ENVIRONMENTAL SCIENCE: AN INTRODUCTION/G. TYLER MILLER, JR.

Environmental Science
An Introduction

G. Tyler Miller, Jr.
St. Andrews Presbyterian College

Wadsworth Publishing Company
Belmont, California
A Division of Wadsworth, Inc.

Science Editor: Jack Carey
Editorial Associate: Ruth Singer
Production Editor: Gary Mcdonald
Managing Designers: Cynthia Bassett, Merle Sanderson
Print Buyer: Karen Hunt
Copy Editor: Brenda Griffing
Illustrators: Darwen and Vally Hennings, John and Judith Waller
Cover and Endpaper Design: Merle Sanderson
Cover Photograph: Jim Brandenberg/Woodfin Camp & Associates. The photo shows a young dog fox on the Alaskan tundra.

Printed in the United States of America

3 4 5 6 7 8 9 10—90 89 88 87

Books in the Wadsworth Biology Series

Biology: The Unity and Diversity of Life, 3rd, Starr and Taggart

Energy and Environment: The Four Energy Crises, 2nd, Miller

Fishes: A Field and Laboratory Manual on Their Structure, Identification, and Natural History, Cailliet, et al.

Living in the Environment, 4th, Miller

Oceanography: An Introduction, 3rd, Ingmanson and Wallace

Biology books under the editorship of William A. Jensen, University of California, Berkeley

Biology: The Foundations, 2nd, Wolfe

Biology of the Cell, 2nd, Wolfe

Cell Ultrastructure, Wolfe

Introduction to Cell Biology, Wolfe

Botany, 2nd, Jensen and Salisbury

Plant Physiology, 3rd, Salisbury and Ross

Plant Physiology Laboratory Manual, Ross

Plants: An Evolutionary Survey, 2nd, Scagel et al.

The environmental crisis is an outward manifestation of a crisis of mind and spirit. There could be no greater misconception of its meaning than to believe it to be concerned only with endangered wildlife, human-made ugliness, and pollution. These are part of it, but more importantly, the crisis is concerned with the kind of creatures we are and what we must become in order to survive.

Lynton K. Caldwell

This book is dedicated to Mother Earth, who sustains us and all other creatures, and to my life partner, spouse, and best friend, Peggy Sue O'Neal, who understands and attempts to live by the message of this book and who has helped me better understand and appreciate the beauty and complexity of nature.

Preface

An Introductory Course in Environmental Science—The purposes of this book are **(1)** to cover the diverse materials of an introductory course on environmental studies or environmental science in an accurate, balanced, and interesting way without the use of mathematics, **(2)** to enable both teacher and student to use the material in a flexible manner, and **(3)** to use basic ecological concepts to highlight environmental problems and to indicate possible ways to deal with them.

This book is one of a pair of related textbooks designed for different introductory courses on environmental concepts and problems. *Living in the Environment* (4th ed., Wadsworth, 1985), a longer version of this book, includes additional topics and details and especially a fuller discussion of environmental economics, politics, and ethics.

Flexibility—To provide flexibility, this book is divided into five major parts:

- Humans and Nature: An Overview
- Some Concepts of Ecology
- Population
- Resources
- Pollution

Once Part Two, containing four short chapters on ecological concepts (see brief table of contents), has been discussed, the remainder of the text can be covered in almost any order that meets the needs of each individual instructor.

Other Major Features—This textbook **(1)** emphasizes the use of fundamental ecological concepts (Chapters 3–6) to illustrate the relationships of environmental problems and their possible solutions, **(2)** provides balanced discussions of the opposing views of major environmental issues, **(3)** is based on an extensive review of the literature (from the thousands of references used, key readings for each chapter are listed at the end of the text), **(4)** is based on extensive manuscript review by experts and instructors who have used one or more of four editions of *Living in the Environment* from which this book is derived, and **(5)** offers a realistic but hopeful view that shows how much has been accomplished since 1965 (when the public was made aware of many environmental problems), as well as how much more needs to be accomplished.

As you and your students deal with the crucial and exciting issues discussed in this book, I hope you will take the time to correct errors and suggest improvements for future editions. Please send such information to me, care of Jack Carey, Wadsworth Publishing Company, 10 Davis Drive, Belmont, CA 94002.

Supplementary Materials—Dr. Robert Janiskee at the University of South Carolina has written an excellent student Study Guide and Instructor's Manual for use with this text. In addition, overhead transparencies of some of the major illustrations are available from the publisher.

Acknowledgments—I wish to thank the many students and teachers who responded so favorably to the first four editions and offered suggestions, including the idea that this shorter volume be developed. I am also deeply indebted to the numerous reviewers who pointed out errors and suggested many important improvements. Any errors and deficiencies remaining are mine, not theirs.

It has also been a pleasure to work with many of the talented people at Wadsworth Publishing Company. I am particularly indebted to Gary Mcdonald for his outstanding job as production editor, to Cynthia Bassett and Merle Sanderson as designers, to Brenda Griffing for her superb and most helpful copyediting, and to Darwen and Vally Hennings and John and Judy Waller for their outstanding art work. Above all I wish to thank Jack Carey, science editor at Wadsworth, for his superb reviewing system and for his help and friendship.

G. Tyler Miller, Jr.

Reviewers

Barbara J. Abraham Hampton College
James R. Anderson U. S. Geological Survey
Kenneth B. Armitage University of Kansas
Virgil R. Baker Arizona State University
Ian O. Barbour Carleton College
Albert J. Beck California State University, Chico
Jeff Bland University of Puget Sound
Georg Borgstrom Michigan State University
Arthur C. Borror University of New Hampshire
Leon Bouvier Population Reference Bureau
Michael F. Brewer Resources for the Future, Inc.
Patrick E. Brunelle Contra Costa College
Terrence J. Burgess Irvine Valley College
Lynton K. Caldwell Indiana University
Faith Thompson Campbell Natural Resources Defense Council, Inc.
E. Ray Canterbery Florida State University
Ted J. Case University of San Diego
Ann Causey Auburn University
Richard A. Cellarius The Evergreen State University
William U. Chandler Worldwatch Institute
R. F. Christman University of North Carolina, Chapel Hill
Preston Cloud University of California, Santa Barbara
Bernard C. Cohen University of Pittsburgh
Richard A. Cooley University of California, Santa Cruz
John D. Cunningham Keene State College
Herman E. Daly Louisiana State College
R. F. Dasmann University of California, Santa Cruz
Kingsley Davis University of California, Berkeley
Thomas R. Detwyler University of Michigan
W. T. Edmonson University of Washington
Thomas Eisner Cornell University
David E. Fairbrothers Rutgers University
Paul P. Feeney Cornell University
Nancy Field Bellevue Community College
Allan Fitzsimmons University of Kentucky
George L. Fouke St. Andrews Presbyterian College
Lowell L. Getz University of Illinois at Urbana-Champaign
Eville Gorham University of Minnesota
Katherine B. Gregg West Virginia Wesleyan College
Paul Grogger University of Colorado
J. L. Guernsey Indiana State University
Ralph Guzman University of California, Santa Cruz
Raymond E. Hampton Central Michigan University
Ted L. Hanes California State University, Fullerton
John P. Harley Eastern Kentucky University
Harry S. Hass San Jose City College
Arthur N. Haupt Population Reference Bureau
Denis A. Hayes Environmental consultant
David L. Hicks Whitworth College
Eric Hirst Oak Ridge National Laboratory
C. S. Holling University of British Columbia
Donald Holtgrieve California State University, Hayward
Marilyn Houck Pennsylvania State University
Richard D. Houk Winthrop College
Donald Huisingh North Carolina State University
Marlene K. Hutt IBM
David R. Inglis University of Massachusetts
Robert Janiskee University of South Carolina
David I. Johnson Michigan State University
Agnes Kadar Nassau Community College
Nathan Keyfitz Harvard University
Edward J. Kormondy University of Southern Maine
Judith Kunofsky Sierra Club
Steve Ladochy University of Winnipeg
William S. Lindsay Monterey Peninsula College
Valerie A. Liston University of Minnesota
Dennis Livingston Rensselaer Polytechnic Institute
James P. Lodge Air Pollution consultant
Ruth Logan Santa Monica City College
T. Lovering University of California, Santa Barbara
Amory B. Lovins Energy consultant
L. Hunter Lovins Energy consultant
David Lynn
Melvin G. Marcus Arizona State University
Stuart A. Marks St. Andrews Presbyterian College
Gordon E. Matzke Oregon State University
W. Parker Mauldin The Rockefeller Foundation
Vincent E. McKelvey U. S. Geological Survey

A. Steven Messenger Northern Illinois University
L. John Meyers Middlesex Community College
Ralph Morris Brock University, St. Catherines, Canada
William W. Murdoch University of California, Santa Barbara
Brian C. Myres Cypress College
C. A. Neale Illinois State University
Jan Newhouse University of Hawaii, Manoa
John E. Oliver Indiana State University
Charles F. Park Stanford University
Robert A. Pedigo Callaway Gardens
Harry Perry Library of Congress
Rodney Peterson Colorado State University
David Pimentel Cornell University
Robert B. Platt Emory University
Grace L. Powell University of Akron
James H. Price Oklahoma College
Marian E. Reeve Merritt College
Carl H. Reidel University of Vermont
Roger Revelle California State University, San Diego
Robert A. Richardson University of Wisconsin
William Van B. Robertson, M.D. School of Medicine, Stanford University
C. Lee Rockett Bowling Green State University
Richard G. Rose West Valley College
David Satterthwaite I.E.E.D., London
Frank R. Schiavo San Jose State University
Stephen Schneider National Center for Atmospheric Research
Clarence A. Schoenfeld University of Wisconsin, Madison
Henry A. Schroeder Dartmouth Medical School
Lauren A. Schroeder Youngstown State University
George Sessions Sierra College
Paul Shepard Pitzer College and the Claremont Graduate School
Kenneth Shiovitz
H. F. Siewart Ball State University
Robert L. Smith West Virginia University
Howard M. Smolkin U.S. Environmental Protection Agency
Patricia M. Sparks Glassboro State College
John E. Stanley University of Virginia
Mel Stanley California State Polytechnic University, Pomona
William L. Thomas California State University, Hayward
Tinco E. A. van Hylckama Texas Tech University
Donald E. Van Meter Ball State University
John D. Vitek Oklahoma State University
L. C. Walker Stephen F. Austin State University
Thomas D. Warner South Dakota State University
Kenneth E. F. Watt University of California, Davis
Alvin M. Weinberg Institute of Energy Analysis, Oak Ridge Associated Universities
Brian Weiss
Raymond White San Francisco City College
Charles G. Wilber Colorado State University
John C. Williams College of San Mateo
Ray Williams Whittier College
Samuel J. Williamson New York University
Ted L. Willrich Oregon State University
George M. Woodwell Brookhaven National Laboratory
Robert Yoerg, M. D. Belmont Hills Hospital
Hideo Yanenaka San Francisco State University

Environmental Science

Brief Contents

Detailed Contents

PART ONE

Humans and Nature: An Overview

EPA Documerica/Bob Smith

It is only in the most recent, and brief, period of their tenure that human beings have developed in sufficient numbers, and acquired enough power, to become one of the most potentially dangerous organisms that the planet has ever hosted.

John McHale

Human despair or default can reach a point where even the most stirring visions lose their regenerating powers. This point, some will say, has already been reached. Not true. It will be reached only when human beings are no longer capable of calling out to one another, when the words in their poetry break up before their eyes, when their faces are frozen toward their young, and when they fail to make pictures in the mind out of clouds racing across the sky. So long as we can do these things, we are capable of indignation about the things we should be indignant about and we can shape our society in a way that does justice to our hopes.

Norman Cousins

1

Population, Resources, and Pollution

We travel together, passengers on a little spaceship, dependent on its vulnerable resources of air, water, and soil . . . preserved from annihilation only by the care, the work, and the love we give our fragile craft.

Adlai E. Stevenson

1-1 A Crisis of Interlocking Problems

Today the world is at a critical turning point. The prospect for humanity is both brighter and darker than at any time in history. Prophets of doom warn that the earth's life-support systems are being destroyed, and technological optimists promise a life of abundance for everyone. We spend billions to transport a handful of humans to the moon, only to learn the importance of protecting the diversity of life on the beautiful blue planet that is our home. We use modern medicine and sanitation to lower death rates from disease, only to be faced with a population explosion. We feed more people than ever before, yet millions die each year from lack of food or from diseases brought on or made worse by too little food.

As more people use the earth's resources, increasing stress is placed on the forests, grasslands, and croplands, and on the air, water, and soil that support all life. Tropical forests are cleared to provide lumber and fuelwood and land for growing crops and grazing livestock, but this also threatens thousands of plant and animal species with extinction. Some experts say we are running out of certain fuel and mineral resources; others say we will never run out. We hear of successes in cleaning up rivers, lakes, and the air in some parts of the world, but we are bombarded with stories about new pollution threats such as leaking hazardous waste dumps, acid rain, and potentially harmful changes in the global climate due to the carbon dioxide added to the atmosphere when fossil fuels are burned and forests are cleared without adequate replanting.

The problems associated with increasing population, increasing use of resources, and pollution are all interrelated. The primary aims of this book are to describe major environmental problems, present ecological concepts that connect them, and use these concepts to evaluate the opportunities we have to deal with these problems in coming decades. Let us begin with a brief overview of the related problems of population growth, resource use, and pollution. In later chapters we will look at these problems and proposed solutions in greater depth.

1-2 Population

The J-Shaped Curve of Population Growth You are used to quantities increasing at an *arithmetic rate*—that is, growing in the sequence 1, 2, 3, 4, 5, 6, and so on. The population size of the earth, however, is increasing at an *exponential or geometric rate*—that is, it is growing by doubling: 1, 2, 4, 8, 16, 32, and so on.

Exponential growth can be illustrated by folding a page of this book. The page is about 0.1 millimeter (about 1/254 inch) thick, so after one fold its thickness would be doubled, after 12 doublings the page would be about 410 millimeters (1.34 feet) high, and after 20 doublings about 105 meters (340 feet)—still a relatively unspectacular change. However, after the 35th fold, its height would equal the distance from New York to Los Angeles. After 42 doublings the mound of paper would reach from the earth to the moon, 386,400 kilometers (240,000 miles) away. Slightly past the 51st doubling the pile would reach the sun, 149 million kilometers (93 million miles) from the earth's surface!

When such **exponential** or **geometric growth** is plotted on a graph the result is an *exponential curve*, or *J-shaped curve*, as shown for the human population in Figure 1-1. Notice that it took 2 million to 5 million years to add the first billion people; 80 years to add the second billion; 30 years

To the student: At the end of the book is a list of readings that served as major references for each chapter; this material can be a source of further information.

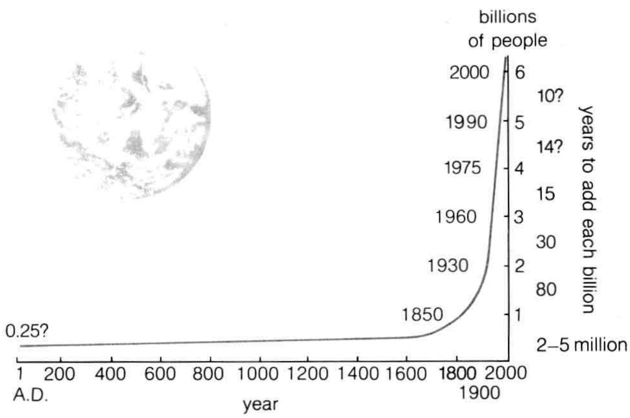

Figure 1-1 J-shaped curve of the world's population growth. Projections assume that the 1984 growth rate of 1.7 percent will gradually drop to 1.5 percent.

to add the third billion; and only 15 years to add the fourth billion. At present growth rates the fifth billion will be added in the 12 years between 1975 and 1987, and the sixth billion will be added only 11 years later, by 1998.

The average number of live births on this planet is now about 249 babies per minute, or approximately 358,000 per day, while the average number of deaths is only 101 persons per minute, or 146,000 per day. In other words, there are about 2.5 times more births than deaths each day. Population growth for the entire planet over a given period is determined by the difference between births and deaths:

population increase = births − deaths
= 358,000 people/day − 146,000 people/day
= **212,000 people/day**

This adds 1.48 million people each week and 77 million people each year to the 4.8 billion passengers already on "spaceship earth." At this rate it takes less than 5 days to replace a number of people equal to all Americans killed in all U.S. wars, less than 12 months to replace the more than 75 million people killed in the world's largest disaster (the bubonic plague epidemic of the fourteenth century), and about 13 months to replace the 86 million soldiers and civilians who died in all wars fought in this century.

All these new passengers must be fed, clothed, and housed. Each will use some resources and will add to global pollution. While some of this population growth is taking place in the *more developed countries* (MDCs) such as the United States and the Soviet Union, most is taking place in the *less developed countries* (LDCs) such as China and India. Currently, 76 percent of the people in the world live in the LDCs, which have only 20 percent of the world's wealth. As a result, the United Nations estimates that at least half the adults on this planet are illiterate; one-fifth of the people are hungry or malnourished; one-sixth have inadequate housing (Figure 1-2); one out of every four lacks clean water; and one out of three does not have access to adequate sewage disposal and effective medical service.

The World Health Organization (WHO) estimates that while you ate dinner today at least 1,600 people died of starvation, malnutrition, or diseases resulting from or worsened by these conditions. By this time tomorrow, 38,000 will have died from starvation or starvation-related diseases; by next week, 269,000; by next year, about 14 million. Half are children under the age of 5. Because this mass starvation of about 14 million people a year is spread throughout much of the world instead of being confined to one country or region, it is not even classified as a famine by most officials.

Population growth, however, is not our only problem. We are also faced with the environmental problems of increasing resource use and pollution, both related to population growth.

1-3 Natural Resources

Types of Natural Resources A **resource** or **natural resource** is any form of matter or energy that is obtained from the physical environment to meet human needs. *Whether something is considered to be a resource depends on technology, economics, and cultural beliefs.* Most resources are created by human ingenuity. Oil was a useless fluid until humans learned how to locate it, extract it from the ground, separate it by distillation into various components, and use it as gasoline, home heating oil, road tar, and so on. Similarly, coal and uranium fuels were once useless rocks.

Resources can be classified as *renewable* or *nonrenewable* (Figure 1-3). A **renewable resource** is one that either comes from an essentially inexhaustible source (such as solar energy) or can be renewed and replenished relatively rapidly by natural or artificial processes if managed wisely. Examples include food crops, animals, grasslands, forests, and other living things, as well as fresh air, fresh water, and fertile soil. The maximum rate at which a renewable resource can be used without impairing or damaging its ability to be renewed is called its **maximum sustained yield.** If this yield is exceeded, a potentially renewable resource becomes a nonrenewable resource. For example, if a species

Figure 1-2 One-sixth of the people in the world do not have adequate housing. Lean-to shelters like these are homes for many families in Dacca, Bangladesh.

of fish is harvested faster than it can reproduce itself, the species may be threatened with extinction.

A **nonrenewable resource** either is not replaced by natural processes or has a rate of replacement that is slower than the rate of use. Natural geological processes taking place over millions of years have created varying deposits of such metallic and nonmetallic minerals (Figure 1-3). Once such deposits have been mined, they are not replaced fast enough to be useful. The easily available and highly concentrated supplies of nonrenewable minerals are normally depleted first. Then it is necessary to look harder and dig deeper to find the remaining deposits, which usually contain lower concentrations of the desired mineral. This normally costs more, although improvements in resource location and mining technology sometimes reduce costs. Higher costs can stimulate a search for new deposits or make the mining and processing of lower grade deposits more feasible. However, if the cost of finding, extracting, and concentrating a given material becomes too high, the resource will no longer be useful even though some supplies remain.

Sometimes a *substitute* or *replacement* for a resource that is scarce or too expensive is discovered. For example, much of the steel used in automobile production is being replaced with aluminum and plastic to produce lighter cars and thus conserve gasoline. Although some resource economists argue that we can use human ingenuity to find a substitute for any nonrenewable resource, this is not always the case. Some materials have unique properties, such that they cannot be replaced; the would-be replacements are inferior, too costly, or otherwise unsatisfactory. For example, nothing now known can replace steel and concrete in skyscrapers, nuclear power plants, and dams. In other cases the proposed substitutes are themselves fairly scarce. Such is the case with molybdenum, the main substitute for tungsten in making hard alloy steels for use in high-speed cutting tools and filaments in electric light bulbs.

Recycling and reuse are other ways of stretching the supplies of some nonrenewable minerals. Nonrenewable resources that can be recycled or reused include *metallic minerals* from which metals such as copper, aluminum, and iron can be extracted. In most LDCs recycling and reuse are necessary for survival. In MDCs, however, economic incentives (such as tax breaks and government