ESSENTIALS OF ECOLOGY / G. TYLER MILLER, JR.

Essentials of Ecology

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PREFACE

For Instructors and Students

How Is This Book Organized? This book is a brief introduction to basic ecological concepts. It consists of the first eleven chapters of the twelfth edition of my longer book, *Living in the Environment* (Wadsworth/Thomson Learning, 2002).

This book is divided into three major parts. The two chapters in Part I provide an overview of **(1)** major environmental problems (Chapter 1) and **(2)** environmental history (Chapter 2). These chapters help students realize the need for understanding basic ecological concepts. However, instructors could omit one or both of these chapters without affecting the ability of students to understand the chapters on basic ecology.

Part II consists of eight chapters covering basic science and principles of ecology. Instructors wishing to cover only basic ecology can omit Chapter 10 on geology.

Part III consists of one chapter on human population growth. Instructors who wish to concentrate only on basic ecology can omit this chapter.

In preparing this book, I have benefited from the more than 250 experts and teachers (a number of them ecologists) who have provided detailed reviews of my related books in environmental science. I also wish to thank Paul M. Rich, systems ecologist at Los Alamos National Laboratory and formerly associate professor of ecology and evolutionary biology and environmental studies at the University of Kansas, for serving as coauthor of Chapters 4 through 9 on basic ecological concepts.

What Are the Key Features of This Book? Each chapter begins with a brief case study designed to capture interest and set the stage for the material that follows. In addition to these case studies, 10 other case studies are found throughout the book (some in special boxes and others within the text). Seven *Guest Essays* present an individual researcher's look at certain topics. Each essay is then evaluated through Critical Thinking questions.

Other special boxes found in the text include **(1)** *Connections boxes* that show connections in nature and between environmental concepts, problems, and solutions, **(2)** *Solutions boxes* that summarize a variety of solutions to environmental or ecological problems proposed by various analysts, **(3)** *Spotlight boxes* that highlight and give insights into key environmental problems and ecological concepts, and **(4)** *Individuals Matter boxes* that describe what people have done to help solve environmental problems. To encourage critical thinking and integrate it throughout the book, all boxes (except Individuals Matter) end with Critical Thinking questions.

The book's 241 illustrations are designed to present complex ideas in understandable ways and to relate learning to the real world.

In-Text Study Aids Each chapter begins with a few general questions to reveal how it is organized and what students will be learning. When a new term is introduced and defined, it is printed in boldface type. A glossary of all key terms is located at the end of the book.

Questions are used as titles for all subsections so that readers know the focus of the material that follows. In effect, this is a built-in set of learning objectives.

Each chapter ends with **(1)** a set of Review Questions covering *all* of the material in the chapter as a study guide for students and **(2)** a set of questions to encourage students to think critically and apply what they have learned to their lives. The Critical Thinking questions are followed by several projects that individuals or groups can carry out.

Internet and Online Study Aids Qualified users of this textbook have free access to the *Brooks/Cole Biology and Environmental Science Resource Center*. The online resource material for this book can be accessed by logging on at

http://www.brookscole.com/product/0534376975s

Users then refer to the site material for Chapters 1 through 11 of my longer book, *Living in the Environment*, which make up the content of this shorter basic ecology textbook.

At this website you will find the following material for each chapter:

- "Flash Cards," which allow you to test your mastery of the Terms and Concepts to Remember.
- "Tutorial Quizzes," which provide a multiple-choice practice quiz.
- "Student Guide to InfoTrac," which will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- "References," which lists the major books and articles consulted in writing this chapter.
- "Hypercontents," which takes you to an extensive list of websites with news, research, and images related to individual sections of the chapter.

Qualified adopters of this textbook also have free access to *WebTutor Toolbox on WebCT* at

http://e.thomsonlearning.com

It provides access to a full array of study tools, including flashcards (with audio), practice quizzes, online tutorials, and Web links.

Students using *new* copies of this textbook also have free and unlimited access to *InfoTrac College Edition*. This fully searchable online library gives users access to complete environmental articles from several hundred periodicals dating back over the past four years. I have put two practice exercises at the end of each chapter to help students learn how to navigate this valuable source of information.

Supplementary Materials for Instructors The following supplementary materials are available to instructors using this book:

- *Multimedia Presentation Manager and Archive*. This CD-ROM, which is free to adopters, allows you to **(1)** create custom lectures using several hundred pieces of high-resolution artwork, images, and Quick Time movies from the CD and the Web, **(2)** assemble database files, and **(3)** create PowerPoint™ lectures using text slides and figures from the textbook. This program's editing tools allow **(1)** slides to be moved from one lecture to another, **(2)** modification or removal of figure labels and leaders, **(3)** insertion of your own slides, **(4)** saving slides as JPEGs, and **(5)** preparation of lectures for use on the Web.
- *Introduction to Environmental Science Presentation CD-ROMs.* This set of five CD-ROMs contains more than 3,500 diagrams and photographs, some from Miller's text, to help you create lecture presentations. One set is available per department with adoptions of 100 or more copies of of this book.
- *Transparency Masters and Acetates.* Includes **(1)** 100 color acetates of line art and **(2)** nearly 600 black and white master sheets of key diagrams for making overhead transparencies. Free to adopters.
- CNN™ *Today Videos*. These videos, updated annually, contain short clips of news stories about environmental news. Adopters can receive one video free each year for three years.
- Two videos, **(1)** *In the Shadow of the Shadow of the Shuttle: Protecting Endangered Species*, and **(2)** *Costa Rica: Science in the Rainforest*, are available to adopters.
- *Instructor's Manual with Test Items*. Free to adopters.
- *ExamView*™. Allows you to **(1)** easily create and customize tests, **(2)** see them on the screen exactly as they will print, and **(3)** print them out.

Acknowledgments I wish to thank the many students, teachers, and reviewers who **(1)** re-

sponded so favorably to the 12 editions of *Living in the Environment* (from which this book is derived), the 9 editions of *Environmental Science*, and the 5 editions of *Sustaining the Earth* and **(2)** corrected errors and offered many helpful suggestions for improvement. Any errors and deficiencies left are mine.

My deepest thanks go to Jack Carey, biology publisher at Brooks/Cole, for his encouragement, help, 36 years of friendship, and superb reviewing system. It helps immensely to work with the best and most experienced editor in college textbook publishing.

I dedicate this book to the earth and to Kathleen Paul, my wife and research assistant.

G. Tyler Miller, Jr.

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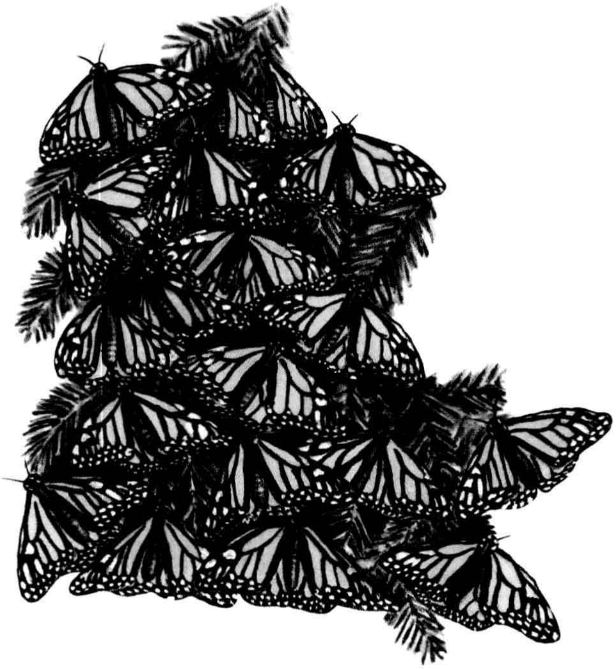
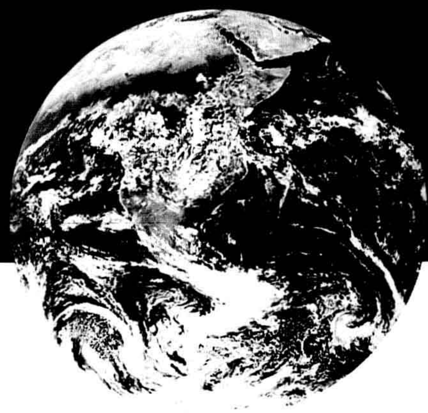


A population of monarch butterflies.

Genetic diversity among individuals of one species of Caribbean snail.



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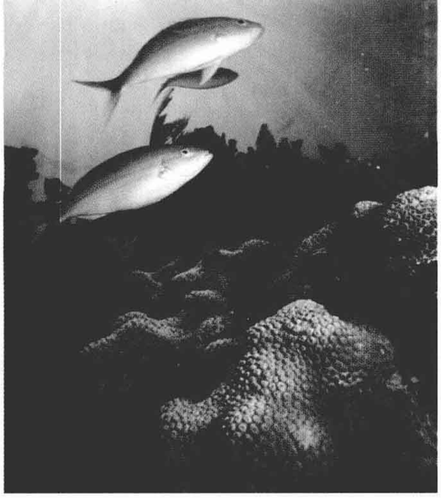

NOAA Corps Collection/Photographer: Commander John Bortniak, NOAA Corps. (ret.)

Coral Reef Sanctuary, Tortugas Marine Ecological Reserve, Florida Keys

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importantly, the crisis is concerned with the kind of creatures we are and what we must become in order to survive.

LYNTON K. CALDWELL

1 ENVIRONMENTAL ISSUES, THEIR CAUSES, AND SUSTAINABILITY

Living in an Exponential Age

Once there were two kings from Babylon who enjoyed playing chess, with the winner claiming a prize from the loser. After one match, the winning king asked the loser to pay him by placing one grain of wheat on the first square of the chessboard, two on the second, four on the third, and so on. The number of grains was to double each time until all 64 squares were filled.

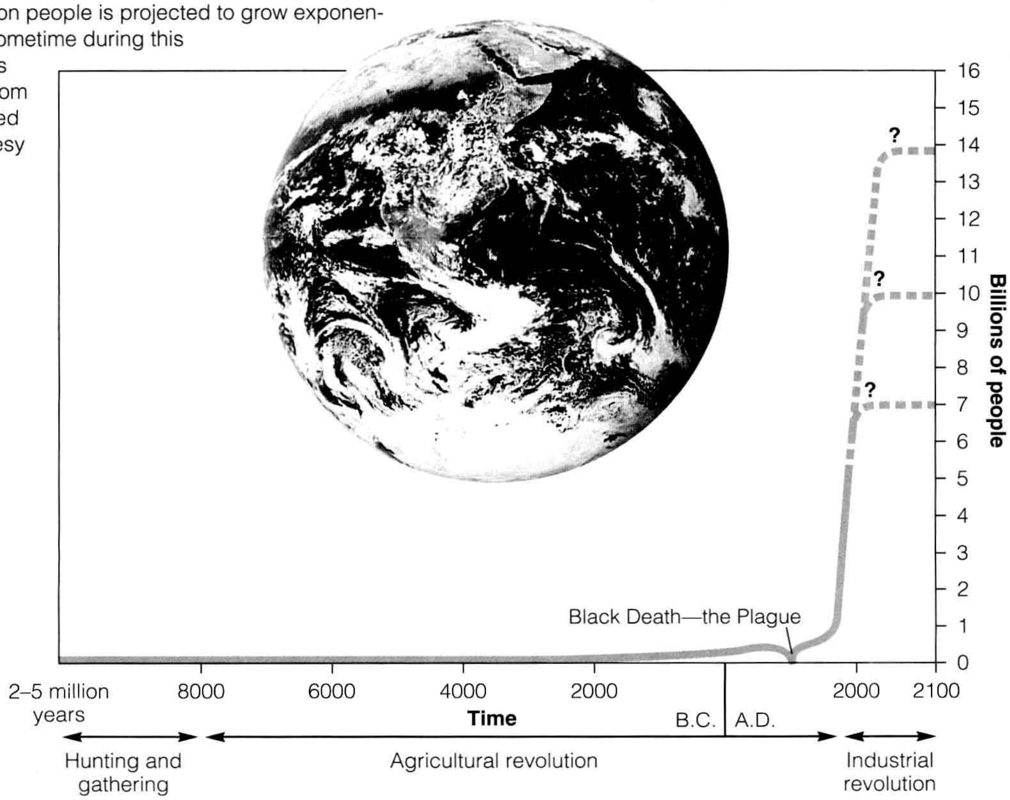
The losing king, thinking he was getting off easy, agreed with delight. It was the biggest mistake he ever made. He bankrupted his kingdom and still could not produce the incredibly large number of grains of wheat he had promised. In fact, it's probably more than all the wheat that has ever been harvested!

This is an example of **exponential growth**, in which a quantity increases by a fixed percentage of the whole in a given time. As the losing king learned, exponential growth is deceptive. It starts off slowly, but after only a few doublings it grows to enormous numbers because each doubling is more than the total of all earlier growth.

Here is another example. Fold a piece of paper in half to double its thickness. If you could do this 42 times, the stack would reach from the earth to the moon, 386,400 kilometers (240,000 miles) away. If you could double it 50 times, the folded paper would almost reach the sun, 149 million kilometers (93 million miles) away!

The environmental issues we face—**(1)** *population growth,* **(2)** *increasing resource use,* **(3)** *destruction and degradation of wildlife habitats,* **(4)** *premature extinction of plants and animals,* **(5)** *poverty, and* **(6)** *pollution*—are interconnected and are growing exponentially. For example, world population has more than doubled in 50 years, from 2.5 billion in 1950 to 6.1 billion in 2000. Unless death rates rise sharply, it may reach 8 billion by 2028, 9 billion by 2054, and 10–14 billion by 2100 (Figure 1-1). Global economic output, much of it environmentally damaging, increased 17-fold between 1900 and 2000 and almost eightfold between 1950 and 2000.

Figure 1-1 The J-shaped curve of past exponential world population growth, with projections beyond 2100. Notice that exponential growth starts off slowly, but as time passes the curve becomes increasingly steep. The current world population of 6.1 billion people is projected to grow exponentially to 7–14 billion sometime during this century. (This figure is not to scale.) (Data from World Bank and United Nations; photo courtesy of NASA)



Alone in space, alone in its life-supporting systems, powered by inconceivable energies, mediating them to us through the most delicate adjustments, wayward, unlikely, unpredictable, but nourishing, enlivening, and enriching in the largest degree—is this not a precious home for all of us? Is it not worth our love?

BARBARA WARD AND RENÉ DUBOS

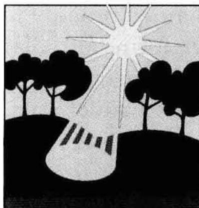
This chapter is an overview of environmental issues, their root causes, the controversy over their seriousness, and ways we can live more sustainably. It addresses these questions:

- What are natural resources and why are they important? What is an environmentally sustainable society?
- How fast is the human population increasing?
- What is the difference between economic growth, economic development, and environmentally sustainable economic development?
- What are the earth's main types of resources? How can they be depleted or degraded?
- What are the principal types of pollution? How can pollution be reduced and prevented?
- What are the root causes of today's environmental problems and how are these causes connected?
- Is our current course sustainable? How can we live more sustainably?

1-1 LIVING MORE SUSTAINABLY

What Is the Difference Between Environment, Ecology, and Environmental Science? **Environment** is everything that affects a living organism (any unique form of life). **Ecology** is a biological science that studies the relationships between living organisms and their environment.

This textbook is an introduction to **environmental science***. It is an interdisciplinary science that uses concepts and information from *natural sciences* such as ecology, biology, chemistry, and geology and *social sciences* such as economics, politics, and ethics to **(1)** help us understand how the earth works, **(2)** learn how we are affecting the earth's life-support systems (environment) for us and other forms of life, and **(3)** propose and evaluate solutions to the environmental problems we face. Many different groups of people are concerned about environmental issues (Spotlight, right).



SPOTLIGHT

Cast of Players in the Environmental Drama

The cast of major characters you will encounter in this book include the following:

- **Ecologists**, who are biological scientists studying relationships between living organisms and their environment.
- **Environmental scientists**, who use information from the physical sciences and social sciences to **(1)** understand how the earth works, **(2)** learn how humans interact with the earth, and **(3)** develop solutions to environmental problems.
- **Conservation biologists**, who in the 1970s created a multidisciplinary science to **(1)** investigate human impacts on the diversity of life found on the earth (biodiversity) and **(2)** develop practical plans for preserving such biodiversity.
- **Environmentalists**, who are concerned about the impact of people on environmental quality and believe that some human actions are degrading parts of the earth's life-support systems for humans and many other forms of life. Some of their beliefs and proposals for dealing with environmental problems are based on scientific information and concepts and some are based on their social and ethical environmental beliefs (environmental worldviews). Environmentalists are a broad group of people from different economic groups (rich, middle-class, poor) and with different political persuasions (conservative and liberal).
- **Preservationists**, concerned primarily with setting aside or protecting undisturbed natural areas from harmful human activities.
- **Conservationists**, concerned with using natural areas and wildlife in ways that sustain them for current and future generations of humans and other forms of life.
- **Restorationists**, devoted to the partial or complete restoration of natural areas that have been degraded by human activities.

Many people consider themselves members of several of these groups.

Critical Thinking

Which, if any, of these groups do you most identify with? Why?

What Keeps Us Alive? Our existence, lifestyles, and economies depend completely on the sun and the earth, a blue and white island in the black void of space (Figure 1-1). To economists *capital* is wealth used to sustain a business and to generate more wealth. By analogy, we can think of energy from the sun as **solar capital** and the planet's air, water, soil, wildlife, minerals, and natural purification, recycling, and pest control processes as **natural resources** or **natural capital**

*Some people prefer to call this *environmental studies* and reserve the term *environmental science* only for the physical science aspects of studying the environment. However, most people use the broader definition of *environmental science* given here.

(Guest Essay, p. 6). **Solar energy** is defined broadly to include direct sunlight and indirect forms of solar energy such as **(1)** wind power, **(2)** hydropower (energy from flowing water), and **(3)** biomass (direct solar energy converted to chemical energy stored in biological sources of energy such as wood).

What Is an Environmentally Sustainable Society? To survive and maintain good health, all forms of life must have enough food, clean air, clean water, and shelter to meet their *basic needs.* Additional needs for humans include enough income to meet basic needs, respectable and safe work, health care, recreation, cultural opportunities, education, and freedom from physical danger.

An **environmentally sustainable society** satisfies the basic needs of its people without depleting or degrading its natural resources and thereby preventing current and future generations of humans and other species from meeting their basic needs. *Living sustainably* means living off the natural income replenished by soils, plants, air, and water and not depleting the natural capital that supplies this income (Guest Essay, p. 6).

For example, imagine that you inherit $1 million. Invest this capital at 10% interest per year and you will have a sustainable annual income of $100,000 without depleting your capital. If you spend $200,000 a year, your $1 million will be gone early in the 7th year; even if you spend only $110,000 a year, you will be bankrupt early in the 18th year.

The lesson here is a very old one: *Don't kill the goose that lays the golden egg*, or *protect your capital.* Deplete your capital, and you move from a sustainable to an unsustainable lifestyle.

The same lesson applies to the earth's natural capital. Environmentalists and many leading scientists believe that we are living unsustainably by depleting and degrading the earth's natural capital at an accelerating rate as our population (Figure 1-1) and demands on the earth's resources and life-sustaining processes increase exponentially.

In 1999, the World Wildlife Fund, the New Economics Foundation, and the World Conservation Monitoring Centre issued *The Living Planet Report.* It was designed to be an "environmental Dow Jones index" measuring the environmental health of the world's forests, rivers, lakes, and oceans. According to this study, the world lost about one-third of its natural capital between 1970 and 1999 because of a combination of exponential growth in population and in the use of the earth's natural resources.

Other analysts do not believe that we are living unsustainably. They contend **(1)** that environmentalists have exaggerated the seriousness of population and environmental problems and **(2)** that any population, resource, and environmental problems we face can be overcome by human ingenuity and technological advances.

1-2 POPULATION GROWTH, ECONOMIC GROWTH, ENVIRONMENTALLY SUSTAINABLE DEVELOPMENT, AND GLOBALIZATION

What Is the Difference Between Linear Growth and Exponential Growth? Suppose you hop on a train that accelerates by 1 kilometer (0.6 mile) per hour every second. After 30 seconds, your speed would be 30 kilometers (19 miles) per hour. This is an example of **linear growth**, in which a quantity increases by a constant amount per unit of time, as in the sequence 1, 2, 3, 4, 5—or 1, 3, 5, 7, 9—and so on. If plotted on a graph, such growth in speed or growth of money in a savings account yields a straight line that slopes upward (Figure 1-2).

However, suppose the train has a motor strong enough to double its speed every second. After 30 seconds, you would be traveling a billion kilometers (620 million miles) per hour!

This is an example of the astounding power of exponential growth. Any quantity growing exponentially by a fixed percentage, even as small as 0.001% or 0.1%, will experience extraordinary growth as its base of growth doubles again and again. If plotted on a graph, continuing exponential growth eventually yields a graph shaped somewhat like the letter J (Figure 1-2).

How long does it take to double the world's resource use or population size or money in a savings account that is growing exponentially? A quick way to calculate this **doubling time** in years is to use the **rule of 70**: 70/percentage growth rate = doubling time in years (a form-

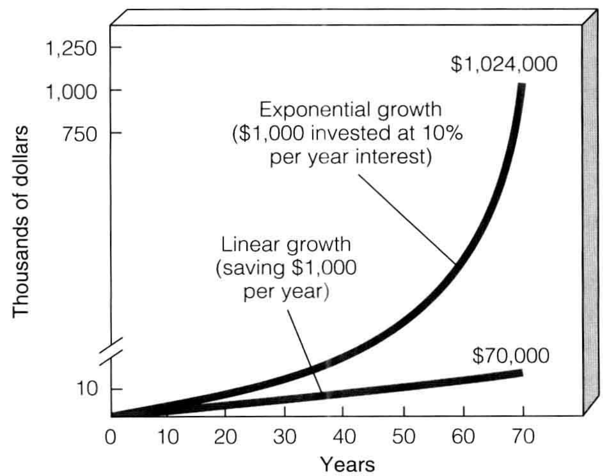


Figure 1-2 Linear and exponential growth. If you save $1,000 a year for a lifetime of 70 years, the resulting linear growth will allow you to save $70,000 (lower curve). If you invest $1,000 each year at 10% interest for 70 years and reinvest the interest, your money will grow exponentially to $1,024,000 (upper curve). If resource use, economic growth, or money in a savings account grows exponentially for 70 years (a typical human lifetime) at a rate of 10% a year, it will increase 1,024-fold.

World Population Reached	
1 billion in 1804	
2 billion in 1927	(123 years later)
3 billion in 1960	(33 years later)
4 billion in 1974	(14 years later)
5 billion in 1987	(13 years later)
6 billion in 1999	(12 years later)
World Population May Reach	
7 billion in 2013	(14 years later)
8 billion in 2028	(15 years later)
9 billion in 2054	(26 years later)

Figure 1-3 World population milestones. (Data from United Nations Population Division, *World Population Prospects*, 1998)

ula derived from the basic mathematics of exponential growth). For example, in 2000 the world's population grew by 1.35%. If that rate continues, the earth's population will double in about 52 years (70/1.35 = about 52 years). In the example of exponential growth of savings by 10% a year (Figure 1-2), your money would double roughly every 7 years (70/10 = 7).

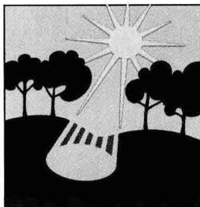
How Rapidly Is the Human Population Growing? The increasing size of the human population is an example of exponential growth (Figures 1-1 and 1-3 and Spotlight, right). The main reason for the rapid growth of the earth's human population over the past 100 years has been a much greater drop in death rates (mostly because of increases in food supply and better health and nutrition) than in birth rates.

Recent studies by researchers at Conservation International suggest that roughly *73% of the earth's habitable land surface (that which is not bare rock, ice, or drifting sand) has been partially or heavily disturbed by human activities* (Figure 1-4, p. 8). What will happen to the earth's remaining wildlife habitat and wildlife species if the human population increases from 6.1 billion to 8 billion between 2000 and 2028 and perhaps to 9 billion by 2054?

What Is Economic Growth? Almost all countries seek **economic growth**: an increase in their capacity to provide goods and services for people's final use. This increase is accomplished by population growth (more consumers and producers), more consumption per person, or both.

Economic growth usually is measured by an increase in several indicators:

- **Gross national product (GNP):** the market value in current dollars of all goods and services produced *within* and *outside* a country by the country's businesses during a year
- **Gross domestic product (GDP):** the market value in current dollars of all goods and services produced *within* a country during a year
- **Gross world product (GWP):** the market value in current dollars of all goods and services produced in the world each year



SPOTLIGHT

Current Exponential Growth of the Human Population

The world's population is growing exponentially at a rate of about 1.35% per year. The relentless ticking of this population clock means that in 2000 the world's population of 6.1 billion grew by 82 million people (6.1 billion × 0.0135 = 82 million), an average increase of 226,000 people a day, or 9,400 an hour.

At this 1.35% annual rate of exponential growth, it takes only about

- 5 days to add the number of Americans killed in all U.S. wars
- 2 months to add as many people as live in the Los Angeles basin
- 1.6 years to add the 129 million people killed in all wars fought in the past 200 years
- 3.4 years to add 276 million people (the population of the United States in 2000)
- 15 years to add 1.26 billion people (the population of China, the world's most populous country, in 2000)

How much is a billion? If you could live for a billion minutes, you would be 1,902 years old. To travel 1 billion kilometers (0.6 billion miles), you would have to circle the earth about 25,000 times.

Critical Thinking

Some economists argue that population growth is good because it provides more workers, consumers, and problem solvers to keep the global economy growing. Environmentalists argue that population growth threatens economies and the earth's life-support systems through increased pollution and environmental degradation. What is your position? Why?

To show one person's slice of the economic pie, economists calculate the **per capita GNP**: the GNP divided by the total population.

Economic development is the improvement of living standards by economic growth. The United Nations classifies the world's countries as economically developed or developing based primarily on their degree of industrialization and their per capita GNP (Figure 1-5, p. 9).

The **developed countries** include the United States, Canada, Japan, Australia, New Zealand, and all the countries of Europe. Most are highly industrialized and have high average per capita GNPs (above $10,000 per year, except for industrialized countries in eastern Europe and some in northern and southern Europe). These countries,