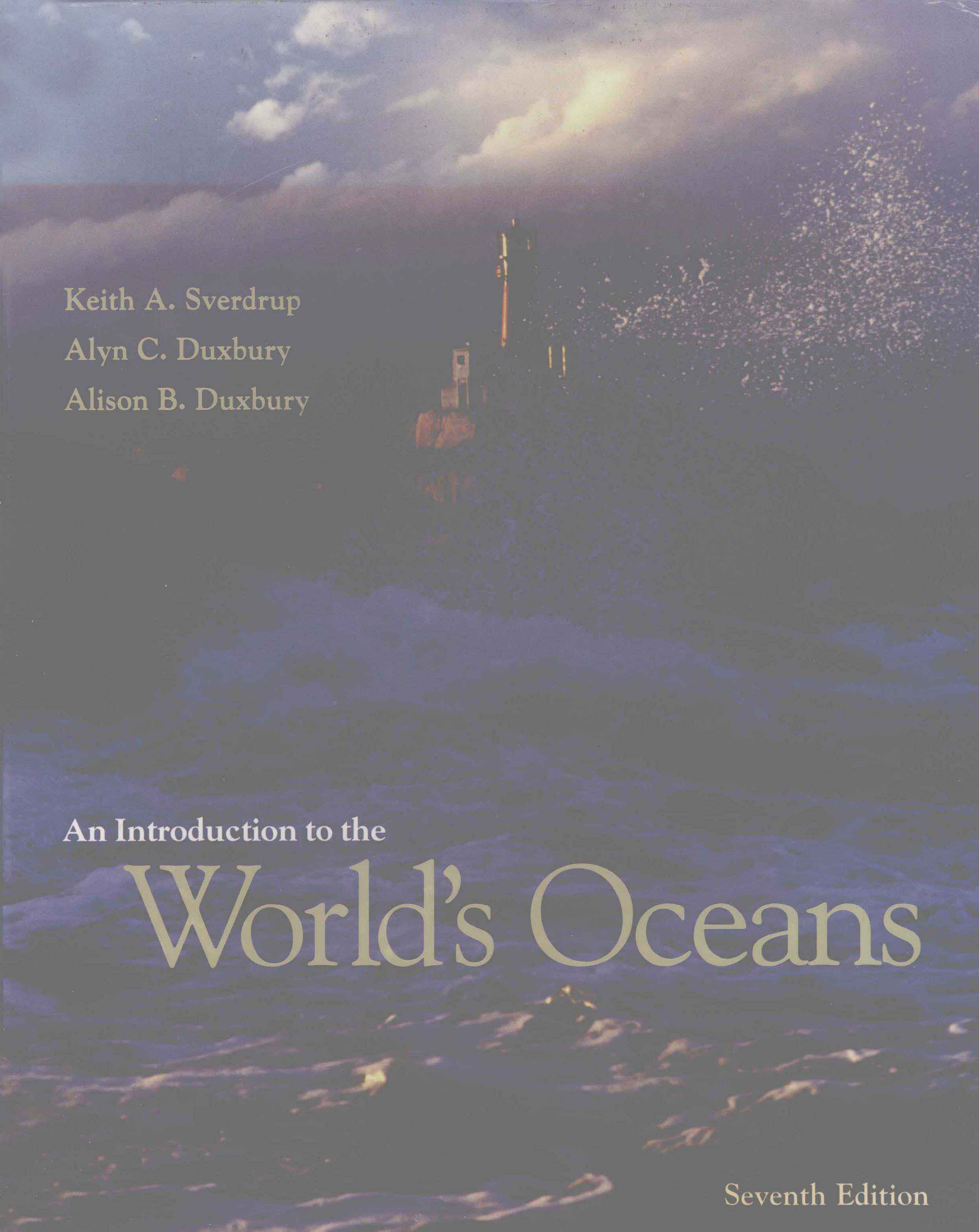

Keith A. Sverdrup
Alyn C. Duxbury
Alison B. Duxbury
An Introduction to the
World's Oceans
Seventh Edition

an introduction to the

World's Oceans

Seventh Edition

Keith A. Sverdrup

University of Wisconsin–Milwaukee

Alyn C. Duxbury

University of Washington

Alison B. Duxbury

Seattle Community College

McGraw Hill

Boston Burr Ridge, IL Dubuque, IA Madison, WI New York San Francisco St. Louis
Bangkok Bogotá Caracas Kuala Lumpur Lisbon London Madrid Mexico City
Milan Montreal New Delhi Santiago Seoul Singapore Sydney Taipei Toronto

McGraw-Hill Higher Education

A Division of The **McGraw-Hill** *Companies*

AN INTRODUCTION TO THE WORLD'S OCEANS, SEVENTH EDITION

Published by McGraw-Hill, a business unit of The McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY 10020.

This book is printed on recycled, acid-free paper containing 10% postconsumer waste.

International 1 2 3 4 5 6 7 8 9 0 VNH/VNH 0 9 8 7 6 5 4 3 2
Domestic 2 3 4 5 6 7 8 9 0 VNH/VNH 0 9 8 7 6 5 4 3

ISBN 0-07-247280-4
ISBN 0-07-119489-4 (ISE)

Publisher: *Margaret J. Kemp*
Sponsoring editor: *Thomas C. Lyon*
Senior developmental editor: *Donna Nemmers*
Executive marketing manager: *Lisa Gottschalk*
Project manager: *Sheila M. Frank*
Senior production supervisor: *Sandy Ludovissy*
Senior media project manager: *Tammy Juran*
Media technology producer: *Judi David*
Coordinator of freelance design: *Michelle D. Whitaker*
Cover designer: *Maureen McCutcheon*
Cover image: *Yngve Rakke/Getty Images*
Lead photo research coordinator: *Carrie K. Burger*
Photo research: *Karen Pugliano*
Supplement producer: *Brenda A. Ernzen*
Compositor: *Shepherd, Inc.*
Typeface: *10.5/12 Goudy*
Printer: *Von Hoffmann Press, Inc.*

The credits section for this book begins on page 497 and is considered an extension of the copyright page.

Library of Congress Cataloging-in-Publication Data

Sverdrup, Keith A.
An introduction to the world's oceans.—7th ed. / Keith A. Sverdrup, Alyn C. Duxbury, Alison B. Duxbury.
p. cm.
Rev. ed. of: An introduction to the world's oceans. 6th ed. / Alyn C. Duxbury, Alison B. Duxbury, Keith A. Sverdrup. ©2000.
Includes bibliographical references and index.
ISBN 0–07–247280–4 (acid-free paper)
1. Oceanography. I. Duxbury, Alyn C., 1932–. II. Duxbury, Alison. III. Duxbury, Alyn C., 1932–. Introduction to the world's oceans. IV. Title.

GC11.2 .D89 2003
551.46—dc21

2002067854
CIP

INTERNATIONAL EDITION ISBN 0–07–119489–4

www.mhhe.com

Dedicated to
George and Jean Sverdrup
and
Andrew, Jeannie,
and Alec Duxbury

preface

A Note to Students

Human beings have been curious about the oceans since they first walked along their shores. As people have learned more about the oceans, they have come to more fully understand and appreciate the tremendous influence these bodies of salt water have on our lives. The oceans cover over 70% of Earth's surface, creating a habitat for thousands of known species and countless others still to be discovered. The sea contains vast quantities of diverse natural resources in the water and on the sea floor; some are actively exploited today, and many more may be recovered in the future with improved technology and greater demand. Global climate and weather are strongly influenced by the oceans as they interact with the atmosphere through the transfer of moisture and heat energy. The ocean basins also serve as the location of great geological processes and features such as earthquakes, volcanoes, massive mountain ranges, and deep trenches, all of which are related to the creation and destruction of sea floor in the process of plate tectonics.

Much of what happens in the oceans and on the sea floor is hidden from direct observation. Although the *Hubble Space Telescope* can form images made from light that has traveled over 10 billion trillion kilometers, we can not see more than a few tens of meters below the ocean's surface even under the most favorable conditions because of the efficient scattering and absorption of light by seawater. Consequently, most of what we know about the oceans comes from indirect, or remote, methods of observation. With constantly improving technology and innovative applications of that technology, we continue to learn more about the geological, physical, chemical, and biological characteristics of the oceans.

Although careful scientific study of the oceans is often difficult and challenging, it is both necessary and rewarding. Our lives are so intimately tied to the oceans that we benefit from each new fact that we discover. Continued research and a better understanding of the oceans become increasingly important as the population of this planet grows ever larger. Early in the new millennium, there is both good news and bad news concerning global population growth. The rate of population increase has slowed with falling birth rates, and there is some indication that the human population will level off by the end of this century. But even if the human population does stabilize, it will not do so before there is an increase of several billion people over today's population. We clearly will continue to face difficult environmental decisions affecting the oceans as well as the land in the foreseeable future. Our best chance of dealing wisely and effectively with these challenges is to promote more widespread understanding of the oceans.

Although it is critical that we continue to train marine scientists to study the oceans, it is no less important for people in all walks of life to develop a basic understanding of how the oceans influence our lives and how our actions influence the oceans. In studying oceanography, you are preparing yourself to be an informed global citizen. It is likely that at some point in the future you will have the opportunity to voice your concern about the health of the oceans, either directly or through the governmental process. Your interest in and study of oceanography will help you participate in future discussions and decision-making processes in an informed manner.

The Online Learning Center at www.mhhe.com/sverdrup provides you with links to Internet addresses applicable to this text. To expand your knowledge of oceanography, there are Internet exercises for many of these sites. The exercises are found within the Online Learning Center.

A Note to Instructors

A major objective of this text is to stimulate student interest and curiosity by blending contemporary information and research with basic principles in order to present an integrated introduction to the many and varied sciences used in the study of the oceans. To do so, we have extensively reviewed and rewritten material from the sixth edition to produce this new seventh edition. In the face of constant and rapid change, we have added new material for both content and interest.

We realize that the students who will use this book come from diverse backgrounds and that for many of them this will be an elective course. The content continues to be reasonably rigorous, but we have chosen to use simple algebra rather than advanced mathematics. For instance, we use centrifugal force to explain tidal principles because most students do not have much background in vectors. More emphasis is placed on the physical and geological aspects of oceanography than on the chemical and geochemical because the latter two disciplines require more background knowledge.

An ecological approach and descriptive material are used to integrate the biological chapters with the other subject fields. We strive to emphasize oceanography as a cohesive and united whole rather than a collection of subjects gathered under a marine umbrella.

In order to understand the constant barrage of information concerning our planet and marine issues, students must have a basic command of the language of marine science in addition to mastering processes and principles. For this reason we maintain an emphasis on critical vocabulary. All terms are defined in the text; terms that are particularly important are printed in boldface. A list of important terms is at the end of each chapter, and a glossary is included at the end of the book. The Online Learning Center for this text also hosts flashcards of key terms for student study.

Summaries at the ends of chapters provide quick reviews of key concepts. Study Problems are included in many chapters, and Study Questions are at the end of each chapter. The Study Questions are not intended merely for review, but also to challenge students to think further about the lessons of the chapter.

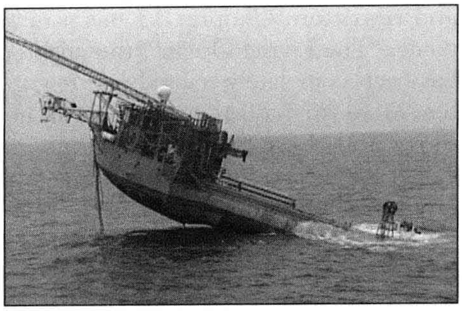
This book may be used in a one-quarter or one-semester course. Because the experience and emphasis of faculty using this book will differ, it is expected that each instructor will emphasize and elaborate on some topic at the expense of other topics. We continue to make each chapter stand as independently as possible and encourage instructors to use the chapters in the order that best suits their purposes. Cross-references from one chapter to another indicate discussion of topics elsewhere in the text. Faculty wishing to expand quantitative material are encouraged to make use of Appendix C, Equations and Quantitative Relationships. The answers to the Study Questions and Study Problems from the text appear in the Instructor's Manual, in the password-protected instructor's area of the Online Learning Center.

Changes to the Seventh Edition

In addition to revisions and updates based on current research, this edition contains several new boxed readings. The Prologue contains a significant amount of new material on the history of oceanography, as well as an updated section on oceanography of the recent past, present, and future. In Chapter 1 we have added material on the origin of the oceans. The discussions of the Earth's internal structure and the characteristics of plates and their boundaries have been extensively rewritten and many new figures have been added. Chapter 3's section describing the characteristics of marine sediments has been completely revised and a new section on gas hydrates has been added. Chapter 4 contains a new section on temperature and heat before the discussion of changes in the state of water. Chapter 5 now begins with a new section explaining the pH scale and the pH of seawater in order to form a foundation for the discussion of seawater chemistry. Both chapters 6 and 7 have been renamed and reorganized. Chapter 6 is now named "The Structure and Motion of the Atmosphere." It focuses exclusively on atmospheric processes critical to understanding the links between the atmosphere and the oceans. Chapter 7 is now entitled "Circulation and Ocean Structure." This chapter includes a revised discussion of ocean density structure and covers topics in vertical circulation, upwelling and downwelling, the layering of the oceans, and updated material on sampling methods and measurement techniques. Chapter 7 also contains two new special interest boxes covering topics including Arctic Ocean studies (with a discussion of the North Pole Environmental Observatory) and Ocean Gliders (independent, unmanned vehicles). The material in Chapter 8 has been reordered and sections on convergence and divergence have been rewritten to enhance clarity. Chapter 9's discussion of Energy from Waves and the boxed reading on Tsunami Warning Systems have both been updated. The tide and current tables have been updated in Chapter 10. The discussions of beach dynamics and beach types in Chapter 11 have been reordered for clarity and the material previously in chapter 12 on modifying beaches has been moved to chapter 11. In Chapter 12 the discussion of the Gulf of Mexico dead zone has been updated and rewritten. Chapter 13 has a new name, "The Living Ocean"; the chapter has been completely revised and rewritten. More emphasis is given to ocean biology and there are new sections on ocean biology, groups of organisms and environmental zones. Symbiotic relationships are now included. Chapter 14 has new information on the roles of nitrogen and iron, and a new boxed reading on CalCOFI—Fifty Years of Coastal Ocean Data. Chapter 15 contains updated material on the krill harvest, more information on the microbial loop, and the section on harmful algal blooms has been revised and updated. There is revised and expanded information on skates and rays, marine mammal populations, and bathypelagic organisms in Chapter 16. In addition, all fisheries data has been updated. Chapter 17 has new and revised information on corals including bleaching, predation, disease, and the effect of human activities. New information on Lost City vents is included in Chapter 17 and all harvesting data has been updated. In addition, Chapter 17 hosts a new boxed reading on ice worms living on deep-sea ice hydrates.

Instructor Supplements

McGraw-Hill offers a variety of supplements to assist the instructor with both preparation and classroom presentation. Materials that are specific to this text and that are available to the instructor include a text-specific **Online Learning Center (OLC),** which contains many useful tools for the instructor. The OLC for this text can be found at www.mhhe.com/sverdrup. Within the password-protected Online Learning Center instructors will find the **Instructor's Manual,** which includes answers to the Study Questions and Study Problems from the text, as well as suggested test questions and answers for each chapter of the text. Also available through the Online Learning Center and on CD-ROM, instructors will have access to the **Digital Content Manager (DCM).** This multimedia collection of visual resources allows instructors to utilize artwork from the text in multiple



formats to create customized classroom presentations, visually-based tests and quizzes, dynamic course website content, or attractive printed support materials. The digital assets on this cross-platform CD-ROM are grouped by chapter within easy-to-use folders. On the CD-ROM version of the Digital Content Manager, instructors will have access to 34 **video segments from Scripps Institution of Oceanography,** grouped by chapter to go with the seventh edition of this text. The Scripps video segments are also available on videotape.

PowerWeb: Oceanography can be accessed through the Online Learning Center, and contains articles from current magazines, newspapers, and journals; weekly updates of current issues; web research tips; an online library of updated research links to help you find the right information; up-to-the-minute headlines from around the world including course-specific and general news; and online quizzing and assessments for your students.

A **Brownstone testing system** is available on a cross-platform CD-ROM to generate tests; and a set of **overhead transparencies** contains over 200 figures from the text.

For those schools offering a laboratory with their oceanography course, McGraw-Hill offers an exceptional lab manual entitled "Investigating the Ocean" by R. Leckie and R. Yuretich of University of Massachusetts-Amherst. Additional earth science supplements offered by McGraw-Hill which are appropriate for this course include the *Journey Through Geology* CD-ROM by the Smithsonian Institution; the JLM Visuals Physical Geology Photo CD; and a geoscience videotape library. Contact your McGraw-Hill sales representative for details on these products.

Student Supplements

The Internet makes oceanographic information and data available to researchers and it also provides images and information in many forms to instructors and students. Public agencies and museums, universities and research laboratories, satellites and oceanographic projects, interest groups and individuals all over the planet provide information that can be publicly accessed. The text-specific **Online Learning Center (OLC)** website, which can be found at www.mhhe.com/sverdrup, provides chapter-sorted links to many websites that contain information pertinent to each chapter's content. In addition, web links are provided within the OLC for further information on many boxed readings and figures within each chapter. Wherever you see this icon web link in your textbook, you will find associated web links for the indicated figure or boxed reading on the OLC. The OLC also hosts a complete Student Study Guide, chapter quizzing, key term flashcards, and Internet exercises to help with chapter study. In addition, **PowerWeb** is a great way to get information you need quickly and easily! Through the OLC, students can access PowerWeb: Oceanography, which contains articles from current magazines, newspapers, and journals; weekly updates of current issues; web research tips; an online library of updated research links to help you find the right information; up-to-the-minute headlines from around the world including course-specific and general news; online quizzing and assessments to measure your understanding of course material, and more!

Acknowledgments

As a book is the product of many experiences, it is also the product of people other than the authors. We extend many thanks to our friends and colleagues who have graciously answered our questions and provided us with information and access to their photo files. We owe very special thanks to faculty and staff of the School of Oceanography, College of Ocean and Fishery Sciences, University of Washington, and to the scientists and staff of the National Oceanic and Atmospheric Administration's Northwest Regional Office, who have answered questions, supplied data and provided many of the illustrations in this edition. We are also grateful to Scripps Institution of Oceanography, who have allowed us the privilege of providing their videotape series as an instructor ancillary to this seventh edition of the text.

We would also like to acknowledge the valuable contributions of the following people:

Marcia McNutt
Monterey Bay Aquarium Research Institute

Charlie Eriksen
School of Oceanography, University of Washington

Suzan Huney
Polar Science Center, University of Washington

Charles Fisher and Erin McMullin
Mueller Laboratory, Pennsylvania State University

Steve Nathan and R. Mark Leckie
University of Massachusetts, Amherst

Reviewers for the Seventh Edition

Claude D. Baker
Indiana University Southeast

Douglas Biggs
Texas A&M University

Wayne V. Bloechl
Cabrillo College

Gregg Brooks
Eckerd College

Hans G. Dam
University of Connecticut

Cynthia Domack
Hamilton College

Nancy Glass
Baldwin Wallace College

Lawrence Krissek
Ohio State University

James McWhorter
Miami-Dade Community College

Keith H. Meldahl
MiraCosta College

A. Conrad Neumann
University of North Carolina at Chapel Hill

Dan E. Olson
Edgewood College

Mike Phillips
Illinois Valley Community College

Reed Scherer
Northern Illinois University

Guatam Sen
Florida International University

Kent M. Syverson
University of Wisconsin at Eau Claire

Margaret Vose
University of Southern Maine

We thank all members of the team at McGraw-Hill, without whose help, enthusiasm, and coordinated efforts this seventh edition could not have been completed.

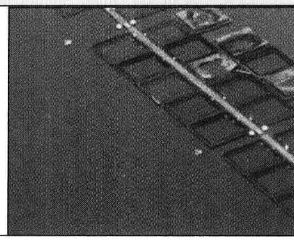
A variety of tools within this textbook have been designed to assist with chapter review and critical analysis of chapter topics.

KEY TERMS

Key Terms are all boldfaced and defined within the text, and end-of-chapter key terms listings indicate the most important terms and their locations within each chapter.

farming, including methods for building the pond, selecting the stock, and harvesting it. In China, Southeast Asia, and Japan, fish farming in fresh and salt water has continued to the present as a practical and productive method of raising large quantities of fish such as carp, milkfish, *Tilapia,* and catfish. Most of these farms are family-run, labor-intensive operations. Fish farmers may practice **monoculture,** raising fish as a single species, or **polyculture,** raising more than one species as surface feeders and bottom feeders to make use of the total volume of the pond.

In the United States fish farming produces only 2% of fishery products, but that amount includes 50% of the catfish and nearly all the trout. To be successful and profitable in the United States, fish farming requires a proven market and large-scale operation combined with the development of technology to reduce costs. The species chosen for farming must reproduce easily in captivity, have juvenile forms that survive well under controlled conditions,



After the area has been restructured it must be monitored, and changes must be made as needed to maintain the desired environment. If these preproject and postproject studies are not made and followed by necessary corrections, the mitigation effort will not succeed. Mitigation may preserve some habitats and species, but it only approximates a lost environment; it cannot duplicate it.

Pressures to develop deep-sea areas for energy and mining projects are likely to increase in the future. Tropical OTEC plants (ocean thermal energy conversion; see chapter 7) will bring cold, nutrient-rich water to the sea surface, changing the surface productivity and potentially interfering with the survival of tropical species. Manganese nodule mining (see chapter 3) will increase deep-sea turbidity, changing the environment for bottom organisms in mined areas. How mitigation might be undertaken in the open ocean has not yet been considered, but the threat of deep-sea exploitation is already causing some scientists to call for the setting aside of marine reserves in the open ocean.

Summary

Marine ecology is the study of interactions between marine organisms and their environment. The organisms of the sea are classified for identification and relationship. Marine organisms are commonly divided into plankton, nekton, and benthos. All organisms are classified for identification and relationship into kingdoms and a new system that includes domains.

The marine environment is subdivided into zones. The major environments are the benthic and pelagic zones; there are numerous subdivisions of each of these zones.

Organisms living in the sea are buoyed and supported by the seawater. Adaptations for staying afloat include low-density body fluids, gas bubbles, gas-filled floats, swim bladders, oil and fat storage, and extended surface areas and appendages.

Most marine fish lose water by osmosis. They drink continually and excrete salt to prevent dehydration. Sharks have the same concentration of salt in their tissues as there is in seawater. They therefore do not have a water-loss problem. Salinity is a barrier to some organisms; others can adapt to large salinity changes.

Temperature affects density, viscosity, and the water's buoyancy, as well as the stability of the water column. The body temperature and metabolism of all marine organisms, except for birds and mammals, are controlled by the sea temperature. Some fish conserve heat in their body muscles and elevate the temperature in these muscles. Temperatures at depth are uniform; sea surface temperatures change with latitude and seasons.

Changes in pressure affect organisms that have gas-filled cavities. Marine mammals have a unique ability to undergo large pressure changes due to their physiology and body chemistry. The swim bladders of fish are affected by pressure changes, and the fish must change depth slowly.

The carbon dioxide—oxygen balance in the oceans influences the distribution of all organisms. The availability of nutrients and light limits plant populations. The depth of light penetration in the oceans is controlled by the angle of the Sun's rays, the properties of the water, and the material in the water. Light limits plant life, but nutrients are also required. Some organisms produce chemical light, known as bioluminescence. Animals use color for concealment and camouflage and also to warn predators of poisonous flesh and bitter taste.

Winds, tides, and currents mix the water. Moving water carries food and oxygen, removes waste, and disperses organisms. Floating populations are not necessarily scattered but keep their place due to movements between surface currents and deeper currents. Upwellings supply nutrients and hold plants in the surface layers. Downwellings are regions of low plant growth.

Different substrates provide food, shelter, and attachment for different groups of organisms. Some live attached to the surface, some move across it, some burrow into the sea floor, and some modify the sea floor, providing habitats for others. Some animals are carnivores; others are herbivores. Large numbers of ocean organisms live in close associations such as commensalism, mutualism, and parasitism. Barriers for marine organisms include water properties, light intensity, zones of convergence and divergence, seafloor topography, and geography.

Development of marine areas, with the consequent loss of habitat and therefore populations, has led to the concept of mitigation. Mitigation requires developers to preserve or replace habitats in an effort to maintain and preserve species.

Key Terms

All key terms from this chapter can be viewed by term, or by definition, when studied as flashcards on this book's Online Learning Center at www.mhhe.com/sverdrup (click on this book's cover).

ecology, 358
plankton, 358
nekton, 358
benthos, 358
taxonomy, 358
pelagic zone, 360
benthic zone, 360
neritic zone, 360
oceanic zone, 360
supralittoral zone/splash zone, 360
littoral zone/intertidal zone, 360
sublittoral zone/subtidal zone, 360
bathyal zone, 360
abyssal zone, 360
hadal zone, 360
buoyancy, 360
ectotherm, 362
endotherm, 363
photic zone, 364
aphotic zone, 364
spicules, 365
bioluminescence, 365
luciferin, 365
luciferase, 365
photophore, 365
substrate, 367
epifauna, 367
infauna, 367
deposit feeder, 367
symbiosis, 367
commensalism, 367
mutualism, 367
parasitism, 367
mitigation, 368
biodiversity, 369

370 THE LIVING OCEAN www.mhhe.com/sverdrup

CHAPTER SUMMARY

The Summary in each chapter provides a quick review of key concepts.

Study Questions

1. The processes that form a stretch of flat, uniform coast depend on whether the land is rising or sinking. Discuss the processes that form a flat coastal area under these two conditions.
2. Why are multiple berms more likely to be seen on a beach between March and August than between September and February?
3. Fjord coasts and drowned river valleys, or ria coasts, are primary coasts. Explain why their appearances are distinctly different. Give examples of each.
4. Describe the processes required to create a tombolo. Consider and discuss (a) the distribution of wave energy and (b) the longshore transport.
5. What conditions are required to maintain a beach with a constant profile and composition? Consider both a static and a dynamic environment.
6. Why does an eroding beach that is supplied with material from the cliffs of an old glacier deposit become an armored beach, while an eroding beach that is supplied by river sediments does not?
7. How does the profile of a sand beach change during alternating seasonal periods of storm waves and more gentle small waves?
8. Sketch a beach section that is stable with respect to the supply and removal of beach sediments. Indicate the source of the sediments and the final deposition of sediments in the system. If the longshore transport or wave energy distribution is altered by a barrier perpendicular to the beach, what changes will occur?
9. What is causing the apparent rise of sea level around the world? Is the rise similar in all places?
10. What processes move beach sediments in a coastal circulation cell?
11. Compare the circulation of a semienclosed basin at 30°N with that of an estuary located at 60°N. Which is less likely to accumulate waste products at depth? Why?
12. Estuaries are classified by their net circulation and salt distribution in this chapter. What other features could be used to describe and classify them?
13. Why are estuaries with short flushing times less apt to degrade when used as the receiving water for urban runoff than estuaries with long flushing times?
14. Compare the circulations and histories of San Francisco Bay and Chesapeake Bay. How do these estuaries differ; how are they similar? What do you see in the future for each?
15. In order to prevent erosion of his beach, your neighbor wants to build a groin. What effect might the groin have on your neighbor's beach? On your beach if you live on the upstream side of the longshore current? On your beach if you live on the downstream side of the longshore current?

Study Problems

1. Determine the flushing time of an estuary in which $T_o = 9 \times 10^7\ m^3/day$ and the volume of water is $30 \times 10^8\ m^3$.
2. An estuary has a volume of $50 \times 10^9\ m^3$. This water is 5% fresh water, and the fresh water is added at the rate of $6 \times 10^7\ m^3/day$. Why does the rate of addition of fresh water from the estuary to the ocean equal the input of fresh water from the land to the estuary? Consider the average salinity of the estuary as constant. What is the residence time of the fresh water?
3. Water entering an estuary at depth has a salinity of 34.5‰. The water leaving the estuary has a salinity of 29‰. The river inflow is $20 \times 10^5\ m^3/day$. Calculate T_o, the seaward transport.
4. A bay with no freshwater input can flush only by tidal exchange. If on each tidal cycle (ebb and flood) 10% of the bay's water volume is exchanged with ocean water, how much of the original water will still be in the bay after four tidal cycles? Solve for (1) no mixing between bay water and ocean water; (2) complete mixing between bay water and ocean water.
5. What is the flushing time of the bay in problem 4 for each case? Which case best duplicates natural conditions?

STUDY QUESTIONS AND PROBLEMS

Study Problems and Study Questions serve not only as a concept review, but challenge students to think further about the lessons within each chapter.

Links to Related Websites

Visit the book's Online Learning Center at www.mhhe.com/sverdrup (click on the book's cover) to find live Internet links for additional topics related to this chapter's content.

- Coastal and marine geology
- Coastal management

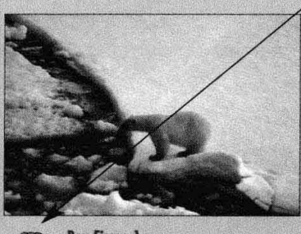
Visit the book's Online Learning Center at www.mhhe.com/sverdrup (click on this book's cover) to find these additional chapter tools: Suggested Readings; links to further information on boxed readings, selected figures, and related chapter topics; and additional study aids.

LINKS TO RELATED WEBSITES

Find Internet links to each chapter's content, boxed readings, and figures within the Online Learning Center for this text at www.mhhe.com/sverdrup. Watch for the special web link icon to indicate Internet-linked material.

The Sea Bear

The sea and sea ice are essential components of the polar bear's environment. The polar bear is the top predator of the Arctic's marine food chains, and its scientific name is appropriate, *Ursus maritimus*, or "sea bear" (box fig. 1). Polar bears are long-lived (fifteen to twenty years or more), late-maturing (four to five years) carnivores with dense fur and a blubber layer for insulation. Adult males weigh 250–800 kg (550–1700 lb) and measure 2.5–3.0 m (8–10 ft) from tip of nose to tail; females weigh 100–300 kg (200–700 lb) and measure 1.8–2.5 m (6–8 ft) see (box fig. 2). In late October and November females make their dens in drifted snow. One or two cubs are born in December or January, and mother and cubs emerge in late March and early April. Most female bears keep their cubs with them until the cubs are about two and a half years old. The bears feed primarily on ringed seals and to a lesser extent on other seal species and whale and walrus carcasses. They use their keen sense of smell to locate seals and hunt by stalking the animals basking on the ice, lying in wait at breathing holes, and breaking into their birth-dens. Polar bears travel long distances over the ice, 30 km (19 mi) or more each day; they are also strong swimmers, swimming continuously for 100 km (62 mi).



web link **Box Figure 1** A polar bear on the ice in the central Arctic Ocean.

Polar bear distribution is circumpolar but not continuous. Populations that return to feeding and denning areas are kept apart by the sea ice, ice movements, and land barriers. The bears move extensively between seasons, depending on regional patterns of freezing and breakup of the sea ice. Polar bears depend on sea ice as a platform from which to hunt and feed and as a base on which to seek mates, breed, and travel long distances. About 68% of the polar ice region appears to be suitable habitat for polar bears.

The world's total population of polar bears is estimated at between 25,000 and 40,000. The Canadian population is about 15,000, or roughly half of the world's polar bears. Polar bears are also found in Denmark (Greenland), Norway (Svalbard Islands), and Russia. There are two Alaska polar bear populations, estimated at 3000 animals; one population is in the vicinity of the Chukchi and Bering Seas and the other is in the Beaufort Sea area.

In the 1950s and 1960s there was growing international concern for the polar bear populations as the number of bears being killed for their hides increased. Russia prohibited all hunting of polar bears in 1956, but poaching increased dramatically. The U.S. Marine Mammal Protection Act of 1972 prohibited the killing of all marine mammals including polar bears, except by native people for subsistence purposes. Norway prohibited all polar bear hunting in 1973, and Canada increased regulations on native peoples' hunting and allowed a limited sport hunt of 500 bears per year. Greenland harvests 100–150 bears annually in a tightly regulated hunt for residents only.

In October 2000 the United States and Russia signed a treaty covering the polar bears in northwest Alaska and the Chukota region of northeast Siberia; the treaty includes the islands of the Chukchi and Bering Seas. New U.S. and Russian commissions were formed in which native tribes participate in setting harvest quotas. For the first time quotas were placed on the number of bears hunted in both countries. Den areas were ruled off-limits; commercial hunting and killing females and cubs under one year are prohibited. No poison, traps, snares, aircraft, or large motorized vehicles and vessels are permitted in the hunt.

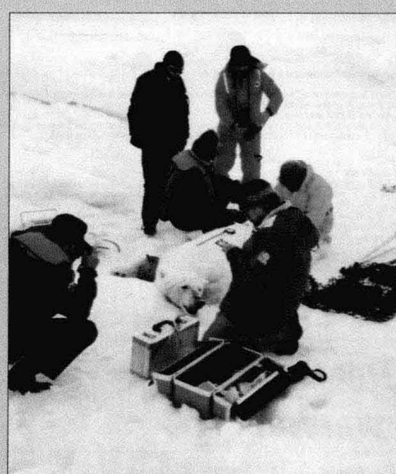
The polar bears still face an uncertain future. If climate change increases ice-free periods, the bears cannot return to the ice to hunt and mate. Other potential problems include toxic contaminants, poaching, disruption of the food chain by overfishing, human activities related to oil and gas exploration and development, and increased tourism and human contacts.

To Learn More About the Sea Bear

Eliot, J. 1998. Polar Bears, Stalkers of the High Arctic. *National Geographic* 193(1): 52–71.

Internet References

Visit the book's Online Learning Center at www.mhhe.com/sverdrup (click on the book's cover) to explore links to further information on related topics.



Box Figure 2 This polar bear is being weighed, measured, and fitted with a tracking collar that will be followed by satellite. A measuring tape is lying on top of the bear. The scientists are members of the 1994 Arctic Section Expedition.

surface for edible refuse, including scraps from ships and fishing boats. Its primary foods are squid, crab, and surface fish. The smallest of the oceanic birds, Wilson's petrel, is a swallowlike bird that breeds in Antarctica and flies 16,000 km (10,000 mi) along the Gulf Stream to Labrador during the Southern Hemisphere winter, returning to the Southern Hemisphere for the southern summer, another 16,000 km.

Penguins (fig. 16.9*a*) do not fly but swim in flocks, using their wings for propulsion and steering with their feet. Their underwater swimming speed is almost 10 mph. They feed on fish, krill, squid, and shellfish. All but the Galápagos penguin are found in the Southern Hemisphere, and two species, the emperor and the Adelie, are found in Antarctica.

Pelicans and cormorants are large fishing birds with big beaks. They are strong fliers found mostly in coastal areas, but some venture far out to sea. A pelican (fig. 16.9*b*) has a particularly large beak from which hangs a pouch used in catching fish. White pelicans of North America fish in groups, herding small schools of fish into shallow water and then scooping them up in their large pouches. The Pacific's

428 THE NEKTON: FREE SWIMMERS OF THE SEA

www.mhhe.com/sverdrup

brown pelican does a spectacular dive from up to 10 m (30 ft) above the water to capture its prey. Cormorants are black, long-bodied birds with snakelike necks and moderately long bills that are hooked at the tip. They settle on the water and dive from the surface, swimming primarily with their feet but also using their wings. Because they do not have the water-repellent feathers of other seabirds, cormorants must return to land periodically to dry out.

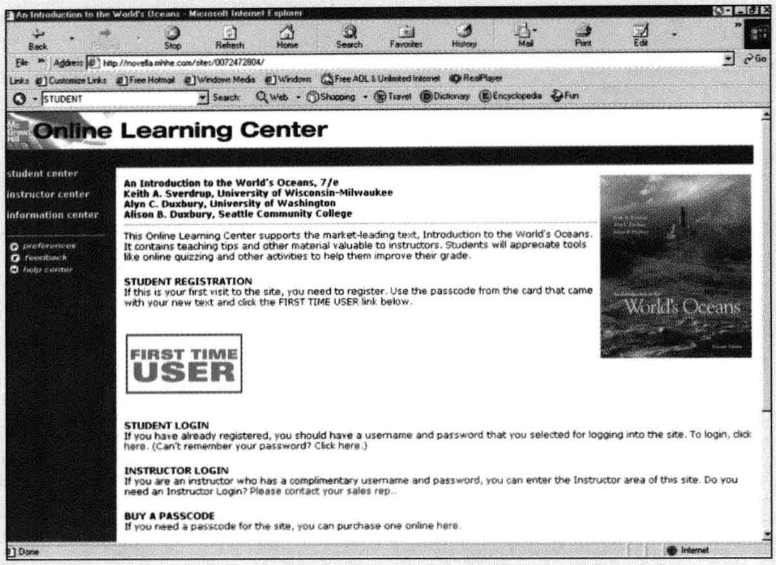
Terns (fig. 16.9c) and gulls are found all over the world except in the South Pacific between South America and Australia. Gulls are strong flyers and will eat anything; they forage over beach and open water. The terns are small, graceful birds with slender bills and forked tails. The Arctic tern breeds in the Arctic and each winter migrates south of the Antarctic Circle, a round-trip of 35,000 km (20,000 mi).

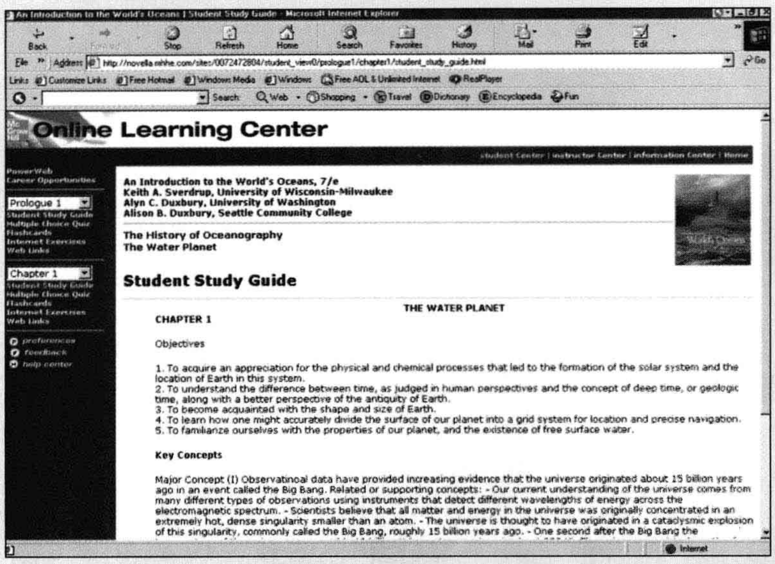
Puffins, murres, and auks are heavy-bodied, short-winged, short-legged diving birds. They feed on fish, crustaceans, squid, and some krill. All are limited to the North Atlantic, North Pacific, and Arctic areas, where most nest on isolated cliffs and islands. The great auk was a large, slow,

Marine Birds **429**

www.mhhe.com/sverdrup

This text-specific website hosts many useful tools for the instructor, as well as features to help students sharpen their study skills and make the grade in their oceanography course. A complete **Instructor's Manual,** as well as the **Digital Content Manager,** can be accessed within a special password-protected instructors' section of the Online Learning Center (OLC). The Digital Content Manager provides photos and artwork from the text in multiple formats to assist in creating customized classroom presentations, dynamic course website content, or attractive printed support materials. Students will find electronic flashcards of the key terms within each chapter, as well as chapter-grouped web links to provide additional information on chapter topics, individual figures, boxed readings, and interactive quizzes for each chapter.



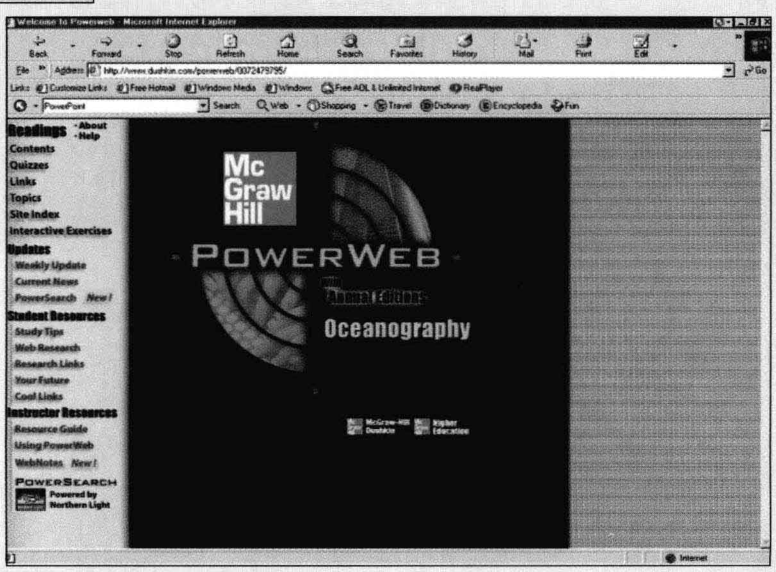


Students: Partner Up with Our Online Study Guide

The Online Learning Center hosts a complete **Study Guide** for each chapter, which includes Chapter Objectives, Key Concepts in lecture outline format, and a variety of self-test features to help you understand and retain the content within each chapter of your textbook.

Charge Up Your Oceanography Research with PowerWeb

Through our Oceanography Online Learning Center you may access **PowerWeb**—your personal research assistant. PowerWeb provides articles from current magazines, newspapers, and journals; weekly updates of current issues; web research tips; an online library of updated research links to help you locate the right information; up-to-the-minute headlines from around the world; plus online quizzing and assessments to measure your understanding of course material.



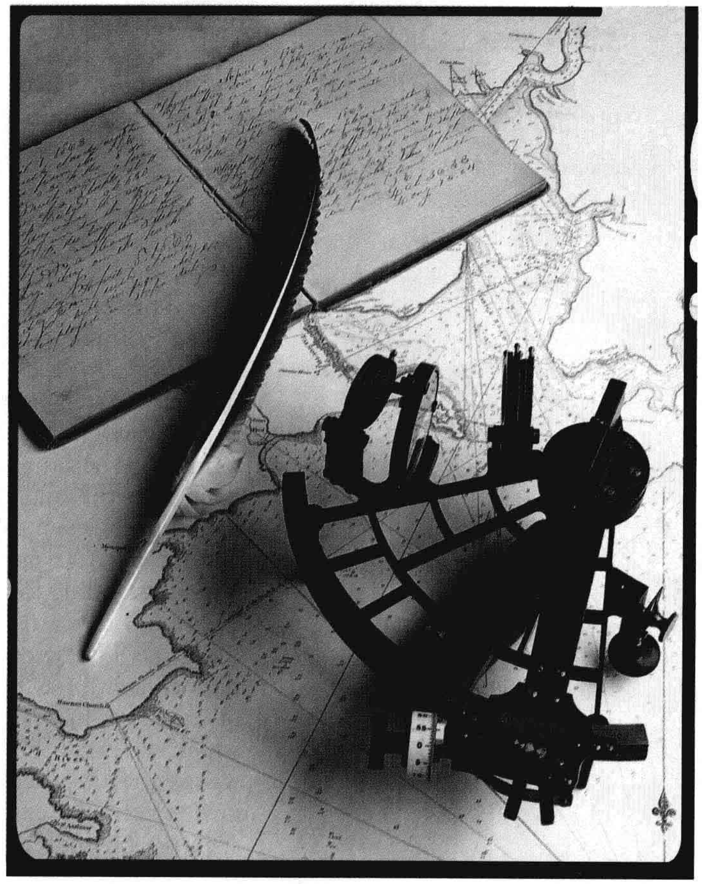
brief contents

contents

The History of Oceanography

Where are your monuments, your battles, martyrs? Where is your tribal memory? Sirs, in that grey vault. The sea. The sea has locked them up. The sea is History.

Derek Walcott
From *The Sea is History*



Navigational aides before electronics: sextant, pen, log book, and map of Falmouth, England.

The History of Oceanography

Oceanography is a broad field in which many sciences are focused on the common goal of understanding the oceans. Geology, geography, geophysics, physics, chemistry, geochemistry, mathematics, meteorology, botany, and zoology have all played roles in expanding our knowledge of the oceans. The field is so broad that oceanography today is usually broken down into a number of subdisciplines.

Geological oceanography includes the study of the Earth at the sea's edge and below its surface and the history of the processes that formed the ocean basins. Physical oceanography investigates how and why the oceans move; marine meteorology (the study of heat transfer, water cycles, and air-sea interactions) is often included in this discipline. Chemical oceanography studies the composition and history of the water, its processes, and its interactions. Biological oceanography concerns marine organisms and the relationship between these organisms and the environment of the oceans. Ocean engineering is the discipline that designs and plans equipment and installations for use at sea.

The study of the oceans was promoted by intellectual and social forces as well as by our needs for marine resources, trade and commerce, and national security. Oceanography started slowly and informally; it began to develop as a modern science in the mid-1800s and has grown dramatically, even explosively, in the last few decades. Our progress toward the goal of understanding the oceans has been uneven, and it has frequently changed direction. The interests and needs of nations as well as the scholarly curiosity of scientists have controlled the rate at which we study the oceans, the methods we use to study them, and the priority we give to certain areas of study. To gain perspective on the current state of knowledge about the oceans, we need to know something about the events and incentives that guided people's previous investigations of the oceans.

The Early Times

People have been gathering information about the oceans for millennia, accumulating bits and pieces of knowledge, passing it on by word of mouth. Curious individuals must have acquired their first ideas of the oceans from wandering the seashore, wading in the shallows, gathering food from the ocean's edges. During the Paleolithic period humans developed the barbed spear, or harpoon, and the gorge. The gorge was a double-pointed stick inserted into a bait and attached to a string. At the beginning of the Neolithic period the bone fishhook was developed and later the net. By 5000 B.C. copper fishhooks were in use (see traditional Native American implements in prologue fig. I).

As early humans moved slowly away from their inland centers of development, they were prepared to take advantage of the sea's food sources when they first explored and later settled along the ocean shore. The remains of shells and other refuse, in piles known as kitchen middens, have been found at the sites of ancient shore settlements. These remains show that our early ancestors gathered shellfish, and fish bones found in some middens suggest that they also began to use rafts or some type of boat for offshore fishing. Drawings on ancient temple walls show fishnets; on the tomb of the Egyptian Pharaoh Ti, Fifth Dynasty (5000 years ago), is a drawing of the poisonous pufferfish with a hieroglyphic description and warning. As long ago as 1200 B.C. or earlier, dried fish were traded in the Persian Gulf; in the Mediterranean the ancient Greeks caught, preserved, and traded fish, while the Phoenicians founded fishing settlements, such as "the fisher's town" Sidon, that grew into important trading ports.

Early information about the oceans was mainly collected by explorers and traders. These voyages left little in the way of recorded information. Using descriptions passed down from one voyager to another, early sailors piloted their way from one landmark to another, sailing close to shore and often bringing their boats up onto the beach each night.

Some historians believe that seagoing ships of all kinds are derived from early Egyptian vessels. The first recorded voyage by sea was led by Pharaoh Snefru about 3200 B.C. In 2750 B.C. Hannu led the earliest documented exploring expe-