SCOPE 70

Watersheds, Bays, and Bounded Seas

The Science and Management of Semi-Enclosed Marine Systems

EDITED BY Edward R. Urban, Jr.
Bjørn Sundby
Paola Malanotte-Rizzoli
and Jerry M. Melillo

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About Island Press

Since 1984, the nonprofit Island Press has been stimulating, shaping, and communicating the ideas that are essential for solving environmental problems worldwide. With more than 800 titles in print and some 40 new releases each year, we are the nation's leading publisher on environmental issues. We identify innovative thinkers and emerging trends in the environmental field. We work with world-renowned experts and authors to develop cross-disciplinary solutions to environmental challenges.

Island Press designs and implements coordinated book publication campaigns in order to communicate our critical messages in print, in person, and online using the latest technologies, programs, and the media. Our goal: to reach targeted audiences—scientists, policymakers, environmental advocates, the media, and concerned citizens—who can and will take action to protect the plants and animals that enrich our world, the ecosystems we need to survive, the water we drink, and the air we breathe.

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About SCOPE

The Scientific Committee on Problems of the Environment (SCOPE) was established by the International Council for Science (ICSU) in 1969. It brings together natural and social scientists to identify emerging or potential environmental issues and to address jointly the nature and solution of environmental problems on a global basis. Operating at an interface between the science and decision-making sectors, SCOPE's interdisciplinary and critical focus on available knowledge provides analytical and practical tools to promote further research and more sustainable management of the Earth's resources. SCOPE's members, national scientific academies and research councils, and international scientific unions, committees and societies, guide and develop its scientific program.

Foreword

This volume was developed in partnership among three organizations of the International Council for Science (ICSU): the International Association for the Physical Sciences of the Oceans (IAPSO), the Scientific Committee on Oceanic Research (SCOR), and the Scientific Committee on Problems of the Environment (SCOPE).

IAPSO (http://iapso.sweweb.net) is a constituent association of the International Union of Geodesy and Geophysics (IUGG) (http://www.iugg.org), an ICSU scientific union. IAPSO has the prime goal of promoting the study of scientific problems relating to the oceans and the interactions taking place at the seafloor, coastal, and atmospheric boundaries insofar as such research is conducted by the use of mathematics, physics, and chemistry. IAPSO participates in SCOR and interacts with UNESCO's Intergovernmental Oceanographic Commission.

SCOR (http://www.scor-int.org), the first interdisciplinary body formed by ICSU, was established in 1957 in recognition that scientific questions about the ocean often require an interdisciplinary approach. SCOR activities focus on promoting international cooperation in planning and conducting oceanographic research and on solving methodological and conceptual problems that hinder research. The SCOR secretariat is located at the College of Marine and Earth Studies at the University of Delaware (Newark).

SCOPE (http://www.icsu-scope.org), founded in 1969, is an interdisciplinary body of natural and social science expertise focused on global environmental issues, operating at the interface between scientific and decision-making instances. A worldwide network of scientists and scientific institutions develops syntheses and reviews of scientific knowledge on current or potential environmental issues. The SCOPE secretariat is located at ICSU headquarters in Paris, France.

Watersheds, Bays, and Bounded Seas is Volume 70 in the SCOPE series, now published with Island Press. This cooperative approach among three ICSU organizations to synthesize and analyze information is an excellent example of how the scientific community can help to address a complex multidisciplinary subject of global significance.

We dedicate this book to Hal Mooney, who has been a mentor to all of us and a pioneer of studies of the importance of biodiversity on human well-being.

Bernard D. Goldstein
Editor-in-Chief, SCOPE Publications

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Introduction

Edward R. Urban, Jr., Bjørn Sundby,
Paola Malanotte-Rizzoli, and Jerry M. Melillo

Why and How This Book Was Created

Observations and images from various regions of the earth provide dramatic evidence that global change is real. Large-scale weather events that erode shorelines and flood low-lying areas make it obvious that global change affects not only the remote parts of the earth, but also the daily life of each of the planet's inhabitants. Melting ice caps and glaciers, eroding shorelines, and floods are indeed spectacular manifestations of global change. But because they are so spectacular, they may overshadow other manifestations of global change that are less visible but no less important. Regrettably, out of sight often means out of mind.

In the ocean, many effects of global change are literally out of sight because they manifest themselves below the sea surface. This also is true in the coastal ocean, the buffer zone between continents and ocean. Although global change's impacts on the hydrologic cycle will vary among regions, increasing air temperatures over the ocean are predicted (on the basis of well-known physical processes) to increase evaporation from the ocean, which may lead to increasing precipitation on the continents and increasing runoff from the continents. Increased freshwater runoff to the coastal zone—carrying with it nutrients, contaminants, and sediments—is worrisome because it can be expected to alter the local ecology; reduce the quality of the habitats of many organisms, including those useful to humans; and affect their health, growth, and ability to reproduce. The effect of global warming on runoff will not be uniformly distributed; runoff may increase in some areas and decrease in others, and regional predictions are notoriously unreliable.

Semi-enclosed marine systems (SEMSs) are important in many coastal regions; they are tightly linked with land and have restricted exchange with the open ocean. SEMSs are important to humans, who are especially numerous at the edges of the continents. Humans rely on SEMSs for often-competing services such as provision of food, protection from natural disasters, navigation and transport, disposal of waste, extraction of minerals and sand/gravel, and leisure. Society has set up institutions to manage coastal areas for the benefit of all, but these institutions often lack information, understanding, and tools to help them with their task. Thus society turns to scientists, who are trained to provide information, develop understanding, and create tools for studying the ocean. The task facing scientists is difficult, for it obliges them to venture onto the often unknown terrain where nature and human forces interact.

To address the overlapping issues of management and research in SEMSs, three organizations of the International Council for Science (ICSU)—the Scientific Committee on Problems of the Environment (SCOPE), International Association for the Physical Sciences of the Oceans (IAPSO), and Scientific Committee on Oceanic Research (SCOR)—pooled their resources and expertise to bring together a carefully designed mixture of natural scientists and social scientists. This group met for four days at the Hanse-Wissenschaftskolleg (HWK) in Delmenhorst, Germany, to deliberate on the special characteristics of SEMSs and identify management approaches and research that should be applied to these special systems. This resulting book is intended to provide information for more-effective management of SEMSs and to serve as a useful reference for coastal managers, policy makers, and scientists. It also includes original analyses of special features of SEMSs (e.g., nutrient inputs, primary production, fisheries production, and socioeconomic indicators) and directions for future research on some topics relevant to understanding SEMSs.

Definition/Description of Semi-Enclosed Marine Systems for the Purposes of This Book

A semi-enclosed marine system (SEMS) is a marginal sea, bounded by land along more than half of its periphery and separated from the open ocean by one or more of the following boundaries (Figure 1-1):

- a strait (as bounds the Baltic Sea)
- a sill and/or island chain (as bounds the East China Sea)
- a front generated by physical processes separating the coastal/shelf water from the open ocean water (as bounds the Bay of Bengal)

The SEMSs that are the focus of this book (Figure 1-2) are those that are most impacted by changes taking place on the surrounding land masses. In fact, the runoff of water with its loads of sediment and chemicals is the most important driver of the systems discussed in this book. SEMSs with positive freshwater budgets (i.e., the total of runoff and precipitation exceeds loss by evaporation) are more susceptible to influx of land-derived materials and were therefore chosen for study in this book. The systems selected are meant to provide examples of a broader set of similar systems.

The degree of openness and the efficiency of water exchange between SEMSs and the

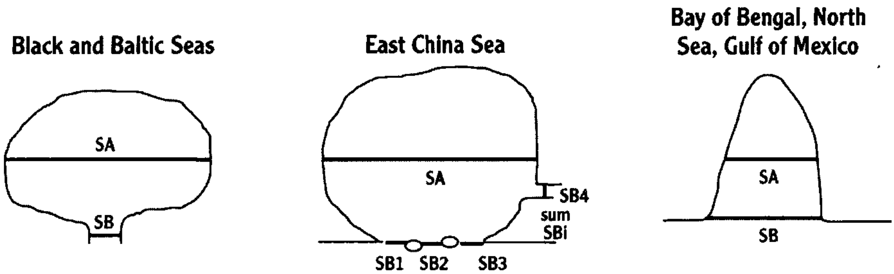

Figure 1-1. Examples of regional seas with different degrees of openness to the ocean. Provided by M. Meybeck.

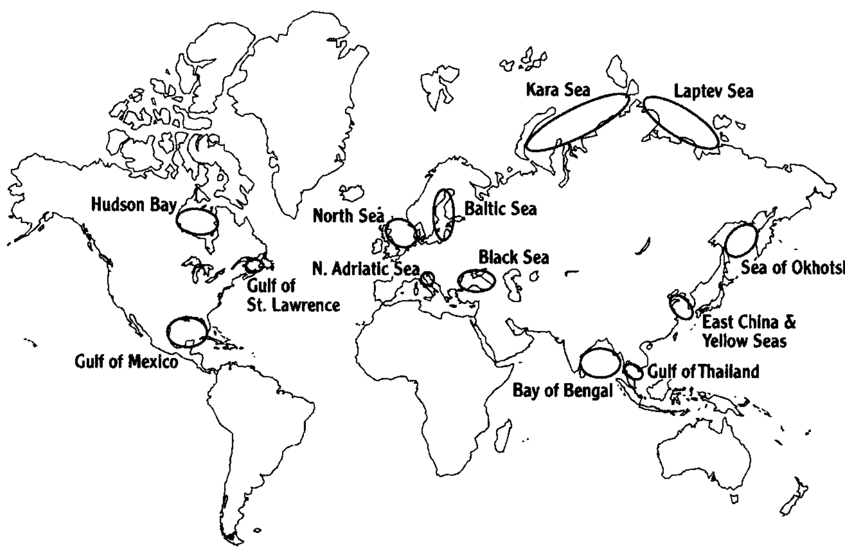

Figure 1-2. Map of the thirteen SEMSs considered in this volume (modified from Figure 10-2).

open ocean are important characteristics. The degree of openness ranges from very low (e.g., of the Black Sea) to very high (e.g., of the Bay of Bengal). As a first approximation, a measure of the degree of openness can be obtained by calculating the ratio of two cross-sectional areas: the cross-sectional area of the opening(s) to the ocean (SB in Figure 1-1) and the average cross-sectional area of the semi-enclosed body of water (SA in Figure 1-1). The thirteen systems that are the focus of this book include the Black Sea, Baltic Sea, Hudson Bay, Gulf of St. Lawrence, Northern Adriatic Sea, Gulf of Thailand, North Sea, Sea of Okhotsk, East China Sea (including the Yellow Sea), Gulf of Mexico, Laptev

Sea, Kara Sea, and the Bay of Bengal (Figure 1-2). These were selected to represent a span of latitudes and encompass different combinations of degree of openness and freshwater influence.

Because of the importance of the inputs from land, SEMSs include not only the coastal water bodies and the underlying seafloor, but also the catchment basins that drain the surrounding lands, and the adjacent ocean—hence the emphasis on system. The regional boundaries derived from this definition do not preclude potential impacts beyond the boundaries of the system.

Structure of the Book

The following chapters fall into two categories. Chapters 2–5 document the discussions that occurred at the workshop. These focused on

- vulnerability of SEMSs to environmental disturbances (Chapter 2)
- threshold effects in SEMSs (Chapter 3)
- governance and management of ecosystem services in SEMSs (Chapter 4)
- integrating tools to assess changes in SEMSs (Chapter 5)

Chapters 6–12 serve as background for the cross-cutting discussions in Chapters 2–5. All chapters and the complete book were peer reviewed.

Chapter 2 discusses the variety of forces that will cause changes to SEMSs in the future and illustrates the many processes involved. Climate change will affect SEMSs in terms of water temperatures, precipitation and ice cover, runoff, salinity, circulation, stratification, mixing, and chemistry. The chapter recommends that SEMSs be assessed as to how well they are understood and what additional research and observations are needed to enable management. Scientists, local and regional managers, and decision makers should work together in both making assessments and developing mitigation measures.

Chapter 3 discusses the concept of thresholds in ecosystems. Thresholds are environmental tipping points: When a threshold is passed, abrupt and dramatic changes, which are difficult or impossible to reverse, take place in the relationships between environmental forces and effects. Once a threshold has been surpassed, the system may not return to its initial state or it may return more slowly than expected from the speed of the initial change, even if the force or combination of forces that brought about the change is reduced to pre-threshold levels. Examples of thresholds include the oxygen level that defines hypoxia; the introduction of invasive species; the combination of light, nutrients, and mixed-layer depth that stimulates a phytoplankton bloom; the ratios of the nutrients that control the plankton species composition; the minimum population size of a fish species that ensures reproduction; and the conditions necessary for larval survival. Chapter 3 recommends that ecosystem research in SEMSs should aim to increase our understanding of thresholds and their consequences.

Chapter 4 is built around the role of the many ecosystem services that provide benefits