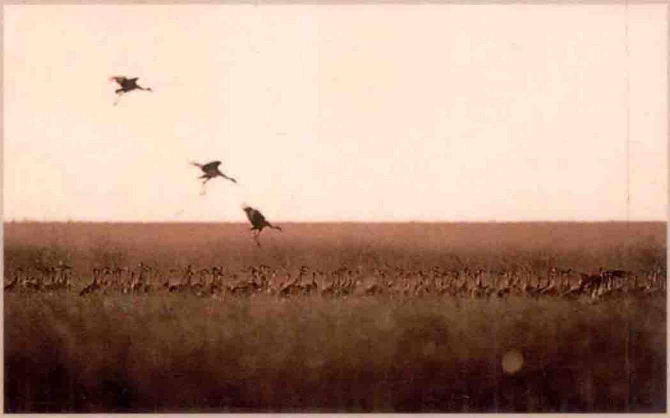
ESTUARINE SCIENCE

A Synthetic Approach to Research and Practice



Edited by John E. Hobbie

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Estuarine Science

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CHAPTER 1

Estuarine Science: The Key to Progress in Coastal Ecological Research

John E. Hobbie

Executive Summary

Situated at the interface between land and ocean, estuaries of coastal rivers are semi-enclosed bodies of sea-water measurably diluted by the fresh water that flows into them. Estuaries are characterized by high biotic diversity and high primary production. They yield large harvests of fish and shellfish and provide transportation routes and recreational opportunities for human populations worldwide. The rise in population and changing land use in coastal regions is inevitably affecting the flow of water, sediments, organic matter, and inorganic nutrients into the estuaries of the world. Successful management of estuaries and their watersheds for sustainable use in the future requires us to bring all applicable knowledge to bear on the development of practical models that predict the results of various strategies.

Despite the extent of research on estuaries, our ability to generalize and predict the consequences of change is primitive. One reason is the inherent complexity and variability of estuaries, which exhibit tremendous temporal and spatial variation in physical and chemical characteristics. Another reason is the restricted nature of the questions asked; most estuarine research has been focused on documenting and solving local and state management problems. Although such studies do answer questions, there is no way to transfer information to other sites and to avoid repetitious data collection. A final reason is the lack of funding for basic research and synthesis of data from estuarine studies. Priorities for marine research have emphasized the open ocean. As a result, there have been few opportunities to develop long-term and intensive studies in coastal regions.

Such studies are necessary for synthesis, which we define as the bringing together of existing information in order to discover patterns, mechanisms,

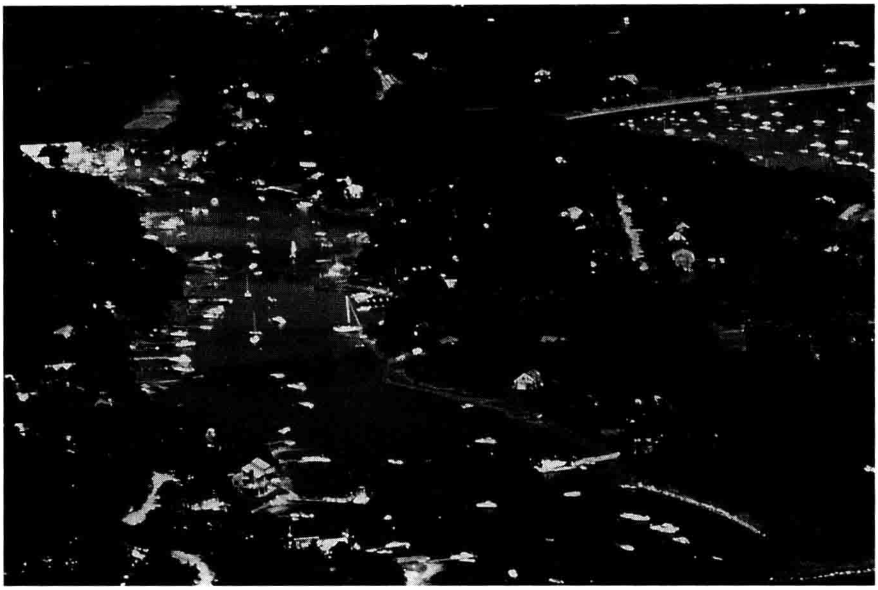

FIGURE 1-1 The Childs River estuary and Waquoit Bay (upper right) are important recreational resources on Cape Cod, Massachusetts.

and interactions that lead to new concepts and models. Synthetic perspectives and methods are necessary to discover the general relationships and develop the models that can be applied to all estuaries. To date, the synthetic aspects of estuarine research have been neglected.

With support from the U.S. Scientific Committee for Problems of the Environment (SCOPE), the National Science Foundation (NSF), and the National Oceanic and Atmospheric Administration (NOAA), forty estuarine scientists met in 1995 to put together the case for synthesis of estuarine data and to show the capabilities of synthetic methods of research. The meeting featured twelve plenary talks that documented a variety of successful approaches to conducting synthetic studies in estuaries. Attendees also took part in five workshops that were charged with identifying important areas for synthesis in the next decade, along with specific ideas about the kinds of process studies or models that would be needed.

The plenary talks and workshop reports from this meeting comprise chapters 2–18 of this book. They are organized into five parts, each of which begins with a short introduction.

Part I takes up the measurement and prediction of changes in the amounts of water, sediment, and nutrients that flow from watersheds into estuaries. These amounts vary widely from estuary to estuary. Resource managers have developed correlations between types of landscape and the runoff of nutrients and sediment that are entirely adequate to describe changes that occur when, for example, land use changes from forests to farming or urban development.

The correlation approach, however, cannot predict changes in nutrient and sediment runoff when climate and vegetation type change drastically. Scientists need to take the next step and develop mechanistic models containing cause-and-effect relationships that combine vegetation and soil processes with hydrology models based on climate and the landscape topography.

Part II presents efforts to couple information on the physical environment of estuaries with biogeochemical and ecological data. Changes in currents, salinity, and sea level in estuaries are correlated with the productivity, survival, and distribution of plants and animals. The survival of postlarval shrimp can be predicted, for example, with the help of a physical model of the changes in salinity and temperature that the shrimp experience as they are transported throughout an estuary.

Although scientists are capable of developing detailed physical models of each estuary, it is more useful to develop general models that allow us to predict changes in physical conditions that affect the ecology of estuaries from information on bathymetry, river flow, climate, and so forth. The conclusion of the workshop reported in this section is that estuarine research over the next decade should emphasize quantitative comparisons among estuaries, combining observations with advanced modeling approaches to address the complex and variable processes within and among interacting estuarine systems.

Part III deals with biogeochemical processes in estuaries and their linkages to the food web. Processes such as denitrification can be studied in a single estuary over time or comparatively in a number of estuaries. The resulting information can be used to create models at the global scale. The effects of nutrients entering estuarine and coastal waters have been studied through measurements of a number of processes. Examples given include the response of biological systems in the Gulf of Mexico to nutrients and of effects on Chesapeake Bay systems of long-term changes in nutrient and water flow.

While links can be made between biogeochemical factors and the lower levels of the food web, links to fish at the top of the food web are extremely difficult to quantify at present. Recommendations for future research and synthesis are to gather more long-term data sets and to construct more mass balances of nutrients, to carry out manipulative experiments to identify causal links, and to bring together information from all sources to construct models reflecting the current understanding. The modeling of linked processes will answer many management questions.

Part IV discusses controls on distribution and abundance of organisms in the estuary; biologists at the workshop reported in this section concluded that good management necessitates an extension of the commonly held concepts of habitat to include the environment of an organism throughout its entire life. Estuaries are so changeable and dynamic that organisms encounter a wide range of environments throughout their life histories.

Although no single model exists of these changing environments, it is possible to simulate some crucial aspects. For example, the dynamics of sediment deposition can explain the distribution of rooted aquatic plants. Furthermore, the productivity and survival of algae and sea grasses in Chesapeake Bay can be simulated through use of coupled physical and biological models of the movement of nutrients throughout the entire bay. Remote sensing can be used to develop a picture of the distribution and abundance of small fish across transects of the estuary; this information allows a bioenergetics model to identify the habitats where predatory fish can survive and grow.

Part V addresses the need for synthesis that would improve the scientific management of estuaries directly. In one example, an integrated model of ecological and economic factors in the Patuxent watershed in Maryland incorporates economic forces as drivers for ecological changes that take place. Workshop participants concluded that the scientific management of estuarine systems would be greatly improved by the formal application of a series of steps. They include:

- designating a lead agency within each estuarine management program to coordinate the activities of other agencies;
- communicating among stakeholders in government, the public, and the scientific community;
- implementing a scientific advisory process that incorporates synthesis of data and comparisons across a variety of systems;
- providing sustained support at the national level for basic research on estuarine processes;
- encouraging comparison and synthesis within national networks of projects and programs to produce generalized models for managers.

Introduction

Why Are Estuaries Important?

Situated at the interface between land and ocean, the estuaries of coastal rivers provide vital habitat for fish, shellfish, and waterfowl as well as transportation routes and recreational opportunities for human populations.

Estuaries are, by definition, semi-enclosed bodies of seawater measurably diluted with fresh water from watersheds. This fresh water carries with it sediments, organic matter, and inorganic nutrients from terrestrial sources. The combination of high nutrients and the stratification and circulation patterns characteristic of estuaries result in high biotic diversity, high primary productivity, and the creation of harvest and nursery areas for fish and shellfish.

The human population has increased rapidly in coastal regions throughout the world in recent years. Worldwide, 61% of the population lives near a coast (Alongi 1998). In the United States, more than half of the population lives in coastal counties, including those bordering the Great Lakes, and the rate of population increase in these counties is higher than that of the country as a whole (Land-Margin Ecosystem Research Coordinating Committee 1992). A 1994 report from the U.S. National Research Council (NRC) titled "Priorities for Coastal Ecosystem Science" lists some of the major effects that the rise in human population has had on estuarine ecosystems:

- Nutrients, especially nitrogen, have increased manyfold in rivers entering estuaries, causing harmful algal blooms and the depletion of oxygen, especially in bottom waters.
- Intertidal and tidal habitats, such as salt marshes vital to the young of commercial fishery species, have been dredged and filled.
- Landscape alterations, water diversion, and damming of rivers have changed the amount and seasonal patterns of fresh water reaching estuaries as well as the amount of transported sediments.
- Overexploitation of natural resources has eliminated some shellfish and fish stocks.
- Industrial pollution has left toxic materials such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) in some estuaries.
- Introduction of nonindigenous animals and plants into estuaries has resulted in loss of biodiversity, degradation of habitats, and reduction in fisheries production.

The NRC report also points out the susceptibility of coastal and estuarine ecosystems to changes in climate and weather patterns. While the effects of sea-level rise have been well publicized, changes in precipitation and estuarine salinity, circulation patterns, and riverine transport of nutrients may be expected as well. Shifts in weather patterns can alter the direction and strength of waves, causing drastic shoreline erosion.

The report concludes that these issues require strategies other than the regulatory and management approaches that are generally taken to problems such as point-source discharge, coastal land use, and spills of toxic chemicals. It notes that "... concern is shifting from problems amenable to single-factor risk assessment paradigms to multiple-factor risk assessment and regulatory strategies that take into account indirect, cascading, and scale-related effects that require an ecosystem perspective (for example, eutrophication, hydrologic and hydrodynamic modification, resource sustainability, loss of biodiversity)" (NRC 1994).

Why Is Synthesis Needed for Improved Scientific Understanding?

Synthesis may be defined as the bringing together of existing information in order to discover patterns, mechanisms, and interactions that lead to new concepts and models. An increased emphasis on synthesis is needed in estuarine research for a number of reasons.

Estuarine research suffers from a lack of integration of knowledge that can be applied across sites. Estuaries are dynamic, complex, and difficult to study. One result is that scientists generally concentrate on studying a single estuary. Little effort is made to integrate data into a coherent whole that makes optimal use of previous estuarine research. We study too many estuaries and treat each as if it were unique.

This approach is extremely costly as each estuary has to be studied in detail, starting with years of observations. The result is that research seldom advances beyond the observational level to answer questions about cause-and-effect relationships and ecosystem processes. Research on single systems needs to be extended to include a search for patterns common to all estuaries, and researchers need to adopt a comparative approach so that predictions can be made about unstudied estuaries.

The winter 1998 newsletter of the U.S. Environmental Protection Agency's (EPA) National Estuary Program (NEP) calls for better use and transfer of information. "There are approximately 130 estuaries in the United States. Do they all need to be part of the NEP? The EPA recognizes that it may not be appropriate, or even necessary, to designate all of these estuaries as NEPs. What may be more important and effective is to transfer the lessons learned within the NEP to other areas" (U.S. EPA 1998).

The results of most estuarine studies are not published in reviewed journals. Most estuarine research projects are aimed at solving local and state management problems. These studies, which are both necessary and important, account for most of the $227 million that federal agencies spent on research in the coastal zone in 1993, the last year for which we have complete numbers. But a focus on solving a particular problem in a particular place is generally associated with a failure to report results to a broader audience. Articles in peer-reviewed journals are the accepted method of reporting scientific data and management solutions. When results are not disseminated, costly research winds up being repeated again and again.

Understanding the complex interactions of physical, chemical, and biological factors is essential to answering many questions about estuarine systems. Concerns about the effect of changes in sea level and freshwater input on estuarine ecosystems require that we understand the interactions of physical properties and processes with the biota. Analyzing these interactions requires the use of models. Similarly, we need to look at the complex interactions of food webs rather than studying single species if we are to understand the impact of human activity on estuarine systems. Relatively simple questions, such as the relationship between nutrient loading and eutrophication, have been well studied. They are being replaced by more complex issues, such as the effects of habitat loss and species replacement on fish production, that require an understanding of whole food webs.

Estuarine research must be able to predict the consequences of future changes in climate or land use in watersheds. Predictions about the future are only possible with synthetic models that incorporate mechanistic understanding of ecological relationships. The key word here is "future." Empirical models are perfectly adequate and cost-effective ways to explain the effects of currently observed phenomena, for example, the present-day loss of sediment from a drainage basin. In these models, the analysis is based on field observations, not on experimental data or mechanistic understanding. These analyses make use of regressions, some of which involve integrated relationships, such as the one between nutrient flux into an estuary and fish production.

If predictions are required about the effects of future changes in climate or water and sediment input, however, the relationships derived by regression may no longer apply. A mechanistic or process-based model can predict outcomes if new inputs or new climate conditions are postulated. These modeling efforts will be successful only if a synthetic approach incorporates all the information necessary to construct and test the models.

The U.S. SCOPE Meeting on Synthesis in Estuaries

Despite the extent of research on estuaries, our ability to generalize and predict the consequences of change is primitive. One reason is the inherent complexity and variability of estuaries. In any estuary, there is tremendous temporal and spatial variability in physical and chemical factors such as salinity or oxygen levels.