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Marine Sciences Research Center
State University of New York
Stony Brook, New York 11794-5000

ESTUARINE PROCESSES

J.R. Schubel

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J.R. Schubel

Marine Science Research Center

SUNY at Stony Brook

Stony Brook, New York 11794

INTRODUCTION

It has been predicted that within ten years 75 percent of the entire population of the United States will live within 50 miles of the ocean and the Great Lakes. Most of the areas of greatest population density will be within the watersheds of estuaries. These large numbers of people will make even more intensive, varied and often conflicting demands on our coastal environments; uses which already have degraded the environmental quality of many coastal areas and which have contributed to substantial reductions in living marine resources.

Because of the enormous importance of coastal areas to society resulting from the numerous and varied constituencies they serve, and because of the stressed nature of many coastal environments from these multiple and conflicting uses, it is not surprising that society has demanded that government direct its attention at protecting and, when necessary, at rehabilitating these valuable natural resources. It also is not surprising that this attention has been directed at developing strategies to abate pollution and to enhance the aesthetic values and living resources of coastal environments. These efforts have been focussed on estuaries.

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The responses of elected officials at all levels to citizens' demands for action and the intent of the estuarine management programs which have been generated by federal and state agencies responsible for protecting and managing our estuaries are laudable. A prudent person would not argue with their intent. But there is a problem. The programs have not worked--at least not very well. Their contributions to improving our understanding of estuarine processes and to assessing how society has affected those process; and their contributions to improving our ability to manage estuaries, both have been marginal. Their failure to generate important new insights into the ways estuaries operate has severely limited their utility for management. The generation of new knowledge and the ability to apply it are tightly coupled.

Why? Why with all the best intentions and with relatively large expenditures have large federally funded estuarine programs fallen short--far short--of the mark? The reasons are of two general kinds: those related to the complexity of the subject of study--estuaries--and those related to program formulation and structure.

THE COMPLEXITY OF ESTUARIES

Estuaries are the most complex part of the entire World Ocean, and the most variable. Characteristic properties which change on time scales of hours in estuaries change by comparable amounts in the open ocean only over periods of years, or even decades, and in some cases centuries. Spatially, changes of these same properties which occur in estuaries over distances of a few meters in the vertical and a few kilometers in the horizontal occur in the open ocean only over distances of tens to hundreds of meters in the vertical and thousands to tens of

thousands of kilometers in the horizontal. There is a further complication in estuaries. In many estuaries man has compounded and confounded to a significant degree the already complex interactions of the natural processes. Human activities have modified the natural processes in estuaries in ways and to degrees that are wrought in the open ocean only over geologic time spans. Understanding of the natural processes and their biological consequences and separating these from the effects of society are needed before effective management strategies can be formulated.

Studies of the physics, chemistry and biology of the deep ocean require definition of the interior dynamics and of forcing by the boundary conditions, but because of the large volume, the former are the prime factor with the latter considered as constant or slowly and regularly varying. Even so, a knowledge of mesoscale variability has proved essential to our present understanding of the larger scale dynamics of the deep ocean.

The variability in the internal structure and function of estuaries is dominated by the inputs at the boundaries which are highly and erratically variable in space and time. A thorough knowledge of the magnitude and variability of the inputs is just as important as a knowledge of the internal properties of the system. Yet much of the theory and description of estuarine systems has been given in terms of gross space and time averages. Although such theories have been useful, their inadequacies are now apparent, especially when we attempt to relate the dynamics of physical, chemical, biological and geological processes. There is compelling evidence for the tight coupling of these processes, and therefore there is a need for integration of theoretical, experimental and observational programs in all four disciplines.

There is a distinct need for intercomparative studies of estuaries so that better and clearer generalization can be derived and more effective generic management strategies developed. National and international coordination of studies of estuaries and estuarine management could be of enormous benefit. There is an unusual opportunity for federal Leadership in the support, design and coordination of such comparative studies. This opportunity continues to be largely ignored.

Because of the complexity and variability of estuaries they are excellent candidate environments for the application of new and emerging remote sensing technologies and for the development of new ones.

THE CASE FOR FEDERAL INVOLVEMENT

Because of the complex and stressed nature of estuarine systems, because their importance extends well beyond the boundaries of the states which border them, in some cases to the entire nation, and because many of their most serious problems are dumped on them, or into them, as a result of activities throughout their drainage basins, it is appropriate that the federal government should enter into partnerships with states to initiate and support fund research and monitoring activities to improve our understanding of estuaries, and to develop and implement management strategies to conserve, and when necessary to rehabilitate, these exceedingly important and precious natural resources. It also would be appropriate and highly desirable to assess the effectiveness of management programs in attaining their objectives and goals. Far too little attention is directed at this activity.

There is an enormous opportunity for a federal agency to take a leadership role in coastal and estuarine sciences. None has. At

present, activities are split among a variety of agencies. None has a well articulated program with clearly defined objectives and goals, and the aggregate of federal efforts is inefficient and worse, ineffective. A favorite fortune cookie saying is "That which is everybody's business is nobody's business". Surely this is an apt description of estuaries in the federal government today.

The Case for a Leadership Role for NOAA

NOAA is the most appropriate agency to take this leadership role; to make the Nation's estuaries "their business". The reasons are manifold and compelling. To begin with, it is consistent with NOAA's mandate. In addition, because NOAA is not a regulatory agency it can and should take a leadership role in estuarine research and assessment.

NOAA has a number of advantages over other federal agencies to bring to the leadership role of a national estuarine program. It has the National Marine Fisheries Service, the Ocean Assessments Division, the National Marine Pollution Program Office, the National Sea Grant Program, the National Estuarine Sanctuary Program, and the Estuarine Programs Office. All have programs of major importance to estuarine research and management.

The National Estuarine Sanctuary Program could play a unique role in coastal and in estuarine research, but to date it has not reached its potential. The selection of "estuaries" for sanctuary status was based largely on political criteria and not on their potential for research, education or management. Not all of the estuarine sanctuaries are even ~ estuaries. Still they exist and they should be utilized.

At a recent workshop an attempt was made to define a niche which the National Estuarine Sanctuaries could fill in estuarine research, management and education. It was the conclusion that they should be considered as a diverse set of natural coastal laboratories each with different characteristics; each suitable in varying degrees for pursuit of different kinds of research. It also was concluded that their value as natural laboratories would be greatly enhanced through long-term observational programs to characterize the variations in laboratory conditions in time and space and to relate these variations to the external forcing functions. Against this backdrop of information, individual experiments could be undertaken within these dynamic natural laboratories and their scientific and management values enhanced greatly. The "research budget" for the National Estuarine Sanctuary Program is grossly inadequate--\$200,000 for 10 sanctuaries.

NOAA also has the Office of Estuarine Programs and one might well ask if it could provide the level of leadership called for in this report. It could not; not with its present staff size, and particularly not with its present placement with NOAA. To be effective it would need to be repositioned to have full access to the entire range of NOAA programs relevant to estuaries. Its staff also would have to be expanded.

NOAA already has in place through the National Sea Grant Program an effective partnership with the coastal states and with the academic community of marine scientists. This partnership is a critical element in a national estuarine program and one which only NOAA has at present. Sea Grant has been responsive to management; it has been successful in attracting good academic researchers; and it has been successful in translating the results of research into forms usable by environmental

managers. If the Sea Grant mechanism were to be used on a larger scale, for multi-year, multi-institutional, interdisciplinary studies, some changes in program design and administration would be desirable. It would require extension of intra-State Sea Grant review panels to include specialists from outside the state, and for many estuaries, more active and coordinated cooperation between two or more different Sea Grant Programs would be required. And, the annual Sea Grant funeral dance would have to be eliminated. Annual threats to the continuation of this important program have been debilitating.

SOME RESEARCH PRIORITIES

In the past few years there have been a number of activities in this Country and abroad to identify research priorities for estuaries. Several reports which are of interest are listed below.

- (1) "Fundamental Research on Estuaries" The Importance of an Interdisciplinary Approach." National Academy of Sciences, 1983.
- (2) "Research for Managing the Nation's Estuaries." 1984. Edited by B.J. Copeland, K. Hart, N. Davis and S. Friday. Univ. of North Carolina Sea Grant Pub. UNC-S6-84-08.
- (3) "Ten Critical Questions for Chesapeake Bay in Recent and Related Matters," Chesapeake Research Consortium, 1983.
- (4) "Research on Estuarine Processes." Natural Environmental Research Council, 1983. (UK)

Through a workshop held in Raleigh (NC) in 1984, the National Sea Grant Universities identified "five critical areas" of research needed to improve our management of estuaries:

- (1) Water management and its relationship to estuarine productivity,

- (2) Sediment management and estuarine productivity,
- (3) Nutrient inputs and other contaminants and control of primary productivity,
- (4) Coupling of primary and secondary productivity,
- (5) Habitat requirements for fisheries production.

The Estuarine Committee of the Marine Division of the National Association of State Universities and Land Grant Colleges (1985) identified the research themes listed below as some deserving particular attention:

- o Nutrient cycles/nutrient enrichment,
- o Anoxia/hypoxia,
- o Habitat alteration and fisheries,
- o Behavior and fate of fine particulate matter,
- o Structure and function of estuarine ecosystems,
- o New technologies for looking at estuaries in new and different ways. (e.g. Remote sensing, but not just from the air).

If one reviews the several documents listed above and others, one finds broad general agreement, not only among U.S. estuarine scientists but among the extended community of estuarine scientists, on the areas of research--on research themes--that require further attention. One also finds broad consensus on the need for multidisciplinary research in estuaries.

Pursuit of research on these themes should begin and be concentrated initially in those estuaries where the important processes of interest are manifested most clearly and where there exists some threshold level of knowledge. These should be the criteria for using

federal funds to do thematic research; not whether an estuary is of "national significance", or whether it has a strong political constituency.

For each of these thematic areas, one might form small working groups of experts to outline the boundaries of the problems and to refine the themes. But, the specifics of problem identification (selection), problem formulation and the methods of attack should be left to the individual scientists. For the purposes of this paper, we provide a few additional comments on a number of the themes identified above.

o Anoxia/Hypoxia

A number of the nation's largest and most productive estuaries are subject to large scale anoxic or hypoxic conditions. These may be large in area extent, annual in frequency and persist throughout the summer months as in Chesapeake Bay; or they may be less extensive, less frequent and less persistent as in western Long Island Sound. Previous studies of estuarine anoxic/hypoxic conditions in estuaries have concentrated on the physical processes and have tended to focus attention either on the advective or on the mixing processes. They have failed to properly evaluate the relative importance of each of the different kinds of physical processes to the formation and maintenance of the anoxic/hypoxic conditions and the contributions of chemical, biological and geological processes remain largely unassessed.

Carefully designed comparative studies of anoxic/hypoxic conditions in selected estuaries could contribute significantly to our understanding of the conditions and processes which form and sustain anoxic/hypoxic conditions in estuaries. This knowledge is a

retain the organisms, but which provide for an appropriate exchange of water with the surrounding environment. Because populations of fishes in different estuaries along a coast may be coupled, regional--comparative--studies are required. In selecting estuaries for study, particular care should be exercised in selecting systems in which the scientific questions of interest can be posed in tractable form. The political process of selecting estuaries for study has had little success.

Relatively low level, low cost, long-term observational programs of environmental quality and living resources of estuaries may provide data which can be converted into valuable information for understanding and managing estuaries. The potential value of the data will be determined in large measure upon our ability to determine the appropriate sampling frequencies in time and space. This knowledge comes only from research.

o The Need for New Technologies for Estuarine Studies

One of the principal factors limiting major advances in our understanding of estuarine processes is our inability to measure important characteristic properties and processes on appropriate scales in time and in space. A major and sustained effort should be directed at developing new measurement technologies tuned to the estuarine environment.

Underwater habitats can be of great value to estuarine scientists, particularly to those interested in the behavioral responses of organisms to changes in the environment, both natural and anthropogenic; and to those interested in the water/sediment interface and the biological, chemical, geological and physical processes which affect it. The vertical distributions of organisms on small scales may also be attacked effectively with habitats in clear waters.

prerequisite to the design of cost effective management strategies to rehabilitate estuaries to relieve anoxic/hypoxic conditions.

Underwater habitats, in situ cameras, and remote sensing all could contribute to improving our understanding of anoxic/hypoxic conditions in estuaries.

o Estuarine Fine Particle Sedimentary Systems

Many, perhaps most, of the most insidious contaminants in estuaries are relatively insoluble in water and have a high affinity for particles. As a result, the transportation and accumulation of these contaminants in an estuary are controlled primarily by the system's fine particle sediment system. Most individual processes that contribute to the patterns of transport and accumulation of fine particles in estuaries are only poorly understood. The interactions and manifestations of the interactions of these processes--biological, chemical, and physical--remain obscure. Far greater attention should be directed at understanding the fate and behavior of fine-grained particulate matter in estuaries. Attention must be focussed on multidisciplinary studies with particular emphasis on fluxes across the benthic boundary layer. New, and innovative ways must be developed to study processes within this dynamic zone. NOAA may be the appropriate agency to take a lead role.

o Habitat Alteration and Fisheries

Interdisciplinary studies are needed to assess how environmental factors affect the survival of eggs and larvae and the recruitment of a number of important species of estuarine-dependent fishes. New and novel ways need to be developed to permit in situ studies of critical life history stages. These might include drifting enclosures which

A NATIONAL PROGRAM

There is an old Chinese saying that "If we don't change direction, we are apt to end up where we are headed". The federal government needs to change directions in its estuarine programs. NOAA could, and should, set the course.

More money for estuarine research is not the answer; not alone. While more research support may well be needed and justified, if it is not preceded or accompanied by fundamental structural (organizational) changes in the ways in which estuarine research programs are designed and conducted, expect to see only marginal improvement in our understanding of estuaries and in our ability to manage them effectively. While more money alone is not the answer, neither are simply more of the same kinds of studies conducted in the past.

Many of the most important first-order disciplinary scientific questions in estuaries have been addressed; few of the second-order disciplinary questions have been considered; and almost none of the most important, complex interdisciplinary questions that relate to the

interactions of the physical, chemical, biological, and geological processes have been studied. It is this level of understanding which is required for effective management. The most important estuarine questions--at least for management--are fundamentally interdisciplinary in character.

This level of understanding which effective management requires also is the level which discourages support NSF. The next generation of estuarine scientific questions will be enormously more difficult than the first, and it is on the first where most scientists make their reputations. This means that if we want to engage the best scientific minds in estuarine research, we must make the situation more attractive--not less.

The second order questions are complex and are not amenable to facile solution or to attack by large, short-term (3-5 year) efforts. Basic research on complex estuarine interactions is still inadequate to provide an adequate scientific basis for effective management of estuarine systems including those that relate to pollution management and estuarine rehabilitation. Such studies fare poorly in competition for funds at the National Science Foundation. Interdisciplinary studies often "fall through the cracks" at NSF since there is no longer any interdisciplinary program. And regional studies are frowned upon.

The Need to Study Estuarine Systems

While fundamental research directed at estuarine processes is necessary for development of improved management strategies, it is not sufficient to ensure that they will happen. As pointed out earlier, the processes acting in all estuaries are the same, but the relative importance of those processes, their interactions and the manifestations

of those interactions, vary substantially not only from one estuary to the next, but in different segments of any given estuary at any given time. In addition, there are large temporal variations in estuarine processes and in the characteristic properties produced by those processes. Programs must be designed to permit us to understand how individual estuarine systems operate. It is this level of understanding--of specific estuarine systems--that is required for the development of effective management strategies. The states should play a major role, perhaps the major role, in supporting studies of estuarine systems. Because the importance of many estuaries extends well beyond the bordering states, sometimes to the entire nation, the federal government should retain a partnership in supporting comprehensive studies of important estuarine systems.

Events

Because estuaries and estuarine ecosystems are particularly vulnerable to events--both natural, such as floods and hurricanes; and man-made, such as large accidental spills--special contingency funds should be established to provide rapid funding to take full advantage of the unusual opportunities these "experiments" offer scientists and managers. Documentation of the effects of events can offer valuable insights to scientists and managers into how estuaries respond to natural and anthropogenic stresses. Conventional funding mechanism can not respond on appropriate time scales to take advantage of events.

NOAA should establish a special contingency fund and a mechanism for responding rapidly to requests for support to investigate events in estuaries and coastal waters.

Monitoring

As a Nation we spend tens of millions of dollars every year in monitoring estuaries and coastal waters. To be useful, the data which result from these programs must be transformed into information which is tailored to the special needs of a variety of different consumers. At present, little attention goes into analyzing and interpreting data and even less goes into transforming the data into information useful to those charged with management of our estuaries.

The establishment of diagnostic monitoring programs to establish the status and trends in estuarine quality must emerge from research which provides the basis for station selection, sampling frequency and the properties to be measured. Seldom does this occur. Monitoring programs which are appropriately designed and executed can provide valuable information about the estuarine environment. Many existing monitoring programs do not meet these criteria and are of little value to managers or scientists. Monitoring programs should be scientifically and technically sound. They also should be modest in extent so that the likelihood of continuing the programs over extended periods (decades) is high. At least as much support should be provided to analyze the data as was provided to collect them.

The management of our estuarine resources is adversely affected by the difficulty of using available scientific data and information in the decision making process. The decision maker who has to make a choice tomorrow, next week, or next month, is not aided by a roomful of reports, computer printouts, journal articles or even attractive atlases that contain data and information relevant to the decision.

Recent advances in computer hardware, and particularly in software, make it possible to develop low cost, highly effective computer-assisted environmental information systems for estuaries; systems which literally can place information in appropriate forms at the fingertips of decision makers. The systems can provide ready, interactive access to a wide variety of space-specific and generic information about the local environment. The systems do not make decisions, rather they enable the decision maker to make more effective decisions more efficiently.

Development of this powerful management tool has been pioneered by NOAA, but its application--the transfer of the technology to the consumer--has been largely ignored. The reasons are varied and complex. They range from computer-phobia to lingering bad impressions of the large, costly, ineffective and inefficient environmental data banks. Data bases are necessary, but they are not sufficient. They are of little value to decision makers.

ON DEFINING A NATIONAL ESTUARINE PLAN

An appropriate goal for a federal estuarine plan might be to take the lead in the generation of new knowledge required for development and implementation of management strategies to accommodate within estuaries those uses upon which society places a high value; and to accommodate them with predictable and acceptable impacts on human health, on the environment, on living marine resources, on economics, and on other uses.

It is implicit that one knows (1) the uses society makes and wants to make of estuaries, (2) the value of the competing uses, (3) their impacts on the environment, and its living resources, and (4) that one has a level of understanding of the estuarine environment sufficient to predict with an acceptable degree of accuracy the effects of different use patterns individually and in different combinations on public health, on the environment, on living marine resources, on economics and on other uses. A tall order!

What's the appropriate federal role in research? Where could the federal government make its greatest contribution? Through supporting basic research in thematic areas responsive to priority management objectives and goals, and in working with the states in partnership to fund comprehensive studies of estuarine systems. Federal support for studies of estuarine systems should be restricted to those estuaries for which the appropriate states make a significant financial investment in the partnership.

