SUSTAINING THE EARTH / FIFTH EDITION / G. TYLER MILLER, JR.

# Sustaining the Earth

## *An Integrated Approach*

FIFTH EDITION

**G. TYLER MILLER, JR.**

*President, Earth Education and Research*

*Adjunct Professor of Human Ecology*
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PREFACE

# FOR INSTRUCTORS AND STUDENTS

**How Did I Become Involved with Environmental Problems?** In 1966, I heard a scientist give a lecture on the problems of overpopulation and environmental abuse. Afterward I went to him and said, "If even a fraction of what you have said is true, I will feel ethically obligated to give up my research on the corrosion of metals and devote the rest of my life to research and education on environmental problems and solutions. Frankly, I don't want to believe a word you have said, and I'm going into the literature to try to prove that your statements are either untrue or grossly distorted."

After 6 months of study I was convinced of the seriousness of these problems. Since then, I have been studying, teaching, and writing about them. This book summarizes what I have learned in more than three decades of trying to understand environmental principles, problems, connections, and solutions.

**Major Features** This book is designed for introductory courses on *environmental science* . It treats environmental science as an *interdisciplinary* study, combining ideas and information from **(1)** *natural sciences* (such as biology, chemistry, and geology) and **(2)** *social sciences* (such as economics, politics, and ethics) to present a general idea of how nature works and how things are interconnected. It is a study of *connections in nature.*

This book is

- ***Science based.*** A total of 96 pages (25% of this book) are devoted to using basic scientific and ecological concepts, laws, and principles to enable students without prior scientific training to understand and think critically about environmental problems and solutions.

- ***Balanced.*** Great emphasis placed on **(1)** giving balanced presentations of opposing viewpoints on controversial environmental issues and **(2)** helping students think critically and decide such issues for themselves. Both *good news* and *bad news* on our progress in dealing with environmental problems are presented.

- ***Solutions oriented.*** A total of 147 pages are used to list and evaluate solutions to environmental problems.

- ***Focused on visual learning.*** The book's 285 illustrations (109 of them new to this edition) have been carefully designed to present complex ideas in understandable ways and to relate learning to the real world. Learning is also stimulated by use of special boxes throughout the text. They include **(1)** *Pro/Con boxes* that present both sides of controversial environmental issues, **(2)** *Connections boxes* describing connections in nature and between environmental concepts, problems, and solutions, **(3)** *Solutions boxes* summarizing a variety of solutions to environmental problems proposed by various analysts, **(4)** *Spotlight boxes* that highlight and give insights into key environmental problems and concepts, and **(5)** *Individuals Matter boxes* that describe what people have done to help solve environmental problems.

- ***Current and accurate.*** This book is updated every two years. In preparing each new edition I typically review about 10,000 printed references and thousands of websites.

- ***Internet integrated.*** The icon

*www.*

is used to link material in the book to our interactive website at http://www.brookscole.com/product/0534385354s. At this website, which is updated constantly, you will find Cool Events, Critical Thinking Questions, Tips on Surfing, Interactive Quizzes for each chapter, and much more. Students and instructors also have access to *InfoTrac*® College Edition, a searchable online database of recent articles from more than 700 periodicals.

To reduce student costs, this book is printed in black-and-white and has a soft cover. It is also printed on acid-free recycled paper with the maximum content of postconsumer waste currently available at an affordable cost.

Instructors who want books covering this material with a different emphasis, organization, and length can use one of my two other books written for various types of environmental science courses

- *Living in the Environment*, 12th edition (758 pages, Brooks/Cole, 2002)
- *Environmental Science*, 8th edition (549 pages, Brooks/Cole, 2001, a shorter version of *Living in the Environment*)

**Major Changes in the Fifth Edition** *This is the most significant revision since the first edition came out.* Detailed changes by chapter are listed in the annotated material in the front of the instructor's version of this book and on this book's website. Major changes include the following:

### *Content*

- Updated and revised material throughout the book.
- 25 new reviewers to improve content and balance.
- 109 new or improved figures.
- 22 Pro/Con diagrams summarizing a large amount of complex information about the advantages and disadvantages of various solutions to environmental problems in a balanced, easy-to-understand manner. Examples include Figures 4-28 (p. 121), 4-41 (p. 131), 4-46 (p. 135), 7-21 (p. 226), and 11-10 (p. 345).
- 125 new topics. Examples include the following: **(1)** ecological footprints of countries (Figure 1-8, p. 7); **(2)** ecological and economic services provided by terrestrial and aquatic systems, examples include Figure 2-39 p. 56 and Figure 2-42 p. 59; **(3)** precautionary principle (p. 72); **(4)** genetically modified food (pp. 219-222); **(5)** drip irrigation (p. 309); **(6)** using the internet to save energy and reduce global warming (p. 112); **(7)** hybrid gas-electric and fuel-cell car engines (p. 109); **(8)** micropower electricity production (p. 139); **(9)** selling services instead of goods (p. 336); **(10)** sustainable timber certification (p. 153); **(11)** biodiversity hot spots (p. 168); **(12)** smart urban growth (pp. 98-99); and **(13)** failure of Biosphere 2 (pp. 378-379).

### *Learning Aids*

- Greater use of numbered and bulleted lists to make the book simpler and help students comprehend and review key material.
- Use of questions as titles for all subsections to spark interest and serve as a built-in list of learning objectives for readers.
- Cross-references by page number to link concepts and material throughout the book. This **(1)** emphasizes the basic ecological concept that everything is connected and **(2)** serves as a textbook version of interconnected Web links.
- Addition of comprehensive Review Questions at the end of each chapter.

**Help Me Improve This Book** Let me know how you think this book can be improved; if you find any errors, bias, or confusing explanations please send them to Jack Carey, Biology Publisher, Brooks/Cole, 10 Davis Drive, Belmont, CA 94002 (e-mail: jack.carey@brookscole.com). He will forward them to me. Most errors can be corrected in subsequent printings of this edition rather than waiting for a new edition.

**Acknowledgments** I wish to thank the many students and teachers who responded so favorably to the 4 previous editions of *Sustaining the Earth*, the 12 editions of *Living in the Environment*, and the 8 editions of *Environmental Science* and who corrected errors and offered many helpful suggestions for improvement. I am also deeply indebted to the more than 200 reviewers who pointed out errors and suggested many important improvements in these three books. Any errors and deficiencies left are mine.

The members of the talented production team, listed on the copyright page, have made vital contributions as well. My thanks also go to **(1)** copyeditor Carol Anne Peschke, **(2)** production editors Brooks Ellis and Hal Humphrey, **(3)** Eileen Mitchell, Michael Gutch, and other members of the staff of Electronic Publishing Services Inc. who have improved the design of this edition and made my life much easier, **(4)** Brooks/Cole's hard-working sales staff, **(5)** Pat Waldo and her talented colleagues, who develop multimedia associated with this book, and **(6)** Richard K. Clements for his excellent work on the *Instructor's Manual*.

My deepest thanks go to Jack Carey, biology publisher at Brooks/Cole, for his encouragement, help, 34 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 research assistant and fiancée.

*G. Tyler Miller, Jr.*

# CONTENTS

## Appendixes

# 1 ENVIRONMENTAL ISSUES, THEIR CAUSES, AND SUSTAINABILITY

*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

## 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, p. 2).

**What Is Exponential Growth?** 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.

Any quantity growing by a fixed percentage, even as small as 0.001% or 0.1%, is undergoing exponential growth. If this growth continues, the quantity will experience extraordinary growth as its base of growth doubles again and again. If plotted on a graph, continuing exponential growth of something such as the size of the human population eventually yields a graph shaped somewhat like the letter *J* (Figure 1-1).

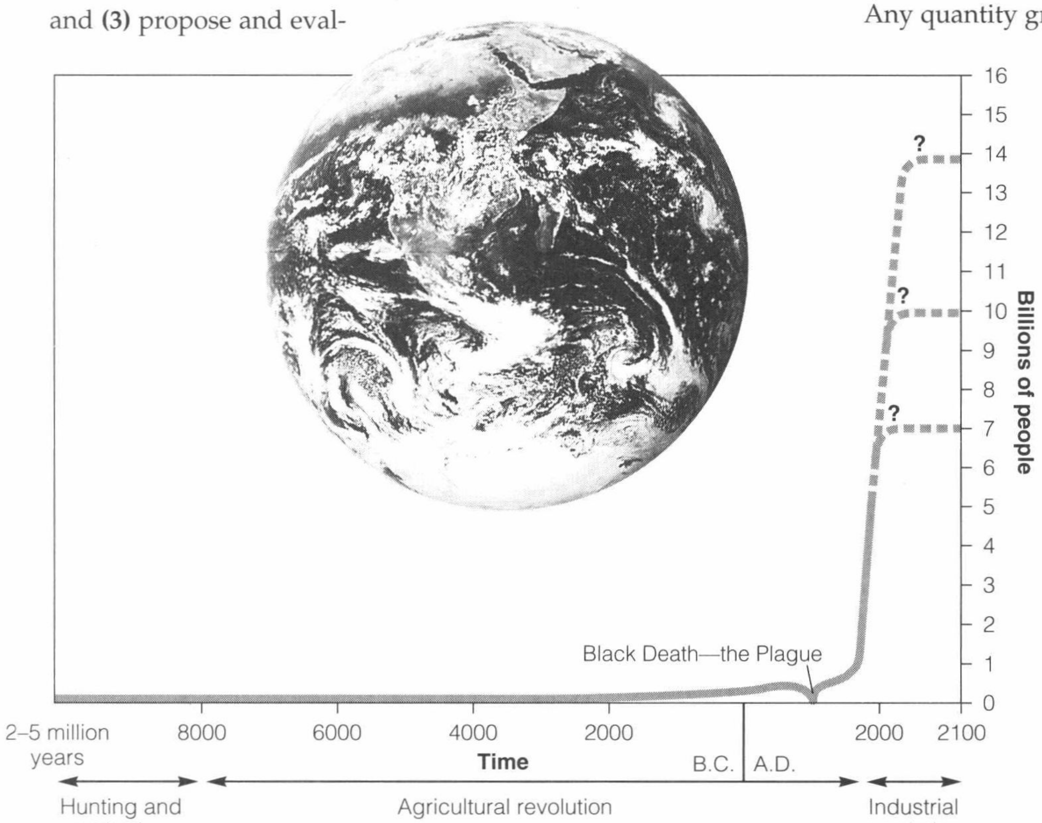


**Figure 1-1** The *J*-shaped curve of past exponential world population growth, with projections beyond 2100. Notice that exponential growth starts off slowly, but as time passes the curve becomes increasingly steep. The current world population of 6.1 billion people is projected to grow to 8–15 billion people during the twenty-first century. (This figure is not to scale.) (Data from World Bank and United Nations; photo courtesy of NASA)

## Cast of Players in the Environmental Drama

SPOTLIGHT

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.

### Critical Thinking

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

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 include **(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*. All these issues are interconnected and are growing exponentially.

For example, world population has more than doubled in 49 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 10–15 billion by 2100 (Figure 1-1). Global economic output, much of it environmentally damaging, is a rough measure of resource use. It has increased almost fivefold since 1950.

There is an abundance of *bad environmental news*. According to leading ecologists and environmental scientists, **(1)** forests are shrinking, **(2)** grasslands are deteriorating from overgrazing by livestock, **(3)** soils are eroding, **(4)** plant and animal species are disappearing, **(5)** fisheries are collapsing, **(6)** rivers are running dry, **(7)** some countries are squabbling over access to shared but limited water supplies, **(8)** underground water is pumped from wells faster than it can be replenished, **(9)** wetlands are disappearing, **(10)** coral reefs are dying, **(11)** temperatures are rising, and **(12)** glaciers are melting. 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.*

During this century, the earth's climate may become warm enough to **(1)** disrupt agricultural productivity, **(2)** alter water distribution, **(3)** drive countless species to extinction, and **(4)** cause economic chaos because of the release of certain gases into the lower atmosphere from burning fossil fuels and the destruction of forests. Extracting and burning fossil fuels (oil, coal, and natural gas) also pollutes the air and water and disrupts the land. Other chemicals we add to the air drift into the upper atmosphere and deplete a gas (ozone) that filters out much of the sun's harmful ultraviolet radiation. Toxic wastes from factories and mines poison the air, water, and soil. Agricultural pesticides contaminate some of our drinking water and food.

There is also some exciting *good news*. Mainly because of improved sanitation and medical advances, average human life expectancy doubled and global infant mortality dropped by almost two-thirds during the 20th century. Since the 1960s global food production has outpaced population growth, thanks mostly to new high-yield forms of agriculture.

Because of improved mining technology, there have been significant increases in proven deposits of almost all the earth's fossil fuel and mineral resources since 1950. Since 1970 air and water pollution levels in most industrialized countries have dropped because of new pollution control laws and technologies. Recently, industrial nations have developed international treaties to phase out production of chemicals that deplete ozone in the upper atmosphere.

**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. 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** (Figure 1-2). **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).

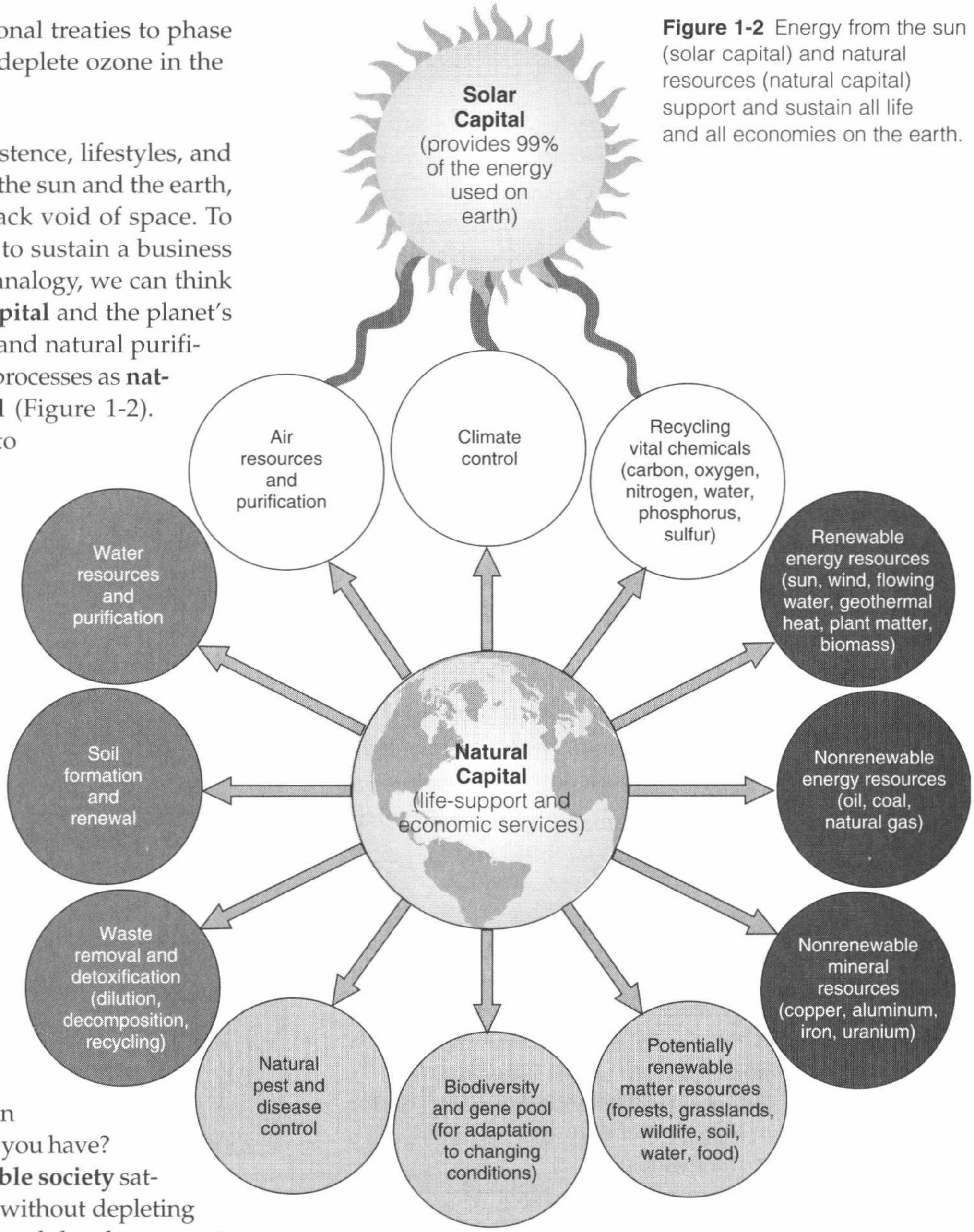


**Figure 1-2** Energy from the sun (solar capital) and natural resources (natural capital) support and sustain all life and all economies on the earth.

**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 respectable and safe work, health care, recreation, cultural opportunities, education, and freedom from physical danger. Can you add any other basic needs that you have?

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 (Figure 1-2) that supplies this income.

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 natural capital (Figure 1-2). 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.

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, AND SUSTAINABLE ECONOMIC DEVELOPMENT

**How Rapidly Is the Human Population Growing?** Evidence from fossils and studies of ancient cultures suggests that the current form of our species, *Homo sapiens sapiens*, has walked the earth for only about 60,000 years (some recent evidence suggests 90,000 to 176,000 years), an instant in the planet's estimated 4.6-billion-year existence.

Until about 12,000 years ago, we were mostly hunter-gatherers who typically moved as needed to find enough food for survival. Since then, there have been three major cultural changes: **(1)** the *agricultural revolution* (which began 10,000–12,000 years ago), **(2)** the *industrial revolution* (which began about 275 years ago), and **(3)** the *information and globalization revolution* (which began about 50 years ago).

These major cultural changes have

- Given us much more energy (Figure 1-3) and new technologies with which to alter and control more of the planet to meet our basic needs and increasing wants
- Allowed expansion of the human population, mostly because of increased food supplies and longer life spans (Figure 1-4)
- Increased our environmental impact because of increased resource use, pollution, and environmental degradation

The increasing size of the human population is an example of exponential growth (Figures 1-1, 1-4, and 1-5 and Spotlight, right). If such exponential growth continues (even at a low percentage of annual growth), eventually the population growth curve rounds a bend and heads almost straight up, creating a *J*-shaped curve (Figure 1-1). The main reason for the rapid growth of the 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 sanitation) than in birth rates.

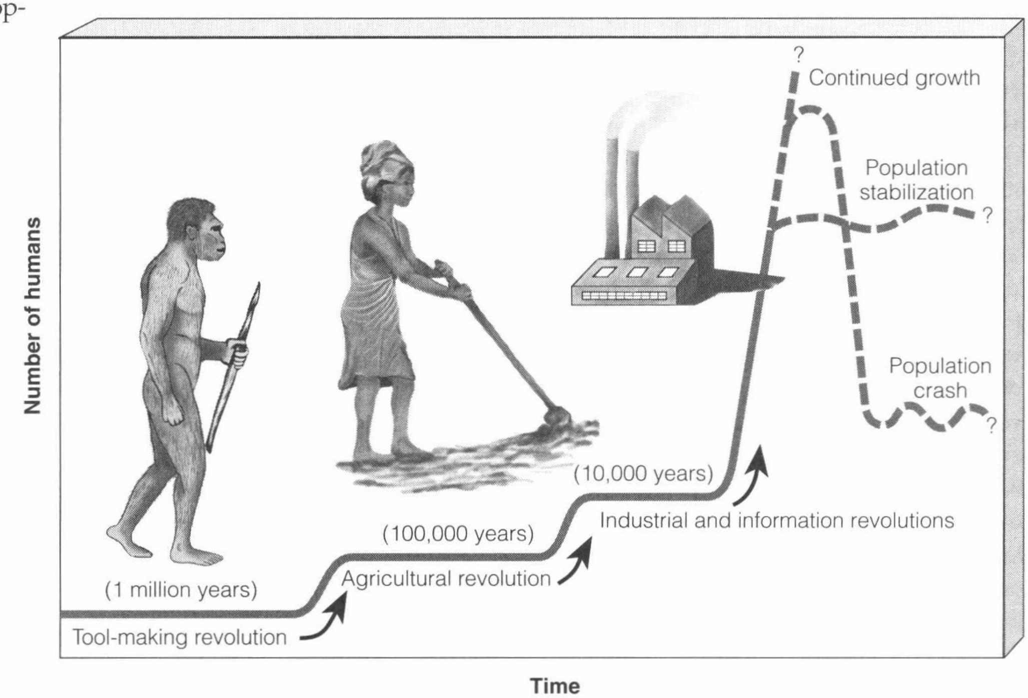


**Figure 1-4** Technological innovations have led to greater human control over the rest of nature and an expanding human population. Dashed lines represent three alternative population futures: **(1)** continued growth (top), **(2)** stabilization (middle), and **(3)** a crash and stabilization at a much lower level.

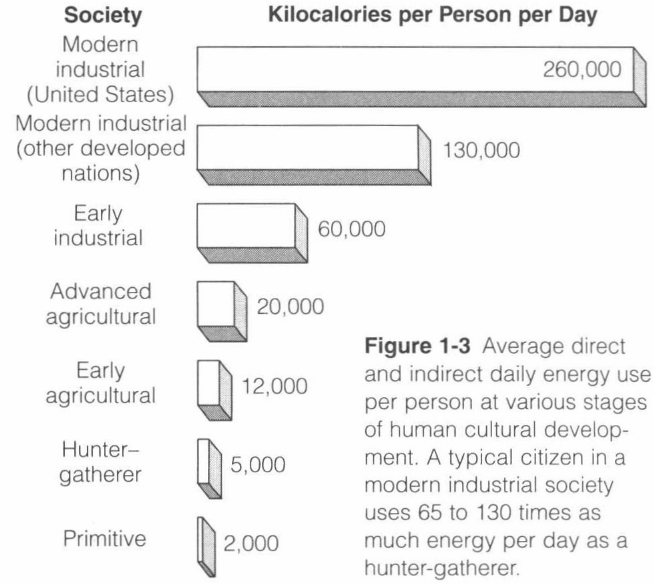


**Figure 1-3** Average direct and indirect daily energy use per person at various stages of human cultural development. A typical citizen in a modern industrial society uses 65 to 130 times as much energy per day as a hunter-gatherer.

**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 for final use during a year
- **Gross domestic product (GDP):** the market value in current dollars of all goods and services produced

## Current Exponential Growth of the Human Population

SPOTLIGHT

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 225,000 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 281 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 1.6 billion kilometers (1 billion miles), you would have to circle the earth about 40,000 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?

**Figure 1-5** World population milestones. (Data from United Nations Population Division, *World Population Prospects, 1998)*

**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)

*within* a country for final use during a year

- **Per capita GNP:** the GNP divided by the total population. It gives the average slice of the economic pie per person.

**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.

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, with 1.2 billion people (20% of the world's population in 2000), **(1)** have about 85% of the world's wealth and income, **(2)** use about 88% of its natural resources, and **(3)** generate about 75% of its pollution and waste.

All other nations are classified as **developing countries**, most of them in Africa, Asia, and Latin America. Their 4.9 billion people (80% of the world's population in 2000) **(1)** have only about 15% of the wealth and income and **(2)** use only about 12% of the world's natural resources. Some are *middle-income, moderately developed countries* with average per capita GNPs of $1,000 to $10,000 per year. Examples are South Africa, Mexico, Argentina, Brazil, Saudi Arabia, Malaysia, and Thailand. Others are *low-income countries* with per capita GNPs less than $1,000 per year. Examples include India, China, Bangladesh, Pakistan, Vietnam, Nicaragua, Haiti, Bolivia, and most of the countries in western, eastern, and central Africa.

More than 95% of the projected increase in the world's population is expected to take place in developing countries (Figure 1-6), *where 1 million people are*

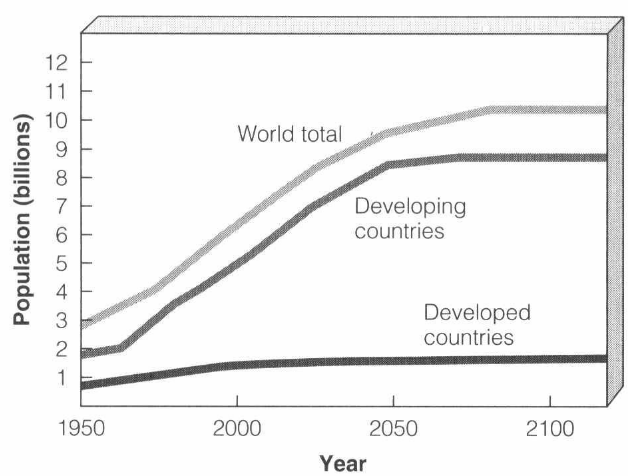


**Figure 1-6** Past and projected population size for developed countries, developing countries, and the world, 1950–2120. More than 95% of the addition of 3.6 billion people between 1990 and 2030 is projected to occur in developing countries. (Data from United Nations)

*added every 5 days*. The primary reason for such rapid population growth in developing countries (1.7% compared to 0.1% in developed countries) is the *large percentage of people who are under age 15* (34% compared to 19% in developed countries in 2000). As these young people move into their prime reproductive years over the next several decades, they will fuel rapid population growth.

**What Is Environmentally Sustainable Economic Development?** Some analysts have called for a shift from emphasis on traditional economic development fueled by economic growth of essentially any type to emphasis on **environmentally sustainable economic development**. This type of development **(1)** *encourages* environmentally sustainable forms of economic growth that meet the basic needs of the current generations of humans and other species without preventing future generations of humans and other species from meeting their basic needs and **(2)** *discourages* environmentally harmful and unsustainable forms of economic growth. In other words, environmentally sustainable economic development is the economic component of *environmentally sustainable societies*.

**What Is the Wealth Gap?** Since 1960, and especially since 1980, the gap between the per capita GNP of the rich, middle income, and poor has widened (Figure 1-7). According to the United Nations, about 1.2 billion people—one person in five—are hungry or malnourished and lack access to clean water, decent housing, and adequate health care. One of every three people lacks enough fuel to keep warm and to cook food and does not have access to electricity. About two-thirds of humanity lacks sanitary toilets and one of every four adults (1.3 billion people) is illiterate.

Daily life is a harsh struggle for the estimated one of every two people on the earth who try to survive on an income of $1–3 per day. Many poor parents have many children as a form of economic security to **(1)** help them grow food, **(2)** gather fuel (mostly wood and dung), **(3)** haul drinking water, **(4)** tend livestock, **(5)** work, **(6)** beg in the streets, and **(7)** help them survive in their old age (typically their 50s or 60s). Poor people

- May deplete and degrade local forests, soil, grasslands, wildlife, and water supplies for short-term survival even though they know it may lead to disaster in the long run
- Often have to live in areas with the highest levels of air and water pollution and with the greatest risk of natural disasters such as floods, earthquakes, hurricanes, and volcanic eruptions
- Spend an average of **(1)** 4–6 hours per day searching for and carrying fuelwood and **(2)** 4–6 hours per week drawing and carrying water

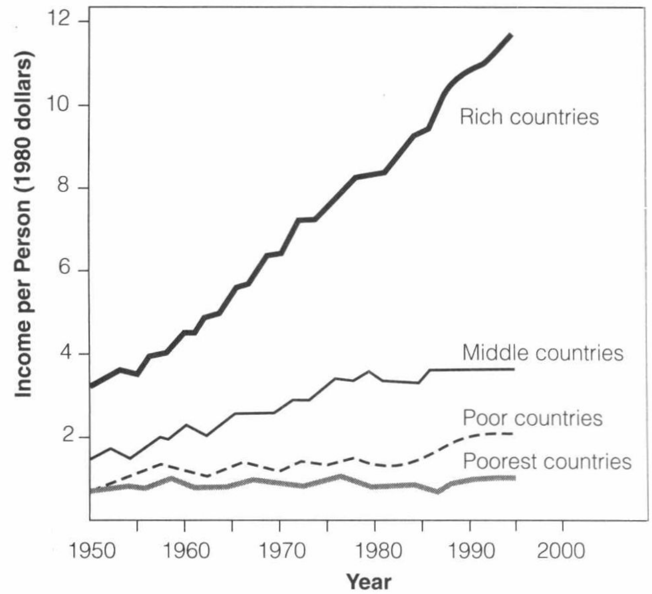


**Figure 1-7** The wealth gap: changes in the distribution of global per capita GNP in high-income, middle-income, low-income, and very low-income countries, 1950–96. Instead of trickling down, most of the income from economic growth has flowed up, with the situation worsening since 1980. More than 1 billion people survive on less than $1 a day. (Data from United Nations)

- Must take jobs (if they can find them) that subject them to unhealthy and unsafe working conditions at very low pay

According to the World Health Organization (WHO), each year, at least 10 million of the desperately poor die prematurely of **(1)** malnutrition (lack of protein and other nutrients needed for good health), **(2)** increased susceptibility to infectious diseases because of their weakened condition from malnutrition, and **(3)** infectious diseases from drinking contaminated water. *This premature death of about 27,400 human beings per day is equivalent to 69 jumbo jet planes, each carrying 400 passengers, crashing every day with no survivors*. Half of those dying are children under age 5.

Mostly because of the high use of natural resources in developed countries, the environmental impact or *ecological footprint* per person in developed countries is large compared with that in developing countries (Figure 1-8).

## 1-3 RESOURCES

**What Is a Resource?** From a human standpoint, a **resource** is anything obtained from the environment to meet human needs and wants. Examples include food, water, shelter, manufactured goods, trans-

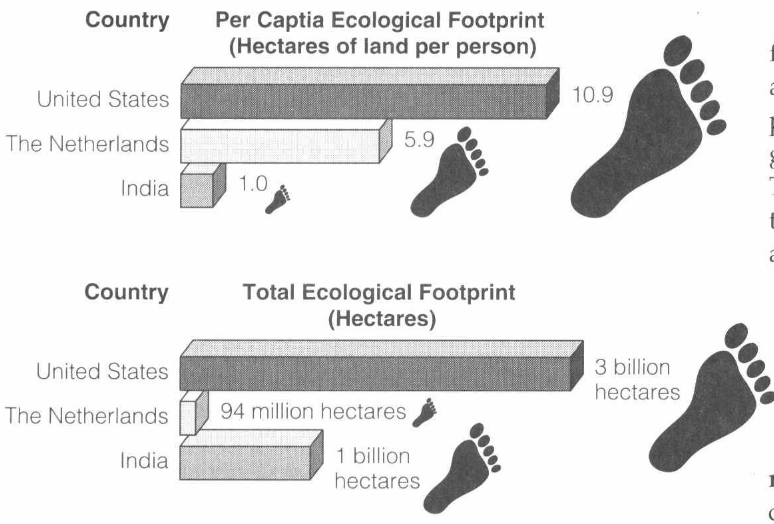


**Figure 1-8** Relative ecological footprints of the United States, the Netherlands, and India. An *ecological footprint* is the amount of land needed to produce the resources needed by an average person in a country. The total ecological footprint for the 16 million people living in the Netherlands is 15 times the country's area. Indeed, it would take the land area of about three earths if all the world's 6.1 billion people consumed the same amount of resources as is consumed by the 281 million people in the United States.

portation, communication, and recreation. On our short human time scale, we classify the material resources we get from the environment as **(1)** *perpetual*, **(2)** *renewable*, or **(3)** *nonrenewable* (Figure 1-9).

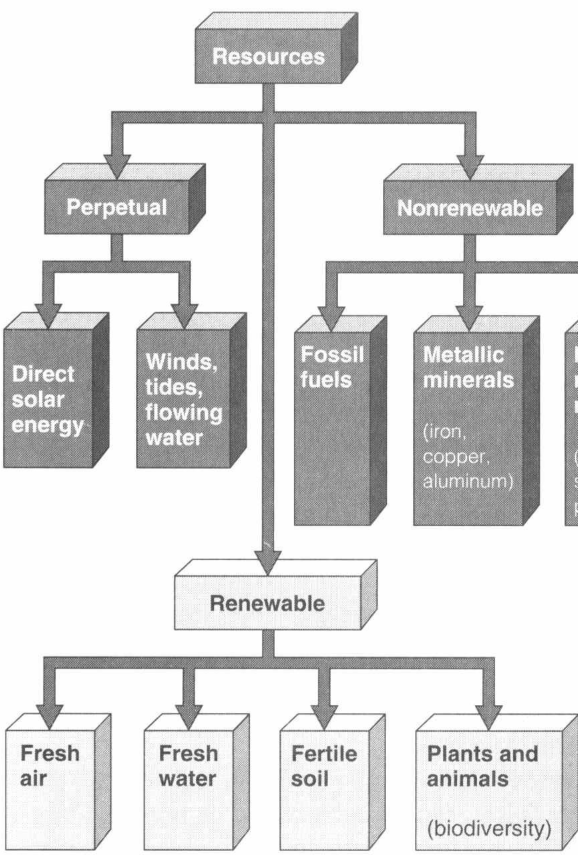


**Figure 1-9** Major types of material resources. This scheme is not fixed; renewable resources can become nonrenewable if used for a prolonged period at a faster rate than they are renewed by natural processes.

Some resources, such as solar energy, fresh air, wind, fresh surface water, fertile soil, and wild edible plants, are directly available for use. Other resources, such as petroleum (oil), iron, groundwater (water found underground), and modern crops, are not directly available. They become useful to us only with some effort and technological ingenuity. For example, petroleum was a mysterious fluid until we learned how to find, extract, and convert (refine) it into gasoline, heating oil, and other products that could be sold at affordable prices.

**What Are Perpetual and Renewable Resources?** Solar energy is called a **perpetual resource** because on a human time scale it is renewed continuously. It is expected to last at least 6 billion years as the sun completes its life cycle.

On a human time scale, a **renewable resource** can be replenished fairly rapidly (hours to several decades) through natural processes as long as it is not used up faster than it is replaced. These resources are *flow resources* that pass through plants, economies, and other systems. They are endlessly renewable but only at the rate at which nature provides them. Examples are **(1)** forests, **(2)** grasslands, **(3)** wild animals, **(4)** fresh water, **(5)** fresh air, and **(6)** fertile soil.

However, renewable resources can be depleted or degraded. The highest rate at which a renewable resource can be used *indefinitely* without reducing its available supply is called **sustainable yield**.

If we exceed a resource's natural replacement rate, the available supply begins to shrink, a process known as **environmental degradation**. Examples of such degradation include **(1)** urbanization of productive land, **(2)** waterlogging and salt buildup in soil, **(3)** excessive topsoil erosion, **(4)** deforestation, **(5)** groundwater depletion, **(6)** overgrazing of grasslands by livestock, **(7)** reduction in the earth's forms of wildlife (biodiversity) by elimination of habitats and species, and **(8)** pollution.

Such forms of environmental degradation can change usable, renewable resources into nonrenewable or unusable resources. A major cause of environmental degradation of renewable resources is a phenomenon known as the *tragedy of the commons* (Connections, p. 8).

CONNECTIONS

## Free-Access Resources and the Tragedy of the Commons

One cause of environmental degradation is the overuse of **common-property** or **free-access resources**. Such resources are owned by no one (or jointly by everyone in a country or area) but are available to all users at little or no charge.

Examples include **(1)** clean air, **(2)** the open ocean and its fish, **(3)** migratory birds, **(4)** wildlife species, **(5)** publicly owned lands (such as national forests, national parks, and wildlife refuges), **(6)** gases of the lower atmosphere, and **(7)** space.

In 1968, biologist Garrett Hardin called the degradation of renewable free-access resources the **tragedy of the commons**. It happens because each user reasons, "If I do not use this resource, someone else will. The little bit I use or pollute is not enough to matter, and such resources are renewable."

With only a few users, this logic works. However, the cumulative effect of many people trying to exploit a free-access resource eventually exhausts or ruins it. Then no one can benefit from it, and therein lies the tragedy.

Two solutions to this problem are to

- *Use free-access resources at rates well below their estimated sustainable yields or overload limits by reducing population, regulating access, or both.* This prevention approach is rarely used because **(1)** it entails establishing and enforcing regulations that restrict resource use or population growth, and **(2)** it is difficult and expensive to determine the sustainable yield of a forest, grassland, or animal population because such yields vary with weather, climate, and unpredictable biological factors.
- *Convert free-access resources to private ownership.* The reasoning is that owners of land or some other resource have a strong incentive to protect their investment. However, this approach is not practical for global common resources (such as the atmosphere, the open ocean, most wildlife species, and migratory birds) that cannot be divided up and converted to private property.

Experience shows that there is another possibility. Just because a resource is easily available to a community does not always mean that people have free and unregulated access to that resource. There are many examples in which communities have established a set of rules and traditions to regulate and share their access to a common-property resource such as fisheries, grazing lands, and forests.

### Critical Thinking

Give three examples of how you cause environmental degradation as a result of the tragedy of the commons. How should we deal with this problem? Explain.

**What Are Nonrenewable Resources?** Resources that exist in a fixed quantity or stock in the earth's crust are called **nonrenewable resources**. On a time scale of millions to billions of years, geological processes can renew such resources. However, on the much shorter human time scale of hundreds to thousands of years, these resources can be depleted much faster than they are formed.

These exhaustible resources include **(1)** *energy resources* (such as coal, oil, and natural gas, which cannot be recycled), **(2)** *metallic mineral resources* (such as iron, copper, and aluminum, which can be recycled), and **(3)** *nonmetallic mineral resources* (such as salt, clay, sand, and phosphates, which usually are difficult or too costly to recycle).

A **mineral** is any hard, usually crystalline material that is formed naturally. We know how to find and extract more than 100 nonrenewable minerals from the earth's crust. We convert these raw materials into many everyday items and then we discard, reuse, or recycle them.

We never completely exhaust a nonrenewable mineral resource, but such a resource becomes *economically depleted* when the costs of extracting and using what is left exceed its economic value. At that point, we have six choices: **(1)** try to find more, **(2)** recycle or reuse existing supplies (except for nonrenewable energy resources, which cannot be recycled or reused), **(3)** waste less, **(4)** use less, **(5)** try to develop a substitute, or **(6)** wait millions of years for more to be produced.

Some nonrenewable material resources, such as copper and aluminum, can be recycled or reused to extend supplies. **Recycling** involves collecting and reprocessing a resource into new products. For example, glass bottles can be crushed and melted to make new bottles or other glass items. **Reuse** involves using a resource over and over in the same form. For example, glass bottles can be collected, washed, and refilled many times.

Recycling nonrenewable metallic resources takes much less energy, water, and other resources and produces much less pollution and environmental degradation than exploiting virgin metallic resources. Reusing such resources takes even less energy than other resources and produces less pollution and environmental degradation than recycling.

Nonrenewable energy resources, such as coal, oil, and natural gas, cannot be recycled or reused. Once burned, the useful energy in these fossil fuels is