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# Sustainable Solutions

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PROBLEM SOLVING FOR CURRENT AND FUTURE GENERATIONS

**Richard Niesenbaum**

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*Professor Muhlenberg College*

New York Oxford  
OXFORD UNIVERSITY PRESS

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Published in the United States of America by Oxford University Press  
198 Madison Avenue, New York, NY 10016, United States of America.

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CIP data is on file at the Library of Congress  
978-0-19-939043-4

987654321

Printed by Sheridan Books, Inc., United States of America

*This book is dedicated to my children Sophie and Jonah, and their  
children and their children and their children . . .*

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## Preface

These are seemingly desperate times as we are bombarded with an endless supply of bad news billed as insurmountable problems that relate both to the declining state of our planet and to the human condition. This book is inspired by these times and the fact that despite their overwhelming nature, there exist realistic solutions to these problems. It serves to negotiate the tension between a growing sense of powerlessness and a palpable desire for effecting change that resides within us. It offers the optimistic possibility for workable solutions to the complex problems that confront us.

### An Integrative, Problem-Solving Approach

Sustainability is an ideal framework for the development of solutions to many of these problems. Broadly defined as meeting the needs of the present without compromising the ability of future generations to meet their own needs, sustainability is a framework that integrates science with justice, economics, and policy. This book offers its readers opportunities to engage in this integration as part of a problem-solving approach. Policy, economics, and social elements are not isolated at the end of chapters, nor as separate chapters at the end of the book. Rather, each chapter provides the scientific basis to problems and their solutions; each does so within the context of economic development, policy, and social justice in order to reveal the complexity of the problems and sustainable solutions to them. This offers the interdisciplinary background that is required to understand many of these complex challenges, and it equips readers with the skills needed to develop solutions to them.

Readers will have opportunities to integrate across disciplines in order to better understand how things such as individuals and institutions, novel collaborations, innovation and entrepreneurship, new

technologies, and policy decisions can be used to achieve sustainable solutions. The book offers readers opportunities for critical thinking, further action, and group work. Also, because of its intended interdisciplinary audience, the book is designed to be accessible to readers with varied backgrounds and interests in science and technology, public policy, economics, social justice, and public health. It provides substantial background for those interested in sustainability/social entrepreneurship, green business, and other careers that incorporate sustainability principles. It is also accessible to a broader audience of non-academic readers with an interest in sustainability.

*Sustainable Solutions* provides both the necessary background in science and a broad, interdisciplinary knowledge base that the reader can then connect to specific disciplines, such as environmental science, engineering, agriculture and food science, business, natural resource management, and public health. It prepares the reader to approach sustainable problem solving at a variety of scales from personal behavior to institutional- and community-level problem solving and up through regional, national, and global scales. Each chapter emphasizes skills such as how to identify and work with stakeholders on a particular issue, program assessment, and systems thinking. My hope is that this book will lay the groundwork for training of sustainability professionals and those in other careers that link to sustainability and that it will also empower everyday citizens to effectively act and engage with others in ways that further sustainability objectives.

### Organization of the Book

Chapters are organized into three overarching sections. Part I, *The Problems We Must Solve*, introduces a variety of global concerns and issues as a context for sustainable problem solving. It then walks the reader through an exercise in developing a working

definition of sustainability by first tracing its history and then extracting the core principles that emerge from that history. Once defined, a detailed approach to applying sustainability objectives to problem-solving skills and assessment of sustainable programs or projects is developed.

Part II, *The Earth as a Resource: Moving Toward a Sustainable Future*, focuses on the use of our planet for meeting the needs of humans. In each of the content areas (air, water, food, energy, non-fuel extractive resources, and waste), issues are identified and solutions are offered using the approach developed in Part I. Potential solutions are examined critically. Tools such as life cycle analysis and systems thinking are used to assess a variety of "sustainable technologies" to reveal both the positive and the negative aspects of things such as wind turbines, genetically modified organisms, and waste-to-energy. A goal of this book is not to get readers to blindly accept an approach as sustainable but, rather, to offer ways to critically examine potential solutions in order to assess their potential to contribute to sustainability and consider ways to improve upon them. Each chapter highlights the barriers to sustainability and ways to overcome them, and each ends with a discussion on assessment and of common elements for success.

Part III, *Integrating Sustainable Solutions at Different Levels of Organization*, focuses on sustainability, starting with the individual and then moving up hierarchically through institutions, communities, and cities to global sustainability and sustainable development. This section allows the reader to make connections among the prior chapters. By working at various levels of organization, the intersectionality of the themes presented in Part II becomes apparent. For example, a community is not simply faced with a single issue such as local food production. Rather, it faces multiple interconnected issues. Food, energy, water, forest and mineral resources, and waste production are all related. These in turn intersect with race, gender, culture, and poverty. It is through these connections that

the systematic causes of problems are exposed, and proposals for larger scale reform such as new economic models, international policy, and approaches to development are explored.

## Features

To help accomplish the goals of this book, a variety of features are employed. At the start of each chapter, the reader is guided with questions framed as **Planting a Seed: Thinking Before You Read**, and opportunities for critical thinking are offered at the end of every chapter under **Digging Deeper: Questions and Issues for Further Thought**. Each chapter concludes with specific ways for the reader to act in order to further sustainability objectives described as **Reaping What You Sow: Opportunities for Action**.

Also included are boxed elements that offer real examples of sustainable problem solving relevant to the focus of each chapter. Boxes on **Individual Action** challenge readers to think about what personal changes they can make to solve the problems by highlighting examples of successful individual actions, including behavioral change, effective dialog, and activism. This is done in a critical way, forcing readers to think about the complexity of their actions and the various implications of these actions. Boxes on **Stakeholders and Collaborators** focus on identifying and working with stakeholders, and they highlight examples in which individuals and groups that at first glance seem at odds with each other can come together on shared values to solve a current problem. Another feature, **Innovators and Entrepreneurs**, presents specific examples of how innovation and social entrepreneurship can be successful in achieving sustainability, offering a business perspective to problem solving. Each chapter also has a boxed element on **Policy Solutions** that emphasizes policy approaches and the role of government in working toward a sustainable future.

## Acknowledgments

So many people have inspired, encouraged, helped, and supported me in writing this book. I have been fortunate to have spent the past 25 years at Muhlenberg College, a liberal arts college that is strong in the sciences and that values integrative teaching and learning across disparate disciplines. I have had the opportunity to collaborate with colleagues who are in academic programs in art, foreign languages, sociology, chemistry, media and communications, mathematics, political science, and entrepreneurial studies. This has made Muhlenberg my laboratory where I have been able to cultivate my expertise in the broad area of sustainability.

I have been surrounded and inspired by students dedicated to the cause of sustainability both as activists and as practitioners. Included among them are Hailey Goldberg, Hannah Bobker, Alison Barranca, Allie Heckerd, Felisa Wiley, and Chris Woods, who served as research assistants and made significant contributions to this book. The Muhlenberg College Provost's Office and Rita and Joseph Scheller and their family that endow my professorship through the RJ Foundation have provided me with both time and resources necessary to complete such an extensive project.

This project would not have been possible without the expert assistance of the many reviewers who offered constructive criticism and helped me get all the details as they should be. These scholars who have truly influenced the direction of this book include the following:

- Lisa Barlow, University of Colorado
- Shaunna Barnhart, Bucknell University
- Richard Bowden, Allegheny College
- John Cusick, University of Hawaii at Manoa
- Mark Davies, Hartwick College
- Chris Doran, Seaver College
- Michael Duncan, Washington and Lee University
- Jim Feldman, University of Wisconsin-Oshkosh
- Eric Fitch, Marietta College

- Robert Giegengack, University of Pennsylvania
- Greg Gordon, Gonzaga University
- Juliette Goulet, Brookdale Community College
- Patrick Hurley, Ursinus College
- Jon Jensen, Luther College
- Dwane Jones, University of the District of Columbia
- Nancy E. Landrum, Loyola University Chicago
- William McClain, Davis & Elkins College
- Sherie McClam, Manhattanville College
- Mark O'Gorman, Maryville College
- Jeffrey Paine, Indiana University-Purdue University Indianapolis
- Jason Patalinghug, Southern Connecticut State University
- Hamil Pearsall, Temple University
- Jay Roberts, Earlham College
- Suzanne Savanick Hansen, Macalester College
- Adrienne Schwarte, Maryville College
- Charles Scruggs, Genesee Community College
- Vincent Smith, South Oregon University
- Alicia Sprow, Alvernia University
- Ninian Stein, Tufts University
- Deborah M. Steketee, Aquinas College
- Jennie C. Stephens, Clark University
- Barbara Szubinska, Eastern Kentucky University
- Laine Vignona, Lake-Sumter State College
- Bill Vitek, Clarkson University
- Kenneth Worthy, University of California, Berkeley
- Jim Zaffiro, Central College

I also thank the many people at Oxford University Press who have been instrumental in making this project happen, particularly Executive Editor Dan Kaveney and Assistant Editor Megan Carlson. They served as my sounding board, my guides, my critics, and my cheerleaders. They have been great listeners and put a lot of faith in me as we boldly navigated into the new academic area of sustainability studies. In addition, I

thank Rachel Schragis, the coordinator of the People's Climate March Arts Team, and the others who contributed to the image *Confronting Climate* for their permission to use part of it as the cover of this book. This work both celebrates the important role of art in social movements and embraces the complexity, breadth, intersectionality, and conflicting imperatives that are central to this book.

Brenda Casper, Daniel Janzen, Peter Petraitis, Andrew Friedland, Norris Muth, Emily Mooney, Graham Watkins, Jack Gambino, Tim Averill, Rita Chesterton, The Sea Education Association, The School for Field Studies, POWER Lehigh Valley, Beth Halpern, Mark Plotkin, David Orr, Kathrine Hayhoe, Kalyna Procyk, Tim Averill, Tammy Lewis, Carlos Fonseca, Elieth Montoya, Clark Gocker, Lora Taub-Pervizpour, and Kimberly Heiman have profoundly influenced my thinking and teaching about sustainability, the connections between people and environment, and social justice. I also owe my gratitude to Krista Bywater, S. Mohsin Hashim, Christopher

Borick, Barry Rabe, Joseph Elliott, and Greta Bergstressor for making direct contributions of their own work in the form of boxed elements or images. Others, such as Barbara Niesenbaum, Elizabeth Dale, Vladimir and Jesse Salamun, Varina Doman, Mohammad Kahn, Nicole Karsch, Megan Leahy, Tracy Librick, Tim Averill, Tim Clarke, Jessie Gocker Nimeh, Jen Jarson, and Almut Hupbach provided other important forms of support.

I would not have been able to complete a work of this magnitude without the love and support of my close friends and family, many of whom have already been mentioned. In particular, I thank one of my closest friends, Jeffrey Frank, a farmer who stimulates and relentlessly challenges my thinking about sustainability, typically over a good meal. Finally, I thank my children Sophie and Jonah Niesenbaum, who taught me empathy, patience, and how to really listen. These abilities are not only essential for working in the area of sustainability but also serve to fuel my optimism and hope in these challenging times.

## CHAPTER 1

# THE PROBLEMS WE MUST SOLVE

We are living in complicated and often frightful times confronted by many serious environmental, economic, social, political, and geopolitical challenges that seem insurmountable. However, it is important to recognize that these problems we face are solvable. Changes in individual behaviors, advances in science and engineering, new technologies, innovative economic and business models, creative government policies, and novel collaborations among diverse members of society have great potential to generate workable solutions. Through innovation and action, we can make our planet a better place to live for all people, not just in the present but for future generations as well. The question, however, is will we make these changes and further develop and implement necessary solutions in order to do so?

### PLANTING A SEED: THINKING BEFORE YOU READ

1. List what you believe to be the five most challenging problems that confront us.
2. Draw a diagram that shows the interrelatedness of these problems.
3. Make a list of the barriers that seem to stop us from solving these problems.
4. Propose some realistic ways to overcome these barriers and examples of possible solutions to these problems.

*Optimism is a strategy for making a better future. Because unless you believe that the future can be better, you are unlikely to step up and take responsibility for making it so.*

—Noam Chomsky

A recent study of US college and university students suggests that the answer to this question is no. It revealed that you, our current generation of young and emerging adults, the likely readers of this book, have disengaged from thinking about social and environmental problems. Your trust in others and interest in government have declined compared to prior generations.<sup>1</sup> Such disengagement and skepticism are apparently due to the fatigue and frustration from hearing about these problems as insurmountable. The majority of books, news, and lectures regarding the environment, the human condition, and sustainability discuss them within the context of impending calamity. They highlight our squandering of resources and the poisoning of our air, water, and children. They place us at a precipice teetering toward global disaster. They refer to conflicts between ecology and economics and to corporate control over government policy. They paint our global citizenry as greedy, ignorant, or both. Individuals are viewed as either powerless victims or selfish overconsumers who have no opportunity to make a difference. You, the generation with relatively fewer opportunities and higher levels of debt than previous generations, see the system as rigged. As a result, positive change often seems out of reach.

Today's students are left with a sense of powerlessness and disempowering guilt. They are justifiably taught that they, as "First World" capitalists, are the primary cause of this impending collapse. However, they are typically not taught that there are indeed solutions to these problems and that they—as the most tech-savvy, collaborative, innovative, connected, and resourceful generation—can contribute to them in significant ways.

Our educational system and even the popular media have typically been effective at making us aware of the problems that confront us, but they have done less to spawn and train new generations of committed problem solvers. Certainly, one must define problems in order to generate solutions. However, this dismal perspective about our future prospects, although very much justified, may be the exact thing that is inhibiting our potential to generate creative, practical solutions to global problems and, more important, to engage our citizenry in working toward those solutions.

Fortunately, there is much to be hopeful about. We have begun to understand that we as individuals, social groups, communities, institutions, and governments can play a major role in the creation of a just

and sustainable future in terms of the health of our planet and the well-being of all people. We have come to recognize that our own education system fails us in that its graduates have been the ones most responsible for our mismanagement of planet Earth.<sup>2</sup> The seeds of transformation in the way we teach, do business, and act as individuals have been planted, and their growth is being amplified through the use of social media, the development of new technologies, and fundamental changes in values.<sup>3</sup>

This transformation is beginning to yield positive results. Here, I list just a few examples drawn from websites, reports, blogs, and news stories that appear across my screens on a daily basis:

- There are now more than 1,530 interdisciplinary, sustainability focused academic programs at 564 campuses in 67 states and provinces and 23 countries. These numbers will continue to rise.
- In 2015, more than 62.8 million US citizens volunteered more than 7.9 billion hours. This included one in five millennials.
- In 2014, China's top legislature approved major amendments to the country's 25-year-old Environmental Protection Law calling for much greater regulation of and stiffer penalties for polluters.
- In Asia, the cost of energy generated by solar photovoltaic cells has substantially decreased so that it is now competitive with fossil fuels without being subsidized.
- Between 1990 and 2010, more than 2 billion people gained access to improved drinking water sources, and the proportion of people using an improved water source increased from 76% to 89%.
- Since 1991, the United Nations has allocated \$8.8 billion and provided \$38.7 billion in co-financing for environmental projects in developing countries.
- One creative entrepreneur, Kavita Shukla, developed a simple, affordable product that can extend the life of fruits and vegetables by two to four times even for the billions of people who live without refrigeration.
- Through the collaborative efforts of diverse community members, Samsø Island in Denmark now generates more power from renewable sources than it consumes and has a net negative carbon footprint.

- From 2010 to 2020, the global market for environmental products and services is projected to double from \$1.37 trillion to \$2.74 trillion per year.

Of course, not all of the news is good, but this list does show tangible improvement in our environmental and human prospects and also that individuals, communities, organizations, and even governments can achieve positive results. The goal of this book is to inspire and empower you, the reader, to become an active participant in generating solutions to the problems we face. You are part of a diverse audience with a variety of backgrounds that might include business, science, engineering, education, international development, policy and law, communications, agriculture, technology, the humanities and arts, or any of the trade professions. This book will allow you to place the presented problems within the context of your own expertise or interest and to see how that expertise connects to these problems and their solutions.

This book will teach you how to develop solutions to environmental and social problems by first providing you with the interdisciplinary background that is required to understand the many complex problems that we face. Then we will provide you with a framework for defining problems and offer specific competencies to approach and solve them. Through globally diverse examples at many different levels of organization we will offer you recipes for success and concrete ways to overcome barriers to change. By critically examining these examples you will begin to see what works and what constrains success, and also how to assess or measure that success.

In this chapter, we first establish a broad context for examining global problems. Then in Chapter 2, we use a historical approach to develop a definition for sustainability that will serve as our lens for examining problems and developing solutions. The next set of chapters are thematically organized by the ways in which we depend on our planet and the impacts we have on it as we do so. These include air, water, food, energy, non-energy extractive resources, and waste. In the final section, we re-organize our thinking around different levels of organization to which we will apply what we have learned in the previous chapters. These levels include the roles of the individual and institutions and how problems can be solved by communities, cities, regions, and on a global scale.

## Natural Resources and Environmental Issues

In this section, we introduce some of the basic background required to understand the environmental issues we face. First, we examine them in relation to the natural resources on which we depend. Then we explore global environmental issues such as climate change and the impacts of invasive species. We next consider the services that our ecosystems perform and the value of biodiversity and the urgent need to protect them and to incorporate their value into our economic system. As we introduce these environmental problems and issues, we begin to suggest the broader possibilities for solutions that will be elaborated on in subsequent chapters.

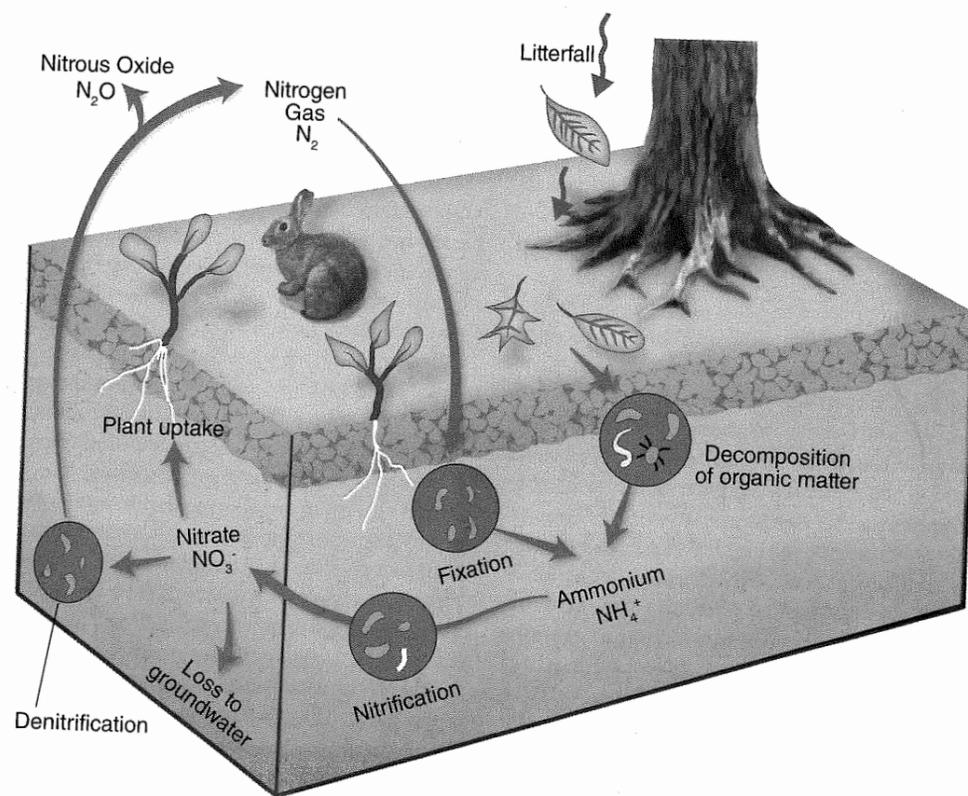
### Natural Resources

To state the obvious, our lives depend on what the Earth provides. Natural resources are materials that can be found within the environment that are either necessary or useful to humans. Resources are often referred to as natural assets that can serve as raw materials to be used for economic production or consumption. **Ubiquitous resources** are those that can be found everywhere, such as sunlight, water, and air. Others, such as mineral resources, occur more locally. Resources can be classified as **biotic** or **abiotic**. Biotic resources come from live organisms and organic matter. Examples include forest and animal products and also fossil fuels, which come from decayed organic matter. Abiotic resources are non-living, inorganic materials such as minerals, metals, air, and water.

Matter can be neither created nor destroyed, and all resources cycle through components of the biosphere or environment occupied by living organisms. For example, nitrogen cycles from the atmosphere to soil and aquatic environments and into living organisms, in which it is often converted into different forms through biological processes (Figure 1.1). The temporal scale of this cycling is highly variable among different resources. The temporal scale of cycling determines the rate of recovery or regeneration. Resources with short periods of regeneration are considered **renewable resources**, and those with slow rates of replenishment are **non-renewable resources**. From a human use perspective, when the rate of extraction outpaces the rate of renewal for a particular

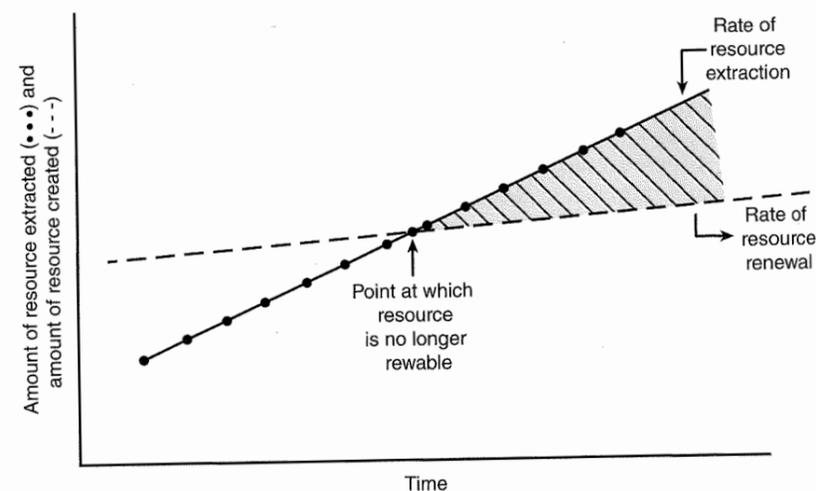
resource, that resource is considered non-renewable (Figure 1.2).

Because most of our natural resources come in fixed amounts and their regeneration is a slow process, there is concern that we will deplete them and therefore will be unable to meet the needs of future generations. Resources on which humans depend are threatened either from overextraction and depletion or from destruction through pollution or other types of human disturbance. Some estimates reveal that our use of resources well exceeds the biosphere's capacity to regenerate them and that within the next 20 years, two planets will not be sufficient to meet human resource needs on our single globe.



**Figure 1.1** Schematic representation of the flow of nitrogen through the environment, including atmospheric, soil, and biotic components. The bulk of nitrogen is in the atmosphere and can only be used by microbes that convert it into useable nitrogen for plants and other organisms through the process of nitrogen fixation. Useable nitrogen is also added to the soil through the decomposition of organic material. Denitrifying bacteria convert nitrate back into atmospheric  $N_2$  to derive energy.

Some question this finite view of resource availability. The case is often made that technological advances will allow us to do more with less or develop new alternative ways to extract resources. This notion was promoted by Julian Simon, who in the 1980s authored a controversial book titled *The Ultimate Resource*.<sup>4</sup> Simon argues that there is no resource crisis. His reasoning is that as a resource becomes scarce, its price will rise, creating an incentive for people to discover more of that resource, ration and recycle it, and eventually, stimulate innovators to find a replacement for that resource. The "ultimate resource" is not any particular physical object but, rather, the capacity for humans to invent and adapt.



**Figure 1.2** The amount of resource extracted (•••) and the amount of resource regenerated (- - -) over time. The slope of each line represents the rate of use or renewal. In this example, the rate of resource extraction exceeds that of renewal. The point at which the lines meet is when the resource can no longer be considered renewable (shaded area). For many of our natural resources, that rate of extraction far exceeds the rate of renewal. Courtesy R. Niesenbaum.

These arguments are somewhat flawed in that they do not take into account impacts beyond the specific resource. For example, recycling technology, such as our ability to recycle aluminum, has allowed resources with slow rates of regeneration to become renewable, but not without the expense of energy. **Hydrofracturing** (fracking) technology has allowed for continued exploitation of fossil fuels beyond limits based on prior extraction technologies, but not without serious impacts and threats to other environmental components such as drinking water. It is useful to explore how technologies can both improve efficiency of extraction and use of natural resources and also how innovation can help us do this and develop alternative resources. However, this must be done within the broader context of natural resource management, energy use, and environmental impact. Next, some examples of natural resources are presented with explanations of how they cycle through the environment and the degree to which they may be renewable.

#### AIR

Air is an abiotic, renewable resource. The manner in which it cycles is more complicated because air consists of a variety of components that enter into

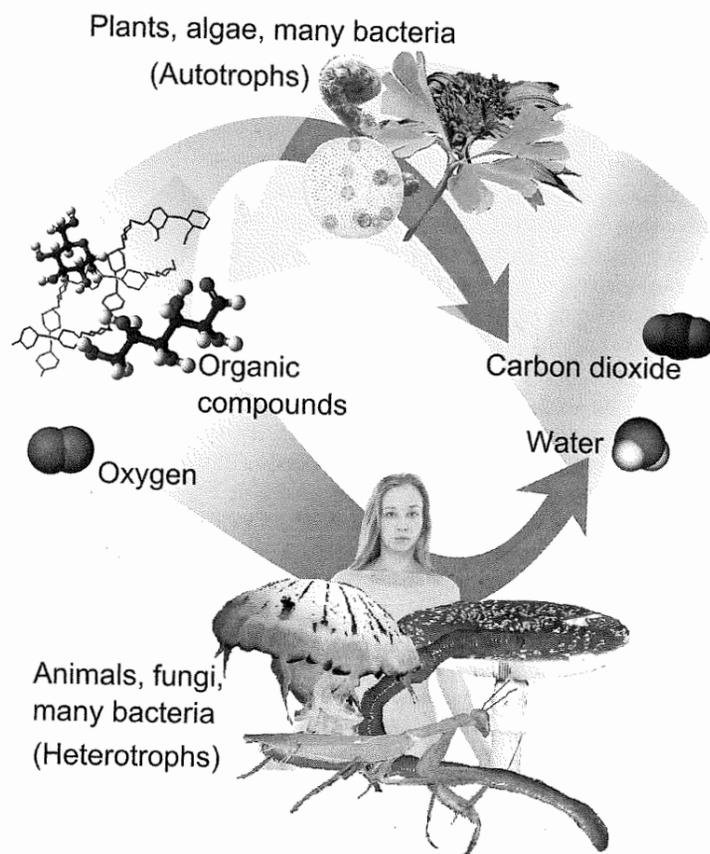
different, somewhat complex cycles. By volume, dry air contains approximately 78% nitrogen, 21% oxygen, and smaller amounts of carbon dioxide, argon, water vapor, and other gases. Oxygen, carbon dioxide, and nitrogen cycle through biotic systems and are vital to living systems (Figures 1.1 and 1.3). Oxygen and carbon dioxide are cycled through the processes of photosynthesis, respiration, and decomposition. They are vital for living organisms. Carbon is stored in a variety of reservoirs, including soil, the ocean, biomass, rock, and as fossil fuels. Carbon dioxide is released during the burning of stored sources including fossil fuels and rock sources through volcanic activity. These have led to a steady increase in atmospheric carbon dioxide, which is a significant **greenhouse gas** contributing to **global climate change**, as will be addressed later in this chapter.

Nitrogen is the most abundant element in our atmosphere. It is also a vital element because compounds essential to living systems, such as protein and DNA, contain nitrogen. Ironically, most life forms, including all plants and animals, are unable to utilize nitrogen in its most abundant form, dinitrogen gas ( $N_2$ ). Fortunately, specialized groups of microorganisms are capable of nitrogen fixation. **Nitrogen fixation** is

the reduction of  $N_2$  gas to ammonia  $NH_4^+$  using a class of enzymes called nitrogenases to catalyze the reduction. This is an energy-intensive process, so these microbes are typically either photosynthetic or in symbiotic relationships with plants. Photosynthesis provides the needed energy. There are also denitrifying bacteria that oxidize useable nitrogen to generate energy and return  $N_2$  back into the atmosphere (see Figure 1.1).

Although air and its constituents cycle over relatively short timescales, making it comparatively renewable, human activity has drastically influenced these cycles and negatively impacted air quality. Air pollutants in the form of carbon, nitrogen, and sulfur oxides; suspended particulates; ozone; and volatile organic and other types of compounds have been a serious threat to human and ecological health. Given the vital nature of air for living organisms, it is important that we develop solutions to the problem of air

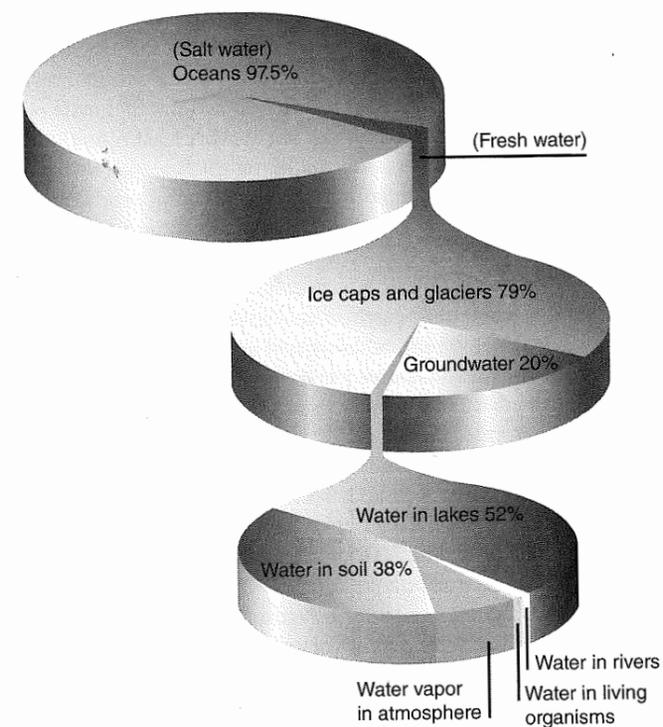
**Figure 1.3** Carbon and oxygen cycle between autotrophs and heterotrophs. Plants, protists, and many bacteria (autotrophs) use carbon dioxide ( $CO_2$ ) and water to form oxygen ( $O_2$ ) and complex organic compounds through photosynthesis. Autotrophs and heterotrophs such as animals and fungi use such compounds to again form  $CO_2$  and water through cellular respiration. *Derivative by Mikael Häggström, using originals by Laghi I, BorgQueen, Benjah-bmm27, Rkitko, Bobisbob, Jacek FH, Laghi L, and Jynto.*



pollution. These must include new policies, changes in individual behavior, and technological innovation that are elaborated on in Chapter 3.

#### WATER

Water, like air, is an abiotic, renewable resource that is vital for all of life. It exists in three forms: liquid, solid ice, and gaseous water vapor. There are well over 300 million trillion gallons of water on Earth, but less than 1% of that is in the form of potentially drinkable fresh water (Figure 1.4). The oceans store approximately 97.5% of the planet's water as salt water, and approximately 2% is frozen in glaciers. Both physical and biological processes are responsible for cycling water. The physical processes include evaporation, freezing and thawing, and condensation and precipitation. Biological activity such as **transpiration** (evaporation of water through plants) and metabolism also contribute to the cycling of water.



**Figure 1.4** Most of the 300 million trillion gallons on Earth is salt water in our oceans (97.5%) and less than 1% is in the form of potentially drinkable freshwater. *Courtesy World Bank Group, <https://goo.gl/images/Roa1rU>*

Given the natural processes and rates of cycling of water, it is considered a renewable resource. However, the availability of water for animal and plant consumption, including that by humans, and for agriculture can be very limiting. The availability of potable water can be limited through overexploitation at local and regional levels. It can also be limited through contamination with either chemical pollutants or biological pathogens introduced through poor or absent sanitation infrastructure. Low access to clean drinking water availability is a crisis especially in developing countries. Globally, an estimated 663 million people lack ready access to improved sources of drinking water, and 2.4 billion people lack access to proper sanitation and hygiene. As a result, 340,000 children younger than age 5 years die annually from related diarrheal diseases, which equates to nearly 1,000 children per day.<sup>5</sup> In addition, aquatic ecosystems including rivers, lakes, estuaries, wetlands, and marine systems are sensitive to and readily impacted by human activity and habitat destruction.

There are ways to solve these water-related problems, including policies and technologies that reduce

water pollution, improved water delivery and sanitation infrastructure, and new innovative approaches to generating and conserving clean water, such as desalination and purification. Enforced policies that protect water and aquatic habitats, promote water conservation, and allow for regional water sharing and distribution are also vital. These solutions are explored in Chapter 4.

#### ENERGY

Energy resources can be either non-renewable or renewable. Examples of non-renewable resources include **fossil fuels**, specifically oil, coal, and natural gas. As the name implies, these fuels are buried combustible geologic deposits of decayed or fossilized organic materials from microbes, plants, and animals. Over hundreds of millions of years, these organic materials have been converted to crude oil, coal, natural gas, or heavy oils by exposure to heat and pressure in the Earth's crust. Also referred to as **hydrocarbons** because they consist of compounds of bound hydrogen and carbon, fossil fuels represent a significant storage reservoir or sink for global carbon, which is released to the atmosphere as carbon dioxide when it is extracted and burned.

Uranium, used in nuclear power plants, is also considered non-renewable because its occurrence is finite and it cannot be replaced through natural processes within the time frame of human extraction. Nuclear power plants produce electricity using neutrons to bombard compounds such as uranium. This process of nuclear fission results in the release of energy in the form of heat that can boil water to create steam that can generate electricity by driving turbines. Nuclear energy allows for energy independence in regions that lack fossil fuel deposits, and it has reduced emissions compared to fossil fuels. However, there have been legitimate concerns about safety, what to do with radioactive wastes, and potential depletion of uranium resources.

Examples of renewable energy resources include solar, geothermal, hydropower, wood, and biofuels. They are considered renewable in that many of them, like solar energy, are not depleted when used or can be produced at rates equivalent to their rate of use. Currently, renewable energy resources represent approximately 20% of the global energy production, and their rate of expansion is exceeding predictions.

The use of non-renewable energies, although central to our lifestyles and economies, has a number of limitations. Our fossil fuels are being depleted. They are not geographically well distributed, resulting in unequal access, and they negatively impact the environment and public health. The world now consumes 85 million barrels of oil per day, or 40,000 gallons per second, and demand is rapidly growing. Oil and other fossil fuel reserves will begin to decline by 2020, but the more easily extracted, less expensive reserves are already nearly depleted. New techniques for extracting less accessible fossil fuels are being developed and expanded, including hydrofracturing, extraction from tar sands, and deep oceanic drilling. However, these have increased costs and extreme environmental and health risks. Because fossil fuels are concentrated in specific regions, there have been geopolitical consequences, including military conflict over access to those resources. In addition to the environmental consequences of fossil fuel extraction, their combustion also contributes to significant environmental change, including air pollution, and climate change, as described throughout this book.

The continued use of fossil fuels has implications for national security, energy independence, and the environment. One response to this has been the increase in development and use of renewable forms of energy.

As the price of fossil fuels rises and that of renewables declines, the use of renewable energy will increase and could be part of potential solutions to our complex energy problems. In addition to the high cost of renewable infrastructure, renewables have other limitations that must be considered. For example, the use of land to grow biofuels may affect food production. Not all geographical locations have sufficient exposure to sunlight to exploit solar energy. Other renewables negatively impact aquatic systems or require non-renewable rare-earth metals in their production. As we develop renewable energy, all of these issues must be considered. Despite these limitations, the transition to renewable energy is essential for the future of our planet and people. In Chapter 6, we explore new advances in renewable energy and examine the barriers to this transition and ways to overcome them.

#### TERRESTRIAL AND MARINE EXTRACTIVE NON-FUEL RESOURCES

We rely on a number of terrestrial and marine resources for things other than fuels. These resources include soil, forest products, fisheries, and mined mineral and rock materials. Soil, particularly the upper fertile layer referred to as topsoil, is an essential natural resource. It provides a medium for plant growth and biological activity. Soil regulates the flow and storage of water and nutrients. Soil can also filter and buffer pollutants. Although one might think of it as an abiotic resource, it is actually a complex living system. One gram of soil contains as much as 10,000 different microbial species. There are 1.5 times as many organisms in a teaspoon of soil as people on Earth. Although soil is renewable, the time span of renewal well supersedes that of human use because the natural processes required to create 1 cm of topsoil take 100–400 years whereas its depletion through human activity occurs much more rapidly.

Certain practices, such as those used in organic agriculture, can both conserve and expedite the restoration of soil resources. Intensive soil use and human impact result in various forms of degradation, including erosion, organic matter loss, salinization, nutrient depletion, compaction, reduced biological activity, and chemical toxicity. Given our reliance on soils for the production of food and other plant products, protecting soil quality, like protecting air and water, should be a central goal of national and international environmental policy. Unfortunately, this has not typically been the case, but in Chapter 5 we will see that

a variety of techniques in agriculture focus on soil health and new policies and technologies have been developed to protect soil.

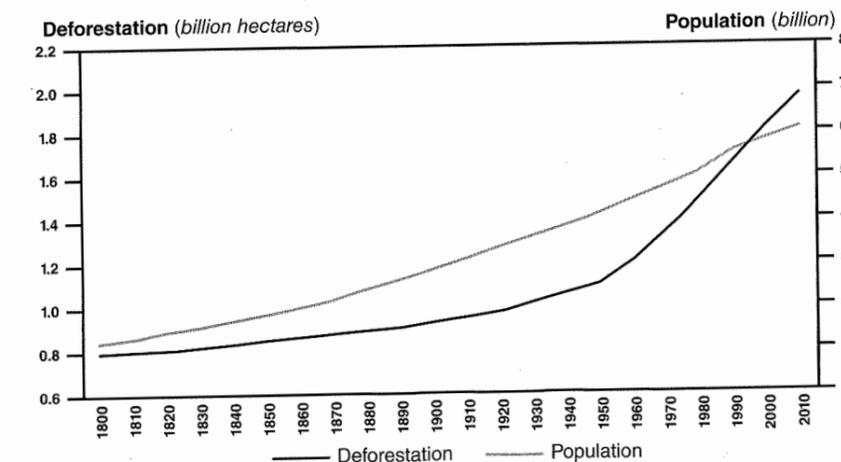
Timber and non-timber forest products are biotic, renewable resources. Timber products are primarily lumber and pulp used in paper production. There are many other useable products from timber. These products are made from the cellulose and lignin in the wood and when refined are used in the manufacture of asphalt, rayon, flavorings, paint, detergents, and plastics. Non-timber forest products include fuel wood, charcoal, resins, fibers, decorative foliage, and edible nuts and fruits. Also, numerous cultures and communities rely almost entirely on the medicinal properties of forest plants for their health care. Furthermore, more than 25% of prescription medications in modern medicine are based on or derived from plant compounds, and there is much potential for future cures to come from plant sources.

In spite of or because of our dependence on forest systems, they are disappearing at an astonishing rate. The average annual net loss of forest is approximately 5.2 million hectares per year. Deforestation has been directly linked to population growth and the increased resource demands associated with it (Figure 1.5). The majority of forested land is cleared for agriculture and livestock grazing. The overextraction of forest resources, forest fires, illegal logging, and insecure tenure of forest land are also resulting in forest decline. The cutting of forest for firewood is also a significant driver of deforestation. In rural areas of developing countries, 95% of total energy consumption

can be from firewood. This not only reduces forest cover but also deteriorates air quality, which negatively affects the health of those who breathe the air. Social and governance-related phenomena, such as increasing settlements, weak law enforcement, rising poverty, and civil conflict, also contribute to the rising rates of deforestation.

Urbanization and sprawl models of development also contribute to loss of forest habitat. There are a variety of approaches to managing forest resources that can enhance the degree to which they can be renewable and that can also decrease environmental damage while providing essential resources and economic potential. These are addressed in Chapter 7. Also, managed development and agriculture can further serve to protect forests (see Chapters 5 and 11).

Another terrestrial resource that often comes from forested ecosystems is hunted animal meat and other products. This is a biotic resource that should be renewable given that under ideal conditions, game or wildlife populations should either be growing or maintained at **equilibrium**, where birth rates equal death rates. Unfortunately, in many areas of the world, such conditions are not met. Most game populations are threatened, and many have been driven to the brink of extinction by habitat loss and overhunting. Even when protected in wildlife preserves, large animals are often subject to poaching or illegal hunting. To effectively protect these populations, there must be alternative ways to meet the nutritional and economic needs of those who resort to poaching in conjunction with enforcement and protection of the animals.



**Figure 1.5** World population and cumulative deforestation, 1800 to 2010. These same trends have continued through 2016. Source: UN FAO *State of the World's Forests 2012*, <http://www.fao.org/docrep/016/i3010e/i3010e02.pdf> - page 3, Figure 1.

In contrast to those being driven toward extinction, there are some game populations that are growing out of control. An excellent example of this is deer in the eastern United States. Because their natural predators have been eliminated, their populations grow unchecked even in the face of hunting. These predators are referred to as **keystone species** because of their major effect on their environment relative to their abundance and also their critical role in maintaining the structure of their ecological communities. The loss of large predators such as wolves in eastern US forests has allowed the deer populations to expand, which in turn assert extreme browsing pressure on the vegetation of forested ecosystems, gravely impacting their ecology. There is evidence that overbrowsing by deer negatively impacts other species, such as **neotropical migrant birds** that nest in these habitats. Effective management programs can protect both the resource and the habitats and other species they are impacting.

Non-fuel mineral resources are materials that are concentrated in or on the Earth's crust that offer economic potential. These are typically considered separately from fossil fuel deposits. They are abiotic, non-renewable resources that are extracted from the Earth using a variety of mining techniques that involve either surface or subsurface excavation. Mined resources include precious metals, metallic ores, and other rock materials. Many industrial processes and products, including those produced by the technology industry, utilize various mineral resources. Historically, mining has had very negative environmental, public health, and social consequences, and it continues to do so. New approaches, policies, and the development of alternative materials that can reduce these consequences are discussed in Chapter 7.

Marine and aquatic resources also have great economic importance and potential. They can include biotic resources such as animal and plant life, including fish and seafood. In this regard, overfishing has been extremely problematic, and as a result we are experiencing a global collapse of natural fisheries, with more than 75–90% of stocks being depleted. In addition, because of marine pollution, many naturally caught fish contain toxins, including polychlorinated biphenyls and mercury. In addition to providing food, the marine environment can provide abiotic materials that are of significant value. Many minerals can be

mined from the deep sea, such as gold, nickel, cobalt, copper, manganese, and zinc. With limited reserves on land, deep sea mining is becoming more attractive despite the high costs of extraction. Marine aggregates such as sand and gravel are extracted and used in the construction industry for the manufacture of building materials such as concrete and manufactured stone. Extraction of such resources may have negative consequences for the marine and aquatic environments and their biodiversity. In addition, both the development and the destruction of coastal habitats and wetlands has had negative impacts. Other types of impacts on marine and aquatic systems include the dumping of wastes, especially plastics; chemical pollution; agricultural and industrial run-off; and ocean acidification and coral reef bleaching associated with rising CO<sub>2</sub> and climate change. Reducing waste, regulating ocean dumping, and reversing climate change are solutions to these problems.

#### WASTE

Although not typically viewed as a natural resource, humans' production of waste and garbage must be considered when contemplating the future of our planet. Globally, we generate more than 3.5 million tons of solid waste per day, and this is expected to triple by 2100. This has drastic economic and environmental costs. Reductions in waste production will require us to rethink our current industrial and economic models; shifts in individual behaviors; and other innovative solutions, including the use of waste as a resource. These solutions are the focus of Chapter 8.

#### The Changing Climate

Climate change is directly linked to our resource use and most environmental issues. Thus, any approach to environmental problem solving must be done so within the context of global climate change. Climate change, also referred to as global warming, is either influenced by and/or impacts every other environmental issue. Climate change is real, it is scientifically documented, and its negative effects are being realized today. In this section, we examine the causes and consequences of climate change. We also examine general solutions to the problem of climate change, with the understanding that it will be dealt with more specifically in practically every other chapter in this book.

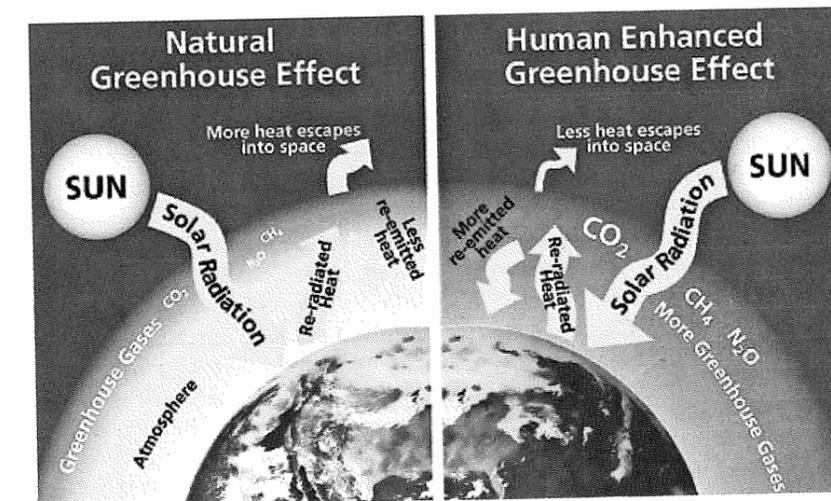
#### UNDERSTANDING CLIMATE CHANGE

One of the first steps in understanding climate change is the differentiation of weather from climate. **Weather** consists of short-term changes in atmospheric variables such as wind, temperature, cloudiness, moisture, and atmospheric pressure. **Climate**, on the other hand, is a measure of the average pattern of the previously mentioned atmospheric variables over a long period of time. Climate is different from weather in that weather only describes the short-term conditions of these variables within a narrow geographical region. Weather is highly variable, whereas climate changes more gradually, is more predictable, and is often considered over wider geographical ranges or even globally. The occurrence of an odd weather event, such as a very warm day in winter in a particular region, does not mean the climate is changing. Changes in global climate are long-term changes in average atmospheric variables over time and across the globe.

Visible light readily passes through the atmosphere and heats the surface of Earth. The Earth reflects or reradiates this energy as heat in the form of infrared thermal radiation (Figure 1.6). This **infrared thermal radiation** is at a longer wavelength than

the visible light spectrum and does not readily pass through the atmosphere back into space. Rather, the gases that comprise the upper atmosphere absorb some of this heat and re-radiate it back to the lower atmosphere and the surface of the Earth. The gases that prevent the heat from leaving the atmosphere and re-radiated it back to Earth are referred to as **greenhouse gases** (GHGs).

GHGs include carbon dioxide (CO<sub>2</sub>), water vapor, methane, nitrous oxide, and ozone. They are called greenhouse gases because like the glass of a greenhouse, shorter wave radiation from the sun readily passes through them and, like the glass, GHGs are responsible for retaining the heat and warming the atmosphere below, but the way heat is retained in a greenhouse is very different. The glass of a greenhouse reduces airflow and prevents loss of heat through convection, whereas the GHGs absorb and re-radiate the heat. Regardless of this difference, this analogy has stuck, and the process of shortwave radiation passing through the atmosphere and reflecting off of the Earth's surface as longer wave infrared radiation that is then captured by the GHGs and re-radiated back to the Earth is still referred to as the **greenhouse effect** (see Figure 1.6). As GHGs



**Figure 1.6** The greenhouse effect explained. Increased GHGs capture and re-radiate longer wave radiation or heat, warming the upper atmosphere and earth surface. Increasing GHG concentrations through human and natural process increase the amount of heat captured and re-radiated, thereby increasing global temperatures. Image courtesy of the Field Museum, <https://climatechicago.fieldmuseum.org/learn>

increase, the extent to which the atmosphere absorbs and re-radiates infrared radiation or heat back to the lower atmosphere and the Earth's surface increases, resulting in global warming.

There is great variation in the extent to which each GHG contributes to global warming. This depends on both the amount of each GHG in the upper atmosphere and the relative measure of heat that each gas traps or its **global warming potential (GWP)**. GWP for a specific gas is based on how long it remains in the atmosphere and how strongly it absorbs heat. It compares the amount of heat trapped by a certain mass of the GHG in question to the amount of heat trapped by the same mass of CO<sub>2</sub>. We further address GWP as we more closely consider specific GHGs in Chapter 3.

The abundance of GHGs in the upper atmosphere—specifically carbon dioxide, methane, and nitrous oxide—has sharply risen during the past two centuries. This is made evident by examining ice cores from the Greenland and Antarctic ice sheets. These cores have in them bubbles of ancient air that can be dated, and their composition can be determined. These data, coupled with contemporary atmospheric measurements, show that GHG concentrations have dramatically increased since the industrial revolution.

Some have argued that the rise in atmospheric CO<sub>2</sub> is the result of a natural fluctuation rather than due to human causes. However, several pieces of evidence have convinced the scientific community that

this is not the case. First, increases in anthropogenic CO<sub>2</sub> emissions starting in 1850 and rising rapidly after 1950 have been directly linked to increases in atmospheric CO<sub>2</sub> (Figure 1.7). Also, the increasing rate of fossil fuel consumption is directly related to the rise in CO<sub>2</sub> emissions. Plant material and things derived from plant materials, such as fossil fuels, have distinctive stable **carbon isotopic ratios** or proportions of different forms of carbon (C<sub>13</sub>:C<sub>12</sub>). Such analyses have revealed that the recent increase in atmospheric CO<sub>2</sub> is due to plant-derived sources such as fossil fuels rather than non-plant-derived carbon sources such as releases from volcanoes and the oceans. Contributions of other GHGs such as methane and nitrous oxides have been directly linked to human activities, including industrial agriculture and waste production. This represents solid scientific evidence that not only are GHGs steadily rising but also this rise is being caused directly by our actions.

Accumulated GHGs have the capacity to retain and reflect heat back to the Earth. Thus, as atmospheric GHGs rise in concentration, so do mean global temperatures. The Intergovernmental Panel on Climate Change (IPCC)<sup>6</sup> reported that during the 20th century, global temperatures rose approximately 0.1°C per decade. However, in the past 20 years, this warming rate has doubled. At current rates of fossil fuel combustion, average global temperatures will warm by 3°C by the middle of this century. The greatest levels of warming will be in the northern polar region, where average temperatures

are predicted to rise by nearly 7°C by next century. This is due to the feedback effect of the melting polar ice caps.

The consequences of this pattern of global warming are serious. We already experience some of these effects, including drought, crop loss, increased wildfire risk, extreme weather events, and flooding and storm damage. These types of impacts will increase in frequency and severity in the next 50 years. In addition, with the continued rise in average global temperatures, sea ice at the poles has been melting. This in turn is causing a rise in sea level that will be devastating to coastal regions and inhabited islands throughout the world, resulting in millions of climate refugees as people migrate from flooded areas (Figure 1.8).

Other impacts of rising CO<sub>2</sub> and climate change include ocean acidification, which is resulting in the bleaching and death of diverse and important ecosystems. It is estimated that 10% of coral reefs are already dead and that 60% of the world's reefs will be dead by 2050.<sup>6</sup> In addition to coral reefs, there will be high rates of extinction in other habitats. Amphibian species are among the most threatened by climate change.

Climate change will also have negative implications for global public health. This will include increased mortality from extreme heat and also deaths due to increased flooding and extreme high sea level events. More frequent droughts will result in food and water shortages, hunger and malnutrition, and increases in waterborne disease. Warming may favor the range expansion of insect vectors of diseases such as dengue fever and malaria, and it may increase the spread of allergens. There will also be significant economic losses of up to 5% of gross domestic product for most nations.<sup>7</sup> These economic impacts are likely to disproportionately affect the poorest people in the world because they live in regions that will be more

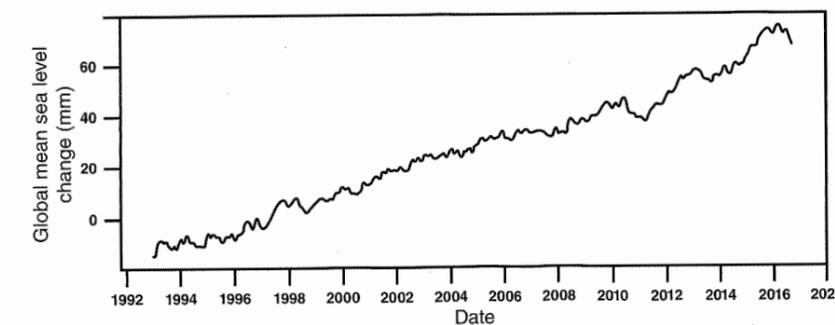
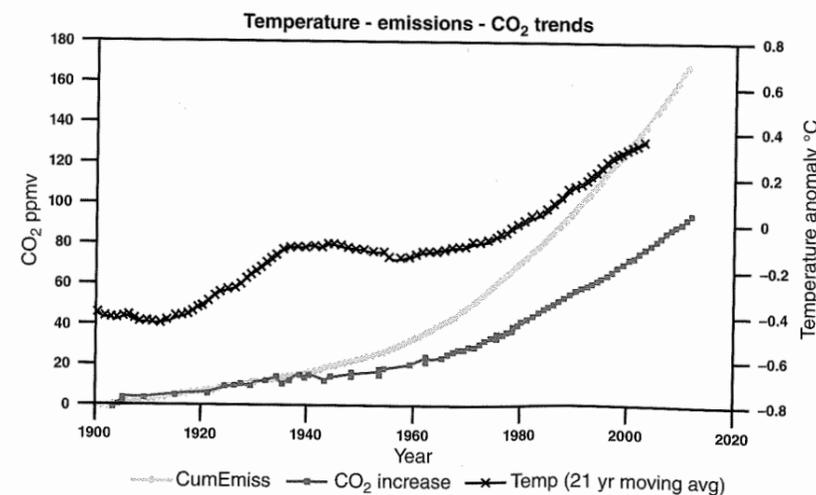
heavily impacted and also because they lack the means to adapt or respond to this change.

Consensus among scientists is often difficult to achieve. This is not the case with global climate change and its cause and consequences, as described previously. Scientists are in agreement that climate change is occurring as the result of human activities, and many of the effects can already be seen. Many corporations are accounting for current and future impacts of global climate change in their long-range business plans. This is particularly true for the insurance industry, which is in the business of assessing risk. A recent report by the IPCC shows that GHGs have risen to unprecedented levels since 2000, and these levels will rise more quickly than previously predicted.<sup>8</sup> This is occurring even in the face of a growing number of policies designed to reduce climate change.

Despite this overwhelming scientific evidence and the early emergence of the devastating effects of climate change, there are groups with their own agendas that deny that climate change is occurring or that it is caused by human activity. This is particularly the case in the United States, where there is a small but adamant denial movement that is primarily politically motivated. However, this movement has begun to decline as both the scientific evidence and actual current impacts of climate change are convincing the broader public and even politicians of its clear and present danger.

What are the solutions to climate change? They can be divided into two types: mitigation and adaptation. **Mitigation** is the attempt to reduce GHG concentrations. This can occur by reducing or stopping emissions and through sequestration or active removal of GHGs from the atmosphere. Because plants actively take up CO<sub>2</sub>, their removal through deforestation will result in increasing its atmospheric

**Figure 1.7** Trends in anthropogenic CO<sub>2</sub> emissions, atmospheric CO<sub>2</sub> concentrations, and temperature. The increase in the concentration of atmospheric CO<sub>2</sub> and global temperatures correspond to cumulative anthropogenic CO<sub>2</sub> emissions from 1900 to 2011. Source: US Department of Energy, Hadley Center, <https://goo.gl/images/yMVNcq>



**Figure 1.8** Global average sea level change (mm) from 1993 to 2017. Data are from satellite measurements. Values are 60-day averages with seasonal fluctuations removed. Source: NASA, <https://climate.nasa.gov/vital-signs/sea-level/>

concentration, but adding plants through reforestation can increase CO<sub>2</sub> uptake from the atmosphere and reverse the trend. **Adaptation** refers to how human communities must adjust their lifestyles in response to changing climate and its impacts. Within the framework of mitigation and adaptation, there are solutions to the problems of global climate change. Our capacity to both mitigate and adapt to climate change will determine our **resilience** or ability of our ecological, social, and economic systems to absorb or cope with the change. To mitigate climate change, we must find new ways to **decouple** greenhouse gas emissions from economic development, a phenomenon that is already occurring in some countries (Figure 1.9). Because of the overarching nature of climate change, it and potential solutions for mitigation and adaptation are addressed in nearly every chapter of this book. Solutions must run the gamut from policy implementation to innovation and entrepreneurship and individual action, and they must bring

together diverse stakeholders. One of the major goals of this book is to develop solutions that meet these criteria. Another is to move beyond mitigation and adaptation and instead consider a **transformation** or radical change or alteration of the way we live our lives on this planet in order to protect it and ourselves from the devastating effects of climate change.

### Invasive Species

Another global environmental problem is that of **invasive species**. Invasive species are those that have ecological characteristics such as high reproductive output and colonizing ability that allow them to invade new habitats once they are introduced. They are often non-native organisms that are introduced to a natural habitat either on purpose or by accident. In their new habitat, natural predators or, in the case of plants, herbivores that normally control them are missing. Left unchecked, these species proliferate and can quickly come to dominate an area. Disturbances

including grazing by livestock and fragmentation of ecosystems further encourage the establishment and proliferation of invasive species.

Unintentional introductions can occur through global commerce as non-native species are transported as "hitchhikers" by air, water, railways, or roads and in wood and wood products. Ballast water taken up at sea and released in port by transoceanic vessels is a major vector for non-native aquatic species through the global transport of their propagules or larvae. Through this process, it is estimated that more than 3,000 different species of aquatic life may be transported on any given day.<sup>9</sup> An example of this is the zebra mussel *Dreissena polymorpha*. The larvae of this small freshwater mussel were transported in ballast from the Black, Caspian, and Azov seas to the Great Lakes and the St. Lawrence Seaway, where they have invaded hard aquatic substrates. In addition to North America, they have invaded much of coastal Europe, where they disrupt the ecosystems through monoculture colonization and damage harbors, ships, and water treatment and power plants.

In addition to accidental occurrence, deliberate introductions have commonly occurred through the introduction of new horticultural varieties, crops, and plants for wildlife management. Failed attempts at biological control in which a potential predator is introduced to control a pest have also resulted in the introduction of invasive species. An example of this is the introduction of the cane toad *Rhinella marina* to Australia in an effort to control the grubs of beetles that were devastating Australia's sugar cane crops. The toad was generally unsuccessful in reducing the targeted pest, and the prolific nature of the toad allowed it to spread and become firmly established throughout much of the continent.

So why are invasive species problematic? Doesn't the introduction of new species increase diversity? The answer is generally no. Invasive organisms tend to drive down native diversity. In the United States, invasive species have contributed to the decline of 42% of all endangered and threatened animals and plants. One example is paperbark, *Melaleuca quinque-ervia*, which was introduced to the Florida Everglades in the late 1800s in an effort to assist in drying out swampy land but established monocultures where it was planted. Its rapid proliferation reduced diversity in areas of the Everglades from 80 species of plants to 4 species.<sup>10</sup>

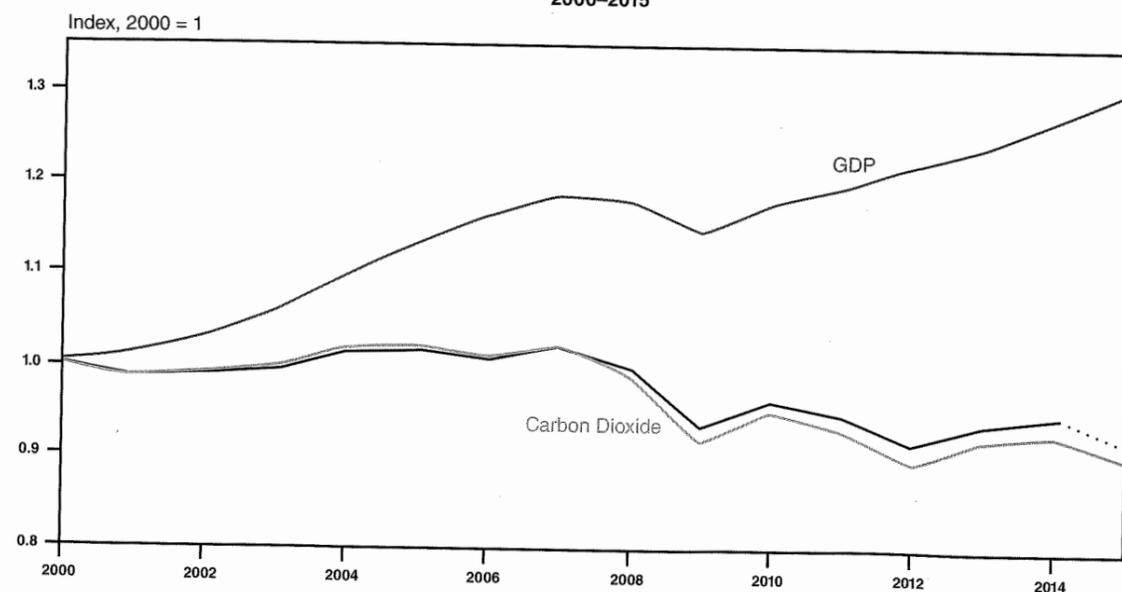
There are numerous other examples of the detrimental effects of invasive species. Those most commonly known that have not already been mentioned include kudzu or "the vine that ate the South"; the starling, which was originally introduced as four pairs in Central Park in New York City; the Asian long-horned beetle, which has caused approximately \$10 billion worth of tree damage in the United States; and the Asian carp, which has devastated the ecology of Lake Victoria in East Africa.

Large economic costs are associated with invasive species. These include costs associated with reduced production in agriculture and forestry, negative impacts on ecological tourism, and the control and management of invasive species. It is estimated that damage and control of invasive species in the United States cost more than \$120 billion per year and that invasive species cause \$7.4 billion in annual productivity losses of 64 major crops.<sup>11</sup> Regarding the example of *Melaleuca* described previously, control efforts within the state of Florida cost more than \$2.2 million annually. These costs do not take into account losses in biodiversity and losses of ecosystem services. As we explore and assess solutions in this book, it will be important to consider the potential for introduction and encouragement of invasive species through those actions.

### Ecosystem Services and the Value of Biodiversity

People who value the natural world and all of its biodiversity often do so for intrinsic reasons. Many people are committed to protecting nature for spiritual, ethical, and even aesthetic reasons. However, when considering environmental problem solving, it is often useful to move beyond the esoteric value of nature and to take into account the services that ecosystems perform and the value of biodiversity. The ways that humans benefit from natural processes are referred to as **ecosystem services**. There are four broad types of ecosystem services. **Provisioning services** refer to the useable materials or energy that people obtain from ecosystems. These include food, water, genetic resources, and the other natural resources described in this chapter. **Supporting services** are those that play a role in the maintenance and function of all other types of ecosystem services. These include pollination and seed dispersal, nutrient cycling, and the provision of habitat for species

GDP and Greenhouse Gas and Carbon Dioxide Emissions, 2000–2015



Note: Total emissions from EPA is available through 2014; 2014–2015 trend is estimated using change in CO<sub>2</sub> emissions from the energy sector from the EIA.

**Figure 1.9** In the United States, GHG emissions are declining while the economy as measured by GDP grows. Source: Environmental Protection Agency, Energy Information Administration, and Bureau of Economic Analysis, <https://wattsupwiththat.com/2017/01/12/obama-whitehouse-gdp-has-been-decoupled-from-co2-emissions/>

that perform other services. **Regulating services** are those that control or maintain environmental conditions. Examples include carbon sequestration and climate regulation, purification of air and water, and flood control. Finally, **cultural services** provide spiritual, aesthetic, or historical value and also venues for science, education, and recreation.

When assigning value to biodiversity, we consider two types: direct and indirect values. **Direct values** include consumptive use values such as foods, medicines, and fuels that are used and consumed locally and not marketed nationally or internationally. **Productive use values** are direct use products that are commercially harvested or produced and sold. **Indirect values** of biodiversity are those that provide indirect benefits to humans that are more difficult to quantify. These include the social and cultural, ethical, and aesthetic value of biodiversity as well as the ecosystems services described previously. **Option values** include currently undiscovered potential benefits of biodiversity. For example, a yet to be discovered plant may offer a cure for cancer or diabetes.

Unfortunately, most economic systems do not take into account the value of ecosystems services and biodiversity. When a for-profit entity impacts the environment, it calculates its bottom line without including contributions from or costs of impacting natural systems that actually serve its interests or those of others. In other words, it reaps the benefits of these services, such as natural water treatment or pollution abatement, without paying for them. When the entity destroys or depletes these resources, it is often not held responsible for the economic losses incurred by this impact. For example, entities involved in industrial agriculture are able to increase their profit margin by producing "cheap food." One reason why this food is cheap and their profits are high is that large producers are not responsible for these sorts of external or indirect costs in the production of this food. These costs might include natural pollination on the use side and pollution of water resources or health or societal problems caused by their actions on the impact side.

These types of costs are termed **externalities**. These are ecosystem benefits or consequences of an industrial or commercial activity that affect other parties and are costs that are not accounted for in the production of goods or services. Externalities are not fully reflected in the price of a good or service or in the determination of profit. As we consider the impacts of

such commercial activity and solutions to associated problems, we must do so within the context of these sorts of externalities.

## The Human Condition

This book is not just about the environment but also about the link between humans and the environment. It is also important to consider our own condition and recognize that our quality of life is both dependent on and impacts the environment. In this section, we consider the problems related to population growth, rates of consumption, economic issues, and education and public health. Again, we begin to broadly establish solutions to these problems that will be specifically addressed in the chapters that follow.

## The Growth of Human Populations and Consumption

**Exponential growth** is when the amount being added to a system is proportional to the amount already present. As an exponentially growing system increases in size, so does the rate of increase. Such populations remain small at first, but the rate of increase escalates with population size. Theoretically, when left unchecked, a population should grow exponentially, and this is essentially what has occurred historically with the global human population (Figure 1.10). In the first 200,000 years of human existence, the population growth rate slowly increased as 1 billion people were added during that time. It took only another 130 years to add the next billion, 14 years to add the next, and this rate of increase continues to rise as the current population size exceeds 7 billion people and rapidly approaches 10 billion.

Exponential growth should eventually level off as resources become limited. The **carrying capacity** of a population is defined as the population size at which the growth rate of a population becomes zero. As a population approaches its carrying capacity, growth rate begins to decline due to resource constraints, eventually leading to the point at which the birth rate equals the death rate. Theoretically and in nature, some populations actually crash and reduce in number well below the carrying capacity under limiting conditions.

Many have argued that the human population has reached its carrying capacity, but so far resource constraints have not seemed to limit population growth,

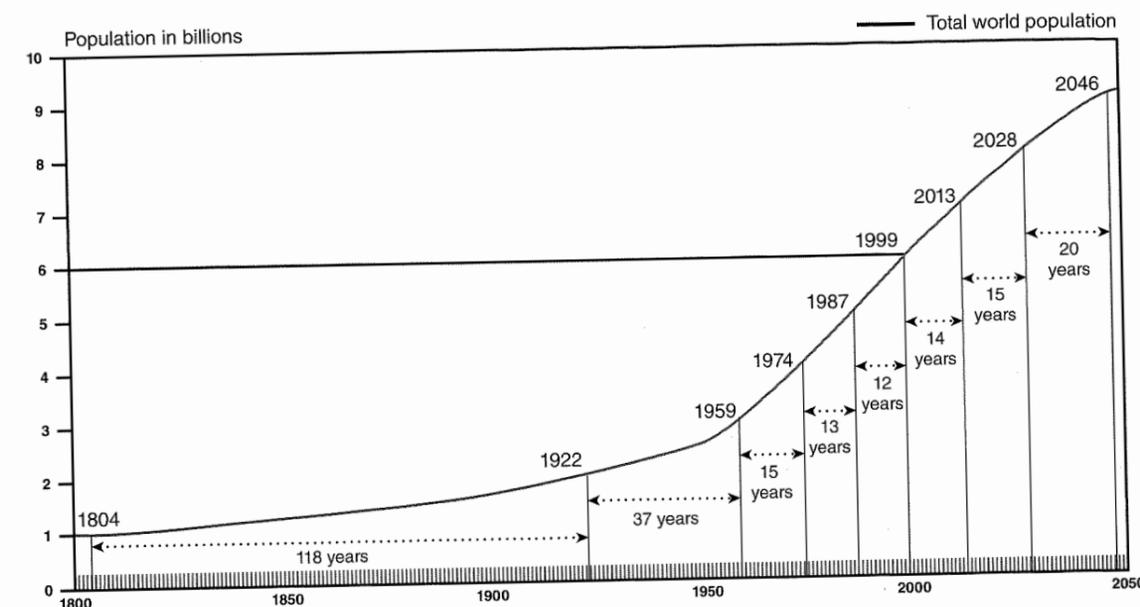


Figure 1.10 Total world population growth. Source: US Census Bureau, International Programs Center, International Database.

as the most constrained regions often have the highest growth rates. This lack of decline in growth rates suggests that the concept of carrying capacity is being misapplied to human populations. Moreover, applying the concept of carrying capacity to human populations is problematic for a number of reasons. The first is based on the argument that humans can defy limits through the discovery of new resources and technologies, and history has reflected this. Second, the point at which populations begin to decline probably should not be our first indicator of crisis. The quality of life at the Earth's carrying capacity may not be something we want to experience because there are likely to be harsh health, social, and environmental implications as death rates approach and perhaps even surpass birth rates.

Currently, approximately 70 million people are added to the planet per year. That is equivalent to adding more than 200,000 people every day, or approximately 140 people every minute. However, this is not occurring uniformly across the planet. In fact, in some areas, populations are declining. In developed, wealthier countries, populations are either holding stable or declining. However, in the least developed areas of the world, populations are rapidly expanding

such that 98% of the world's population growth is occurring in middle- to low-income countries, where the potential for economic opportunity is the least.

There are a number of factors driving the differences in population growth between the industrialized, developed areas of the world and poorer, developing countries. The first is **fertility rate**, or the average number of children each woman has in her lifetime. A fertility rate of two is essentially a replacement rate that stabilizes population growth. In many developed countries, fertility rates are either at two or below, resulting in stable or declining populations. In developing countries, the fertility rate ranges from three to seven, contributing to their population expansion. A second contributing factor to the disparity is average age of first reproduction, which tends to be younger in less developed countries. A younger age at first reproduction not only increases fertility rate by lengthening the time of childbearing age but also decreases the generation time or the average time between two consecutive generations. A population in which the average age of first reproduction is 20 years will yield five generations in 100 years, whereas an average age of first reproduction of 25 years will yield four generations. Thus, the average age of first

reproduction is one of the most important determinants of population growth rate. A third factor is the age structure of a population. If a population has a large number of young people just entering their reproductive years, the rate of growth of that population will rise even with low fertility rates; again, this is a common pattern in less developed, poorer nations.

Another important influence of population growth in relation to development is the rate of mortality. Developed countries tend to have reduced birth and death rates, which stabilize populations. Death rates are rapidly declining in many poorer countries as they begin to experience the benefits of development, such as improved medical care and public health; however, reductions in birth rate tend to lag behind. Today, this sharp decline in death rates followed by slowly declining birth rates is characteristic of most of the less developed regions of the world, resulting in rapid population growth. It is expected that if these countries continue to develop, birth rates will eventually decline and populations will begin to stabilize.

The changes in birth and death rates and hence population size with development are referred to as the **demographic transition** (Figure 1.11). This transition can be divided into essentially four phases. Phase 1 is referred to as "primitive stability," with equally high birth and death rates. Phase 2 exhibits declining mortality with increased medical care and public health but precedes any decline in birth rate. Population growth rapidly increases during this phase. In Phase 3, birth rate begins to decline and approach death rates, reducing population growth. In Phase 4,

birth rates and death rates are both low, resulting in a stabilized population (see Figure 1.11).

Currently, most developing countries are in Phases 2 and 3, in which population growth rates are the highest. Few are transitioning into low growth phases, and approximately half of them have been "trapped" in this phase of rapid population growth for more than 50 years. This has evoked questions about the potential of this model to necessarily predict future population growth, particularly in the less economically developed countries. Demographic transition theory also does not account for recent phenomena such as HIV, which has increased mortality in a number of sub-Saharan African nations, nor does it necessarily take into account government interventions such as population control programs. The model also assumes that population changes are caused by increased wealth associated with industrial changes, and to a lesser extent it considers the role of social change in determining birth rates. But as a model, it serves to elucidate mechanisms by which patterns of birth, mortality, and population growth change with development. The following are two examples of developing countries that have made the transition to reduced birth and death rates, resulting in decreased population growth; these cases are used to flesh out the mechanisms by which population growth is stabilized:

**Sri Lanka:** Prior to World War II, advances in public health had been largely limited to affluent, industrialized countries. But since then, improvements in public health have been made in many of the poorer countries of the world, resulting in sharp declines in

death rate. An example of this is the South Asian country of Sri Lanka, which has a population of approximately 20 million. In 1945, the death rate in Sri Lanka (then called Ceylon) was high. In 1946, a large-scale program of mosquito control using DDT to eradicate malaria was started. This was quite successful and cut the death rate by more than 50%. From the 1940s until the mid-1970s, death rates were relatively low, while birth rates had not substantially declined. As a result, the population was increasing at an annual rate of 1.2%, with a doubling time of 57.5 years. But by the 1980s, fertility rates began to decline and life expectancy continued to rise, resulting in an aging population. Today, fertility rates average approximately two children per woman, and the population growth rate has fallen below 1% per year. This was achieved through government health and education reforms. This proved to be a wise investment because the demographic shift resulted in a growing working-age population and a decrease in the number of dependents per family. This ultimately allowed for continued economic development and improvements in the general standard of living.<sup>12</sup>

**Bangladesh:** Bangladesh is a small country with a population of 150 million people. It is ranked seventh in the world for population size, with more people than Russia. However, it is smaller in area than the US state of Florida so that it is ranked number one in population density, with 950 people per square kilometer. This density is equivalent to half of the people in the entire United States living only in the state of Florida. In the 1960s, fertility rates were as high as 7 or 8 children per family, and it was believed that culture and religion would make it impossible to reduce this number and slow population growth. However, after independence in 1972, the child mortality declined from 24% and fertility rates declined to approximately 2.5 children per family. This dramatic change is often referred to as the Bangladesh Miracle.<sup>13</sup>

These two case studies reveal several potential ways to stabilize population growth in developing countries. In Sri Lanka, health care and education reform was a clear priority. In Bangladesh, the completion of the demographic transition coincided with independence from Pakistan in 1971. This was followed by the development of an open culture of research-based innovation in community-based health care that brought key health interventions to every household that directly led to drastic reductions in population growth.

In addition to improvements in health care, a number of other common changes contributed to the demographic transition in these two countries. These included improvements in nutrition and education, including the introduction of family planning. Economic growth and poverty reduction have also played a major role. But probably the most important factor has been the empowerment of women. As women have obtained educational opportunities, improved literacy, and entry into the formal labor market, marriage and pregnancy have been delayed and fertility rates have decreased.

#### THE POPULATION BOMB

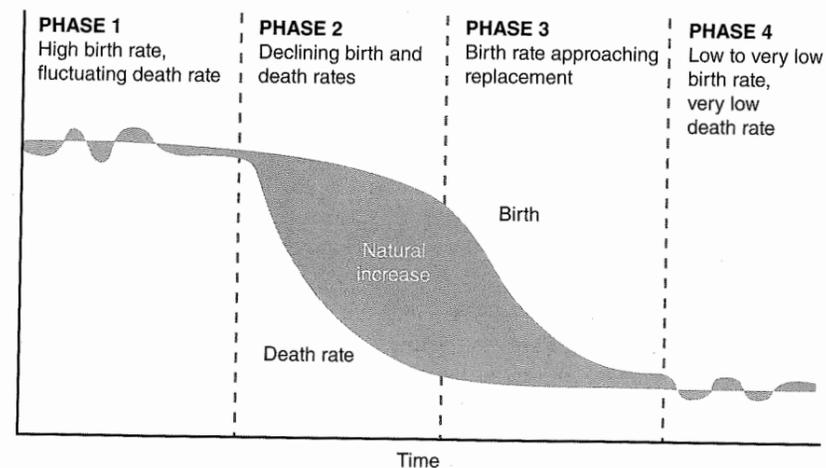
*The Population Bomb*, a bestselling book written by Stanford University Professor Paul R. Ehrlich in 1968, identified overpopulation as the single most important issue confronting humans.<sup>14</sup> It warned that the "population explosion" would result in mass starvation and major societal upheaval. The book advocated for immediate action to limit population growth as a means to save our species, and it argued that the only way to save the planet was to stabilize global population growth rates. The book served to bring the issue of overpopulation to a wider audience, but it has been criticized for its alarmist tone and its inaccurate predictions.

One additional problem is that the emphasis on population growth and disparities in rates between developed and developing countries places the focus of these global problems on the developing world. But population growth rate is not the only disparity between developing and developed nations. Rates of consumption vary and are often inversely related to population growth rates. Higher per capita rates of consumption by individuals in a population may do more to impact our planet and the depletion of its resources than the number of individuals in a population.

#### CONSUMPTION DISPARITIES

The most developed countries of the world consume approximately 32 times more total resources per capita compared to the least developed countries. The United States is home to approximately 4.5% of the world's population but consumes more than 25% of the world's resources. Per person per year, the most developed nations of the world, such as the United States, consume fossil fuels at 3.6 times the rate of the world average and 15.1 times the rate of Africa. It has been too easy to blame the developing world and its population pressures for its impact on the planet, but

**Figure 1.11** The four phases of demographic transition. Courtesy of *The Encyclopedia of Earth*, [https://editors.eol.org/eoearth/wiki/File:Figure\\_4\\_classic\\_stages\\_of\\_demographic\\_transition\\_438x0\\_scale.gif.jpeg](https://editors.eol.org/eoearth/wiki/File:Figure_4_classic_stages_of_demographic_transition_438x0_scale.gif.jpeg)



when we consider rates of resource consumption and depletion, true patterns of impact become clear.

One way to integrate population size with consumption to determine impacts is through the **IPAT model**.<sup>15</sup> This model takes into account per capita negative impact (I) on the environment, expressed as the product of population size (P), affluence (A), and technology (T). Affluence is assumed to be directly related to the average consumption of each person in the population. Technology represents how resource intensive the production of affluence is. The greater these two variables are, the greater the environmental impact.

There have been a number of criticisms of the IPAT model, including its simplicity, the interdependency of the variables, and that technology can also decrease impact through increased efficiencies. Regardless, this model illustrates that in industrialized countries, in which levels of affluence and technology are high, there is potential for large environmental impact even at lower population sizes. Solutions that reduce environmental impact must move beyond population control in the developing world and include reductions in consumption in industrialized countries. These are considered throughout the book, but an in-depth discussion of them is provided in Chapter 8.

### Fiscal Crises and Economic Opportunity

According to the World Economic Forum,<sup>16</sup> 3 of the top 10 global risks of highest concern are severe economic disparity, structurally high unemployment or underemployment, and the potential for fiscal crises in key economies. If these global risks are not effectively addressed, there could be far-reaching social, economic, and political fallout. These issues are interconnected with resource use, climate change, and population growth and/or decline, as previously described in this chapter. The Forum suggests that these risks can only be addressed through long-term thinking and collaboration among businesses, governments, and civil societies.

The Forum reports that the wealth of the world is divided between two groups: the richest 1% and the remaining 99%. There is extreme economic disparity between these groups. This gap between the rich and the poor has been steadily increasing and is at its highest level in 50 years. The average income of the richest 10% of the population is approximately nine times that of the poorest 10%. This is up from seven times that of the poorest 10% 25 years ago. The poorest half of the world's population has a shared wealth

equal to that of the richest 85 individuals. The **gross domestic product (GDP)**, a measure of the monetary value of all the finished goods and services produced within a country's borders in a specific time period, is an estimate of that country's wealth. The GDP of the 41 most indebted, poor countries with a total population of 567 million people is less than the wealth of the world's 7 richest people combined.

Almost half of the people in the world, more than 3 billion people, live in extreme poverty, living on less than \$2.50 per day. Some countries, such as Brazil and a number of developing countries in Asia and Africa, have effectively reduced poverty. However, large inequities in wealth remain. Economic inequality disproportionately affects women and children. In the poorest areas of the world, the earning potential and educational opportunities for women are further reduced. Globally, 1 billion children live in poverty (1 in 2 children in the world), 640 million live without adequate shelter, 400 million have limited access to safe water, 270 million have no access to health services, and 10.6 million died in 2003 before they reached the age of 5 years (or roughly 29,000 children per day).

Economic inequity is caused by a variety of factors, including a regressive pattern of taxation that reduces the rate for the highest income groups. Since the 1970s, these rates have significantly declined in many countries throughout the world, but particularly in the United States and United Kingdom. Other factors contributing to inequity are deregulation of industry, international trade policy, exploitation and the disempowerment of labor, and unequal access to technology. There is still strong political pressure to continue all these trends and to maintain this inequity.

Another global risk is chronically high unemployment and underemployment. In contrast to cyclical patterns that have occurred in the past, today's globally high rates of unemployment appear to be structural, which means that employment opportunities will not increase without significant change or reform. One major cause of this is that education and training programs are either non-existent or have not adapted to the changing job market, resulting in a mismatch between jobs offered by employers and the skill set of potential workers. Other causes include reduction in the labor force due to automation, movement of industry to areas where labor is cheaper, and large-scale bankruptcy in locations where a single industry has been a dominant employer.

The World Economic Forum places the threat of major fiscal crisis at the top of its list of global risks. The cause of these crises will be increasing deficits and debt characteristic of the majority of both developed and developing nations of the world. A fiscal crisis occurs when investors begin to doubt a government's ability to repay its debt. This results in escalating interest rates on further borrowing. This in turn adds more debt and creates more fear and potential that a country will default on its debt. Debt development such as this leads to the instability of financial systems and eventually forces governments to cut expenditures and raise taxes, triggering recession and massive unemployment.

Advanced economies are currently in danger of such fiscal crisis, as indicated by the large amount of debt in the United States (>100% of GDP) and Japan (well over 200% of GDP). The collapse of key economies such as these will result in a cascading effect of global economic failure. Again, this failure will disproportionately impact the global poor. Such crises result in increased unemployment and reduced wages. At the same time, financially strapped governments and aid agencies are forced to cut funding for vital social and public health services, and environmental protection efforts, including options for adapting to climate change, are weakened. A number of realistic economic reforms that include collaboration between the public and private sector will help ensure that fiscal frameworks become more resilient.

### Education and Public Health

In addition to global disparities in wealth and economic opportunity between developed and developing countries, there are also grave differences in education and public health. Nearly 1 billion people entered the 21st century unable to read a book or sign their names. More than 25% of all children in 18 countries have never been to primary school, and in 23 countries, more than 75% of adolescents have not completed lower secondary school. These numbers are considerably greater for lack of secondary and post-secondary education. Often, girls and women are the ones who lack these opportunities. Access to education has been shown to be linked to fertility rates and population growth, public health, economic opportunity and equity, and effective natural resource management. Accordingly, universal primary education that ensures access for all children everywhere has become an important objective of the United

Nations and the world's leading development organizations. We focus on ways to improve global education in Chapter 12, and ways in which education connects to specific issues are considered throughout the book.

During the past several decades, people living in developing countries have experienced considerable improvements in health. For example, during the past 40 years, annual mortality among children younger than age 5 years has been reduced by 50%. Unfortunately, since 2000, these gains have slowed or even reversed in some areas of the world. The countries experiencing these setbacks are primarily in sub-Saharan Africa and some areas of South Asia, where patterns of disease and mortality in less developed countries have changed markedly. This includes the HIV/AIDS epidemic, the re-emergence of tuberculosis, increases in the incidences of insect-borne diseases, the emergence of new infectious diseases, and increases in violence associated with political unrest. Also, a number of chronic diseases that were thought to be of concern primarily in developed countries are exhibiting increased incidence in developing countries. These include the increased occurrence of coronary artery disease, cancers, diabetes, and cerebrovascular damage. Many of these trends can be reversed by increasing access to health care, including medicines and vaccines, and effective education programs specifically with regard to HIV/AIDS and mosquito control.

A number of public health problems are directly linked to environmental issues, including the limits of the environment to provide nutritious food and water to meet the needs of all people. These limits are primarily due to mismanagement. Globally, it is estimated that approximately 870 million people are undernourished, and more than 100 million children younger than age 5 years are undernourished and underweight. A sufficient supply of water that is of high enough quality for drinking is essential for the well-being of humans. Naturally occurring water systems are being depleted and contaminated at alarming rates. As noted previously, millions of people die each year from water, sanitation, and hygiene-related causes.

Pollution and climate change will impact the health and lives of people throughout the world in complex and very serious ways. For example, the increased use of toxic chemicals without sufficient environmental and occupational regulation has resulted in increases in a variety of acute and chronic diseases. The connection between the environment and human health is emphasized throughout this book.

## Developing Sustainable Solutions

When many think of the environment or the natural world, they think of its awesome power and magnificent beauty; they think of it as something pristine; and they want to protect and save it for its intrinsic value. They are reminded of all the incredible species and their amazing adaptations that allow them to survive and reproduce in the natural world. But they often forget about one species. It is a wide-ranging species that occurs in tropical and temperate forests, on mountaintops, and in desert and polar regions. Like all species, its survival is dependent on the natural world. That species is *Homo sapiens*. Yes, our species is inextricably linked with the environment. Nature and the environment are worth saving not just for their intrinsic value but also because our lives depend on it. There is also a clear link between environmental factors and diseases such as cancer.<sup>17</sup>

Our planet has been in existence for 4.6 billion years. The evolution of early humans occurred less than 5 million years ago; thus, humans have occupied Earth for 0.003% of its existence. This is proportional to just a few seconds in an entire day. Despite our short time here on Earth, human activities have had a significant global impact on its ecosystems. Because of this, many scientists now argue that we have entered into a new geological epoch referred to as the **Anthropocene**, the portion of the Earth's history during which human activity has begun to cause significant global change by approaching or exceeding **planetary boundaries**. These boundaries are biophysical thresholds that define

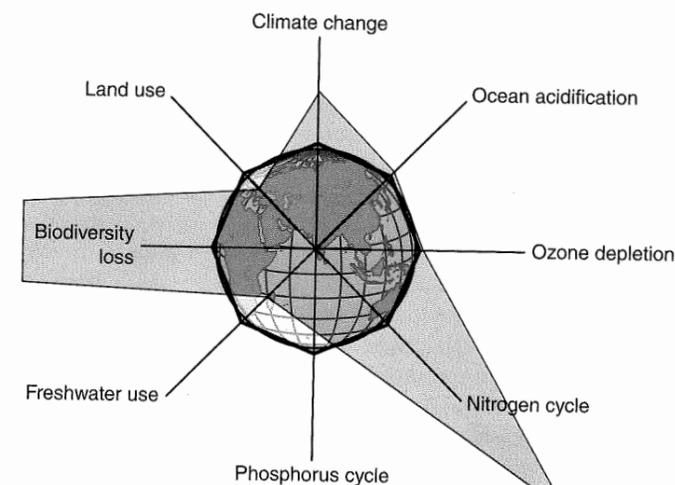
the safe operating space for planetary life support systems essential for human survival. According to Johan Rockström and his collaborators, three of nine of these interlinked planetary boundaries have already been overstepped (Figure 1.12). It is also argued that these planetary boundaries should be the basis for defining preconditions for human development.<sup>18</sup>

Recognizing that our actions threaten our own life support system is an important first step in beginning to protect and restore it. But we must also acknowledge the complicated connection among natural resources, biodiversity, climate change, human population growth and consumption, economic issues, education, and public health, and we must realize that they need to be considered in concert to solve the problems that confront us and our planet. History has taught us that preserving and protecting the environment without considering the needs of the people who depend on it will not work.

The notion that we need to protect our planet because we use it to meet our diverse needs is central to what we call sustainability. In this book, we examine the question of how we can continue to do this without ruining our ability to do so in the future by wrecking the planet on which we depend. Although defined in many ways, sustainability almost always refers to managing the environment for current and future generations so that members of those generations have opportunities to live full and healthy lives.

In Chapter 2, we examine the history of the sustainability movement and use the context from this

**Figure 1.12** The nine planetary boundaries for Earth systems on which human survival depends. The shaded areas indicate the boundaries in the three systems that have already been exceeded. (Adapted from the Stockholm Resilience Center, [https://commons.wikimedia.org/wiki/File:Planetary\\_boundaries.svg](https://commons.wikimedia.org/wiki/File:Planetary_boundaries.svg))



chapter along with that history to develop a useful definition of sustainability. We apply this definition to the variety of problems we face on planet Earth. Sustainability is presented as a way to analyze problems and develop solutions to them. We explore specific solutions, programs, and projects, and we examine how they are implemented and assessed. We do this through a critical lens and with an open mind to allow us to see the potential benefits and limitations of each approach. Our goal is to develop interdisciplinary solutions to complex problems in an effort to sustain our planet in order to meet the needs of the current and future generations of *our* species.

## Chapter Summary

- The goal of this book is to offer the interdisciplinary background that is required to understand the many complex problems that we face and to do so in a way that will both inspire and equip its diverse audience to develop solutions to these problems.
- Natural resources are materials in the environment that are either necessary or useful to humans. They cycle naturally in the environment. When the rate of extraction of a particular resource outpaces its renewal in natural cycles, that resource is considered non-renewable.
- The fundamental resources of air and water are abiotic and theoretically renewable, but human pressure has negatively impacted their quality and accessibility.
- Humans rely on terrestrial and marine resources such as soil, forest and animal products, and mined materials. Current practice results in depletion of those resources and negative impacts on environment and public health.
- Terrestrial and marine environments also provide energy on which humans rely heavily. Non-renewable fossil fuels are rapidly being depleted and contribute to global climate change. Their continued use has implications for national security, energy independence, and the environment. Examples of renewable energy resources include solar, geothermal, wood, and biofuels. Currently, renewable energy resources represent less than 20% of global energy production and use.
- Climate change or global warming is linked to human activity through our contribution to

atmospheric greenhouse gases and the removal of natural carbon sinks. The consequences of global climate change are serious and include drought, crop loss, extreme weather events, damage due to increased fires and flooding, coral reef destruction, and rising sea levels.

- Another global environmental problem is that of invasive species, which are non-native organisms that when introduced to an environment dominate and drive down native diversity.
- Natural ecosystems provide a diversity of services that benefit humans, and biodiversity has potential value as new foods and medicines. Most economic systems and business models do not take this value into account. This value should be accounted for when considering the impact of commercial activity and the cost of products and services.
- Developing countries tend to have higher population growth rates, whereas developed countries have disproportionately higher rates of consumption. These need to be considered in tandem as ways to reduce environmental impact and resource limitations and depletion.
- Other threats to the human condition include the potential for fiscal crisis, severe economic disparity, incomplete or ineffectual education, and public health issues. Environmental, economic, and social issues need to be considered in concert to solve the problems that confront our species and our planet.

## Digging Deeper: Questions and Issues for Further Thought

1. Julian Simon argued that there is no resource crisis—that as resources become scarcer, they increase in cost and in turn there is economic incentive to discover more, ration, recycle, and develop alternatives to them. Can you think of examples in which such human ingenuity generated solutions that eliminated a resource crisis? Were there any other consequences associated with that solution? Are there areas in which solutions have not yet been generated? What are the limitations of this way of thinking?
2. By the end of this chapter, connections between the problems we confront and social justice have begun to emerge. Pick one problem (e.g., climate

- change, population growth, and fiscal crises) and explore the linkage of the problem to social justice.
3. A number of conservation programs that protect specific areas of nature by strictly banning human economic activity have failed. Why? What might be a more effective approach to conservation?
  4. What are the criteria for designating a resource as renewable? Give examples of renewable and non-renewable resources? Are there aspects or components of some renewable resources that are not completely renewable? What might be a better term for such resources?

### Reaping What You Sow: Opportunities for Action

1. We have seen that there are large disparities in per capita consumption of resources between developed and developing countries. Either for yourself or for your community, develop a plan to reduce individual consumption of one or more resources. How would you measure or quantify that reduction?
2. For one or more of the issues presented in this chapter, identify some organizations that directly address them. What is their approach? How are they funded? Choose one that appeals the most to you, and explore ways to either directly get involved with it or support its efforts.

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## CHAPTER 2

# DEVELOPING SUSTAINABLE SOLUTIONS

In Chapter 1, we saw that the state of the environment and human actions and quality of life are all complexly interconnected. Thus, solving problems in either realm requires simultaneous consideration of the other. We must consider the environment as something that is required to sustain human life while recognizing that our ability to do this is contingent on how we live our lives. The principle of sustainability embraces the notion that lasting solutions to environmental problems are difficult to achieve if they do not also improve the quality of life of those who live in and depend on that environment. However, sustainability has had numerous loosely applied definitions. Also, because it has been co-opted and deceptively used to market products or services as environmentally friendly, it has at times been maligned or discredited.

Problem-solving frameworks require precise definitions and approaches so that strategies can be implemented and ultimately assessed. Given that our framework is that of sustainability, we must precisely define it in a practical way. This definition must be broad enough so that it can be applied to a wide range of issues while also providing specific objectives that can be used to develop measurable outcomes. This chapter establishes a robust definition of sustainability that will serve as a framework for identifying and solving problems. We begin by placing sustainability within a historical context. Then we examine the terminology and definitions that emerged from that history and extract those elements that will be most useful in solving problems at the interface of the environment and human needs. We then use these to develop a working definition of sustainability that will allow us to identify problems related to it, most effectively develop creative solutions that can solve those problems, and determine how best to assess the effectiveness of these solutions.

### PLANTING A SEED: THINKING BEFORE YOU READ

1. List five key terms that come to mind when you think of the definition of sustainability. Explain how they differ and what common ideas they share.
2. Do an internet search and locate three rather different definitions of sustainability.
3. What are the "must have" elements of a good, working definition of sustainability?

*The great challenge of the 21st century is to raise people everywhere to a decent standard of living while preserving as much of the rest of life as possible.*

—Edward O. Wilson