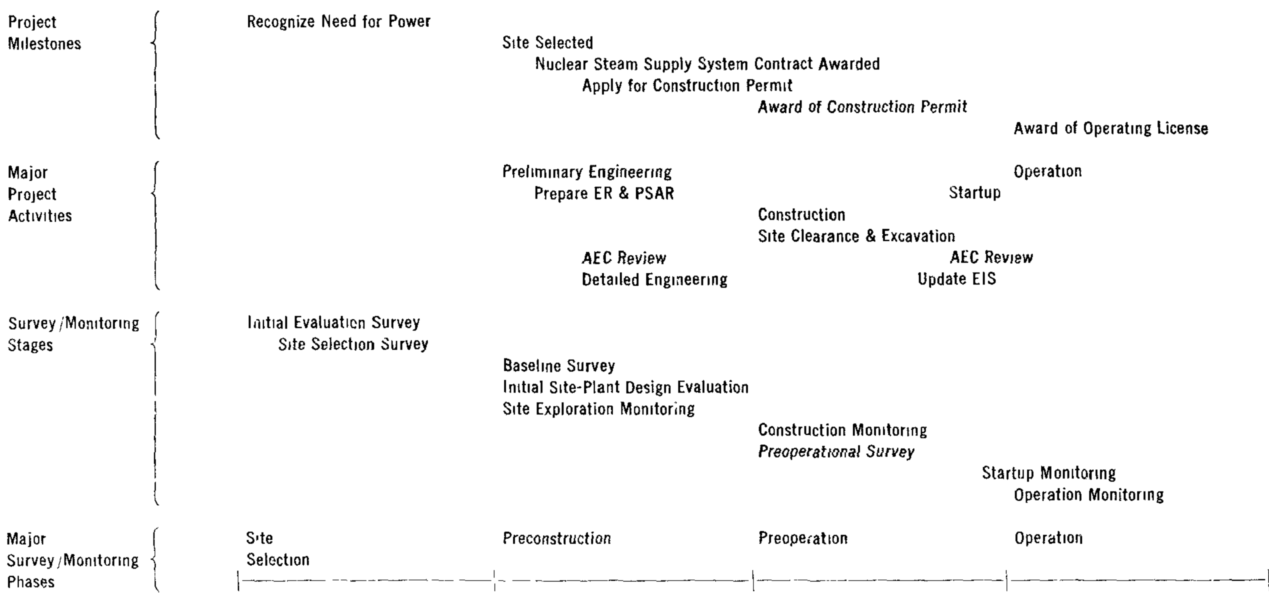


Figure 4.—Typical development schedule for nuclear power plants in the United States in 1974 with major survey phases and their corresponding survey stages indicated.

to evaluate potential impacts of plant operations on the biota of the immediate site area and to determine other information required by regulation. The potential major aquatic impacts to be considered are:

1. Attraction and impingement/entrapment of organisms by intake structures;
2. Entrainment of aquatic biota through the cooling system and resultant exposure to changes in thermal, chemical, physical and mechanical parameters;
3. Alteration of water quality in intake and discharge areas;
4. Scouring and silting of bottom habitat near intake and discharge structures;
5. Changes in water level or quality due to consumptive use;
6. Changes in currents in intake and discharge areas;
7. Thermal exposure of aquatic biota within mixing zone;
8. Blockage or delay of fish and shellfish movement by thermal or physical barriers;
9. Removal of habitats by structures.

The potential for these impacts will vary in importance between once-through and closed cycle cooling systems; therefore, plant design alternatives for the biological matrices acknowledge these variations.

Similarly, the ecological role or relative importance of each grouping varies from site to site. Some sites for example may have few or no important fish, or macrophytes, or may have poor substrate for supporting benthic invertebrates. Groupings actually selected for study at each site should be based on professional biological judgement. The life stage of a particular group to be studied should depend on specific site circumstances and the potential impacts to be evaluated. Thus the matrices present the highest level of information suggested for each organism grouping in relation to various survey stages. The purpose of the matrix is to serve only as a check list to be certain such groups are considered for possible inclusion in studies, and it may frequently happen that study will show that some groups should be included, and that others have no credible link to a specific proposed power plant project.

Consideration ought to be given to those organism groupings and important species within each which would be utilized to evaluate the aquatic community at a site. Important species or groups are those most valuable and/or vulnerable by the criteria set by civilization, but presumably will include protection of major food-web pathways. Certainly it would be unnecessary (and impossible) to study all or most species within each organism grouping at a site.

Species considered should be of commercial or recreational value, threatened with extinction, or dominant at the specific site. If a species is essential to the maintenance of an important species it should also be considered. Important species should have some plausible relationship to power plant operation. Abundance or biomass of the species should be such that sampling can occur without serious depletion of the organism population. Species selected would hopefully have taxonomic characteristics which would facilitate accurate identification.

For those important species or organisms, detailed studies may need to be conducted so plant-induced impacts can be estimated and separated from natural variations. In the early survey stages preliminary estimates should be made of the particular role of each organism grouping, at the site under consideration, in order to determine whether important species are within the group. Following selection of a site, greater consideration should be given to determining important species and important organism groupings. A checklist of organisms likely to be especially vulnerable to the specific stresses proposed should be developed.

Throughout all surveys, the site-plant design evaluation should be performed through evaluation of site specific information. The purpose of this evaluation is to note ecological information on sensitive or critical biological aspects of the site that need to be designed around. The following are examples of structures, systems, and plant outputs which could affect aquatic ecological conditions and for which alternatives exist for modifying the potential impacts: maximum thermal power output, locations of major structures, type of cooling water system, location of access roads, rail lines, and transmission line rights-of-way, locations and designs of intake and discharge structures, and types of radiological, chemical, and biocide waste discharge systems. Initial information must be available from the ecological studies at the early baseline survey stage so that such data can be used in a timely evaluation during preliminary engineering of the plant. The aquatic ecologist in charge of the baseline survey should consider, even on the basis of just a few months of data from the initial survey, what aquatic aspects of the site are important to safeguard.

OPTIMIZING SEARCHES FOR EXISTING DATA

Finally, one must address efficient solutions to the problems presently inherent in obtaining necessary biological information for environmental reports from literature. Currently, it is not really possible to keep up with the tremendous quantity of data, and interpretation, appearing each year in the published technical literature, and very difficult to even learn what data have been collected but not published at all, or published only in the "grey" literature of informal or internal reports.

One may first try to use available biological literature research tools, such as BioAbstracts, Oceanic Index, et cetera, and within limits they are rather easy to use, if one wants to locate information either in very broad categories such as physiology, or taxonomy, or in very narrow categories such as one specific organism. While these indexing categories are quite helpful to research projects concerned with a single species, and perhaps a single aspect thereof, they are of extremely limited use to those who need to quickly and efficiently locate existing knowledge relating to a specific geographic location. This then is a basic need of bio-environmentally oriented scientists and engineers working with both industry and regulatory agencies.

It appears, however, that several potential solutions are almost available; that is "almost available" in the sense that they have been applied successfully to similar purposes.

At least two computerized systems are now in use for storage and recovery of physical-chemical water quality data: The Environmental Protection Agency

(EPA) STORET system and the National Oceanographic Data Center (NODC) files. In each of these a search can be conducted on the basis of geographical location (and by chronology). The NODC data can be retrieved by Marsden Squares—each of which includes a large number of square miles, but a size which is not inappropriate to the relatively gentle gradients characterizing oceanic parameters. The EPA STORET system is accessible by specification of either geographic points (river-mile, or latitude/longitude) or area (between river miles indicated as up and downstream boundaries, or within a polygon each apex of which is indicated by latitude and longitude). The further ability to sort the data chronologically to contrast recent vs. older data, or to look for seasonal patterns, is a significant additional aid to ecological analysis.

Another major source of information, which also needs improved indexing, is the vast compilation of data in the variety of water-use permit applications: NPDES, Section 316, and federal, state and local environmental impact statements. A comprehensive index to these on a geographic locator system would be extremely valuable.

Other major literature search services, e.g., Bio-Abstracts, Oceanic Index, and the Smithsonian Institution's Science Information Exchange, are set up for "keyword" access searches.

Only a negligible, relatively minor expense would be involved to ensure that a geographic locator, a keyword, or latitude-longitude specification, were used also in all papers/reports that relate to field biological studies, or even those studies which utilize organisms collected at field-locations. One must assume of course that authors would cooperate, and provide the needed information in the paper/report (and in its abstract submitted for use of literature search tools). Once that habit was ingrained, the addition of this one extra index would represent a very low cost to index services in absolute terms, let alone in relation to the benefits accrued in being certain all relevant data are integrated into impact statements. If such geographic locators were to include latitude-longitude, in addition to a named body of water (lake, ocean, watershed, river basin), or land area, utilization would be greatly enhanced by the easier incorporation of references into the STORET/NODC type systems with a numerical index access, without need for knowledge of the name of each body of water or land area.

Similar organization of air quality data by "air-shed" would greatly enhance full use of existing knowledge in overall evaluation of more complete environmental interactions.

Thus the key to continued progress in making knowledgeable, realistic, and consistent evaluations on environmental impact lies with improving both the comprehensiveness of the data base available—at reasonable cost—and improving our ability to determine which data are indeed important to the decision under consideration.

REFERENCE

Ebehardt, L. L. and R. O. Gilbert, "Environmental Impact Monitoring on Nuclear Power Plants, Section 3—Monitoring Methods, Part 9—Biostatistical Aspects," National Environmental Studies, Project No. 4, Atomic Industrial Forum, Inc., Washington, D.C. (1974) 181.

THERMAL DISCHARGES AND ESTUARINE SYSTEMS

JOSEPH A. MIHURSKY
University of Maryland
Solomons, Maryland

ABSTRACT

Interactions between steam electric station operations and estuarine aquatic systems are described. Environmental problem areas are discussed under two broad categories: (1) the predator role of a power plant in terms of larger organisms impinging upon water intake structures, or of effects on smaller organisms upon passage through cooling water condenser systems; and (2) the discharge water or plume impact on resident and migratory organisms in the receiving water. Biological damaging effects are described from many factors other than excess heat alone, e.g., mechanical, biocides, et cetera. A number of siting and operating design options to achieve better compatibility are described. Integration of field and laboratory programs is urged at both national and regional levels. Present trends are reviewed. Four recommendations are made with regard to national and regional policies. Eleven recommendations are made with regard to research activities.

INTRODUCTION

Management, research and legislative concern with the environmental problem of excess heat production from the electric generating industry have spawned the development of many new terms in the last 10 years. Thermal pollution, thermal loading, thermal addition, thermal enrichment, and calefaction are the more common ones now used. This same period, especially the last five years, has seen the production of numerous bibliographies, national and international symposia and workshop volumes, review treatises, journal publications on basic and applied research results, legislative committee documents, "pre- and post-operative" survey reports, consultant reports, and environmental impact statements, all in some manner pertinent to the problem caused by excess heat release due to an activity of man.

In spite of the above described efforts, a consensus of opinion as to whether thermal discharges have significant environmental effects on a site or region is difficult to obtain. This difficulty can be traced to a number of factors, among them:

1. Inadequacy of research data, attributed to:
   a. The inability of field studies to overcome the "noise" in natural systems caused by inherent natural variations.
   b. A lack of coordinated and well-designed investigations (both field and laboratory) of a regional or national scope. We are still shot-gunning and not always asking the right questions.
   c. A relatively large segment of the research community being reluctant to engage in applied research.
2. Adherence to traditional economic-ecologic philosophies or activities.
   a. As stated by recent administrations in Washington, energy independence and economic recovery are believed best achieved by relaxing environmental concerns.
   b. External diseconomies are still permitted with regard to environmental losses, sometimes because of an inability to factor environmental values into economic input-output models.

Thus, the man-environment excess heat problem has not been solved, or resolved, and with regard to waterways, the volume of thermal discharges has been increasing.

WHAT IS THE PROBLEM?

Although all excess heat must eventually enter the atmosphere, traditionally water has been used as a "middle man" to carry excess heat energy away from steam electric stations (SES). Water's unique characteristics have provided useful economic and engineering advantages to the electric utility industry. These advantages have in turn been reported as disadvantageous to aquatic resources (see Clark and Brownell (1973) for one such treatment).

In general, for every 1 megawatt of electricity produced, 1.7 megawatts of heat are rejected by a steam electric station, corresponding roughly to 33 percent energy conversion efficiency for a typical fossil fuel plant (Engstrom, Bailey, Schrothe, and Peterson, 1972a). New fossil fuel units achieve about 40 percent efficiency while nuclear units achieve about 32 percent efficiency. A typical water requirement for a 1000 MW_e[1] installation is about 1,500 cubic feet per second. Taking into account differences in plant and stack heat losses, fossil fuel units reject about 4.2×10^9 BTU/hr., while nuclear units reject about 6.6×10^9 BTU/hr. to the condenser cooling water supply. Thus, average increases across condenser systems are 12°F for fossil and 20°F for nuclear (Committee on Power Plant Siting, 1972). Increasing size of single installations may require up to 50 square mile feet of water per day to be pumped for condenser cooling purposes if open once-pass systems are used to dissipate excess heat. Environmental concern with regard to excess heat in aquatic systems stems from the acknowledged role of temperature as the biological master factor in these same systems (Kinne, 1963; Mihursky and Kennedy, 1967).

OPERATING CHARACTERISTICS OF OPEN ONCE-PASS COOLING SYSTEMS OF STEAM ELECTRIC SYSTEMS PERTINENT TO BIOLOGICAL EFFECTS

Given on Figure 1 is a schematic of an open once-pass cooling water system used in a typical steam electric station design. Included also are three columns: (1) Design Parameter, (2) General Preference and (3) Ecological Basis. Although thermal effects have gained the most attention as a possible limiting factor of SES on biological systems, the above figure calls attention to a number of additional features that may affect resident biota. Mechanical damage may occur to organisms such as fish, crabs, combjellies, jellyfish, and salps that impinge on intake screening. Smaller organisms, e.g., phytoplankton, zooplankton, fish eggs and larvae, that are pumped into and through the cooling water system can be mechanically damaged from impingement on the ends of condenser tubes and from moving parts of pumps. These same "pumped-entrained" organisms can be subjected to pressure changes, turbulence (shearing forces) as well as to damaging effects from biocides such as chlorine which are used to keep metal surfaces clean of fouling organisms (Coutant, 1970).

Still other more complex consequences of SES operations must be understood. One, for example, is the use of chlorine as a biocide. Although the chemistry of chlorine in seawater is imperfectly known, information indicates that not only can chlorine kill organisms but it can oxidize the organic component of bottom sediments and thus release absorbed heavy metals (Hill and Helz, 1973). These effects, especially when combined with heavy metal releases from SES condenser systems due to erosion or corrosion (Leschber, 1972) can result in magnifier-concentrator organisms such as shellfish incorporating and accumulating excessive levels of metals and consequently being rendered unfit for human consumption (Roosenburg, 1969). Becker and Thatcher (1973) have produced a review publication entitled "Toxicity of Power Plant Chemicals to Aquatic Life." This review discusses the various chemicals actually or potentially associated with power plants. Eighteen chemical categories and over 125 separate chemicals are listed.

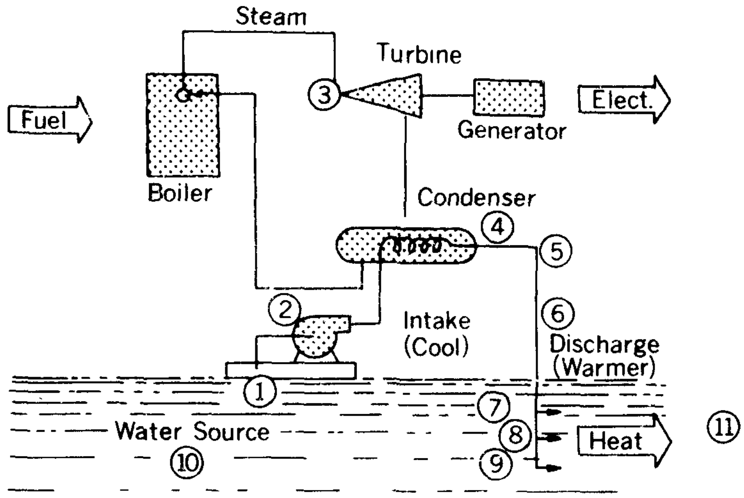
From an aquatic resource viewpoint, two major considerations are important when SES employ open, once-pass cooling systems (Figure 2). The first is the concept of the SES acting as a predator and "cropping" or consuming organisms, the so-called pumped-entrainment and/or pumped-entrapment effects. Thus, site selection, engineering designs and operating characteristics for minimum biological damage becomes critical under such circumstances and the relative rates of destruction and recovery must be determined. If plant operations "crop-off" organisms at a rate faster than organisms can regenerate in open receiving systems, depletions in natural populations can be expected (Mihursky, 1969).

The second consideration deals with discharge plume effects on near-field and far-field biota. Discharge plumes may have various physical configurations depending upon the characteristics of the receiving water body and the design and location of the discharge structure itself (Committee on Power Plant Siting, 1972). Biological effects of plumes are determined by the following factors:

1. Temperature elevation
2. Rates of temperature change
3. Chemical characteristics
4. Hydraulics

Abnormal migrations of mobile animal species into and away from discharge plumes (Elser, 1965; Moore, et al., 1972; Trembley, 1960) and occasional massive kills (Alabaster and Downing, 1966; Mihursky, 1969; Trembley, 1965; Wagenheim, 1972) under various seasonal and SES operating conditions are recognized facts. Positive as well as negative responses on the part of non-mobile benthic plant and animal species are also known to occur (e.g., Anderson, 1969; Cory and Nauman, 1969; Nauman and Cory, 1969; Warinner and Brehmer, 1966).

[1] 1000 MW: 1,000,000 kilowatts of electricity.



DESIGN PARAMETER	GENERAL PREFERENCE	ECOLOGICAL BASIS
1. Intake design	Behaviorally avoidable or provide safe return to environment	Poorly designed intakes trap fish, crabs, etc.
2. Volume of water pumped	Low (but site dependent)	Numbers of organisms affected
3. Turbine backpressure	Lowest feasible heat rates	Lowest backpressure permit low temperature discharges to environment (7) highest feasible efficiencies
*4. Temperature rise	Site and season dependent	Temperature-time relationships of effects
5. Length of cooling water piping in plant	Short (minimum transit time)	Temperature-time relationships of effects on entrained organisms
6. Length of transit to receiving waterway (canal or pipeline)	Short (minimum transit time)	Temperature-time relationships of effects, fish entrapment
7. Discharge location	Beyond littoral contact	Shoreline abundance of organisms (may be seasonal)
8. Discharge depth	Semistratified plume	Keep highest temperature water away from resident bottom organisms
9. Turbulence (exit velocity, port size or number)	High	Temperature-time relationships and areal extent of effects
10. Dilution (near field)	High	Plume entrainment, temperature-time relationship
11. Circulation (far field)	High	Temperature buildup for recirculation may change overall species composition

*Subject to mutual trade-offs at specific sites.

FIGURE 1.—Schematic of once-pass cooling water design and a summary of cooling system design needs (from Committee on Power Plant Siting, 1972).

SOME MAJOR UNANSWERED QUESTIONS

In brief, although the major interactions between SES and aquatic environments can be reduced to (1) pumped-entrainment and entrapment (= predation) and (2) discharge plume effects (= behavior, growth and reproduction), and many studies have attempted to sort out biological responses and identity limiting factors, no single study has really

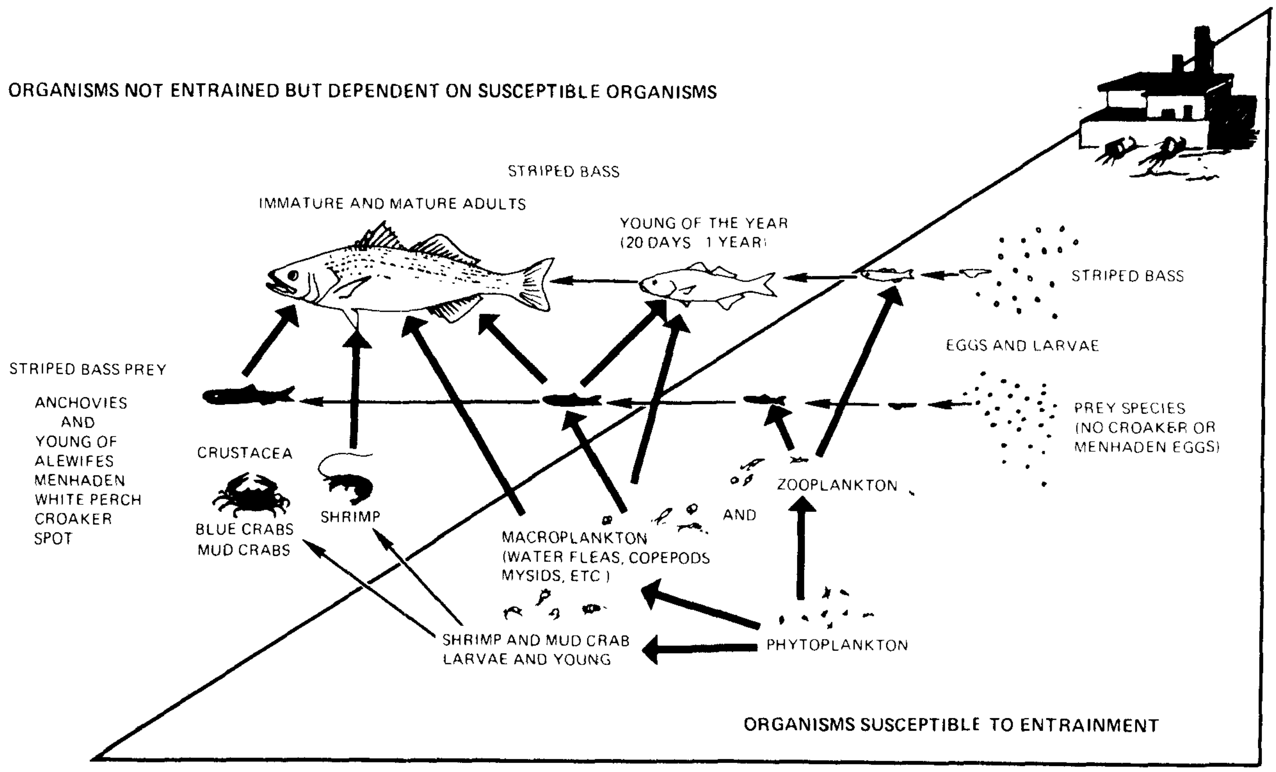


FIGURE 2.—Potential power plant effects on striped bass and associated food items (from Bongers et al., 1972).

answered the two most important questions:

1. Regardless of whether biological community structure has been altered (different species mix or different relative abundance of various species), is biological energy flow still going into the production of a similar quantity of useful biological material as occurred before any SES influence?
2. If concern is for one or more target species, are socially (= man's interest) acceptable sustained yields still produced within the estuarine system or subsystem for the species in question?

These questions are not easy to answer; however, let us briefly examine some of the information that should be acquired if we seriously try to answer them and thus manage the energy-environment question from a scientific as opposed to a political, economic or emotional point of view.

1. Develop a better understanding of the processes operative within estuaries.
   a. Understand the population dynamics of key estuarine organisms.
   b. Determine limiting factors to a species' success, e.g., predator-prey, host-disease, host-parasite relationships, food web relationships (who eats what and how much), physical and chemical threshold levels for biological success at the species and community level.
   c. Determine sources, cycles and sinks of critical (or limiting) items, e.g., heavy metals, biological energy and material flow.
2. Develop biogeographic maps of estuarine systems, identifying the following for key species:
   a. Quantitative seasonal and daily distributional patterns in both horizontal and vertical gradient systems for all life history stages.
   b. Spawning areas.
   c. Nursery areas.
   d. Over-wintering areas.

FIELD VERSUS LABORATORY RESEARCH

The importance of properly coordinated field and laboratory programs cannot be overemphasized. Development of typical information needed requires considerable laboratory as well as field efforts to understand the processes operative within estuarine systems; biogeographic mapping must depend on extensive field operations.

The variability inherent in field data due to patchiness in distribution of organisms both temporally and spatially, will require one of two approaches: (1) improve the design, sampling effort, and methodologies to increase field quantification; or (2) assist judgements through the use of appropriately designed laboratory experiments.

Approach #1 will add greatly to the cost of traditional field studies. As an example, our present program to understand the population dynamics of one species, the striped bass, and the relationship to power production in the Potomac Estuary, Md., required the following for 1974.

Sub-program	*Staff*	*Direct Costs*
Spawning stock assessment	8	$ 90,000
Ichthyoplankton	10	125,000
Hydrography	7	75,000
	24	$290,000

If indirect costs are added, the total dollar expense would approximate $500,000 for a coordinated field project that is attempting quantification for a single fish species. As another example, Carpenter's (1974) recent analysis of the number of zooplankton field samples needed to accurately quantify the community at a single station for a single collection date at the 5 percent confidence level was over 300 discrete samples! Carpenter's work also is being applied to power plant investigations. Such large field efforts are not always possible due to limited funds or staff.

Lack of statistically valid field quantification forces one to resort to judgements. Such judgements can be greatly improved if laboratory studies, coordinated with field programs, are permitted to assist in decision making. In many cases, laboratory programs can provide exceptional insight and information at modest cost. For example, recent laboratory work on time-temperature mortality experiments on egg and larval stages of some estuarine shellfish species (Kennedy, et al., 1974) required the direct capital outlay of less than $2,000/year. Indirect costs (inhouse salaries) were less than $30,000/year. This latter work singled out various temperatures and time exposure combinations necessary for survival (Figures 3, 4, and 5). Such data cannot be acquired under field conditions; however, they are useful and necessary to be incorporated into population dynamics studies, pumped-entrainment effects and development of engineering designs and operating characteristics of SES.

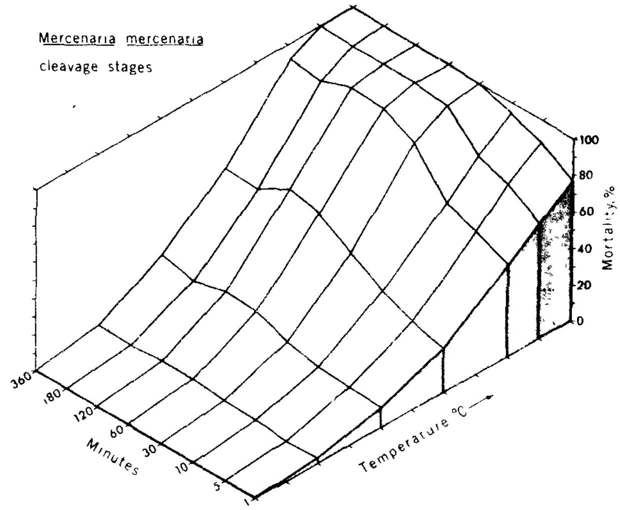


FIGURE 3.—*Mercenaria mercenaria* cleavage stages. Response surface generated from multiple regression analysis of percentage mortality on temperature and time (from Kennedy et al., 1974).

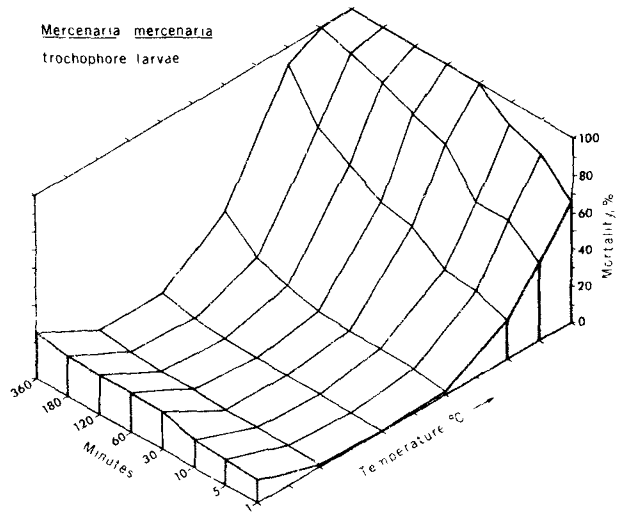


FIGURE 4.—*Mercenaria mercenaria* trochophore larvae. Response surface as in Fig. 3 (from Kennedy et al., 1974).

SOME EXAMPLES OF SITING AND ENGINEERING DESIGN OPTIONS

From an aquatic resource viewpoint, SES sites should be selected on the basis of two considerations: (1) Avoid sites that are environmentally vulnerable to SES activity; (2) Locate in estuarine areas that have environmental and biological flexibility to accept SES operations. In order to achieve the above one must first have adequate knowledge of the biogeography of the region and understand the

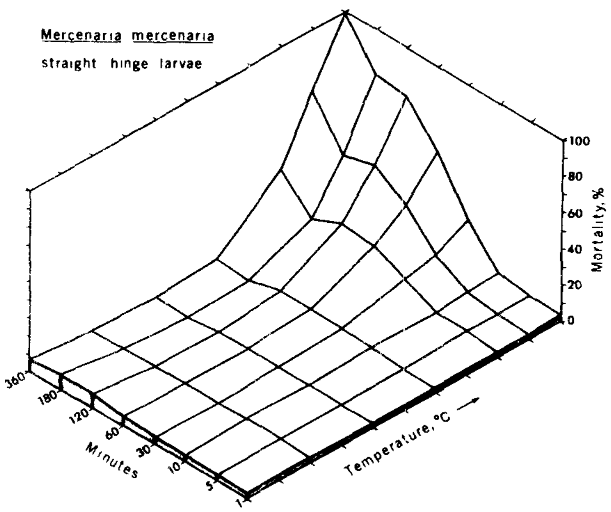


FIGURE 5.—*Mercenaria mercenaria* straight-hinge larvae. Response surface as in Fig. 3 (from Kennedy et al., 1974).

processes responsible for maintaining its biological integrity and utility. For example, within the Chesapeake system the striped bass is an extremely important commercial and recreational species providing social and economic value to the region. The species' spawning sites have been identified (Fig. 6) and are recognized as important geographic areas that seasonally contain concentrations of critical life history stages of this species.

A number of such critical estuarine zones can be identified and located. Similarly, within the Chesapeake system, oyster growing areas, and areas of important "seed" or spat production have been described. Protection of this extremely important economic species dictates that areas of high seed production not be encroached upon by industrial operations requiring large volumes of water for process purposes. The oyster management program in the bay system depends on redistribution of the spat from these areas of high production, but slow growth, to other areas of low or no production, but high growth.

Certain environmental flexibilities can be recognized within estuarine systems if one appreciates their basic characteristics. For example, greater volumes of water (mass flow) move by a point in an estuary as one proceeds from the low salinity inland reaches to the higher salinity, oceanic end. Thus more water is available for dilution purposes. Biologically speaking, along this same salinity gradient (from low to high salinities) the biological value of a given cubic meter of water seems to decrease, e.g., primary production rates decrease, quantities of fish eggs and larvae decrease (Dovel, 1970). Thus, if a given volume of water must be utilized or sacrificed, lesser biological damage per unit volume of water would occur as one progresses from the lowest to the highest (oceanic end) salinity reaches.

Concurrently, SES engineering design and operational characteristics must factor in other biological information to avoid damaging effects on existing biota:

1. Multiple intake and outfall options must be considered for any given site. A surface water intake may be desirable in the daytime when plankton are concentrated in bottom waters, while a bottom night-time intake location may be desirable when plankton organisms tend to migrate to surface waters (Figure 7). Such strategies are capable of minimizing pumped-entrainment of planktonic organisms. Similarly, an offshore deepwater intake may be optimum in summer while a nearshore shallow intake may be optimum in winter due to temperature and water quality advantages as well as differences in distributional patterns of organisms.

2. Volume of cooling water pumped can be manipulated in order to increase or decrease temperature elevations or the number of pumped-entrained organisms. This approach may have value if mechanical or shearing forces are limiting, rather than temperature. Under these circumstances, minimizing water volume pumped can minimize cropping below limiting levels for planktonic organisms. On the other hand, if an absolute temperature is limiting to a site, and "spreading it thin" is possible without other limiting factors operative, then simply increase pumping volumes.

3. Similarly, if biocide use for cleaning purposes is limiting (Becker and Thatcher, 1973), dilution may be one solution; however, use of mechanical cleaning devices such as recycled sponge or brush balls in condenser systems are decidedly to the advantage of the biota.

4. Manipulation of discharge plume characteristics (Committee on Power Plant Siting, 1972) has decided biological advantages. Where important, one may wish to (a) keep the plume in surface waters in order to avoid impingement on important benthic species, (b) minimize surface to bottom gradients so as not to interfere with diurnal vertical migration patterns (Gehrs, 1974), (c) maximize high grade heat zone, or (d) maximize low grade heat zones.

5. Alternation of cooling systems to accommodate the biota also has utility. Critical and entrainable early life history stages may be present at a site only for one or two months (Figure 8); at such time an SES could switch from an open once-pass cooling

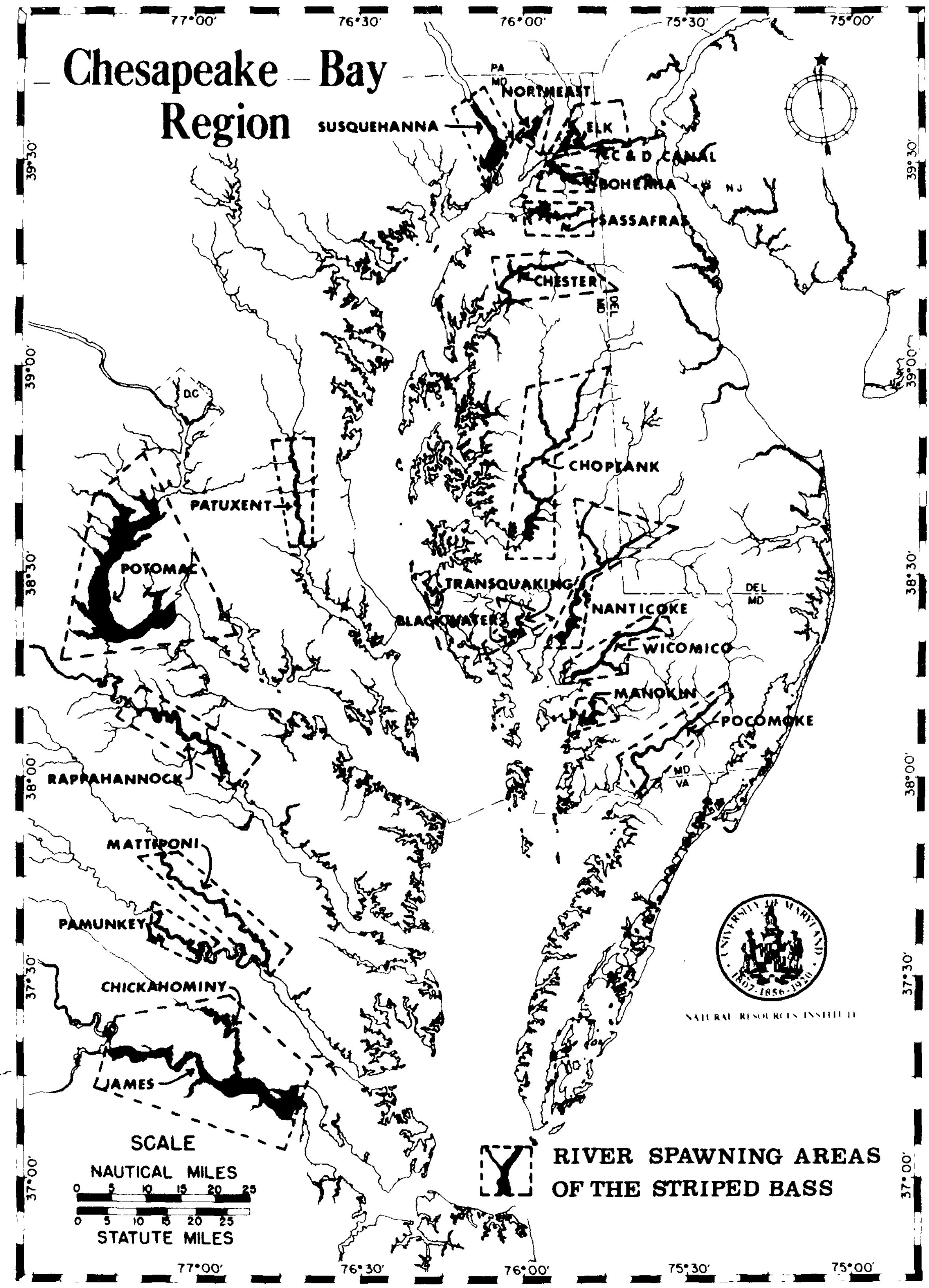


FIGURE 6.—Distribution of striped bass spawning areas in the Chesapeake Bay region.

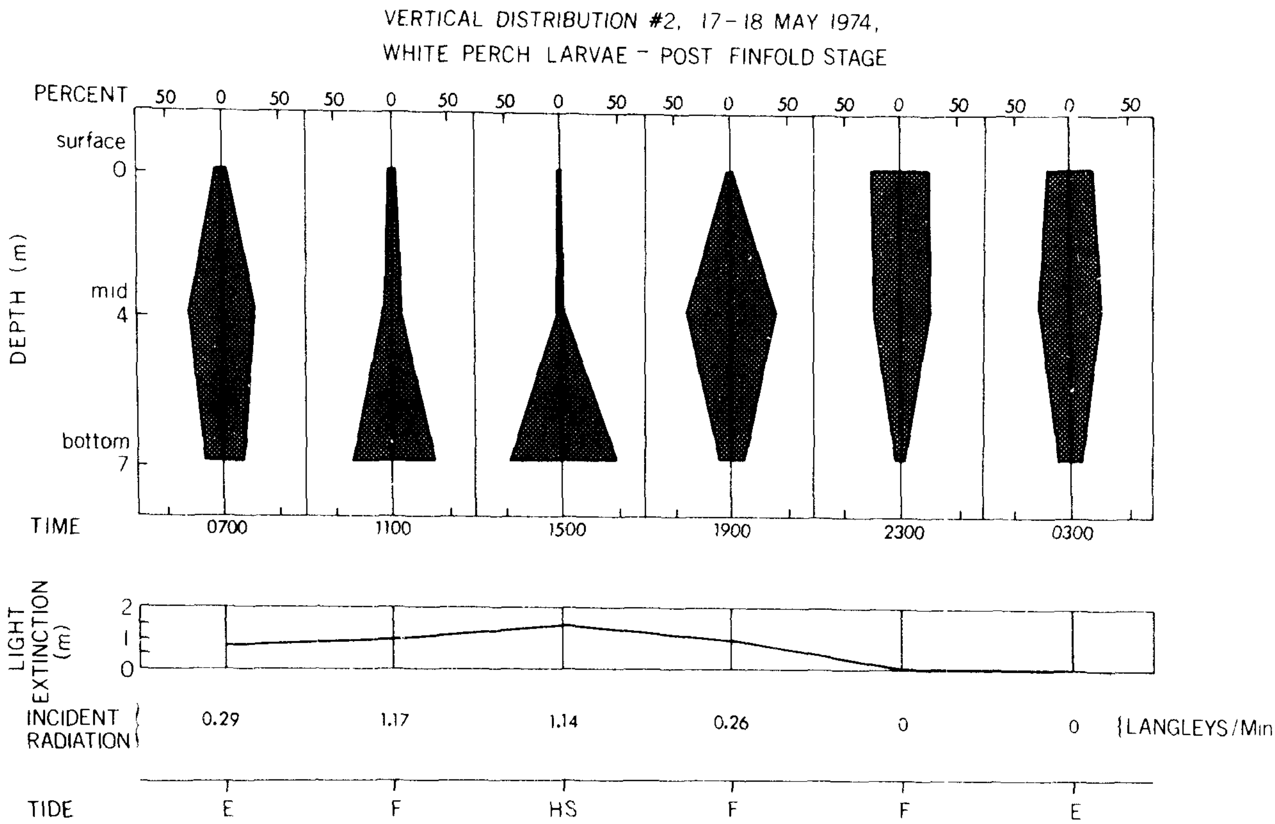


FIGURE 7.—Kite diagrams giving percent vertical distribution of white perch larvae (post-finfold stage) at a single station in the Potomac Estuary over a 24-hour period.

system to a closed or semi-closed one to minimize damage.

PRESENT TRENDS

Many projections have been made on regional, national and world-wide energy needs. The increase in our national energy demand curve has been impressive. Exactly what our growth will be in view of recent energy supply developments is difficult to ascertain. The recent discussion by Mihursky and Cronin (1973) gives one prediction:

> Based on 1960 estimates of U.S. population of 300 million by 2000 A.D., energy usage per capita is expected to increase some 250 percent, and electrical energy is expected to increase by 1,350 percent in the same period (Figures 9 and 10). Electrical energy use is projected to go from 24 percent of the national energy consumption total in 1970 to 34 percent in 1980, 42 percent by 1990 (Anon, 1970) and to 52 percent by 2000 (Jaske, 1970). However, . . . Lees (1971) stated that . . . even assuming near zero population growth, a drop to one half of the present rate of growth in individual wealth, and a corresponding 50 percent reduction in the current rate of increase in power use in the next decade, U.S. consumption of electricity will still triple by 1990! (See also Hammon, Metz and Maugh, 1973). Landsberg (1970) indicated that increases in per capita consumption has accounted for 90 percent of electric generation since 1940.

It seems that in spite of possible changes in life styles, and consequent energy use and consumption patterns, substantial growth demands for electricity

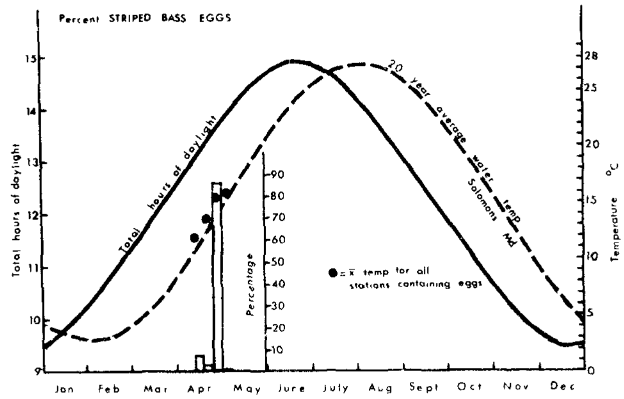


FIGURE 8.—Percent weekly abundance of striped bass eggs in Potomac Estuary for 1974 plotted against total hours of sunlight and 20 year average surface water temperature at Solomons, Md.

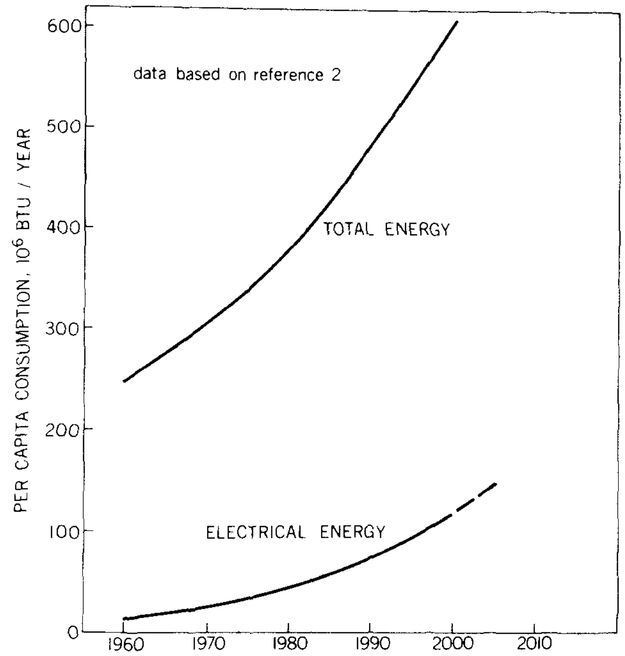


FIGURE 9.—Per capita energy use by decades through 2000 A.D. (from Jaske, 1970).

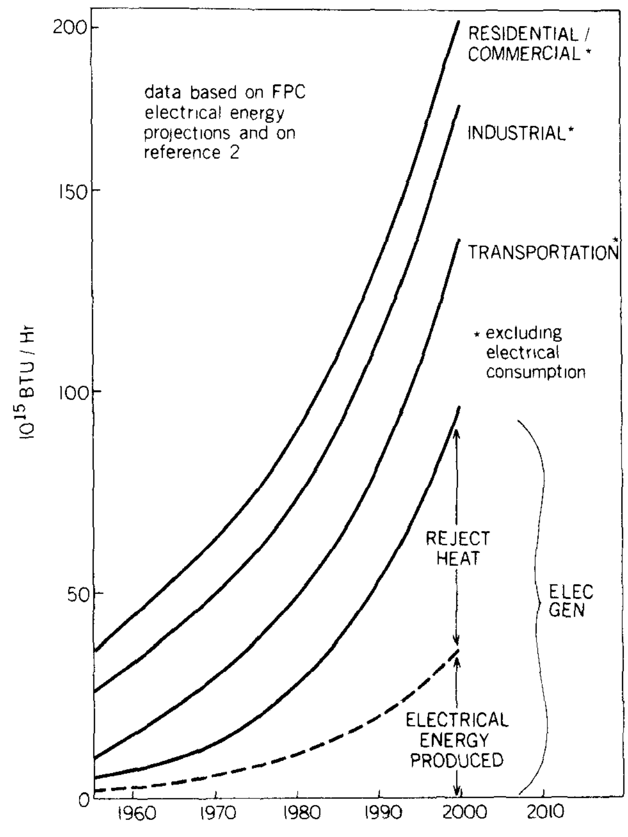


FIGURE 10.—Projected total energy demand in U.S. (from Jaske, 1970).

will continue. Present methods of electricity production still require large volumes of water for excess heat dissipation. Examination of alternative electricity production schemes for the near term (to year 2000) and long term (after year 2000) is possible. Table 1 lists information on electrical power generating technologies and presents data and estimates for three categories: (1) present systems such as hydroelectric, fossil and nuclear fueled SES, and gas turbines; (2) developing systems for the short term (1970–2000) such as breeders, magneto-hydrodynamics, and geothermal; and (3) developing systems for the long term (after year 2000) such as thermoelectricity, fusion, and solar. In summary, the major energy conversion systems presently employed and available for the near term (to year 2000) dictate that great quantities of waste heat will be discharged into our environment.

The next question is where and how the waste heat should be discharged. Recent studies evaluating waste heat assimilation capacities of various river basins of the U.S. as determined by limitations imposed by present state water quality standards, conclude that much of these existing water resources are insufficient to cool on a once through basis, the anticipated growth in the electrical generating industry (Engstrom, et al., 1972a, b).

It seems, therefore, that SES siting efforts by industry will continue towards larger water bodies such as the Great Lakes, estuaries, coastal and nearshore coastal zones. Recent rulings by the Environmental Protection Agency (1974) with regard to the possible use of cooling systems other than once-pass, e.g., cooling towers, has recently added

Table 1.—Estimated reduction in striped bass young of the year*

	Percentage Reduction According to Flow Year Simulated						
CONDITION	1949	1955	1964	1967	1968	1969	1970
No plants (base)	0	0	0	0	0	0	0
Danskammer	5.9	4.5	10.5	6.7	1.8	3.4	4.8
Lovett	12.4	16.0	9.5	9.7	4.5	15.6	15.1
Bowline	13.9	18.4	10.6	9.7	21.9	22.6	18.5
Roseton, Danskammer	15.1	12.2	23.7	16.9	5.3	9.4	12.8
IP 1 & 2	32.9	42.8	25.6	26.8	14.4	41.7	39.9
Roseton, Danskammer, Lovett, Bowline	37.1	40.9	40.4	33.3	29.2	41.5	40.5
Roseton, Danskammer, IP 1 & 2, Lovett, Bowline	55.4	64.0	54.4	48.7	38.2	63.8	61.4

* Assuming flow conditions similar to the year specified.

another dimension to the economic and engineering aspects of SES construction and siting by the industry. As presently stated:

> With respect to any point source otherwise subject to the provisions of section 301 or section 306 of this Act, whenever the owner or operator of any such source, after the opportunity for a public hearing, can demonstrate to the satisfaction of the Administrator (or, if appropriate, the State) that any effluent limitation proposed for the control of the thermal component of any discharge from such source will require effluent limitations more stringent than necessary to assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on the body of water into which the discharge is to be made, the Administrator (or, if appropriate, the State) may impose an effluent limitation under such sections for such plant, with respect to the thermal component of such discharge (taking into account the interaction of such thermal component with other pollutants), that will assure the protection and propagation of a balanced indigenous population of shellfish, fish and widlife in and on that body of water.

The final operating procedure may or may not require a greater use of alternate cooling systems such as cooling towers, than as had been required in the past. Many alternate wet-evaporative cooling methods require considerably less water than open once-pass systems (≈2 percent); however, chemical discharges are increased from blow-down cleaning of cooling towers (Becker and Thatcher, 1973). Hence, in estuarine systems the investigator may have a new task to contend with, namely, cycles, sinks and biological responses to a large array of chemical compounds.

The interaction between the electric utility industry and biologists is expected to continue. Increasingly, industry will continue to develop less damaging operations in response to biological and environmental data.

Examples of such improvements are given in Figures 11 and 12, which are schematic illustrations of water intake and discharge arrangements of two SES on tidal arms of the Chesapeake Bay in Maryland. These illustrations indicate temperature elevation patterns and transport times of cooling water from point of intake to point of discharge into the estuary. Scheme one (Figure 11) reflects an old design (built in the early 1960's) that has summer temperature elevations across the condensers of 6.5°C and a transport time from intake to discharge in the estuary of 2.7 hours. Discharge temperatures reached nearly 38°F, within the old water quality standards of the state. The recessed cooling water intake is located in a relatively shallow shelf zone. This installation used chlorine to keep heat exchange surfaces clean of fouling organisms.

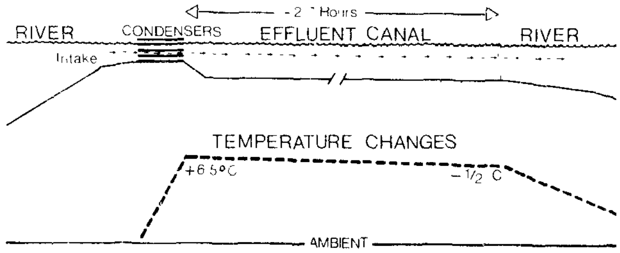


FIGURE 11.—Cooling water system design, temperature changes and discharge time for the Chalk Point SES on the Patuxent Estuary.

Scheme two (Figure 12) is the design of a new plant by the same company. Intake water is from cooler and deeper zones (30–50 ft.) and water transport time is 15 minutes from intake to the estuary. Ambient temperature estuarine water is added immediately on the discharge side of the condenser in order to augment temperature reduction. Maximum temperature differential between intake and outfall water is designed to be 5.2°C and the summer discharge maximum is designed to be approximately 32.2°C, which is about equal to the maximum reached by surface waters in the bay under natural conditions. The above conditions meet the new state water temperature standards. In addition, condenser cleaning is assisted by using sponge rubber balls forced through the cooling system. Scheme two has less effects on entrained organisms than scheme one.

The existing temperature isotherms for a cross section of the Chesapeake Bay for a typical summer day are given in Figure 13. Notice that the hottest temperatures occur at the surface and on the shelf zone. SES have typically pumped cooling water from this shallow shelf zone, the zone that naturally is the hottest during the summer. In the Chesapeake Bay a number of important animal species are at

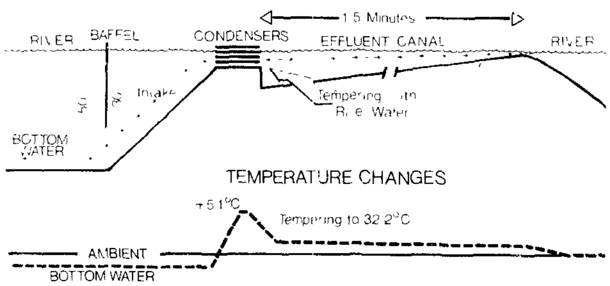


FIGURE 12.—Cooling water system design, temperature changes and discharge time for the Morgantown SES on the Potomac Estuary.

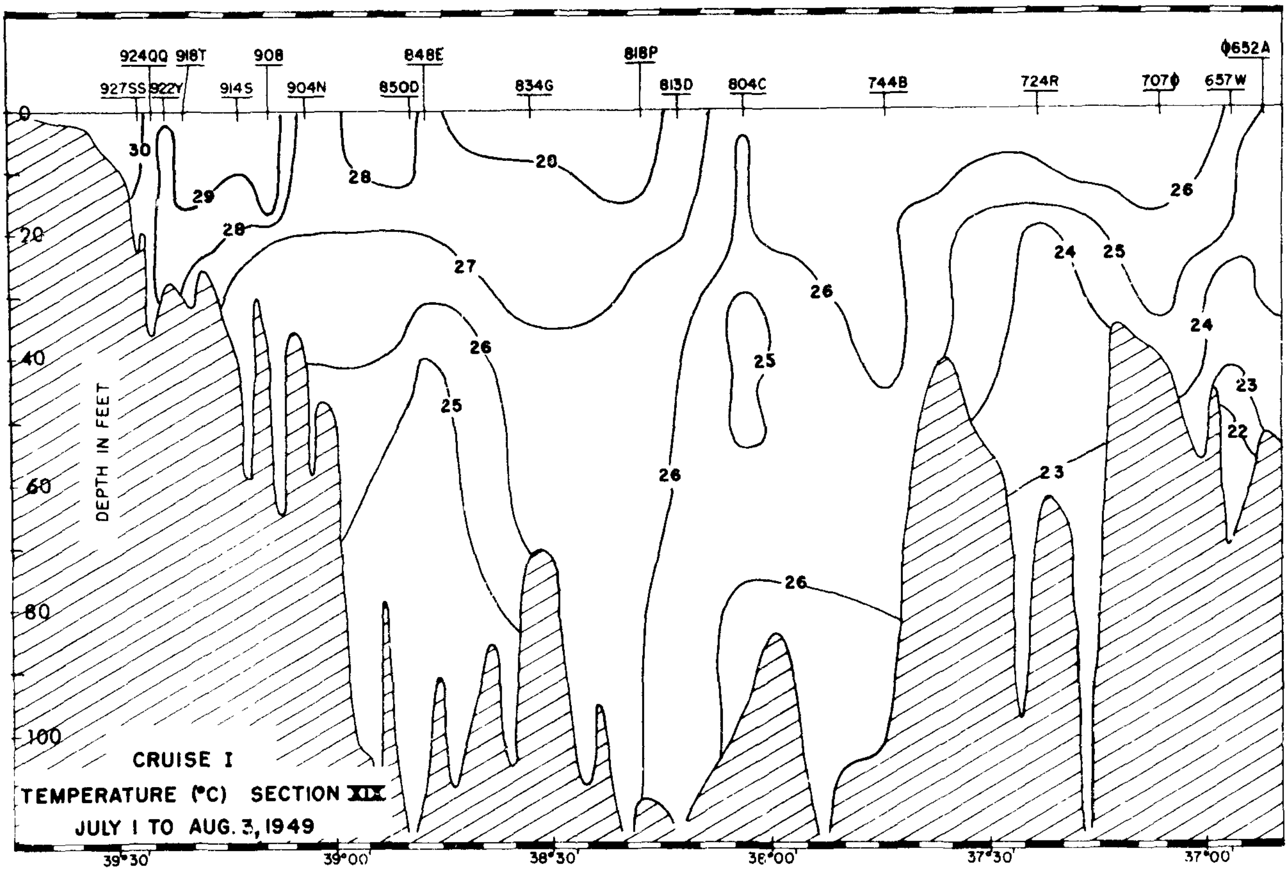


FIGURE 13.—Various temperature isotherms in a cross section of the Chesapeake Bay (from Whaley and Hopkins, 1952).

their southernmost limit of distribution on the east coast, e.g., the soft shell clam. Its southern distribution appears to be limited by high natural temperatures, and any relatively small heat addition in its shallow shelf zone habitat can therefore have detrimental effects (Kennedy and Mihursky, 1971).

It has been observed that below about 40 feet in depth the bay system between Annapolis and the mouth of the Rappahannock (Figure 14) tends to become deficient in oxygen during the summer, and as a result probably contains fewer organisms than surface waters. Waters from these cooler depths may be useful as an industrial cooling water supply in summer. A new nuclear SES is locating in the bay midsection (Figure 14, arrow) and will pump in a cooling water supply from a depth of 28 to 40 feet. This same installation will also have a short intake-discharge passage time (about 4 minutes) and will use sponge balls for cleaning condenser tubes instead of chlorine. A number of design decisions have been made that reflect a certain awareness of and response to environmental vulnerabilities and flexibilities.

The field of ecology is also gaining in sophistication by developing predictive models with regard to proposed environmental modifications. Figure 15 is one such thermal-biotic predictive model for an estuarine system developed for use in the Chesapeake Bay. The model presents optimal and sub-optimal summer temperature levels for the bay animal community.

Figure 16 presents a model that describes the flexible temperature zone existing for bay species for the various seasons. From the maximum allowable temperature elevation line (MATE—dotted line) one is able to predict the maximum increase in temperature that will still permit optimum functioning and production of the bay ecosystem throughout the year (Mihursky and others, 1974).

Biological data and analysis will continue to provide sound guidance to the establishment of proper water quality criteria and standards pertinent to thermal discharges. Coutant's (1972) recent review

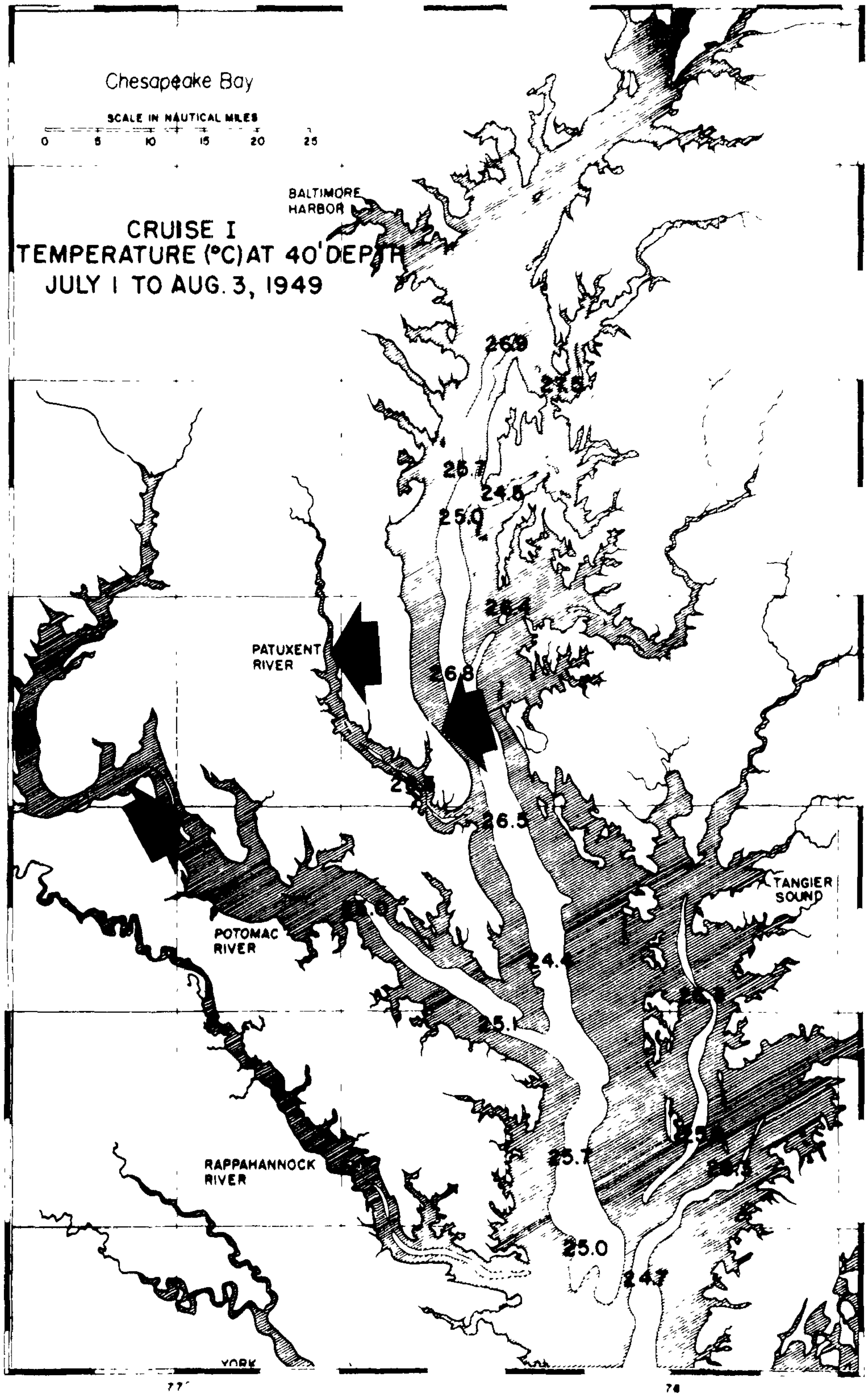


FIGURE 14.—Forty-foot depth areas (in white) in the Chesapeake Bay and existing water temperatures. Arrows indicate SES locations (from Hopkins and Whaley, 1952).

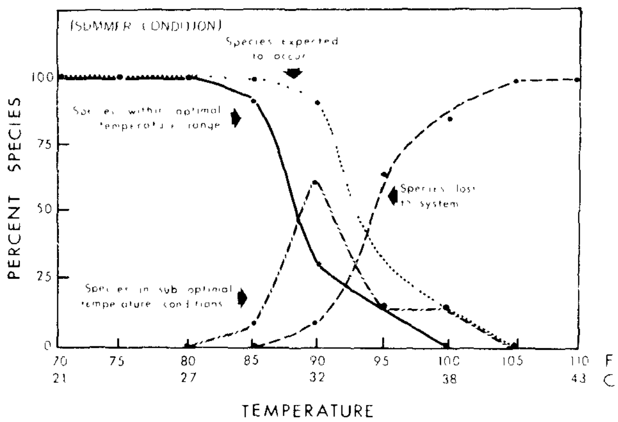


FIGURE 15.—Thermal-biotic predictive model for an estuarine system (summer condition).

entitled "Biological Aspects of Thermal Pollution II. Scientific Basis for Water Temperature Standards at Power Plants" is an excellent example of such guidance.

Another continuing and unfortunate trend is that the initiative for selecting SES sites is still residing with the electric utility industry. State and federal management and regulatory agencies are still responding to industry's initiatives that are often not

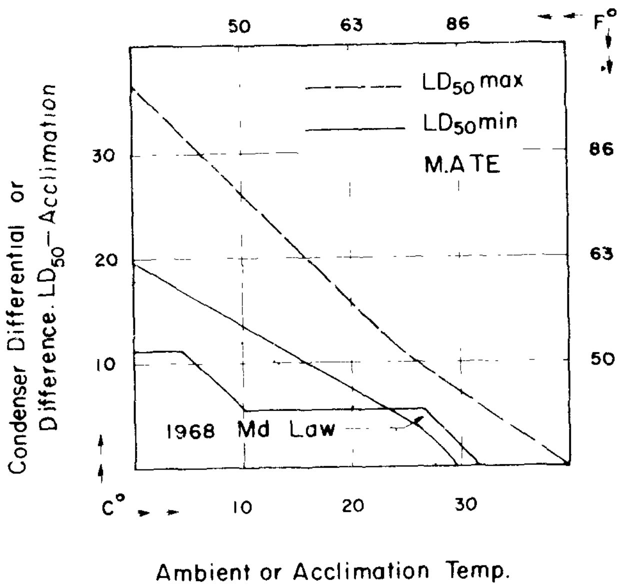


FIGURE 16.—Summary of laboratory TL_m testing on estuarine organisms. Individual lines have been omitted and only the extreme (minimum and maximum) TL_m slopes are plotted. The "old" and "new" (1968) Maryland temperature standards are also plotted. M.A.T.E. is the predicted maximum allowable temperature elevation permitted to protect estuarine species.

based on natural resource interests. In addition, considerable reliance is still being placed upon industry's data, or analysis and interpretation by their consultants in describing "effects" and their "significance."

RECOMMENDATIONS—POLICY

Everyone now recognizes that we have had in the past, two important unwritten national policies with regard to energy and water. Namely, that both shall be abundant and cheap. It is quite clear that our growing inability to provide our human population with cheap and abundant energy and water is forcing changes in our conceptual and operational strategies.

- *National and regional energy policies must be established.* Obviously we must establish energy priorities and sound energy use policies. National and regional management strategies should dictate that we meet legitimate social objectives by means of least energy use pathways. Regional thermal loading should not exceed thresholds that cause unwanted natural resource or climatological responses.
- *The objective of achieving a quality environment in order to achieve a quality society should not be compromised.* Recent commentary that we cannot afford to maintain necessary environmental quality standards fails to incorporate all hidden costs and is an improper conclusion.
- *Federal and state management and regulatory agencies must maintain a high level of internal expertise in order to assess and evaluate actual or proposed environmental changes.* Reliance must not rest solely upon the resource user to design studies, gather, and evaluate data.
- *Initiative and guidance for siting and operation of SES must emit from agencies having national or regional responsibilities, and step by step methodologies must be followed in order to achieve siting and operating of SES with the best environmental fits.* The Water Working Group of the Committee on Power Plant Siting (1972) illustrated in a schematic fashion (Figure 17), and discussed in some detail, the types of procedures to follow. Their recommendations are still valid.

RECOMMENDATIONS—RESEARCH

It is quite clear that we must proceed to manage ourselves from an objective scientific basis, more so than ever before. Environmental costs and benefits are indeed social costs and benefits. Objective decisions must be based on quantitative data, with "all

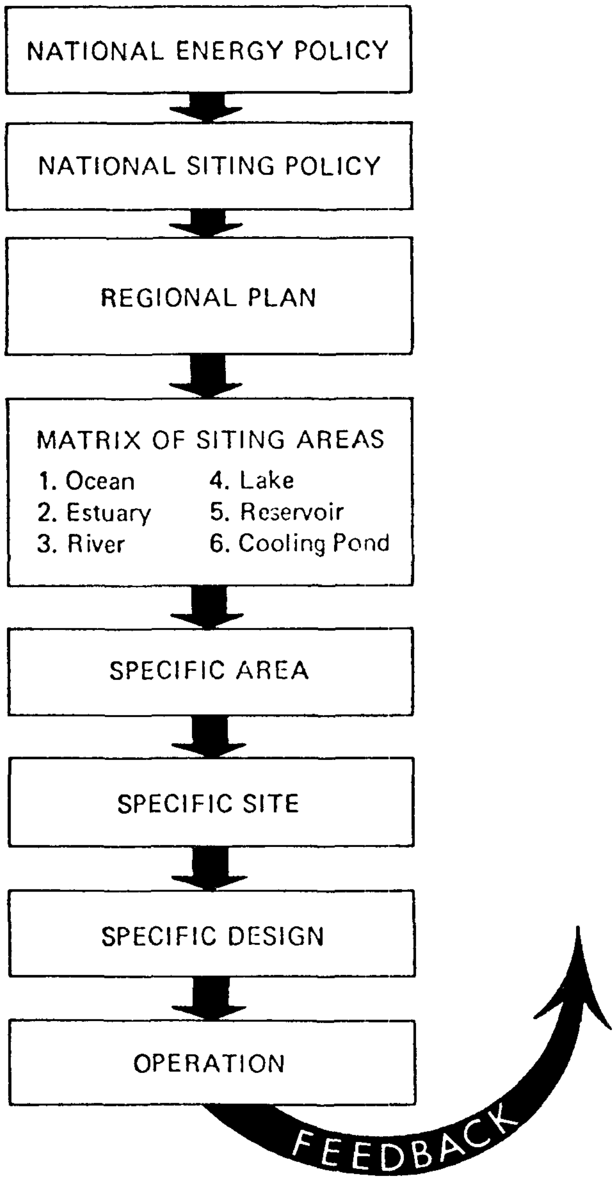


FIGURE 17.—Flow diagram for power plant siting considerations (after Committee on Power Plant Siting, 1972).

the cards on the table." Future generations should not resent our present decisions due to our lack of honest objectivity in meeting legitimate social goals.

• *Basic research activity must be maintained, e.g., the process important in estuarine systems must be understood.* In order to factor in proposed perturbations due to SES operations, a full quantitative understanding must be achieved as to how estuaries function.

• *Biogeographical mapping must be completed for estuarine systems.* Such mapping can provide dynamic regional impressions of priority resource characteristics. Lippson's (1973) recent atlas of the major natural resources of the Maryland portion of the Chesapeake Bay is an excellent example of one such effort.

• *Management and research dealing with thermal discharges should be based on natural estuarine biotic zones.* The Water Working Group of the Committee on Power Plant Siting (1972) proposed the following zones:

1. Canadian border to Cape Cod.
2. Cape Cod to Cape Hatteras.
3. Cape Hatteras to Ft. Lauderdale, Fla.
4. Fort Myers to the Mexican border.
5. Mexican border to Point Conception.
6. Point Conception to Canadian border.
7. Coast of Alaska—probably should be two or three zones.
8. Tropical islands and tip of Florida south of a line from Fort Lauderdale to Fort Myers.

• *A list of important species should be determined for each estuarine zone in order to establish priority of target species for which critical data are to be developed.* Important species must meet one or more of the following criteria:

1. Important as a commercial species.
2. Important as a recreational species.
3. Important in biological energy flow.
4. Present in large biomass.
5. Unique, e.g., for research, aesthetic value, endangered.

• *Quantitative data must be provided concerning population dynamics of these important estuarine species.* Information should at least include the following:

1. Quantitative estimates of numerical abundance, as well as location of various life history stages, from eggs to adult.
2. Estimates of natural mortality rates for each life history stage.
3. Longevity times for each life history stage and generation time (egg to egg) for each important species.
4. Minimum numbers of spawning stock required to produce the next generation at some desirable sustained yield.
5. Second order effects on population dynamics from any altered predator-prey, host-parasite, host-disease changes in the system.

• *It must be determined whether cropping rates from SES activity on these various life history stages are interfering with production of a desirable sustained yield of the important species.* SES site and operational specific, pumped-entrapment and pumped-entrainment studies, must be coupled with laboratory experimentation to assess what, if any, cropping rates may be assigned to specific SES operating sites and to specific operational conditions.

• *Quantitative biological responses to physical and chemical changes attributable to near and far-field discharge plume characteristics must be acquired.* Behavioral, growth, and reproductive responses of species must be determined.

• *The effects of entrainment and plume characteristics on biological energy flow in estuarine systems must be evaluated.* Basic information on who eats who and how much, i.e., bioconversion, must be developed. In the final analysis, from a management viewpoint, changes in species composition or relative abundance may not be as important as maintaining desirable quantities of energy flow into useful species.

• *Regional physiological-ecology facilities must be established to carry out much needed studies under controlled laboratory conditions.* Single variate and multi-variate experiments must be performed in order to assist in evaluating the effects of physical and chemical changes proposed by SES operations upon behavior, growth, and reproduction of important species. Such laboratory studies should also determine optimum and sub-optimum environmental conditions for a species.

• *The above developed estuarine field and laboratory data must be used to produce biostat models, e.g., predictions as to what conditions are to be maintained in order to produce desirable crops, i.e., sustained yields.* Although Goodyear (1973) has come under some criticism, his attempt to predict the effects of various SES on the Hudson River estuary upon striped bass yields (Table 2) was an excellent pioneering effort. He has conceptually pointed the way.

• *Quantitative biostat predictions must be converted to some economical equivalent to permit incorporation into regional and ecosystem input-output models in order to assist decision makers in establishing ecosystem strategies and objectives.* (Cumberland, 1966).

CONCLUSIONS

The tasks outlined above are substantial and costly; their completions however, will have important spin-off value to many other resource management and regulatory problems. Many of the major points made in the text have been made before. Indeed one gains the impression that everything has already been said that should or could be stated. The challenge is to affect priorities, procedures or policy, traditionally a difficult task for environmentally oriented interests in our society.

Table 2.—Electrical power generating technologies (after Anon., 1972)

Method of Generation	Heat Disc. to Cond. Cooling Water BTU/KWH	Expected % of Total Capacity Year 2000
PRESENT SYSTEMS		
Hydroelectric (Conventional & Pumped Storage)	0	5
Fossil Fuel	3,900	10–20
Shale Oil, Coal Gasification & Coal Liquification (new fossil fuel)	3,900	10–15
Internal Comb. Eng.	0	<1
Gas Turbine	0	<1
Topping G. T. w/Waste Heat Boiler		<1
Light Water Reactors	6,600	30–40
DEVELOPING SYSTEMS FOR THE SHORT TERM (1970–2000)		
Gas Cooled Reactors	4,800	10–20
Nuclear Breeders	4,500	10–15
Fuel Cells	0	<5
EGD	0	<5
MHD	0	<5
MHD Topping Cycles	1,700	<5
Geothermal		<1
DEVELOPING SYSTEMS FOR THE LONG TERM (AFTER 2000)		
Thermoelectricity		0
Thermoionic		0
Fusion	small	0
Solar		<1

REFERENCES

Alabaster, J. S. and A. L. Downing. 1966. A field and laboratory investigation of the effects of heated effluents on fish Fishery Invest., London, Ser. I 6(4):1–42.

Anderson, R. R. 1969. Temperature and rooted aquatic plants. Chesapeake Sci. 10:157–164.

Anon. 1972. Water use and management aspects of steam electric power generation. NWC-EES-72-046. Report to the National Water Commission prepared by the consulting panel on waste heat. Nat. Tech. Info. Ser. Springfield, Va.

Becker, C. D. and T. O. Thatcher. 1973. Toxicity of power plant chemicals to aquatic life. Battelle Memorial Institute, Pacific Northwest Laboratories, Richland, Wash.

Bongers, L. H., W. F. Furth, A. J. Lippson and H. J. Obremski. 1972. An aquatic program strategy-power plant siting program. Research Institute for Advanced Studies. Martin Marietta Corp., Baltimore, Md.

Carpenter, E. 1974. Copepod and Chlorophyll a concentrations in receiving waters of a nuclear power station and problems associated with their measurements. Estuarine and Coastal Mar. Sci. 2:83–88.

Clark, J. and Brownell. 1973. Electric power plants in the coastal zone: environmental issues. American Littoral Society, Publ. No. 7. Highlands, N.J.

Committee on Power Plant Siting. 1972. Working Group 1(b) Environmental Protection: Water. pp. 81–150. In: Engineering for Resolution of the Energy-Environment Dilemma. National Academy of Engineering. Wash., D.C. 1972.

Cory, R. L. and J. W. Nauman. 1969. Epifauna and thermal additions in the upper Patuxent Estuary. Chesapeake Sci. 10:210–217.

Coutant, C. C. 1970. Biological aspects of thermal pollution. I. Entrainment and discharge canal effects. C.R.C. Critical Reviews in Environmental Control 1 (3):341–381.

Coutant, C. C. 1972. Biological aspects of thermal pollution. II. Scientific basis for water temperature standards at power plants. C.R.C. Critical Reviews in Environmental Control. August, 1972.

Cumberland, J. H. 1966. A regional interindustry model for analysis of development objectives. Regional Sci. Assoc. Papers 17:65–95.

Dovel, W. L. 1971. Fish eggs and larvae of the upper Chesapeake Bay. Univ. of Md. Natural Resources Institute Spec. Rept. #4.

Elser, H. J. 1965. Effects of a warmed-water discharge on angling in the Potomac River, Md., 1961–1962. Prog. Fish. Cult. 27(2):79–86.

Engstrom, S. L., G. F. Bailey, P. M. Schrothe and D. E. Peterson. 1971a. Thermal effects of projected power growth: North Atlantic River basins. HEDL-TME 72-141. Hanford Engineering Development Laboratory, Richland, Wash.

Engstrom, S. L., G. F. Bailey, P. M. Schrothe and D. E. Peterson. 1972b. Thermal effects of projected power growth: South Atlantic and Gulf Coast River basins. HEDL-TME 72-131. Hanford Engineering Development Laboratory, Richland, Wash.

Gehrs, C. W. 1974. Vertical movement of zooplankton in response to heated water. In: Thermal Ecology. Symposium Proceedings. CONF-730505 Nat. Tech. Info. Serv. Springfield, Va. pp. 285–290.

Goodyear, C. P. 1973. Probable reduction in survival of young of the year striped bass in the Hudson River as a consequence of the operation of Danskammer, Roseton, Indian Point Units 1 and 2, Lovett and Bowline steam electric generating stations. (Mimeo) U.S. Atomic Energy Commission. Hearings on Consolidated Edison Company's Indian Pt. nuclear generating unit No. 2, Docket No. 50-247.

Hammond, A. L., W. P. Metz and T. H. Maugh II. 1973. Energy and the future. American Association for the Advancement of Science.

Hill, J. M. and G. R. Helz. 1973. Copper and zinc in estuarine waters near a coal-fired electric power plant—correlation with oyster greening. Environ. Letters. 5:165–174.

Jaske, R. T. 1970. Thermal pollution and its treatment—the implications of unrestricted energy usage with suggestions for moderation of the impact (Mimeo). Paper for presentation and publication in session notes of Environmental Management for Industry and Government training course sponsored by the Industrial Management Center Inc., Austin, Tex., 1970–71 sessions.

Kennedy, V. S. and J. A. Mihursky. 1971. Upper temperature tolerances of some estuarine bivalves. Chesapeake Sci. 12:193–204.

Kennedy, V. S., W. H. Roosenburg, M. Castagna and J. A. Mihursky. 1974. *Mercenaria mercenaria* (Mollusca: bivalvia): Temperature time relationships for survival of embryos and larvae. Fish. Bull. 72:1160–1166.

Kinne, O. 1963. The effects of temperature and salinity on marine and brackish water animals. I. Temperature. Oceanogr. Mar. Biol. Ann. Rev. 1:301–340.

Landsberg, H. E. 1970. Man-made climatic changes. Sci. 170:1265–1274.

Lees, L. and others. 1971. People, power pollution, environmental and public interest aspects of electric power plant siting. EQL Rept. #1. Calif. Inst. of Tech., Environ. Qual. Laboratory, Pasadena.

Leschber, E. W. 1972. Premature failure of type 316 stainless steel condenser tubing in brackish water. (Mimeo). Presented at the American Society for Metals (ASM) Show and Materials Engineering Congress. Clev. Ohio. Oct. 17–19, 1972.

Lippson, A. J. (Ed.) 1973. The Chesapeake Bay in Maryland, an atlas of natural resources. The Johns Hopkins Univ. Press. Baltimore, Md.

Mihursky, J. A. 1969. Patuxent Thermal Studies—Summary and Recommendations. Univ. of Md. Natural Resources Institute Spec. Publ. #1.

Mihursky, J. A. and L. E. Cronin. 1973. Balancing needs of fisheries and energy production. Proc. Thirty-eighth North American Wildlife and Natural Resources Conference. Wash., D.C.

Mihursky, J. A. and V. S. Kennedy. 1967. Water temperature criteria to protect aquatic life. In: Symposium on water quality criteria. Amer. Fish. Soc. Spec. Pub. 4:20–32.

Mihursky, J. A. and others. 1974. The thermal requirements and tolerances of key estuarine organisms. Tech. Rept. No. 26. Water Resources Research Center, University of Maryland. College Park, Md.

Moore, C. J., G. A. Stevens, A. J. McErlean and F. H. Zion. 1973. A sport fishing survey in the vicinity of a steam electric station on the Patuxent Estuary, Md. Chesapeake Sci. 14:160–170.

Nauman, J. W. and R. L. Cory. 1969. Thermal additions and epifaunal organisms at Chalk Point, Md. Chesapeake Sci. 10:218–226.

Roosenburg, W. H. 1969. Greening and copper accumulation in the American oyster, *Crassostrea virginica*, in the vicinity of a steam electric generating station. Chesapeake Sci. 10(344):241–252.

Trembley, F. J. 1960. Research project on effects of condenser discharge water on aquatic life. Prog. Rept. 1956–59. Institute of Research, Lehigh Univ., Bethlehem, Pa.

Trembley, F. J. 1965. Effects of cooling water from steam electric power plants on stream biota. In: Biological Problems in Water Pollution. 3rd. Seminar, Aug. 1962. PHS Publ. No. 999-WP-25 pp. 334–345.

U.S. Environmental Protection Agency. 1974. Proposed guidelines for administration of the 316(a) regulations. Draft.

Wagenheim, K. 1972. Oyster Creek fish kill. Smithsonian Institution, Center for short-lived phenomena. Event 7-72, 26 Oct., 1972.

Warinner, J. E. and M. L. Brehmer. 1966. The effects of thermal effluents on marine organisms. Int. J. Air Water Pollut. 10:277–289.

EFFECTS OF THERMAL DISCHARGES UPON AQUATIC ORGANISMS IN ESTUARINE WATERS WITH DISCUSSION OF LIMITING FACTORS

LOREN D. JENSEN
Ecological Analysts, Inc.
Baltimore, Maryland

ABSTRACT

A descriptive summary of both thermal and nonthermal power plant effects is presented with an attempt to provide an insight into the total ecological impact of power generating stations operating in estuarine systems. Specific effects of thermal and other plant associated stresses are summarized for aquatic organisms exposed to a range of time and temperature exposures resulting from once-through cooling systems. This review presents specific summaries of representative case histories of thermal effects in east coast, gulf coast, and west coast estuarine systems with an attempt to identify regional characteristics that may influence the response of aquatic populations to thermal effluents.

INTRODUCTION

Considerable attention has been given to the effects of thermal elevations in the condenser cooling system upon aquatic organisms exposed to the discharges for once-through cooling systems. Certainly, much of this concern is justified on the basis that aquatic organisms are vulnerable to physiological shock caused by such exposures. Indeed, thermal deaths have occurred and short of outright death, considerable stress has been detected within surviving members of individual species populations. While we should attempt to keep thermal exposures to a minimum in terms of both amplitude and duration of exposure, other flow related influences should not be overlooked. Indeed, in attempting to reduce the effects of thermal exposures, many design and operational changes at once-through power systems have created new problems for aquatic organisms. My comments are brief and summary in scope. We can assume that our interests in protecting the fisheries populations adjacent to electric power generating systems require the consideration of those aquatic organisms that are of ecological significance to the survival of fisheries populations. Briefly then, I would like to discuss biological monitoring programs and the kinds and levels of effects that have been noted in connection with power generating stations operating within estuarine systems.

FREQUENCY OF DATA COLLECTION PROCESSES

Biological monitoring programs have been used for the past 10 to 12 years to assess the influence of thermal discharges upon surface waters used in the condenser cooling systems of both fossil and nuclear power plants. Initially, studies were limited in both biological scope and frequency, stimulating considerable confusion and debate over the value of individual data programs. Although such studies were intended to monitor effects from specific power plant systems, necessary plant operational fluxes were frequently omitted from data collection programs. Such operational data is relatively easily obtained but, due to the necessity of using power plant personnel with specific engineering expertise, it was often not included by aquatic scientists during either the formulative period in the data collection processes or the interpretable phase of biological data review.

Earlier studies of aquatic biological populations influenced by individual power stations were conducted by teams of specialists, on a quarterly or at best, bimonthly basis. Such studies were assumed to be sufficient to indicate significant effects, but they often resulted in the documentation of seasonal, temporal, and spatial fluxes of populations within each surface water system with such statistical variability from period to period as to make subsequent correlation with physical data exceedingly difficult, if not impossible, to make.

More recent biological monitoring programs have been conducted on a much more intensive basis. Data on daily fluctuations in vertical and horizontal stratification are now commonly collected for all major biological groups on a seasonal basis with the results that monthly data efforts reflect a tremendous range of technical skills and sampling techniques. These studies involve an increasing effort to conduct presiting data programs that can be used to avoid the location of power plants within areas of critical or high biological significance. Moreover, presiting data collection programs have the potential value of improving design criteria for minimizing biological impacts at appropriate sites.

The incorporation of intense presiting biological data programs to new power plant programs provides quantities of data spanning a longer number of years before thermal and other condenser system effects are initiated. The result of such programs is to provide much more confidence to the documentation of the normal biological distributions around a specific site. Annual pulses or fluxes in numbers of individuals of a given species are also much more readily disassociated from the effects of the combined influences of the condenser cooling systems of individual power plants. The following lists of levels of data and areas of potential effects represent common efforts of current estuarine thermal research projects.

WATER INTAKE AREA EFFECTS

The first engineered interface of a power plant with its surface cooling water supply is the water intake structure including, of course, screening hardware and associated structures. Design engineers currently expend both effort and ultimately considerable expense to control approach velocities to reduce the potential for hydraulic capture of both debris and fish. Although most new screen intake structures have velocities of 1 fps or less, the experimental basis for this constraint is based more upon the demonstrated fact that such velocities have much less impingement potential than higher velocities. Unfortunately, while these numbers are on a practical basis useful to design engineers as a general guide, the fact of life is that even at these relatively low design velocities, hydraulic capture of fish populations occurs on an all too frequent basis and the reduction or the solution of the problem is much more of an art than a science.

A more experienced applied biologist colleague of mine once offered a very useful observation to me on the occasion of his retirement from the faculty at our institution. His observation was, essentially, that the best explanation of natural events and incidents involving fish populations was that the fish as a biological group were quite prone to suicide. Since his retirement, I have found many a power plant engineer who agreed with him. An obvious explanation for the accumulation of fish at intake screening structures involves the fact that screening equipment does collect debris relatively efficiently and dead or dying fish are easily collected along with other debris at intake equipment. Obviously, not all fish at such screening equipment are there on the basis of chance. The attraction of fish to hydraulic flows is explained both physiologically and ecologically in terms of energy conservation. If fish are prone to suicide, they, like many other biological groups, do not waste energy looking for a food source when they can remain relatively stationary and just select appropriate food as it comes by. Even predator species can take advantage of the concentration of prey species in these current systems. The end result is, of course, the establishment of a relatively concentrated biological food chain within the area where these abnormal flow gradients occur for the system. Other aquatic organisms such as crabs, shrimp, and forage feeders can be found at intake systems of gulf and coastal system intake areas.

At those power stations where water quality is uniformly high and where approach velocities are not so high as to entrap and then impinge these organisms, no particular significance can be made for these accumulations. However, when the water withdrawn and used for cooling purposes periodically fluctuates to sub-optimum values for individual species, stressing conditions and, ultimately, death of concentrated populations in these areas occurs and the screening equipment must handle the removal and disposal of the bodies of these organisms. Such events as upwelling, seiching, and surface currents can also produce these events.

Unfortunately, many intake structures and areas have been built with such high velocities that exhaustion and physiological collapse by fish in front of the screening equipment occurs. The result is, of course, that such fish populations are highly vulnerable to additional and extraneous stresses that can cause an "incident" at the screening equipment.

Unfortunately, discharges of heat into intake areas, discharges of chlorine and other products required by the condenser cooling system for either fouling or corrosion control can also adversely influence the survival of relatively dense populations of fish in such intake areas. Solutions to these intake and screening equipment problems will require considerable research relative to the ability of fish to maintain both sustained and darting swimming efforts in a mixed assemblage of species involving both predator and prey species. Age-class differences in endurance must also be considered in such experimental systems. Observations of plants where intake problems are relatively scarce, or at least less detectable, suggest that short, stubby cul-de-sac or funnel shaped intakes have considerable potential for the capture and impingement of fish. Such systems have very few areas where recuperation and resting by swimming organisms can occur. Flush shore intake systems have not been involved with fish impingement problems as frequently as have intake channel sites. Presumably, opportunities for bypassing screening equipment provide for the escape to lower velocity areas by swimming fish. Tidal and shoreline currents also act to carry fish away from screening surfaces in this area.

CONDENSER COOLING SYSTEM EFFECTS

The term "entrainment" has been borrowed from the hydraulics field and used to describe the combined experiences of planktonic organisms from the time of their first exposure to the intake pumps, through the condenser cooling system and subsequent mixing with receiving waters downstream from discharge structures or canals. A distinction is made between "pump entrainment" of planktonic organisms that are subsequently exposed to maximum thermal elevation, turbulence, sheer, and pressures, and "plume entrainment" or planktonic interaction with the thermal plume by organisms that have not experienced the combined experiences of the condenser system. Obviously, the experiences of these two types of entrainment are quite different and they should be distinguished because the temperature and time of exposure as well as turbulence, sheer, and other mechanical stresses are distinctly different for the two types of experiences. Research has shown strikingly different results from these two types of entrainment experiences. The term plankton refers to organisms that are at or near neutral buoyancy and thus, the term is more indicative of the relatively free floating character rather than taxonomic relationships between organisms composing the plankton. Thus, three major groups of planktonic organisms can be described, each with relatively different individual response and population susceptibility to the entrainment experience.

Phytoplankton

These microscopic algal cells are, by definition, always planktonic (Euplanktonic) and thus as primary producers of organic energy, they represent a highly important and vulnerable level for entrainment damage. Phytoplankters reproduce within minutes to hours and thus the recovery potential of these organisms is relatively high. That is, should destruction of a portion of the population occur due to either pump or plume entrainment damage, the species population has a relatively high reproductive potential for recovery within a few hours. Moreover, death of these algal cells does not change the nutriment value of the population since most aquatic predators do not distinguish between dead and living cells.

Experience in attempts to measure the stresses upon phytoplankton during exposures to the combined experiences in the condenser cooling system suggest that the response of phytoplankters is most related to the prevailing ambient water temperatures and the temperature rises (ΔT) of particular condenser cooling systems. That is, if death of living plankton occurs it is most predictable on the basis of seasonal high water temperatures, usually occuring only a few weeks or months during each year. At other times of the year the phytoplankton appear to be stimulated by the entrainment experience as indicated by increases in the rates of photosynthetic processes, chlorophyll levels, and absolute numbers of cells of individual species found in discharge and mixing areas (Warriner and Brehmer, 1966, Gurtz, 1973, Brooks, et al., 1974, Jensen, et al., 1974, Smith, et al., 1974).

The above effects should not be considered as necessarily beneficial to the aquatic population residing in a cooling water body. Numerous water bodies do not need such stimulation by living plankton populations and in some cases the destruction of phytoplankton can contribute to oxygen problems due to the BOD demands of the dead plankters downstream from the discharge areas. Thus, the significance of damage to this level of aquatic populations should be determined on a site specific basis.

Zooplankton

This term describes a very rich assemblage of invertebrates that are, in most cases, microscopic. Many zooplankters are truly planktonic, and only a few groups are consistently neutrally buoyant. Thus, effects of the entrainment experience at this level is likely to be much more species specific, and, in fact, current research appears to verify this assumption. Moreover, potential mechanical damage to these types of organisms is considerable, especially with larger crustacean forms of the zooplankton;

such damage has been found to be both size and species dependent.

Behavioral excursions of zooplankton from lower to upper water levels has been shown by Kelly, 1971, Kelly, et al., 1971, Kelly and Chadwick, 1971, Icanberry and Adams (1972), Davies and Jensen (1974) and others to bring these zooplankters into water volumes where they can be affected by both pump and plume entrainment experiences. Considerable variation has been found relative to the vulnerability of different life cycle stages of zooplankters to the effects of both thermal and mechanical damage; eggs, early naupliar stages, appear to be more resistent than larger, older and somewhat more physiologically complex stages. Moreover, prolongation of thermal exposures by residence within long discharge canals has been shown by Davies and Jensen (1974) to promote thermal damage to zooplankters. Sheer and mechanical turbulence of discharge structures may inflict physical damage on larger plankters. Little evaluation of zooplankters during turbulent plume mixing has been made. Research by Carpenter (1974) suggests that alterations in behavioral activities of microcrustacean zooplankters can result in decreases in the population downstream from once-through power plants. Depending on levels applied and individual toxicity of each species, chlorination activities can destroy all plankton organisms when and if used for the control of biofouling in the condenser system. Recirculated heat, as a control system, appears to achieve the same degree of damage.

Meroplankton

By definition, these transient plankton forms are only present for a brief period during which growth and development proceed to either a sessile or swimming juvenile stage, leading ultimately to either the sessile or nectonic adult form. Numerous invertebrates such as crabs, lobsters, shrimps, clams, oysters, and other taxonomic groups have meroplanktonic eggs and larvae. Most fish have meroplanktonic egg and larval stages (known as ichthyoplankton) that are present for a period of days to weeks following spawning activities. Thus, prevailing currents and tidal flows can bring these temporary plankton into contact with thermal plumes with effects that are not readily measured.

Moreover, entrainment damage of meroplankton stages can have considerable influence upon the populations of fishes and invertebrates well beyond those detected in the near field mixing area. These organisms are likely to have a reproductive potential considerably less than that of euplanktonic forms. Damage to these stages can influence the population structure of individual species and communities. Thus, the ecological significance of this type of planktonic entrainment within the condenser cooling system is rather obvious. Experience by biologists studying this problem suggests that considerable physical damage occurs with the rather delicate larval forms of both invertebrates and vertebrates. Egg stages appear to be less susceptible to such physical damage. Excessive turbulence and pressure such as cavitation tend to promote this type of damage. Indeed, some power stations have been reported to produce near total destruction of meroplankton while other stations seem to produce much less damage to the plankton. Current research and modeling of condenser cooling structures should reveal the reasons for these observed differences.

Obviously, the ecological significance of point source types of entrainment such as has been described above must be considered by the use of biological modeling that has, unfortunately, not been developed successfully at the present time. Thus, the ecological significance of these types of entrainment damage can only presently be approximated on the basis of percent of waters used for cooling versus total water available for the support of such planktonic stages. Special or peculiar concentrations of these stages such as clusters or patches can lead to disproportionate effects of entrainment damage upon the individual populations and thus, considerable sampling effort should be made of the near and far field areas to ascertain such distribution differences of individual power plants and plant sites. Such sampling efforts represent a relatively unusual and rather expensive effort.

DISCHARGE AREA EFFECTS

The geometry and site specific characteristics of the discharge area have, like the intake area, a highly plant specific impact on aquatic organisms. The decision to either rapidly mix thermal discharges into the receiving water body through such devices as momentum jets or submarine diffusers can cut the time of exposure to maximum thermal elevations, effectively reducing discharge effects, especially those affecting fish populations attracted into the discharge area.

Discharge canals have been shown to produce highly variable results in terms of impacts upon local aquatic populations. Effects of thermal exposures, cold shock, chlorination "incidents," and other adverse influences have been promoted by the use of long, low velocity discharge canals. These effects have been shown at west coast, gulf coast, and east coast estuarine areas.

MIXING AREA EFFECTS

Considerable effort has been expended by hydrologists in an attempt to describe the dimension of thermal effluent mixing areas. These modeling efforts provide an existing and exceedingly useful series of time-temperature distributions with information relative to changes in these plumes caused by tidal and other natural currents. Their high value and significance to biologists who are attempting to assess the ecological effects and interactions of these effluents in surface waters is obvious. In fact, it would be quite impossible to accurately model the stresses of near field and far field distributions of waste heat without such predictive hydraulic and mathematical modeling research.

Measurements of these downstream effects from the combined pump entrainment and plume entrainment experience suggest that some of these effects are so subtle as to not be readily detected by existing field population census techniques. Certainly some avoidance of and attraction to the thermal plume has been historically seen by many workers.

SUMMARIES OF REPRESENTATIVE CASE HISTORIES OF THERMAL EFFECTS IN ESTUARINE AREAS

The estuarine environment is an exceedingly complex ecological system. Indigenous finfish, migratory finfish, anadromous species, shellfish, and such crustacea as crabs and shrimp depend upon the estuaries for at least some part of their life cycles. The economic importance of specific fisheries in the above categories can be considerable.

Large tidal bodies of water, such as the Chesapeake Bay, Galveston Bay, and others, could, theoretically, offer considerable quantities of cooling waters if the aquatic populations of each estuarine system could be protected from a uniform and complete thermal elevation throughout the system. Again, considerations of specific sites must consider the amount of "new water" passing by a given site and the relative quantity of such waters needed for cooling waters by particular plants. Behavioral and reproductive phenomena such as schooling, spawning, and nursery areas must be protected from thermal elevations. In such systems, mixing of discharge effluents into tidal waters can reduce the effective temperature rise (ΔT) to only one or two degrees above ambient levels. Caution must be given to intake and discharge levels so as to withdraw only the least populated water levels. When the cooler and more saline bottom waters are used as a cooling water source, considerable research should precede plans for the discharge of the thermally elevated, saltier waters. Such discharges have been shown to sink to a mid-depth in response to combined thermal-saline density factors. When and if this occurs, the influence upon local populations must be predictable before alternative discharge plans are rejected.

Moreover, in smaller bays and estuaries, withdrawal of large fractions of water have altered circulation patterns in local areas (Jensen, 1974). As mentioned above, such influences can change behavioral patterns with local populations of fishes and invertebrates. Tidal influences in terms of the direction of discharge plumes complicate the above predictions to the extent that hydraulic models are often used to simulate flow patterns. Such an application has been made in the James River estuary model located at the U.S. Corps of Engineers Waterways Experiment Station in Vicksburg, Miss. The model has a horizontal scale of 1:1000 and a vertical scale of 1:100. The time scale is 1:100 so that one day in the prototype occurs in 14.4 minutes time in the model. The proposed discharge of the Virginia Electric and Power Company Surry Nuclear Power Station has been simulated in the model, and temperature measurements have been recorded along various transects across the model through many tidal cycles and under different freshwater inputs. Since it was not possible to simulate all conditions in the model, theoretical conditions were applied, and the empirical data were thereby adjusted to conditions expected in the prototype. The predicted distribution of excess heat in the estuary will be verified in the James River estuary, after the Surry Power Plant begins operation during the spring of 1973.

Another such model is being planned for the entire Chesapeake Bay. Several hydraulic models of limited areas of the bay and its tidal arms have been built by the Alden Research Laboratory of the Worcester Polytechnic Institute in Worcester, Mass., and are used to predict the physical behavior of thermal discharges. A similar model of the San Francisco Bay and Sacramento-San Joaquin Delta has been used to simulate thermal distribution at various power-plant sites in northern California.

The control of biofouling in tidal systems is considerably more difficult than in freshwater systems. The application of wide-spectrum biocides for such fouling control, both within the intake system as well as the condenser system, must be made with caution to avoid killing fish and invertebrates residing in discharge canals and receiving waters. Excessive chlorination and use of widely active compounds such as copper sulfate have lead to dramatic incidents that have mistakenly been reported as thermal kills.

As mentioned previously, the temperate estuarine populations of southern latitude species are often living close to their upper thermal tolerances during summer periods. These species have much narrower thermal tolerance ranges than northern populations of the same species which can withstand wider thermal fluctuations. Thus, if an appreciable heat load is introduced into a mid-latitude estuary, it must be recognized that the local thermal distribution might actually favor the growth of more southerly species (or subspecies) in limited areas. One difficulty with such changes is that it is likely that some disagreement will occur between local biologists as to what constitutes a "desired species." A conservative ecologist might contend that only those species that exist normally in the outfall area are the desired ones, while other ecologists might be willing to settle for a slightly different fauna and flora in a limited area.

Studies made at the Chalk Point Generating Station on the Patuxent River estuary in Maryland before and after the operation of the power plant showed that local populations of striped bass increased while concentrations of white catfish and hogchokers declined. White perch populations remained constant during the study. Total gillnet catches by commercial gear were approximately the same at the station nearest the power plant and increased at the two other stations farther downstream. Sport fishing in the area has increased in winter months (Maryland Department of Natural Resources, 1969).

Studies of the oyster *Crassostrea virginica* on beds within 1,200 feet of the discharge canal at the Chalk Point plant showed no major effects on the growth, condition, and gonadal development as a result of plant operation (Rosenberg, 1968, Patrick, 1968). Invertebrates harmful to the oyster, the oyster crab *Pinnotheres osterum*, and the worm *Polydora* were no more common in 1965–67 after the plant went into operation than in 1962–63. The accumulation of copper in oyster tissues was also reported from beds in the vicinity of the Chalk Point plant. Subsequent investigations showed that the copper concentrations in water upstream from the power station were 1.97 parts per billion, while that in the outfall was 3.01 parts per billion (Patrick, 1968). This apparently is not common to power plant operation in estuarine areas, but was the result of improper design and metallurgy in the condenser tubing. Cory and Nauman (1969) reported that the number of fouling organisms, including barnacles, increased at the locations influenced by the discharge of the Chalk Point station, decreased upriver from the power plant, and that the increase was associated with the warmer effluent waters.

Studies by Patrick (1968) on the Chalk Point station indicated a well-diversified flora throughout the area influenced by the thermal discharge in August, 1968. Nutrient additions upriver from the plant were reported by Patrick to complicate the assessment of the plant's effects on the standing crop of algae, though the cyclic seasonal patterns observed before the plant went into operation were lost at stations above and below the discharge canal.

Morgan (1969) studied the effect of temperature and chlorination procedures on the passage of phytoplankton through the condensers at the Chalk Point Plant and found that when the effluent temperatures were between 88.7 and 92.4° F (chlorination levels were not known), photosynthetic capacity was reduced by 68.6 to 94.3 percent. During colder seasons, photosynthesis was reduced by as much as 85.7 percent. However, Morgan (1969), Mihursky (1967), and others believe that chlorination procedures were responsible for much of this reduction.

Patrick (1968) found no significant difference in the composition of the zooplankton and/or phytoplankton at the Chalk Point station at similar times of the years 1963, 1967, and 1968.

Two microscopic crustacea, the copepods *Acartia tonsa* and *Eurytemora affinis*, were the dominant species, and *Acartia tonsa* standing crops were greater during the summers after the Chalk Point station began operating. Two jellyfish, *Mnemiopsis leidyi* (a comb jelly ctenophore) and *Cryasora quinquecirrha* (a sea nettle) were more prevalent before the plant began operating. Mihursky (1967) reported that thermal changes were responsible for this decline.

Warriner and Brehmer (1966) studied the effects of condenser discharge water on the benthic invertebrates in the York River estuary at the Yorktown Generating Station of Virginia Electric and Power Company. Community composition and abundance were affected over a distance of 980 to 1,300 feet from the discharge canal. All sampling stations, including the controls, showed a marked seasonal change in abundance, with a minimum in summer and a maximum in winter. The lowest diversity of species was found in a small area within 980 feet of the discharge, and this was interpreted by the authors to be an indication of stress on the benthic community in which only the more thermally tolerant species could survive.

Studies with a laboratory heat exchanger using natural York River water without chlorination showed that primary productivity of natural phytoplankton was depressed by a 10.1° F increase in water temperature when the ambient temperature was 59 to 68° F. A temperature rise of 6.3° F was sufficient to depress production when the ambient summer water temperature was 80° F. In cold weather, productivity was enhanced after passage through the exchanger (Warriner and Brehmer, 1966).

Thermal studies at a power plant at Turkey Point, a unique tropical area in South Biscayne Bay, Fla., have been reported by Tabb and Roessler (1970), Reeve and Cooper (1970), and Lackey and Lackey (1972). The benthic macroalgae *Acetabularia crenulata* and *Batophora oerstedi* were the only species observed at the mouth of the discharge canal during the period of February to September, 1969. The number of species of macroalgae increased at increasing distances from the discharge canal out into the Biscayne Bay. The stations nearest the canal mouth had the lowest numbers of species and thus the lowest diversity index (Tabb and Roessler, 1970). However, these reductions in benthic algae have been suggested to be due to the combined effects of dredging and construction of the power plant canal system along with the hydraulic scour that the discharge canal system imposed upon the areas of Biscayne Bay immediately adjacent to the plant site.

In September 1968, turtle grass, *Thalassia testudinum*, was reported to be killed over a 30–35 acre area which had apparently increased to 50 acres a year later. Benthic invertebrates and fish populations associated with the turtle grass and macroalgae populations were also reported to show decreased numbers in an area of 170 acres surrounding the discharge canal. An unspecified number of dead fish were reported to have been associated with the impact area in June of 1969.

Studies by Tabb and Roessler (1970) have suggested that these effects were primarily due to the thermal effluent from the Turkey Point Power Plant. However, unusually low salinities (16–17 ppt) and relatively high copper concentrations (15 mg/l) were also detected in waters with temperatures of 91 to 95° F (Lackey and Lackey, 1972). Such low salinities for the area (normal summer salinities are 27–33 ppt) coupled with the toxic levels of copper could have been partially responsible for the reported fish kill.

Moreover, the presence of such levels of copper could also account for the reductions in benthic grasses and their associated animal populations, as noted above. In the absence of more definitive data, however, such conclusions are speculative. Recent observations by Lackey and Lackey, 1972 suggest a recovery of the impacted area in the discharge canal and adjacent Biscayne Bay areas since the observations of earlier workers in 1968. Because of the tropical and relatively shallow nature of the Biscayne Bay, these ecological effects may suggest the types of effects that can occur in such estuarine systems.

Research on the thermal impact of a power generating station on Galveston Bay, Tex., was reported by Strawn and Gallaway (1970). Seasonal abundance, distribution, and growth of commercially important crustaceans were investigated. Temperature, conductivity, dissolved oxygen levels, pH, and biological samples of blue crabs, *Callinectes sapidus*, white shrimp, *Penaeus setiferus*, and brown shrimp, *Penaeus aztecus*, were taken once a month through 1968 and 1969. Collection stations were in and around the discharge canal of the power plant. The impact of the thermal effluent upon the above species was related, significantly, to the season, the relative abundance of each species, thermal tolerance, and thermal preference of each species studied. Blue crab populations appeared to be beneficially influenced by the power-plant activities (thermal increases and circulation improvements caused by pumping activities). White shrimp populations appeared to show both detrimental as well as beneficial effects, but the overall effect was judged by the authors to be beneficial. Brown shrimp were adversely affected in a limited area of the Galveston Bay surrounding the power plant (Strawn and Gallaway, 1974).

A study of the thermal impact of a Pacific Coast generating station at Morro Bay was reported by North (1968). Results of studies of the discharge canal and the coastal zone immediately adjacent to the power station indicated that seaweeds were almost completely eliminated from the discharge canal, while in a transition region beyond the canal, seven algal species of a total of 20 species in normal, non-thermally influenced areas were found. The transition area was fished rather intensively, and North suggests that schools of grazing Opaleye (*Girella nigricans*) and various invertebrates account for some of this reduction. Thus, the marine flora of Morro Bay appears to be much more thermally sensitive than the fauna and the impact of the Morro plant effluent on the seaweeds might be explained by the thermal sensitivity of reproductive cells in association with relatively heavy grazing by fish and invertebrates within the area.

Mitchell and North (1971) examined the temperature and time of contact of marine plankton which were passed through the cooling water systems of two Southern California Edison Generating Stations located on the Pacific coast. Sampling at intake and discharge structures and subsequent incubation on site at the San Onofre and Huntington Beach Generating Stations simulated temperature time exposure met by plankters passing through the condenser system and traversing the discharge and mixing areas. Typical zooplankton mortality ranged from 12.7 to 28.4 percent with the high mortalities due to sampling error introduced during sample examination. The copepods *Acartia tonsa, Euterpe acutifrons, Corycaeus affinis*, and *Oithona helgolandica* and the mysid shrimps represented nearly all of the mortalities. Smaller soft-bodied invertebrates (polychaete larvae, *Sagitta* sp.) and protozoans showed little effects of passage. Analysis of carbon-14 and chlorophyll studied of phytoplankton populations passing through the condenser cooling system suggest that little damage to the populations occurred as evidenced by comparisons of ^{14}C uptake rates and chlorophyll *a*, phaeophytin *a* levels after a standard incubation-culture procedure of intake and discharge samples collected from the two generating stations. Some evidence of phytoplankton stimulation in discharge samples was noted during these studies and normal chlorination procedures resulted in obvious damage in the plankton populations collected in the discharge area during the chlorination period.

Icanberry and Adams (1972) have described the survival of zooplankton after passage through the cooling water systems of four California coastal power plants. A statistically significant increase in discharge mortalities of less than 11 percent compared to intake mortalities was found at all plants, suggesting average overall survival of approximately 90 percent. A statistically significant linear relationship was noted between the discharge temperatures and percent mortality in all four of the power plants examined. Twenty-four hour delayed mortality did not occur when intake and discharge samples were held at ambient intake water temperatures. Considerable mortality occurred when discharge samples of zooplankton were held at discharge temperatures for periods up to 24 hours of continuous exposure. Immature zooplankton stages exhibited increased mortality only after the first six hours, followed by adult copepods which died between 12- and 24-hour periods. Soft bodied invertebrate larvae were resistant to these combined effects of temperature and time of exposure. Surveys of actual temperatures occurring around the discharges of these four power plants revealed that these time and temperature conditions (discharge temperatures lasting 12–24 hours) do not occur due to the mixing and dilution of the thermal discharges with cooler Pacific coast waters. Thus, this research suggests that the very small increase in mortality (approximately 11 percent) due to passage through the cooling water system of these four power plants does not (in all probability) significantly affect the zooplankton populations of the Pacific Ocean in the areas surrounding the power plants examined by these researchers.

Extensive research has been underway over the past five years to evaluate the impact of once-through cooling systems of power plants located within the Sacramento-San Joaquin Delta area under the sponsorship of Pacific Gas and Electric Company. Field studies of the temporal and spatial distributions of thermal effluents of the Pittsburg and Contra Costa Power Plants in the central delta area have been supplemented by biological sampling in and out of the thermal plumes to locate populations of striped bass (*Morone saxatilis*), king salmon (*Oncorhynchus tshawytscha*), and other fish as well as fish food organisms such as the opossum shrimp *Neomysis awatschensis* (Adams, 1969, Adams and Doyle, 1971, Chadwick, 1971, Hair, 1971, Kelly, 1971, Wickmire and Stevens, 1971, Kelly et al. 1971, Kelly and Chadwick, 1971, Orsi, 1971, Rogers and Stevens. 1971, Gritz and Stevens, 1971, and Gritz, 1971). Distribution of young striped bass indicated that densities were always greatest at mid-depth and bottom as contrasted to surface areas in stratified areas of the delta. Intensity of stratification fluctuated with the stage of tides and size of fish. Small bass less than 9 mm were higher than larger fish and densities increased at all depths during flood tide. Lateral distribution varied but densities were lowest in surface and mid-depths of the Pittsburg thermal plume suggesting preference for the cooler bottom areas in the vicinity of the thermal effluent.

Further studies on fish distribution within the thermal plume of Pittsburg (Gritz, 1971) have revealed that striped bass, splittail, carp, white catfish, American shad, Sacramento western sucker and Sacramento blackfish were more abundant within the thermal plume of the plant than in control areas of ambient water temperature but equivalent habitat type. Stomach contents of striped bass suggest that the importance of the opossum shrimp *Neomysis awatschensis* diminished and the importance of fishes (including small king salmon) increased with striped bass size (Gritz, 1971). Unfortunately, these studies did not distinguish between increased predator concentration (striped bass) within the thermal plume and physiological stress of king salmon which increased their vulnerability to predators as was suggested by Coutant, who described similar reactions within a thermal plume discharged into the Columbia River (Coutant, 1969). In a laboratory study, Kelly and Chadwick (1971), examined the tolerance of young striped bass in the size range of 5 to 38 millimeters in length. The LD_{50} for striped bass held for 48 hours ranged from 86 to 91° F with variations within this range not related to either acclimation temperature or size of fish. Instantaneous temperature increases (0 to 6 minutes duration) followed by return to ambient temperature resulted in little mortality until the maximum temperature approached 90° F. Below this temperature instantaneous increases of up to 18° F caused little mortality. However, loss of equilibrium was often noted at temperatures above 85° F.

By contrast to the distribution food habits and thermal response of striped bass, Gritz and Stevens (1971), studied the distribution of king salmon in relation to the thermal plume of the Pittsburg station. Occurrence of this salmon was primarily at the surface (in contrast to the location of striped bass at lower depths). Numbers of king salmon decreased from the north shore to the power plant on the south shore. Numbers of salmon caught in the plume of warm water discharged from the plant were significantly lower than numbers caught at ambient water temperature. Catches of marked hatchery-reared salmon released upstream suggest that these young king salmon migrate rapidly through the section of the estuary influenced by the thermal discharges of the Pittsburg plant. Gritz (1971) suggested that some of these salmon might be more vulnerable to predation by the increased number of larger (>16 inches) striped bass residing in the thermal plume. Orsi (1971) studied the thermal tolerances and thermal shock of king salmon. Rapid temperature rises within the limits of an 18° F increase and a 0–6 minute exposure period did not cause mortality until the acclimation temperature exceeded a temperature between 60 to 65° F. The ability of young salmon to withstand short exposures to relatively high temperature improved as acclimation temperatures were elevated. Exposure time was crucial to survival at 83° F with all fish surviving at 0–2 minute exposures to 83° F and only half the test fish surviving at exposure periods of 4–6 minutes.

The opossum shrimp *Neomysis awatschensis* has been shown to be an important food source for game species of fish in the Sacramento-San Joaquin Delta. The distribution of these mysid shrimp has been shown by Kelly et al. (1971) to be influenced by light, tidal stage, and water velocity. During the daylight period, density of *Neomysis* population increased with depth and lateral densities indicating little ability to avoid being carried by intake and discharge flows in the vicinity of the Pittsburg plant (Kelly et al., 1971). The mortality of *N. awatschensis* caused by passage through the Pittsburg plant was determined by Kelly (1971) from comparisons of live and dead *Neomysis* at the plant's intake and outlet. Observed mortalities correlated with the water temperature of the discharge (less than 10 percent at temperatures of 80–86° F compared to approximately 65 percent at temperatures approaching 90° F). Those *Neomysis* surviving higher temperatures showed no evidence of delayed mortality when held under laboratory conditions for up to 36 hours.

These mortalities were similar to those induced by Hair (1971) under laboratory conditions in which the upper lethal temperature of adult *Neomysis awatschensis* was found to be within the range of 75.6 to 77.8° F under conditions of 48-hour static bioassay. Tolerances to rapid laboratory exposures decreased as acclimation temperatures increased but this species resisted temperature elevations of up to 25° F provided the ultimate temperature did not reach 87° F. Temperature rises above 25° F caused significant mortality even though the upper temperature did not reach 87° F. As has been shown with numerous other aquatic organisms, survival decreased rapidly with increased exposure time at temperatures approaching the lethal temperature for these mysid shrimp.

In summary, these excellent field and laboratory studies of ecologically significant aquatic organisms in the Sacramento-San Joaquin Delta have revealed both techniques and information that can be used to evaluate the impact of similar industrial operations in other estuarine systems. These studies have shown no significant adverse effects upon aquatic organisms in the Sacramento-San Joaquin estuarine system. Volumes of water used for cooling purposes constitute but a small fraction of tidal and river flow in the Sacramento-San Joaquin Delta area at Pittsburg. Consequently, thermal elevations (above demonstrated upper lethal levels for important aquatic organisms) occur over a relatively small area and for a relatively short period of time. Thus, consideration of these physical and biological factors should permit the siting, design, and operation of power plants in similar systems—where the volumes of cooling water are sufficient to preclude adverse local or system-wide impacts.

Lauer et al. (1974) have studied the response of aquatic organisms in the Hudson River at Indian Point from 1971 through 1974. An upper area of the Hudson River estuary between Newburgh and Yonkers, N.Y., was sampled in order to establish the kinds, numbers, and seasonal fluctuations in aquatic organisms residing within this section of the estuary. In these studies emphasis was placed upon estimating the effects of both pumped and plume entrainment of planktonic organisms during both day and night sampling periods.

The rated thermal capacities of the combined three units at the Indian Point Station, was approximately 15° F during these studies. Laboratory studies of bacterial decomposers indicated that the above thermal exposures did not decrease populations except during periods of intermittent chlorination when decreases in discharge samples were noted. Primary producers indicated variable degrees of effect during similar and varying thermal exposures above ambient temperatures suggesting that seasonally variable populations of algae respond with increases, decreases, and relatively little change in rates of primary production as measured by ^{14}C uptake and algal biomass. During periods when discharge rates were depressed over intake rates, recovery of populations as measured by restoration of intake rates was noted. Chlorination, when it occurred, always reduced primary production rates for algal populations entrained into the condenser cooling units. No population shifts from the predominant diatom populations to any other algal group within the Hudson River in the study area were observed.

Laboratory studies of zooplankton populations suggested that calanoid copepod populations might experience some mortality at the rated ΔT of 15° F. Unfortunately, during these studies, discharge temperatures did not reach design levels and field verification of these laboratory results was not possible. Some degree of stratification of zooplankton was noted in the area of thermal influence by the Indian Point plant, but both species lists and abundance of river populations of zooplankton were similar, suggesting that the combined thermal and chlorination effects that occurred within the condenser cooling system were not affecting populations within the Hudson River in a significant way.

Laboratory studies of the dominant zooplankters at Indian Point (*Gammarus* sp., *Neomysis americana*, and *Monoculodes edwardsi*) suggested that a 15° F ΔT during summer ambient water temperatures would result in 50 percent or greater mortality of entrained *N. americana* while the other two species would not suffer mortalities as a result of the entrainment experience. Actual mortality due to entrainment was subsequently found to be 54 percent. All three species showed diel periodicity with higher abundances at night. *Gammarus* sp. occurred on a year round basis at Indian Point while *N. americana* occurred primarily during summer periods. *M. edwardsi* was a year-round resident except for early summer periods when it was not detected in the area. Although laboratory studies of the design ΔT of 15° F suggested no direct mortality would occur to *Gammarus* sp., direct measurement of discharge samples of entrained animals indicated a small but statistically significant mortality had occurred with this species. Chlorination levels during daytime periods did not produce statistically significant effects due to the low densities of these macrozooplankton forms. At higher nighttime densities, mortality was approximately 40 percent of entrained organisms.

Results of studies of egg and larval fish entrained into the Indian Point Plant were variable as to species, life stage, and plant operational features such as number of cooling water pumps in operation during sampling periods. Only six of the 50 species of fish occurring in the Indian Point area were actually represented in the ichthyoplankton entrained into the condenser cooling system. These were, in order of decreasing abundance: anchovy, alewife, and blueback herrings, striped bass, white perch, and tomcod. Most of the anchovy and clupeid larvae were dead in both intake and discharge canal samples. Striped bass were too sparse to permit statistical evaluation of entrainment effects.

Jensen et al. (1974) studied the thermal response of aquatic organisms in a small mid-Atlantic estuary in Delaware just south of the confluence of the Delaware River estuary with the Atlantic Ocean. The Indian River Plant is situated midway between the freshwater and saltwater boundaries of a small estuary east of Millsboro, Del. Cooling water at 148,000 gpm is elevated an average of 12° F and rejoins the Indian River estuary 1-3 hours later via a 2 mile discharge canal. Temperatures at the mouth of the canal are typically 5° F above ambient and are reduced to about 1° F above ambient within about two miles downstream of the mouth.

Chemical data collected in the vicinity of the plant suggests generally high water quality; dissolved oxygen levels, for example, never fall below 5.00 mg/l at the surface nor below 3 mg/l near the bottom. Diverse flow and fauna inhabiting this region of the estuary reflect both high water quality as well as the strong salinity gradient existing along the length of the estuary.

Destruction of algal cells during passage through the condenser system was consistently apparent during periods of chlorination (30 min. duration, 2–3 times daily), but was never observed in the absence of chlorination. Algal production rates measured at the discharge of the power plant were depressed due to temperature elevations for approximately four months of the year when ambient temperatures were about 71.6° F, although there was no evidence of lowered production rates at any distance from the discharge canal. During the cooler periods, (eight months), temperature elevations at the plant discharge resulted in up to two-fold stimulation of production rates and up to 20 percent increases approximately ½ mile downstream from the mouth of the discharge canal.

Little effect on the zooplankton behavior or population distribution could be attributed to the operation of the Indian River Plant. This lack of influence was presumably related to the average thermal elevation of only 10.8° F and the less than two minute travel time through the plant. It was concluded that the naturally wide range of salinity in the vicinity of the plant (2.2–19 ppt) was more influential to zooplankton ecology in this estuary than direct effects of thermal discharges from the Indian River Plant. Little change in mortality of zooplankton was observed throughout the entire seasonal range of ambient intake temperatures, even during periods of chlorination, which produced up to 0.5 mg/l free residual chlorine as measured in the discharge canal.

During the summer, however, prolonged contact with the thermal effluent resulted in a decrease in population densities of zooplankton passing down the discharge canal. By contrast, short-term intake-discharge evaluations to the same temperatures during passage through the condenser cooling system showed no die-off of zooplankton. Other factors not detected in these studies resulted in a decrease in discharge canal populations. In spite of these reductions, zooplankton populations in the receiving waters of the Indian River estuary did not appear to be affected by these losses.

The distribution of benthic invertebrates was shown to be associated with the large salinity gradient (0–22 ppt) within the study area of approximately 6.8 miles. Sediment temperatures were highest in the discharge canal and decreased to ambient temperatures through the mixing zone. Effects from the thermal discharges were limited to the discharge canal and the confluence point of the canal with the Indian River.

The upper Indian River estuary supports a large fishery biomass in the form of forage species. The estuary is also essential as a spawning and nursery area for game and commercially important species of fish. Undoubtedly, the power plant has some effects on the distribution of resident fishes in the estuary, but this would seem to be in a rather small, well-defined area within and adjacent to the discharge canal from the plant. These distributional effects appear to be restricted to the summer months when ambient water temperatures reach the seasonal and annual maxima. At other periods, the plant did not appear to seriously affect the survival, distribution, or well-being of any of the native or anadromous species residing within the estuary.

SUMMARY AND CONCLUSIONS

The rapid reduction of excess temperatures near existing thermal discharges into relatively large estuarine waters is largely a result of dilution rather than heat dissipation to the atmosphere. The spatial distribution curves for heated discharges can be shown to be directly related to the momentum of the discharge volume. In large, natural surface waters such as the Chesapeake Bay, it can be shown that such momentum jet discharges offer considerable advantages in terms of thermal decay curves. Thermal losses of waste heat to the atmosphere from such large bodies of water involve rather large surface areas at relatively small temperature increases (5–10 percent of original ΔT).

With the possible exception of tropical waters, the location of power-generating stations on large estuaries and open coastal locations appears to provide the relatively large volumes of water needed for modern once-through generating plants without producing serious damage to the biota of such areas. Ecological impacts can be minimized by careful siting, design, and operation so as to reduce temperature elevation and duration of aquatic organisms to thermal effluents. Momentum mixing of the heated discharge waters into receiving waters appears to rapidly reduce the temperatures to only a fraction of the original thermal rise. Such temperature reductions within a few minutes after the passage through the cooling water condenser system, would also appear to minimize the effects of entrainment upon planktonic forms residing in surface waters used for once-through cooling.

RESEARCH NEEDS—THERMAL EFFECTS

Physical Mixing Process

1. Knowledge of buoyant jet diffusion is nearly adequate for the design of thermal outfalls, including multiple port diffusers, to achieve a prescribed initial jet dilution and mixing plume. Further

research is needed to fully understand line sources and to determine how well multiple jet diffusers may be represented by line sources.

2. Research is needed to develop better methods for predicting the size and shape of heated effluent mixing zones that are developed at the end of the initial jet-mixing stage. Research is also needed (in close concert with the above dimensional data) to understand the phenomena of lateral spreading caused by density differences between the thermal plume and receiving waters.

3. In coastal waters, submerged diffusion structures are not yet in use, and some problems of large single jets, such as the behavior of a buoyant, surface jet injected into a cross-current, need special study. The impact of potential scouring of bottom areas adjacent to such momentum discharges is also needed.

Heat Dissipation Processes

1. More research is needed to establish the natural temperature variations of future receiving waters, especially large water bodies such as the Chesapeake Bay. Such information pertinent to diurnal and seasonal temperature fluctuations is essential for the prediction and assessment of the relative impact of proposed thermal discharges.

2. As more information becomes available on the biological responses to thermal discharges in terms of both thermal amplitude and duration relationships, as well as rapid rates of temperature change, improvements will be needed in methods for predicting these characteristics of thermal discharges relative to short-term fluctuations in power demand, meteorological conditions, and operations of auxillary cooling devices.

3. More effort is needed to evaluate and verify temperature predictions based on hydraulic models of thermal discharges, particularly models of large prototype receiving waters in which surface cooling processes are not negligible and are generally represented inadequately.

4. Relative to item 3, more work is needed in developing techniques for computer simulation of thermal discharges in three dimensions, taking into account all the effects of momentum, entrainment, buoyancy, surface cooling, wind, coriolis forces, and other factors affecting receiving water behavior.

Biological Processes

1. Both field and laboratory research is needed concerning the biological response to time-spatial and thermal amplitude levels characteristic of situations involving once-through cooling in surface waters. Unfortunately, much of the existing laboratory data does not appear to be relevant to such thermal histories due to the atypical temperature-time exposures. Additional field studies of existing thermal discharges are essential if adequate consideration of the biological response (both physiological and behavioral) is to be used in predicting the ecological impact of proposed thermal discharges into natural surface waters.

2. Long-range, properly designed, detailed, quantitative baseline studies of the structure and dynamics of animal and plant communities and their relationship to increasing domestic and industrial influence should be established and supported. These areas should include those that are presently relatively little affected, those that are being affected at an increasing rate, and those that are already seriously affected.

3. There is enough promise in the various possibilities of beneficial uses of heated water effluents that research and demonstration-level work should be encouraged as adjuncts to energy development. Discharges have been used to provide water flow and favorable temperatures for the culture of molluscs, crustaceans, and fishes such as catfish and pompano. Major fish kills due to low-water temperatures are of regular occurrence in shallow inshore waters of the Gulf of Mexico and many lakes in temperate areas. Heated effluents could be used to save fish that otherwise would be lost from such systems It is, of course, important that all possible benefits of thermal effluents be included in site selection planning, and projected cost-benefit analysis.

4. Evaluations of the effects of the entrainment and subsequent exposure to condenser cooling systems are specific to individual power plants operating on specific estuarine systems. Studies of macrozooplankton and meroplankton effects appear to be worthy of much of this entrainment research effort.

5. Impingement and post-impingement studies of intake systems are also highly site and plant specific and they should be conducted with sufficient frequency to permit a determination of the relative importance of such effects upon local populations of important species. Research efforts designed to clarify behavioral characteristics of fish in intake systems should be intensified to provide data for the refinement and redesign of both operational and mechanical characteristics of screening devices used at power plant intake systems.

6. Research is also needed relative to the environmental impact of alternative cooling devices, such as cooling towers. The impact of mineral loss through drift upon vegetation and metalic surfaces in sur-

rounding areas has not been evaluated for cooling towers of a size applicable to modern fossil or nuclear-fueled plants. The blowdown of dissolved solids and biocides such as chlorine and heavy metals from such towers must also be evaluated in terms of their impact on receiving waters and their associated biota.

REFERENCES

Adams, J. R. 1969. Ecological investigation around some thermal power stations in California tidal waters. Chesapeake Sci. 10(3–4):145–154.

Adams, J. R. and M. J. Doyle, Jr. 1971. Thermal power plant site studies in California—State of the art—1971. Presented at the American Fisheries Society, Western Division Annual Conference, Aspen, Colo., July 19–23, 1971.

Brady, D. K., J. C. Geyer and J. R. Sculley. 1971. Analyses of heat transfer at cooling lakes. Am. Inst. Chem. Eng. Symposium Series, 67(119):120–125.

Brooks, A. S., R. A. Smith and L. D. Jensen. 1974. Chapter 3, Phytoplankton and Primary Productivity. In L. D. Jensen (ed.), Environmental responses to thermal discharges from Indian River Plant, Indian River, Delaware. The Johns Hopkins Univ. Cooling Water Res. Project, Report No. 12, Electric Power Res. Inst., Palo Alto, Calif. pp. 77–93.

Carpenter, E. J., et al. 1974. Summary of entrainment research at the Millstone Point Nuclear Power Station, 1970 to 1972. In L. D. Jensen (ed.), Proceedings of the Second Entrainment and Intake Screening Workshop. February 5–9, 1973. Cooling Water Studies for the Electric Power Research Institute, Research Project RP-49, Report Number 15. The Johns Hopkins University, Department of Geography and Environmental Engineering. pp. 31–35.

Chadwick, H. K. 1971. Thermal effects of power plant discharges on fishery resources in the Sacramento-San Joaquin estuary, California. Presented at the American Fisheries Society, Western Division Annual Conference, Aspen, Colo., July 19–23, 1971.

Cory, R. L. and J. W Nauman 1969. Marine fouling and thermal additions in the upper estuary of the Patuxent River. Patuxent Thermal Studies, Supplement Report, U.S. Geological Survey, Washington, D.C.

Coutant, C. C. 1969 Responses of salmonid fishes to acute thermal shock. In Biological effects of thermal discharges: Annual progress report for 1968. Battelle Memorial Institute, U.S Atomic Energy Commission Research and Development Report Number BNWL-1050:1–8

Davies, R. M. and L. D. Jensen. 1974. Effects of Entrainment of Zooplankton at Three Mid-Atlantic Power Plants. Cooling water studies for the Electric Power Research Institute, Research Project RP-49, Report Number 10. The Johns Hopkins University, Department of Geography and Environmental Engineering.

Gritz, W. J 1971 Distribution and food habits of fishes in relation to the thermal plume at Pacific Gas and Electric Company's Pittsburgh Power Plant in the Sacramento-San Joaquin Delta. California Fish and Game, Anadromous Fisheries Branch. Adm. Report Number 71-14 Sacramento, Calif.

Gritz, W. J. and D. E. Stevens 1971. Distribution of young king salmon *Oncorhynchus tshawytscha* in the Sacramento-San Joaquin River near Pittsburgh. California Fish and Game, Anadromous Fisheries Branch. Adm. Report Number 71-13. Sacramento, Calif.

Gurtz, M. E. 1973. Field investigations of the response of phytoplankton to thermal stress. Dept. of Environ. Sci. and Eng., University of North Carolina, Chapel Hill.

Hair, J. R. 1971. Upper lethal temperature and thermal shock tolerances of the opossum shrimp *Neomysis awatschensis* from the Sacramento-San Joaquin estuary, Calif. Cal. Fish and Game (57)(1):17–27.

Icanberry, J. W. and J. R. Adams. 1972. Interim report—zooplankton survival after passage through the cooling water systems of four thermal power plants on the California coast, March 1971–January 1972. Pacific Gas and Electric Company, Department of Engineering, Research Report Number 7598. Emeryville, Calif.

Jensen, L. D., et al. 1974. Environmental Responses to Thermal Discharges from the Indian River Station, Indian River, Delaware. Cooling Water Studies for the Electric Power Research Institute, Research Project RP-49, Report Number 12. The Johns Hopkins University, Department of Geography and Environmental Engineering.

Kelly, R. 1971. Mortality of *Neomysis awatschensis* Brant resulting from exposure to high temperatures at Pacific Gas and Electric Company's Pittsburgh Power Plant. California Fish and Game, Anadromous Fisheries Branch. Adm. Report Number 71–3. Sacramento, Calif.

Kelly, R. O. and H. K. Chadwick. 1971. Some observations on striped bass temperature tolerance. California Fish and Game, Anadromous Fisheries Branch. Adm. Report Number 71-9. Sacramento, Calif

Kelly, R. O., J. R. Hair and D. E. Stevens. 1971. *Neomysis awatschensis* Brant distribution in the Sacramento-San Joaquin Delta with regard to physical parameters at Pittsburgh and Collinsville. California Fish and Game, Anadromous Fisheries Branch. Adm. Report Number 71-8. Sacramento, Calif.

Lackey, J. B. and E. W. Lackey. 1972. Thermal Effects at Turkey Point—A Study. Consultants report to Florida Power and Light Company, Miami, Fla.

Lauer, et al 1974. Entrainment studies on Hudson River organisms. In L. D. Jensen (ed.) Proceedings of the Second Workshop on Entrainment and Intake Screening. Electric Power Research Institute, Research Project RP-49, Report Number 15. The Johns Hopkins University, Department of Geography and Environmental Engineering. pp. 37–82.

Maryland Department of Water Resources. 1969. Report of the Thermal Research Advisory Committee. Annapolis, Md.

Mihursky, J. A. and V. S. Kennedy. 1967. Water temperature criteria to protect aquatic life. In A Symposium on Water Quality to Protect Aquatic Life American Fisheries Society, Spec. Publ. Number 4, pp. 20–32.

Mitchell, C. T and W. J North. 1971. Temperature time effects on marine plankton passing through the cooling water system of the San Onofre Generating Station. Marine Biological Consultants, Inc. Costa Mesa, Calif.

Morgan, R., et al. 1969. Phytoplankton studies. Patuxent Thermal Studies, Supplemental Report. Natural Resources Inst., Ref. Number 69-6, University of Maryland.

North, W. J. 1968. Biological effects of a heated water discharge at Morro Bay, Calif. Symposium Proceedings IV International Seaweed Symposium, Madrid, Spain, September 1968.

Orsi, J. J. 1971. Thermal shock and upper lethal temperature tolerances of young king salmon, *Oncorhynchus tshawytscha*, for the Sacramento-San Joaquin River system. California Fish and Game, Anadromous Fisheries Branch. Adm. Report Number 71-11. Sacramento, Calif.

Patrick, R. 1968. Patuxent River, Maryland, Statistical studies of oysters and associated organisms. Acad. Natural Sci. Philadelphia, Dept. of Limnology.

Reeve, M. R. and E. Cooper. 1970. Acute effects of power plant entrainment on the copepod *Acartia tonsa* from a subtropical bay and some problems of assessment. F.A.O. World Conf. on Mar. Pollution in the Ocean. Mimeo.

Rogers, R. D. and D. E. Stevens. 1971. Distribution of young striped bass (*Morone saxatilis*) in the Sacramento-San Joaquin Delta at Collinsville and Pittsburgh. California Fish and Game, Anadromous Fisheries Branch. Adm. Report Number 71-12. Sacramento, Calif.

Rosenberg, W. H. 1968. A study of the effects of thermal pollution on *Crassostrea virginica* (Gmelin) in the Patuxent River estuary. November 1966–1967, Final Report, Subproject Number 3-23 R-2. U.S. Department of the Interior, Bureau of Commercial Fisheries.

Smith, R. A., A. S. Brooks and L. D. Jensen. 1974. Chapter 4, Primary Productivity. In L. D. Jensen (ed.) Environmental response to thermal discharges from the Chesterfield Station, James River, Virginia. The Johns Hopkins Univ. Cooling Water Res. Project, Report Number 13, Electric Power Res. Inst., Palo Alto, Calif.

Strawn, K. and B. Gallaway. 1974. Final report on the seasonal abundance, distribution, and growth of commercially important crustaceans at a hot water discharge in Galveston Bay. Cont. Mar. Sci., University of Texas, September, 1974.

Tabb, D. C. and M. A. Roessler. 1970. An ecological study of South Biscayne Bay, Florida. Progress Report to FWPCA. Univ. of Miami, Rickenbacker Causeway, Miami, Fla.

Warriner, J. E. and M. L. Brehmer. 1966. The effects of thermal effluents on marine organisms. Int. J. Air Water Pollution. 10:277–289.

Wickmire, R. H. and D. E. Stevens. 1971. Migration and distribution of young king salmon, *Oncorhynchus tshawytscha*, in the Sacramento River near Collinsville. California Fish and Game, Anadromous Fisheries Branch. Adm. Report Number 71-4. Sacramento, Calif.

EFFECTS OF SELECTED POWER PLANT COOLING DISCHARGERS ON REPRESENTATIVE ESTUARINE ENVIRONMENTS

R. H. BROOKS
Pacific Gas and Electric Co.,
San Francisco, California

M. L. BREHMER
Virginia Electric and Power Co.,
Richmond, Virginia

A. S. AUTRY
Tampa Electric Co.,
Tampa, Florida

F. N. MOSELEY
Central Power and Light Co.,
Corpus Christi, Texas

ABSTRACT

Results of investigations into the effects of power plant cooling water discharges into selected, representative estuaries are presented. These studies performed at mid-Atlantic, mid-Pacific, and Gulf of Mexico locations indicate that, at these stations, the cooling water discharges have not adversely affected the surrounding, estuarine receiving water environment. The conclusion is reached that power plants can be operated on estuaries without adverse effects with the result that each potential or existing estuarine site should be evaluated on a "case-by-case" basis.

INTRODUCTION

Large estuaries around the continental United States are used for the cooling and dissipation of heat resulting from thermal electric generation. It is realized that estuaries generally constitute ecosystems of unique importance where adverse intrusions should not be tolerated. However, actual field studies have failed in most instances to reveal such adverse effects resulting from power plant cooling. As an example, the results of environmental studies conducted at electric generating stations on selected representative estuaries are described in this paper.

The power plants' studies as described herein employ conventional once-through cooling systems with one exception where thermal dilution is also utilized. The information presented herein is summarized from reports on studies conducted by:

1. Pacific Gas and Electric Company—Pittsburg, Contra Costa, and Moss Landing Power Plants, Pacific Coast of California.
2. Virginia Electric and Power Company—Surry Power Station, Surry County, Va.
3. Tampa Electric Company—Big Bend Station, Hillsborough County, Fla.
4. Central Power and Light Company—E.S. Joslin Power Generating Station, Cox Bay, Tex.

PACIFIC GAS AND ELECTRIC COMPANY

Pacific Gas and Electric Company (P G and E) operates three electric generating facilities in estuarine environments. Two plants, Pittsburg Power Plant and Contra Costa Power Plant, are located on the Sacramento-San Joaquin Estuary, the great tidal estuary at the head of the San Francisco Bay. The third station, Moss Landing Power Plant, is located on Elkhorn Slough, a coastal lagoon that drains into Monterey Bay and then into the Pacific Ocean.

Facility and Site Description

SACRAMENTO-SAN JOAQUIN ESTUARY

Pittsburg and Contra Costa power plants are located in similar environments, on the south shore of the Sacramento-San Joaquin estuary. (Contra Costa Power Plant is actually on the San Joaquin River, just above its confluence with the Sacramento River). Typical vegetation types in the area include tidal and impounded salt marsh, and drained land that is used agriculturally. On the northern shore of the estuary is Suisun Marsh, a large and productive area for waterfowl and shorebirds. Several federal and state wildlife refuges are found in the area.

The nutrient-rich waters of this system are well-mixed by the diurnal tidal cycle. Salinity variations are seasonal, with ranges from 4 to 10 parts per thousand (ppt). Regulated freshwater inflows determine these salinity profiles. Ambient water temperatures also vary with the season, ranging from 45–72°F.

This nutrient-rich system supports a diverse aquatic food chain, at the top of which are king salmon and striped bass. These anadromous fishes constitute a major sport fishery. Shad, sturgeon, and catfish also form the basis of a growing sport fishery. These fishes feed largely on opossum shrimp, which in turn is supported by a variety of other planktonic species.

The turbid waters of this system, and other available evidence, lead to the conclusion that primary production is limited by low light penetration. The phytoplankton of the estuary is dominated by diatoms, green algae, and flagellates, with some seasonal variation in species composition of these organisms. Bluegreen algae are rare in this estuary; thus, noxious blooms associated with eutrophication have not been a problem.

ELKHORN SLOUGH

Moss Landing Power Plant takes in water from the oceanic Moss Landing Harbor and discharges into Elkhorn Slough. This body of water has experienced several shoreline changes, beginning as a freshwater lagoon draining the Pajaro River. In the early 20th century, the area was developed as a whaling station and smuggling port. Construction of Moss Landing Harbor in 1946 altered the flow characteristics, so that Elkhorn Slough was left with an outlet to the ocean and became subject to the resultant tidal action.

Elkhorn Slough exhibits characteristics of both a true estuary and a coastal lagoon, depending upon the time of year. During the fall and winter rainy season, runoff from local creeks and land drainage provides the slough with sufficient freshwater to dilute the salt incursion from the ocean. In the summer dry season, however, the creeks dry up and land drainage decreases, so that salinities rise and Elkhorn Slough displays most of the characteristics of a lagoon.

Water quality in Elkhorn Slough is primarily dependent upon tidal action and the dairy and cannery waste discharges that have contaminated the Slough and Moss Landing Harbor for several years. Salinity in the system ranges from approximately 20 to 37 ppt. Ambient temperatures range from 50–61°F.

The marine environment of Elkhorn Slough is characterized by muddy bottoms, with a benthic fauna dominated by venus clams. Crabs, shrimps, and oysters are also found. Stands of eelgrass provide sheltered spawning areas for flatfish, which are a major sport fish in the area. Other important sport fish, such as perch and Pacific herring, spawn in Elkhorn Slough.

POWER PLANT OPERATING CHARACTERISTICS

These three power plants are fossil-fuel fired and employ once-through cooling water systems. Significant characteristics of these facilities are as follows:

Power plant	*Year of initial operation*	*Rated output, MW*	*Cooling water flows, cfs*	*Temperature increase, °F*
Pittsburg				
Units 1–4	1954	630	900	15.0
Units 5–6	1960	650	722	18.0
Contra Costa				
Units 1–3	1951	348	600	16.0
Units 4–5	1953	232	245	12.0
Units 6–7	1964	680	681	24.0
Moss Landing				
Units 1–3	1950	348	629	15.5
Units 4–5	1952	234	223	24.0
Units 6–7	1964	1,478	1,354	20.0

Moss Landing's Units 6 and 7 do not affect the estuarine environment, as the cooling water source and discharge sink is the Pacific Ocean.

Results of Studies Performed

P G and E conducted 1-year studies at these and five other coastally-located power plants during 1971–1972. Requirements for these physical and biological studies were set by the Regional Water Quality Control Boards. The general objectives of the studies were to determine the areal distribution of the thermal plume in the physical environment, to investigate the effects of each thermal discharge on the principal levels of the local food chains, and to determine measures of protecting the beneficial uses of the receiving waters.

PHYSICAL STUDIES

Synoptic physical studies were performed to simultaneously measure water-quality characteristics over a wide area at each power plant. Parameters measured included surface water temperature, horizontal and vertical water temperature profiles, salinity and dissolved oxygen at three depths, bathymetry and temperature decay rates. Analysis of these measurements not only delineated the extent and physical impact of the thermal plume, but also enabled the biological investigators to select appropriate sampling stations and methods.

Physical studies showed that the average extent of the thermal plume (area enclosed by the 4°F isotherm) was 50 acres at Pittsburg and Contra Costa and 230 acres at Moss Landing. No effects were found on salinity and dissolved oxygen concentrations.

BIOLOGICAL STUDIES

Quantitative biological studies focused on three major groups of organisms: zooplankton, benthic organisms, and fish. Standard methods of collection, such as Ponar grabs for benthic sampling and otter trawls and gillnets for fish sampling, were used wherever possible. Some situations required the development of special equipment. In most studies, organisms were collected in a systematic fashion, usually by transect, and identified as precisely as possible. The data were analyzed to give the total number of individuals present, the total number of species present, and an index of species diversity. These parameters were correlated with physical parameters such as temperature, salinity, depth, and time of year.

The zooplankton studies at Moss Landing Power Plant made a further analysis of mortality to zooplankton passing through the cooling water system. This was done by sampling with a specially-designed filter pump at the intake and discharge, coordinating the sampling with the measured travel time of 10.9 minutes. Live and dead zooplankters were manually counted under a stereomicroscope and percent mortality due to passage through the cooling water system was determined by subtracting intake mortality from discharge mortality.

In general, the biological studies yielded the following results:

1. Zooplankton mortality varies from plant to plant and from species to species, within a range of zero to 15 percent. At Moss Landing, the average net mortality was about 11 percent. That is, 89 out of 100 zooplankters passing through the cooling water system can be expected to survive the expected physical and thermal effects.

2. Benthic species diversity was not significantly correlated with temperature differentials. This result is consistent with the observation that the dominant plant influence, the thermal plume, lies in a buoyant surface layer separated from the benthic organisms by water of ambient temperature.

3. Different fish species showed preferences for different temperature regimes. In the Sacramento-San Joaquin estuary, for example, white catfish were most often found near the power plant discharge areas.

Summary of Effects Upon Receiving Waters

The studies conducted at Pittsburg, Contra Costa, and Moss Landing Power Plants have shown that the major detectable influence upon the environment is the thermal plume. No other physical-chemical parameters have been affected. Biological studies show that the aquatic communities have not been significantly altered. Finally, the power plant operations have had no detrimental effects upon beneficial uses of the receiving waters.

VIRGINIA ELECTRIC AND POWER COMPANY

Facility and Site Description

The Surry Nuclear Power Station of the Virginia Electric and Power Company (Vepco) is located on Gravel Neck in Surry County, Va. adjacent to the tidal James River, a major tributary of Chesapeake Bay. The station consists of two Westinghouse pressurized water reactor units, each capable of generating 822.5 MW. Water is required at a rate of 1871 cubic feet per second (cfs) per unit to handle a heat rejection rate of 11.8×10^9 Btu/hr by once-through cooling. This results in a temperature rise across the station of 14°F.

The cooling water discharge structure, located on the upstream side of the Gravel Neck peninsula, is about five miles from the intakes, and is designed with an exit velocity of 6 feet per second to promote rapid mixing with ambient water in the three-mile-wide James River. Physical model studies at the U.S. Army Corps of Engineers facility at Vicksburg, Miss., were conducted to determine the optimum design of the discharge structure.

The James River in the vicinity of the station is shallow, but has a maintained shipping channel. River widths vary from about three miles at the discharge to about four miles at the intakes. Salinity varies from freshwater to about 15 ppt, being dependent on freshwater inflow from the upstream 9,886-square mile watershed of the James.

Surry Units 1 and 2, which began commercial operation in late 1972 and early 1973, are base-load units that operate at an annual average capacity factor of approximately 80 percent.

Results of Studies Performed

PHYSICAL STUDIES

The James River around Surry has been, and is, the object of a continuing and intensive physical study that began in 1969. As stated previously, the distribution of the summertime thermal plume was predicted through the use of a physical model. Wintertime thermal predictions were made by Pritchard-Carpenter, Inc., using a mathematical model.

Several methods are being used to field-test model predictions. Tower and buoy locations in a 10-mile section of the river encompassing the station have been instrumented to provide continuous temperature data. In addition, monthly boat surveys are conducted to determine surface to bottom profiles.

Since, during the course of a year, salinity in this part of the James is highly variable, monthly boat surveys are also used to determine cross-sectional and longitudinal salinity profiles. These studies will determine if the pumping of 3740 cfs of slightly higher salinity water into an area of lower salinity will alter the natural salinity regime.

Results of the temperature studies indicate that the physical model predictions were conservative; that is, the excess temperature plume mixes rapidly with the river water, and water at a given temperature does not encompass as large an area as had been predicted. Studies have shown that the salinity regimens of the river have not been significantly altered by the present station operation.

Biological studies at Surry have attempted to determine the preoperational "health" of the aquatic ecosystem by examining specific food chain components; and to determine the effects, if any, of Surry Power Station operation on that health. Studies to date, which include both preoperational and post-operational data have shown that operation of the Surry Power Station has had no observable adverse effect on any of the various components of the aquatic community in the James River.

Studies that are site-specific to Surry were begun in early 1969 by Virginia Institute of Marine Studies. These studies encompass almost every level of the food chain and include phytoplankton, zooplankton, bottom organisms (benthos), and fouling organisms. In the spring of 1970, Vepco personnel began a study of the young fishes that inhabit the shallow water zones of the area.

Although many theoretical, but as yet unproved, implications of thermal discharges have received widespread publicity, one parameter of power station operation is of immediate concern. That parameter, fish impingement on intake trash screens, receives adverse publicity when fish numbers become relatively large even though the biological significance might be small.

To alleviate the problem, Vepco invented and installed at Surry a unique intake screen designed specifically to return impinged fish to the water alive. Results of studies to date show that an average of 85 percent of the impinged fish are returned alive to the water; survival of most species approaches 100 percent. This screen represents a significant development in the industry and may prove to be one of the best available technologies in dealing with the impingement of fish at intake structures.

Summary of Effects Upon Receiving Waters

The data developed from comprehensive biological (phytoplankton, zooplankton, benthos, fouling organisms, and finfish), chemical, and physical studies in the tidal segment encompassing the Surry Power Station indicate that operation has not modified any of the measured parameters beyond the limits of natural associated variation. Finfish, the major class of organisms with commercial or recreational importance in this tidal segment, have exhibited consistent diversity, evenness, and richness during the four years of study. This is illustrated by the enclosed figure.

TAMPA ELECTRIC COMPANY

Four years of intensive investigation at Big Bend Station have shown that the operation of the plant has not significantly altered the marine life of Hillsborough Bay. The study began in April 1970, seven months before the startup of the first unit and has continued through the operation of two 375 MW coal-fired units.

Facility and Site Description

Big Bend Station is located on the eastern shore of Hillsborough Bay, an extension of Tampa Bay, in Hillsborough County, Fla. Tampa Bay is located on the west central gulf coast of Florida and is a complex system of bays and estuaries including the Hillsborough River, Manatee River and Alafia River estuaries, and Tampa Bay, Old Tampa Bay, Hillsborough Bay, and McKay Bay.

Hillsborough Bay, a natural arm of Tampa Bay, is approximately eight miles long and four miles wide. Two rivers, the Hillsborough River and the Alafia River, and numerous streams flow into Hills-

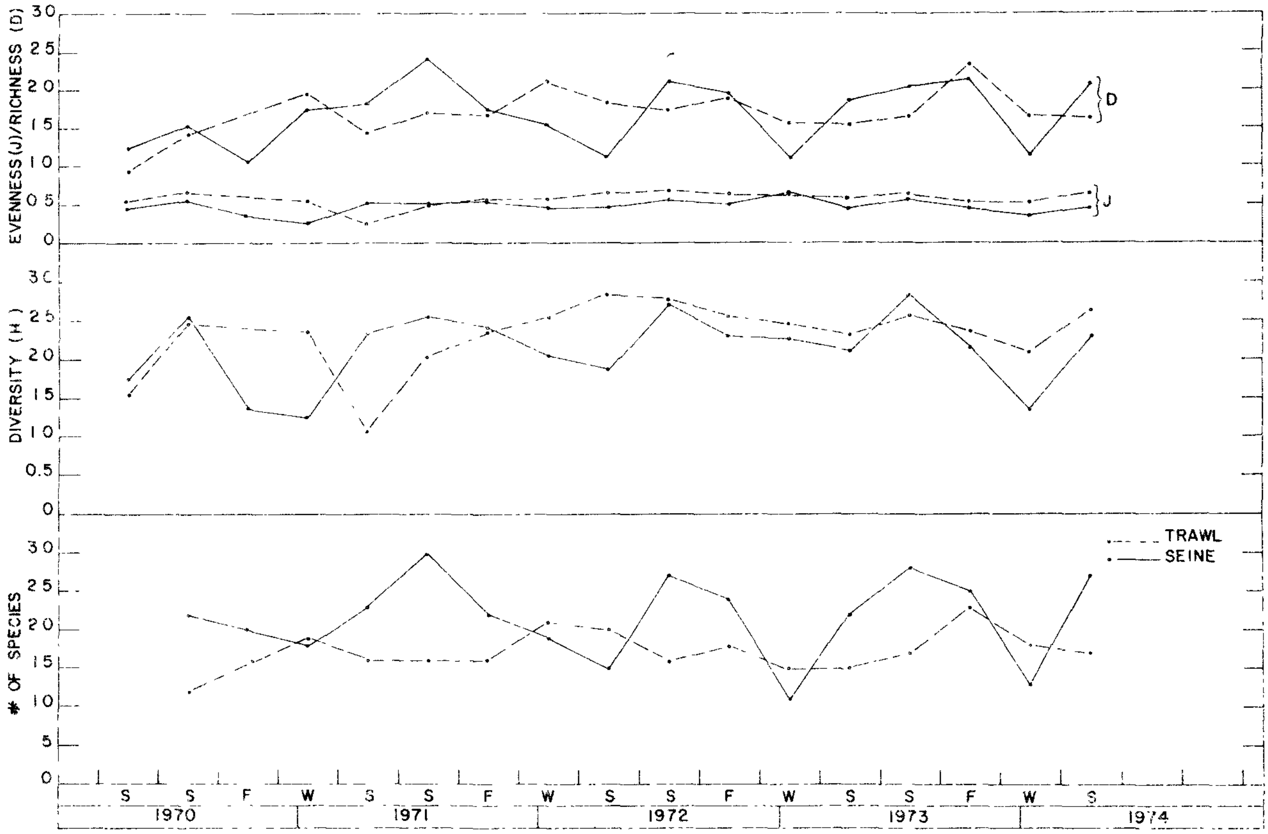


FIGURE 1.—Composite of numbers of species, diversity (H′), evenness (J), and richness (D) by season for seine and trawl samples—Surry Power Station.

borough Bay. The natural shore line is typical of this section of Florida, with coastal mangrove lowlands and pine-palmetto uplands. Much of the natural shore line has been developed and altered by dredge and fill activities.

The maximum natural depth in Hillsborough Bay is 28 feet with improved ship channels maintained at 34 feet. The surface area is 39.6 square miles. The diurnal tide range is 2.8 feet and the mean level is 1.4 feet. The average depth at mean tide is 8.95 feet.

Water quality in Hillsborough Bay is the worst of the bay systems. Effluent from numerous industries and several sewage treatment plants flows into the bay. Monthly temperature averages vary from 61.8–88.4°F over the year. The salinity range is 0.5–30.0 ppt.

High chlorophyll *a* determinations (maximum of 48.76 milligrams per liter) indicate that Hillsborough Bay exists in a high trophic state, carrying a large plant biomass. This is consistent with the high nutrient levels generally found in these waters. Light penetration is sufficiently low to preclude significant stands of rooted algae. Most of the biomass is present as plankton and floating algae.

Benthic organisms present in the bay are mostly filter feeders, which utilize the large amount of plankton present.

Big Bend Station is a coal-fired station consisting of two operating units rated at 375 MW each. One 425 MW unit is under construction.

Unit No. 1 went into operation in October 1970 with once-through cooling and a maximum temperature increase of 17°F. The cooling water flow rate was 240,000 gallons per minute (gpm). Because of pressure from the Florida Department of Pollution Control, Unit No. 2, which went into operation in April 1973, was constructed with a thermal dilution cooling system. This system consists of a 400,000 gpm pump and associated sheet pile walls to deliver the unheated mixing water to the discharge point of Units 1 and 2. This 1:1 dilution reduces by 50 percent the temperature rise to the bay, so that the maximum temperature increase for both units is [illegible] approximately 9°F.

Unit No. 3, which should go into operation in the spring of 1976, will have a closed-loop spray cooling system for control of thermal effluent.

Results of Biological Studies Performed

Beginning in April 1970, regular sampling was done near the Big Bend Station to determine the effects of operation on the bay. Trawls, seines, traps, plankton nets, bottom dredges, sample bottles, et cetera, were employed to gather the necessary data. The program began with two full-time scientists conducting the study and peaked last year with six full-time biologists and several other part-time people working on the project. Seven months of preoperational data were gathered, and data collection has continued through the startup and operation of two units. The area around the plant was divided into four ecosystems with 20 sampling stations. The stations were visited at least monthly; many were sampled weekly and some daily. The samples were collected, analyzed in the TECO Marine Research Laboratory, and the data reported to Tampa Electric Company in four quarterly reports and one annual report per year.

The water around Big Bend Station was analyzed for the following parameters: temperature, salinity, transparency, depth, dissolved oxygen, pH, carbon dioxide, phosphate, hydrogen sulfide, trace metals, and pesticides.

Studies to date indicate there is little difference between the intake water and the discharge water with the exception of temperature, which can be attributed to the operation of the power plant.

The following biological parameters were studied in the vicinity of Big Bend Station: fish, plankton, benthic organisms, algae, invertebrates, chlorophyll *a* and miscellaneous observations.

Collections of fish from the Big Bend study were compared with a 22-month study of the fish of Tampa Bay conducted during 1957-1959 by the Florida Department of Natural Resources (DNR).

At Big Bend a total of 86 species of fish were caught in a relatively small area near the plant, compared to 73 species caught by DNR in all of Tampa Bay. The Department of Natural Resources collected 11 species not collected by the Big Bend Lab. The Big Bend Lab collected 24 species not found by the DNR study. It would, therefore, appear that the area around Big Bend Station contains a fish species diversity indicative of a low stress condition.

More than 150 species of phytoplankton have been [illegible]. There seemed to be little significant difference between the number of species and individuals in the intake water and the discharge water. The biggest variations in numbers occurred during plankton blooms, and were not associated with plant operation.

Over 70 species of zooplankton have been identified during the study. These represent a normal, balanced community typical of waters of this type.

Benthic populations in the vicinity of the plant and other portions of the bay are sparse, primarily because of the poor substrate in the area. Years of improper dredge and fill operations and other activities have left a layer of soft, silty mud over much of the bottom.

As mentioned previously, turbidity of the water precludes significant stands of rooted algae and the most abundant species of algae found in the area are *Gracilaria* and *Ulva*. Both of these occur in nuisance proportions and are indicative of the nutrient-rich bay waters.

Differences in chlorophyll *a* readings at the intake and discharge were slight. The biggest variation occurred during plankton blooms that were not associated with plant operation.

After evaluating all of the data gathered in four years of study at Big Bend Station, the staff concluded that the operation of Big Bend Station has not significantly altered the marine life in the vicinity of the plant.

Summary of Effects Upon Receiving Waters

Studies completed to date show that little change attributable to power plant operation has occurred. Although temperatures have increased in the receiving waters, other physical and chemical effects are undetectable. The biological studies have shown that phytoplankton, zooplankton, and fish populations near the plant have similar, if not greater diversity and richness than that found in all of Tampa Bay. The benthic community is sparse, but this is probably unrelated to plant operations.

CENTRAL POWER AND LIGHT COMPANY

The E. S. Joslin steam electric power generating station is owned and operated by Central Power and Light Company and is located near Point Comfort, Tex., on a small, tertiary estuary called Cox Bay. Cox Bay is part of a larger estuarine system known as the Matagorda Bay System located in central south Texas.

Facility and Site Description

Cox Bay, the receiving bay for Joslin Power Station, is similar to most Texas estuaries. It has an area of approximately 6,000 acres with an average depth of five feet or less. It generally varies from an oligohaline (brackish water) to a mesohaline (medium salinity) bay. It serves as a nursery area for many marine organisms and is valuable as a shrimp nursery area, particularly for white shrimp.

Texas estuaries are among the most productive of the estuarine systems. A number of characteristics separate them from many of the classic examples referenced in the literature. Among these characteristics are: 1) Lunar tidal influences are slight (less than 1 foot), and as a result, tidal variations are more susceptible to wind velocity and direction. 2) Texas estuaries are generally very shallow and often vertically mixed rather than stratified (exceptions being deep areas in channels). For this reason, these areas are subject to wide temperature ranges. Sudden temperature variations may occur within a short period of time, resulting in fish kills due to cold weather. 3) In many areas, primary productivity is from the watersheds of the coastal streams or by marine grass flats rather from phytoplankton. 4) Salinities vary widely from low saline systems along the northern coast to high saline systems in the south. Salinity characteristics of these systems are governed primarily by freshwater runoff via coastal streams, which also regulates to some extent the abundance and types of organisms present in each system.

As in the case of most coastal systems, Texas estuaries serve as important nursery areas for many marine organisms. Most of the organisms present in these bays are migratory, and spawning occurs offshore in the Gulf of Mexico. Postlarvae and juveniles migrate into the bays to grow up. This immigration movement is timed so that peaks occur in spring and autumn, corresponding to peak annual precipitation patterns. These two peaks coincide because most nutrients and organic materials are available in the estuaries following heavy freshwater runoff, so that "dinner is on the table" when the young organisms arrive. Thus, Texas estuaries are very dynamic systems, varying continuously on a daily, annual, and seasonal basis.

POWER PLANT OPERATING CHARACTERISTICS

Joslin Power Station has a generating capacity of 240 MW and utilizes once-through cooling. Cooling water is taken from the Matagorda ship channel and discharged into the northern portion of Cox Bay. Pumping rate of the power plant is approximately 150,000 gpm with a maximum 15°F increase across cooling condensers. Two additional waste stream discharges enter into the cooling water prior to its discharge into the bay. These are the waste material from a secondary sewage treatment plant located on the power plant property, and a demineralizer waste discharge that has been treated for neutralization.

Originally, the power plant was equipped with amertap as a cleaning device for cooling condensers. However, after one year's operation, the system was found to be inefficient for keeping condenser tubes cleaned, and chlorination was added to the treatment facilities. Chlorination generally occurs two hours a day, five days a week, with a discharge residual of 1 part per million.

The power plant began operation in June 1971 and has continued to operate until the present time. Two years prior to power plant operation, an environmental study was initiated on the Cox Bay estuary. That study has continued to the present time. Therefore, data are available to evaluate the bay prior to the operation of the power plant and to determine its effects upon the receiving waters.

Results of Studies Performed

Biological samples were collected monthly at 21 stations, beginning in August 1969, and continuing to the present. Samples consisted of phytoplankton, zooplankton, benthos (bottom-dwelling organisms such as clams and worms), and nekton (free-swimming fish and large invertebrates). In addition to these biological samples, chemical samples such as dissolved oxygen, salinity, temperature, and pH were taken at all biological stations. Additionally, plume analyses were made by plant personnel and occasionally by biological sampling crew. Results of these studies have been written up in a report entitled, "Final Report. Ecology of Cox Bay, Texas, 1969–73." Results shown here are excerpts from the Final Report.

Typical summer plumes vary considerably depending upon several factors. One is the electrical load of the power plant at the particular time the data were taken. Since the intake pumps at a constant rate, temperature at the discharge varies with the load on the plant at any given time. Maximal temperature increase above ambient varied from 6 to 13°F at the discharge. The shape and extent of the plume is also dependent upon wind speed and direction. Prevailing winds in the area are from the southeast and tend to keep the plume pushed against the northwestern shore. However, in wintertime when northern winds are common, the plume may extend over a larger area of the bay surface.

Another way of looking at temperature effects is to determine the average temperature rise at the discharge, and to determine the temperature die-off and distance away from the discharge. In 1971–72, when average temperature increase was slightly less than 12°F, a sharp temperature decline occurred about 1,000 to 1,500 feet away from the discharge. Temperatures were then steady for some distance out to about 3,000 feet away from the discharge. It should be noted that the discharge area in the northern portion of Cox Bay is extremely shallow, with depths of less than five feet along the shoreline. Thus, plume size may be larger than would be expected in deeper water bodies, especially where bottom discharges are feasible.

Circulation changes resulting from power plant operations were minimal. Prevailing winds are from the southeast, and currents in the bay are for the most part wind-driven. Little change could be seen from power plant operation except, of course, the flow of water southward from the north shore in the vicinity of the discharge with some eddying effect in that area. Circulation patterns over the rest of the bay remained the same. No recirculation of heated water was determined during the course of the study.

Diversity indices were calculated for all groups sampled, i.e., phytoplankton, zooplankton, benthos, and nekton. In all cases, no significant changes in diversity patterns were observed after the power plant went into operation. This is true of both the discharge area as well as the unaffected areas of the bay. In fact, during the two years of power plant operation, nekton diversity indices remained higher in the outfall area than anticipated. Diversity indices were generally highest in Cox Bay at the discharge area, both before and after power plant operation began. Since diversity indices, not only of nekton but all other trophic levels, were relatively unchanged resulting from power plant operations, it appears that the overall health of the community has not been significantly affected by the operation of the power plant.

Another way of examining the effects of the power plant is to look at spatial distributions in Cox Bay related to seasonal occurrence. As stated earlier, Texas estuaries are highly transient systems with migrations of organisms occurring in and out of the bays almost continuously. Seasonal distribution data for total nekton biomass (total weight of free-swimming organisms) indicate that no significant change occurred after the power plant went into operation. These data, coupled with no significant changes, indicate clearly that there is no significant impact on the bay resulting from power plant operation.

It should be noted, however, that there are variations from season to season and from year to year. These are deemed natural fluctuations and are influenced little, if at all, by power plant operations.

White shrimp exhibit some avoidance of the immediate area of power plant discharge, especially during summer months. Since these data were collected, additional studies have indicated that white shrimp generally avoid the hottest portion of the discharge. However, at certain times, especially during early fall and late summer, the white shrimp tend to congregate in the general mixing zone area where temperatures are generally 3 to 4°F above ambient.

Patterns similar to white shrimp distribution have been indicated for other organisms. It generally appears that most organisms avoid the immediate vicinity of the discharge during extreme summer conditions. However, these same areas are often used even more heavily during spring, winter, and fall. Thus, considering the overall annual utilization of the area, there appears to be little, if any, total loss of habitat. As in the case of nektonic organisms, phytoplankton, zooplankton, and benthic samples seem to follow the same general distributional patterns.

Summary of Effects on Receiving Waters

Study results indicate that the thermal plume generated by the E. S. Joslin Power Station is relatively small, with rapid temperature die-off occurring within approximately 1,200 feet of the discharge under normal wind conditions. It appears that species diversity indices at various trophic levels remained relatively unchanged after the power plant went into operation, and that the overall health of the community is not endangered. Additionally, seasonal and spatial distributions indicated that, with some minor exceptions, minimal distributional change had occurred. Thus, it appears that little environmental degradation has occurred as a result of the operation of the power plant.

CONCLUSION

Examples have been selected to demonstrate that power plants can be sited and operated on estuaries without adverse effects on the receiving water environment. However, since it is recognized that there are instances where adverse effects have been found due to a variety of site dependent reasons, any conclusions as to the effects of power plants on estuarine environments must be drawn for site specific factors as supported by actual field data.

REFERENCES

Pacific Gas and Electric Company

Browning, B. M. 1972. The natural resources of Elkhorn Slough: Their present and future use. Calif. Dept. Fish & Game, Coastal Wetlands Ser. No. 4 p. 33.

Cayot, R. F., R. H. Brooks, M. J. Doyle, Jr., and J W. Warrick, 1974. Environmental studies at eight thermal power plants. Presented at ASCE Nat. Meet. on Water Resour. Eng. Los Angeles, Calif. Jan. 21–24, 1974.

PGandE, 1973a. Evaluation of the effect of cooling water discharges on the beneficial uses of receiving waters at Contra Costa Power Plant. Rep. to Calif. State Water Resour. Contr. Board.

PGandE, 1973b. Evaluation of the effect of cooling water discharges on the beneficial uses of receiving waters at Moss Landing Power Plant. Rep. to Calif. State Water Resour. Contr. Board.

PGandE, 1973c. Evaluation of the effect of cooling water discharges on the beneficial uses of receiving waters at Pittsburg Power Plant. Rep. to Calif. State Water Resour. Contr. Board.

Virginia Electric and Power Company

Information contained in this report was derived from Semi-Annual Operating Reports submitted to the Atomic Energy Commission in compliance with Technical Specifications for Vepco Surry Power Station, Units 1 and 2, Docket Nos. 50-280 and 50-281.

Tampa Electric Company

Hagen, J. E., III. et al. 1969. Problems and management of water quality in Hillsborough Bay, Fla. Southeast Reg., Fed. Water Pollut. Contr. Admin.

Ingle, R. M. 1973. Preliminary notes on the ecology of Tampa Bay. Rep. to Tampa Elec. Co.

Stewart, V. N. et al. 1973. Third annual report to Tampa Electric Company. Conservation Consultants, Inc.

Stewart, V. N. et al. 1974. Fourth annual report to Tampa Electric Company. Conservation Consultants, Inc.

Central Power and Light Company

Carpenter, E. J. 1971. Annual phytoplankton cycle of the Cape Fear Estuary, N.C. Chesapeake Sci. 12:95–104.

Copeland, B. J., and E. G. Fruh. 1970. Ecological studies of Galveston Bay. Rep. to Texas Water Qual. Board.

Gunter, G. 1945. Studies on marine fishes of Texas. Univ. of Texas. Publ. Inst. Mar. Sci. 1 (1):1–190.

Moseley, F. N., and B. J. Copeland. 1972. Ecology of Cox Bay, Texas. Rep. to Central Power and Light Co.

Odum, E. 1971. Fundament of ecology. W. B. Saunders Co., Philadelphia, Pa.