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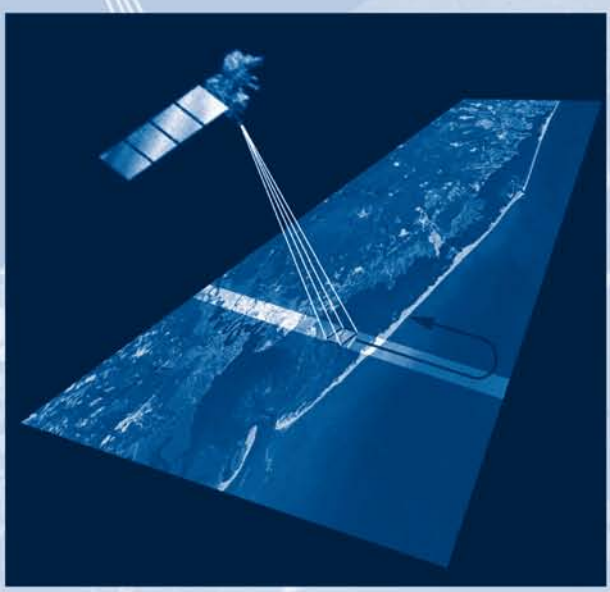

Michael J. Kennish

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ESTUARINE RESEARCH, MONITORING, and RESOURCE PROTECTION

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CRC PRESS

Boca Raton London New York Washington, D.C.

The cover design was created by Scott M. Haag of the Center for Remote Sensing and Spatial Analysis at Rutgers University. It is a Landsat image of the Jacques Cousteau National Estuarine Research Reserve and surrounding coastal bays and watersheds of New Jersey. The original satellite image is from the U.S. Geological Survey EROS Data Center, Sioux Falls, South Dakota (http://idcm.usgs.gov/).

Library of Congress Cataloging-in-Publication Data

Estuarine research, monitoring, and resource protection / edited by Michael J. Kennish.
p. cm. -- (Marine science series)
Includes bibliographical references and index.
ISBN 0-8493-1960-9
1. National Estuarine Research Reserve System. 2. Estuarine ecology--United States--Case studies. 3. Environmental monitoring--United States--Case studies. I. Kennish, Michael J. II. Series.

QH76.E86 2003
577.7′86′0973--dc21 2003053062

Visit the CRC Press Web site at www.crcpress.com

International Standard Book Number 0-8493-1960-9
Library of Congress Card Number 2003053062
Printed in the United States of America 1 2 3 4 5 6 7 8 9 0
Printed on acid-free paper

Dedication

This book is dedicated to
the National Estuarine Research Reserve System.

Preface

Estuarine Research, Monitoring, and Resource Protection is principally designed as a reference volume for estuarine and watershed scientists, resource managers, decision makers, and other professionals who deal with coastal zone issues. Information contained in this volume will be useful to individuals conducting either basic or applied research on estuaries. It will also be valuable to administrators engaged in coastal resource management programs.

This book is an outgrowth of my work as research coordinator of the Jacques Cousteau National Estuarine Research Reserve (JCNERR) in New Jersey. I thank my colleagues at the JCNERR who comprise a remarkably cohesive and competent group of researchers, administrators, and support staff. They include Michael P. DeLuca (reserve manager), Scott Haag (GIS coordinator), Josephine Kozic (volunteer coordinator), Janice McDonnell (assistant manager), Eric Simms (education coordinator), and Lisa Weiss (watershed coordinator). These individuals are dedicated professionals who have played major roles in the successful development and expansion of the program site.

Estuarine Research, Monitoring, and Resource Protection provides an overview of the National Estuarine Research Reserve System (NERRS). I would like to thank many members of the NERRS program who have supplied data, site profile reports, and other information vital to the production of the volume. At the Estuarine Reserves Division of the National Oceanic and Atmospheric Administration (NOAA), I thank Laurie McGilvray (chief), Maurice Crawford (research coordinator), and Erica Seiden (program specialist). At NERR program sites, I thank Betty Wenner (research coordinator) and Saundra Upchurch (reserve biologist) of the Ashepoo–Combahee–Edisto (ACE) Basin NERR, Lee Edmiston (research coordinator) of the Apalachicola NERR, Julie Bortz (research coordinator) of the Chesapeake Bay (Maryland) NERR, Willy Reay (reserve manager) and Ken Moore (research coordinator) of the Chesapeake Bay (Virginia) NERR, Bob Scarborough (research coordinator) of the Delaware NERR, Kerstin Wasson (research coordinator) of the Elkorn Slough NERR, Brian Smith (research coordinator) of the Great Bay NERR, Rick Gleeson (research coordinator) of the Guana Tolomato Matanzas (GTM) NERR, Chuck Nieder (research coordinator) of the Hudson River NERR, Carmen Gonzalez (reserve manager) of the Jobos Bay NERR, Carl Schoch (research coordinator) of the Kachemak Bay NERR, Kenny Reposa (research coordinator) of the Narragansett Bay NERR, Steve Ross (research coordinator) of the North Carolina NERR, Chris Buzzelli (research coordinator) of the North Inlet-Winyah Bay NERR, Dave Klarer (research coordinator) of the Old Woman Creek NERR, Doug Bulthuis (research coordinator) of the Padilla Bay NERR, Mike Shirley (research coordinator) of the Rookery Bay NERR, Dorset Hurley (research coordinator) of the Sapelo Island NERR, Steve Rumrill (research coordinator) of the South Slough NERR, Jeff Crooks

(research coordinator) of the Tijuana River NERR, Chris Weidman (research coordinator) of the Waquoit Bay NERR, Scott Phipps (research coordinator) of the Weeks Bay NERR, and Michele Dionne (research coordinator) of the Wells NERR. Special thanks to Tammy Small, Manager of the Centralized Data Management Office, for providing water quality data on NERRS program sites. Dwight Trueblood, Co-Director of the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET), is likewise thanked for his involvement in the NERRS Program. Special gratitude is extended to the Waquoit Bay NERR, Delaware NERR, ACE Basin NERR, Weeks Bay NERR, and Tijuana River NERR, whose profile reports constituted valuable sources of information for this publication.

I would also like to acknowledge the work of Ken Able (Rutgers University) and his staff on the JCNERR system in New Jersey, Skip Livingston (Florida State University) on the Apalachicola NERR in Florida, Ivan Valiela (Boston University Marine Program) on the Waquoit Bay NERR, and Joy Zedler on the Tijuana River NERR in Southern California. These investigators have produced extensive databases on important estuarine systems in the NERRS program.

I am especially grateful to the editorial and production personnel of CRC Press who are responsible for publishing this book. In particular, I express appreciation to John B. Sulzycki, senior editor, and Christine Andreasen, production editor, of the editorial and production departments, respectively.

This is Publication Number 2003–17 of the Institute of Marine and Coastal Sciences, Rutgers University, and Contribution Number 100-23 of the Jacques Cousteau National Estuarine Research Reserve. Work on this volume was conducted under an award from the Estuarine Reserves Division, Office of Ocean and Coastal Resource Management, National Ocean Service, National Oceanic and Atmospheric Administration.

Editor

Michael J. Kennish, Ph.D., is a research professor in the Institute of Marine and Coastal Sciences at Rutgers University, New Brunswick, New Jersey, and the research coordinator of the Jacques Cousteau National Estuarine Research Reserve in Tuckerton, New Jersey. He holds B.A., M.S., and Ph. D. degrees in geology from Rutgers University. Dr. Kennish's professional affiliations include the American Fisheries Society (Mid-Atlantic Chapter), American Geophysical Union, American Institute of Physics, Estuarine Research Federation, New Jersey Academy of Science, and Sigma Xi.

Dr. Kennish has conducted biological and geological research on coastal and deep-sea environments for more than 25 years. While maintaining a wide range of research interests in marine ecology and marine geology, Dr. Kennish has been most actively involved with studies of marine pollution and other anthropogenic impacts on estuarine and marine ecosystems as well as biological and geological investigations of deep-sea hydrothermal vents and seafloor spreading centers. He is the author or editor of 11 books dealing with various aspects of estuarine and marine science. In addition to these books, Dr. Kennish has published more than 130 research articles and book chapters and presented papers at numerous conferences. His biogeographical profile appears in *Who's Who in Frontiers of Science and Technology, Who's Who Among Rising Young Americans, Who's Who in Science and Engineering,* and *American Men and Women of Science.*

Introduction

Estuaries rank among the most productive aquatic ecosystems on earth. They also rank among the most heavily impacted by human activities. Kennish (2002a) recently assessed the environmental state of estuaries and predicted their condition by the year 2025. He identified ten principal anthropogenic stressors on estuaries that, taken together, can mediate significant changes in the structure, function, and controls of these vital coastal ecotones (Table 1). Tier I anthropogenic stressors (i.e., habitat loss and alteration, eutrophication, organic loading, and fisheries overexploitation) are the most serious, having the potential to generate global-scale impacts.

Anthropogenic impacts can be differentiated into three major groups, including those that degrade water quality (e.g., pathogens, nutrients, chemical contaminants, and sewage wastes), result in the loss or alteration of habitat (e.g., wetland reclamation, shoreline development, and dredging), and act as biotic stressors (e.g., overfishing and introduced/invasive species). Nearly all U.S. estuaries are affected in some way by anthropogenic activities, and the scientific literature is replete with reference to human-induced alteration of these coastal systems (for a review see Kennish, 1992, 1997, 2001a). It is critically important to understand these anthropogenic impacts in order to formulate sound management decisions regarding the protection of coastal resources.

Estuaries are particularly susceptible to anthropogenic stressors because of rapid population growth and development in coastal watersheds nationwide. Demographic trends indicate that the coastal zone will continue to be the target of heavy human settlement during the 21st century (Kennish, 2002a). Hence, human activities potentially impacting estuaries will likely become more pervasive in the years ahead.

Kennish (2002a) has shown that an array of estuarine impacts will accompany coastal watershed development during the next 25 years. Among the most severe will be habitat loss and alteration associated with large-scale modifications of coastal watersheds (e.g., deforestation and construction, marsh diking and ditching, and channelization and impoundments), estuarine shorelines (e.g., bulkheads, revetments, retaining walls, and lagoons), and estuarine basins (e.g., dredging and dredged material disposal, channel and inlet stabilization, harbor and marina development, and mariculture and commercial fishing activities). Nutrient enrichment and inputs of oxygen-depleting substances will accelerate as impervious surfaces and hydrological modifications increase in watershed areas. Eutrophication is expected to become more widespread, with greater incidences of hypoxia and anoxia, particularly in shallow coastal bays with limited circulation and flushing. Bricker et al. (1999) recorded moderate to high eutrophic conditions in more than 80 estuaries in conterminous U.S. waters, mostly located along the Atlantic and Gulf of Mexico coasts. They also projected that eutrophic conditions will worsen in 86 U.S. estuaries by 2020. Nutrient overenrichment is thus a serious concern.

TABLE 1
Ranking of Future Anthropogenic Threats to Estuarine Environments Based on Assessment of Published Literature[a]

Stressor	Principal Impacts
1. Habitat loss and alteration	Elimination of usable habitat for estuarine biota
2. Eutrophication	Exotic and toxic algal blooms; hypoxia and anoxia of estuarine waters; increased benthic invertebrate mortality; fish kills; altered community structure; shading; reduced seagrass biomass; degraded water quality
3. Sewage	Elevated human pathogens; organic loading; increased eutrophication; degraded water and sediment quality; deoxygenated estuarine waters; reduced biodiversity
4. Fisheries overexploitation	Depletion or collapse of fish and shellfish stocks; altered food webs; changes in the structure, function, and controls of estuarine ecosystems
5. Chemical contaminants Higher priority Synthetic organic compounds Lower priority Oil (PAHs) Metals Radionuclides	Adverse effects on estuarine organisms including tissue inflammation and degeneration, neoplasm formation, genetic derangement, aberrant growth and reproduction, neurological and respiratory dysfunction, digestive disorders, and behavioral abnormalities; reduced population abundance; sediment toxicity
6. Freshwater diversions	Altered hydrological, salinity, and temperature regimes; changes in abundance, distribution, and species composition of estuarine organisms
7. Introduced invasive species	Changes in species composition and distribution; shifts in trophic structure; reduced biodiversity; introduction of detrimental pathogens
8. Sea level rise	Shoreline retreat; loss of wetlands habitat; widening of estuary mouth; altered tidal prism and salinity regime; changes in biotic community structure
9. Subsidence	Modification of shoreline habitat; degraded wetlands; accelerated fringe erosion; expansion of open water habitat
10. Debris/litter (plastics)	Habitat degradation; increased mortality of estuarine organisms due to entanglement in debris and subsequent starvation and suffocation

[a] For example, McIntyre, 1992, 1995; Windom, 1992; Yap, 1992; Jones, 1994; Kennish, 1997, 1998, 2000, 2001a, b; Goldberg, 1995, 1998.

Source: Kennish, M.J. 2002. *Environmental Conservation* 29: 78–107.

Other serious stressors are overfishing, which will threaten some fish and shellfish stocks and alter estuarine food webs (Sissenwine and Rosenberg, 1996), and chemical contaminants (especially synthetic organic compounds), which will continue to be most problematic in urban industrialized estuaries (Kennish, 2002b).

Altered stream hydrology coupled to freshwater diversions will also be a problem, and these modifications could affect broad geographic regions. Introduced/invasive species, coastal subsidence, and sediment input/turbidity will likewise impact many estuarine systems. All of these stressors can cause shifts in the structure of estuarine biotic communities or the degradation of valuable estuarine habitat.

Kennish (2002a, p. 102) stated, "As the coastal population increases during the next two decades, anthropogenic impacts on estuaries will likely escalate unless effective management strategies are formulated. Best management practices must be initiated to protect freshwater and coastal wetlands, to minimize input of toxic agents, nutrients, and disease vectors to receiving water bodies, to mollify physical alterations of river–estuary systems that could lead to adverse changes involving nutrient transfer and salinity distribution, and to maintain adequate freshwater inflow to sustain natural productivity and the important nursery function of the systems (Livingston, 2001). It will also be advantageous to limit shoreline development, reduce invasive species, and prevent overfishing. These measures may entail adapting strict management guidelines."

More monitoring and research are needed to identify impacts in the estuarine basins themselves and to develop remedial measures to revitalize altered habitat. In particular, ecosystem level research is necessary to fundamentally understand the natural and anthropogenic processes operating in these coastal environments. Assessment programs must specifically delineate water quality and habitat conditions. Improved nonpoint source pollution controls are required to ameliorate water and sediment quality impacts. Alternative landscaping (e.g., replacing lawns with ground covers, shrubs, trees, and other natural vegetation), modified agricultural practices (e.g., application of new methods to reduce erosion, runoff, and sedimentation), and structural controls (e.g., constructed wetlands, detention facilities, and filtration basins) can significantly mitigate stormwater runoff and contaminant mobilization in adjoining watersheds. In addition, proper restoration efforts should be instituted to return degraded habitat to more natural conditions (NOAA/NOS, 1999). However, these efforts are typically labor intensive, time consuming, and costly. Moreover, they often fall short in terms of the recovery goals of the impacted habitat.

Several federal government programs are providing valuable data for assessing environmental conditions in U.S. estuaries and coastal watersheds. These include the National Estuarine Research Reserve System (NERRS), National Estuary Program (NEP), Coastal Zone Management (CZM) Program, National Status and Trends (NS&T) Program, National Coastal Assessment Program, Environmental Monitoring and Assessment Program, National Marine Fisheries Service National Habitat Program, U.S. Fish and Wildlife Service Coastal Program, and National Wetlands Inventory. Of these programs, NERRS is unique because it consists of a network of 25 protected sites that yield information on national estuarine trends of local or regional concern vital to promoting informed resource management. This network of protected areas represents a federal, state, and community partnership in which environmental monitoring and research as well as a comprehensive program of education and outreach strengthen understanding, appreciation, and stewardship of estuaries, coastal habitats, and associated watersheds. NERRS encompasses more than a million hectares of estuarine, wetland, and upland habitats in all biogeographical regions of the U.S.

NERRS sites are essentially coastal ecosystems used as demonstration sites for long-term research and monitoring and resource protection, as well as education and interpretation. The objective of this book is to examine in detail the NERRS program, focusing on environmental research, monitoring, and restoration components. The NERRS sites generally represent pristine and undisturbed areas that can serve as reference locations to assess other estuarine systems impacted by anthropogenic activities. One of the principal reasons for creating the NERRS program was to improve the management of estuarine resources by providing an integrated mechanism for the detection and measurement of local, regional, and national trends in estuarine conditions. Increasing and competing demands for coastal resources require a coordinated program such as NERRS to improve coastal zone management. Research and education programs of NERRS can guide estuarine and watershed management for sustained support of coastal resources.

This initial volume of *Estuarine Research, Monitoring, and Resource Protection* describes the workings of the NERRS program — its organization, goals, and management strategies. It does not provide a critique of the program aims and achievements, which will be the focus of a later volume. The second volume will assess how the NERRS program has succeeded overall in achieving technical and management objectives.

Chapter 1 of *Estuarine Research, Monitoring, and Resource Protection* is a comprehensive treatment of the principal components of the NERRS program. Chapters 2 to 7 concentrate on the physical, chemical, and biological characterization of selected NERRS sites, as follows:

- Chapter 2: Waquoit Bay National Estuarine Research Reserve
- Chapter 3: Jacques Cousteau National Estuarine Research Reserve
- Chapter 4: Delaware National Estuarine Research Reserve
- Chapter 5: Ashepoo–Combahee–Edisto (ACE) Basin National Estuarine Research Reserve
- Chapter 6: Weeks Bay National Estuarine Research Reserve
- Chapter 7: Tijuana River National Estuarine Research Reserve

These case studies offer a cross section of NERRS sites on the Atlantic, Pacific, and Gulf of Mexico coasts and therefore give broad coverage of the program.

It is important to specify that the success of the NERRS program depends on the unselfish cooperation of government agencies, academic institutions, public interest groups, concerned citizens, and the general public. These entities must all work together to ensure protection of the water quality, habitat, and resources in the system of estuarine and coastal watersheds comprising the NERRS program. The case studies of reserve sites reported in this book demonstrate how critical it is to maintain the ecological integrity of our coastal environments.

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