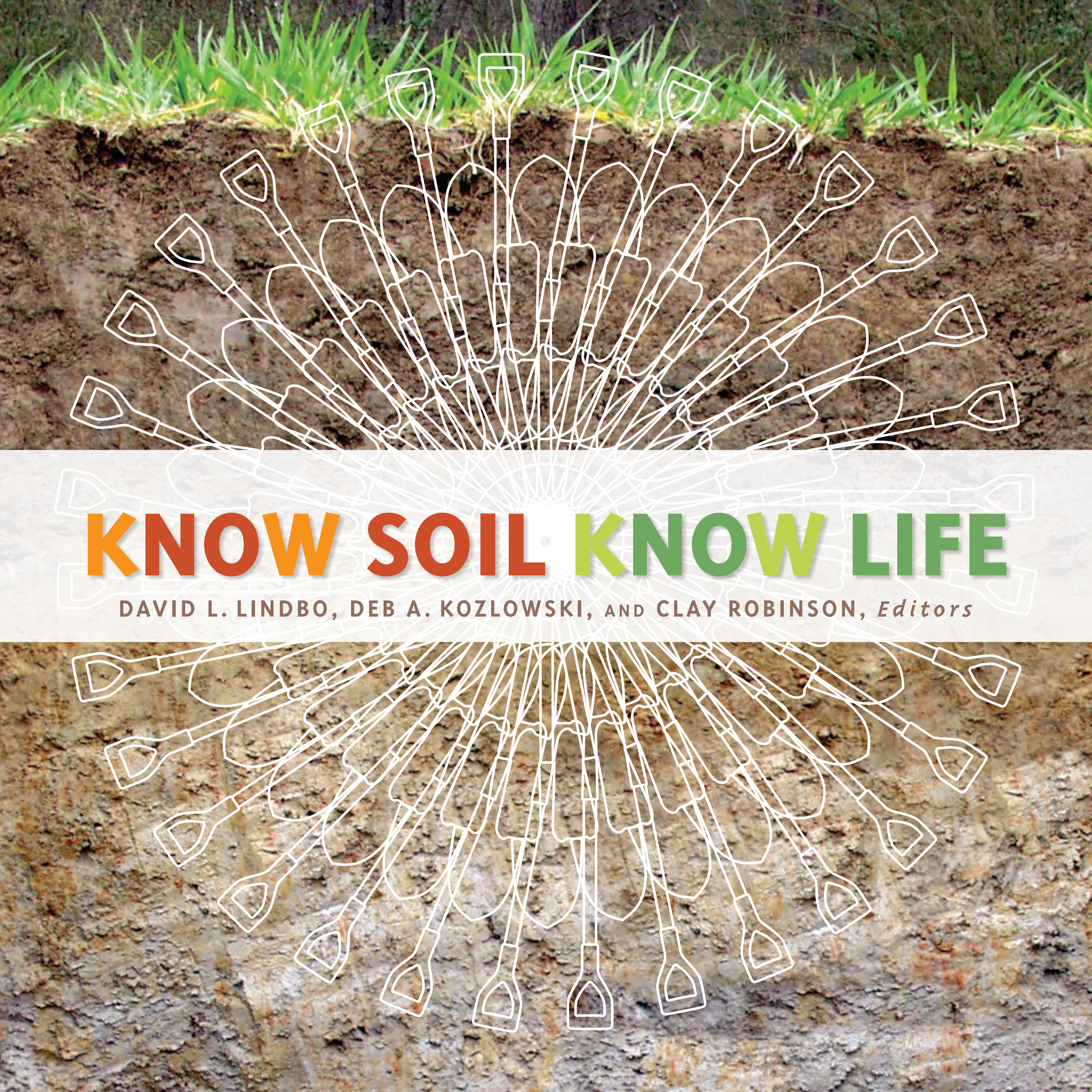

KNOW SOIL KNOW LIFE

DAVID L. LINDBO, DEB A. KOZLOWSKI, AND CLAY ROBINSON, *Editors*

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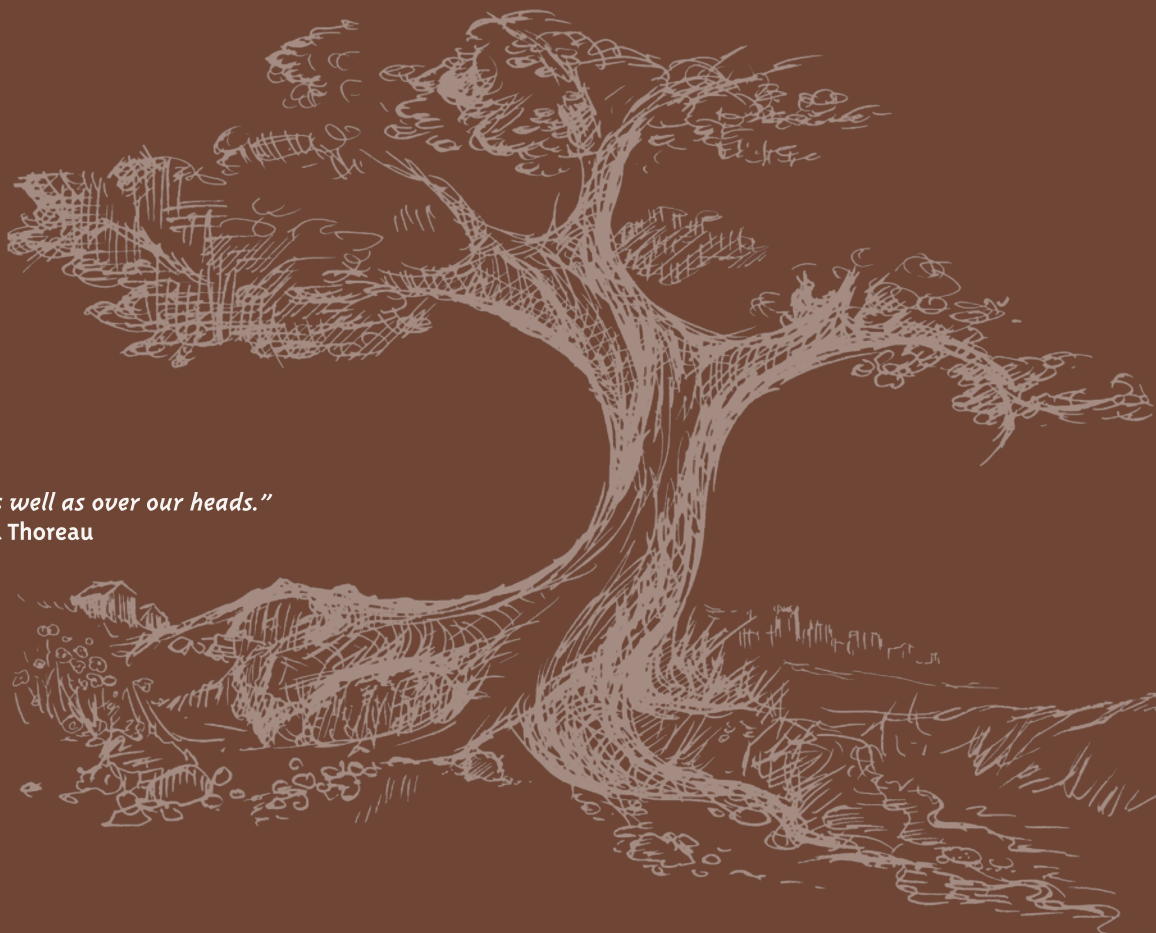
KNOW SOIL KNOW LIFE

To all our introductory soil science professors.
You helped us see soil
as something other than dirt.

To all our students, past, present, and future,
who we hope will come to view soil with awe and fascination.



"Heaven is under our feet as well as over our heads."
Henry David Thoreau

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PREFACE

You are about to begin a tour of an often overlooked part of our natural world—the soil. True, it does not have the immediate appeal of the cute, cuddly creatures that live in the forests or the power of a volcano or the vastness of space, yet soils have an inner beauty of their own. This book will expose you to the nature of soils and soil science. You will see that the stuff you probably call dirt (and please do not use that word again!) is just as complicated, interesting, and varied as any other part of our world. We have distilled a complex science down to about 200 pages. This writing is geared towards a young adult audience. High school students studying environmental science or participating in Envirothon or Science Olympiad will have an easily accessible resource. Undergraduate students in introductory ecology classes will have a manageable soils textbook. However, this book's information is for all ages. See it as an appetizer, a teaser, or an advertisement for soils. Everyone from the young naturalist to the home gardener can find something of interest in these pages. This book is your gateway to soils, soil science, and the world you tread upon every day.

Studying soils makes you better able to understand the world around you; soil science is truly an applied science. You will see how an understanding of biology, chemistry, physics, and ecology will open your eyes to the complexity of the world underfoot. You will learn the language that soil scientists use to communicate with each other. You will see that soils are dynamic and constantly changing. When left alone soils are resilient, but as we use them for our own purposes they can be fragile. It is in our own best interest and the interest of our human civilization to preserve them. Soils are classified in ways to help us make wise land use decisions as our population grows. Soils feed the world and will continue to do so. They dictated the rise and fall of ancient civilizations; have figured in art from the classics to the post-modernist, in warfare, and in literature. But soils are more than that; they are the foundation of life as we know it on Earth.

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SSSA is an international scientific society that fosters the transfer of knowledge and practices to sustain global soils. SSSA is the professional home for 6,000+ members dedicated to advancing the field of soil science. It provides information about soils in relation to environmental quality, ecosystem sustainability, bioremediation, waste management and recycling, crop production, and wise land use. A common thread across the programs and services of SSSA is the dissemination and transfer of scientific knowledge to advance the profession.

SSSA is also focused on outreach to students, teachers, and the public to tell the story of soil and build greater awareness of the value of soil to life. Visit our outreach sites:

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CHAPTER 1

KNOW SOIL, KNOW LIFE

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The world around us is teaming with life. We see it every day. We study it in school so we can fully appreciate and know something about the natural living world around us. But how deeply do we really know life? We know that it is necessary in all its complexities and diversity for our well being. We know that life on Earth makes us unique in the solar system. But rarely do we ponder the fundamental connection between soil and life. Do we ever consider that with *no soil* there would be *no life*?

This book will introduce you to an amazing world—the world beneath your feet. Soil is the foundation our natural living world depends on, the often-unappreciated substance of life, the *dynamic* material that civilization is built on, the *critical zone* of the earth. Once you *know soil* in its complexity and beauty, you will *know life* with broader horizons. You will see that "heaven is under your feet as well as over your heads," in the words of Henry David Thoreau. Soil is not dirt. Soil is life!

This chapter highlights the importance of soil to our everyday lives and introduces some basic facts about soil that will be explored in depth in this book.

SOIL'S IMPORTANCE TO PEOPLE

As you consider the world around you, it comes as little surprise that everything depends on a few basic things: food, a place to live, and water. In the bigger picture, energy is critical, the ultimate source of which is the sun.

People have a few other particular needs. We need air for oxygen, as well as fiber for clothing. Upon further consideration it may come as a surprise that much of what we depend on—food, water, fiber, shelter—are all related to a single, often overlooked item. This is soil! Soil (the *pedosphere*) represents the critical zone of the earth where life (the *biosphere*), water (the *hydrosphere*), minerals (the *lithosphere*), and air (the *atmosphere*) intersect and interact (see figure 1–1). We are reminded that to know soil is to know life, and that with no soil there is no life.

A close look at what you ate for breakfast illustrates this point. You may have had cereal, milk, and orange juice, or maybe toast. Where did each of these items come from? The wheat in your cereal or flour in your toast started out as plant seeds. The milk came from a cow that ate grass. The juice came from oranges that grew on a tree. If you ate sausage or bacon remember that meat comes from animals that are fed grain and forage, which also come from plants. So all your breakfast foods, and food in general, can be traced to plants. But think about where plants come from: plants grow in soil! The soil provides water as well as the nutrients plants need to produce the food we eat. When you eat, you are eating soil, although several steps removed. We rely on plants to supply us with the food we need to survive. Without soil to produce the plants we would have no grains, no bread, no cereal, no milk, no meat, no fruit, no pizza, and therefore would not be able to survive (figure 1–2).

Next, consider your clothes. Your t-shirt and jeans are probably made of cotton—a plant that depends on soil. Other natural

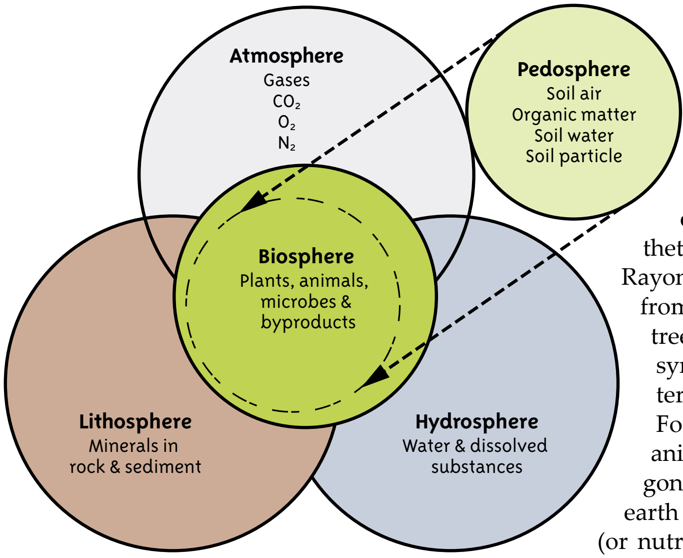


Figure 1–1. The intersecting spheres on Earth: rock, life, air, water, and soil.

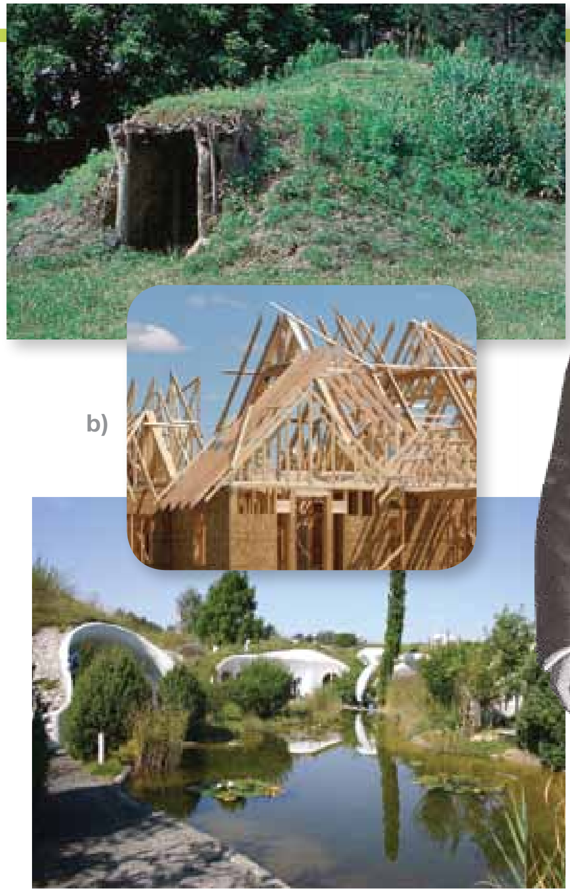
fibers like wool, linen, and silk are also directly related to plants—wool comes from animals that eat plants, linen from flax plants, and silk from silk worms that eat plants. Even many synthetic fibers can be related to soil. Rayon is a synthetic fiber made from cellulose, which come from trees and other plants. Other synthetic fibers such as polyester are derived from fossil fuels. Fossil fuels are ancient plant and animal remains that have undergone extreme changes deep in the earth but nonetheless needed soil (or nutrients from soils and weathering) when they were living. Through a few steps we can indeed link fossil fuels to soil.

Finally, think about the home you live in. In general, houses are made from lumber and bricks. It is easy to see that bricks are connected to the soil, since they are made from clay and sand. Lumber takes a few more steps to connect to soil: lumber is wood; wood comes from trees; and trees, like other plants, need soil to survive as we saw above. Very simply, your house as you know it would not exist without soil.

SOIL'S IMPORTANCE IN THE ENVIRONMENT

We've seen that soil is critical to our food, fiber, and shelter. It also plays an important role in the cycling of another essential item: water. The amount of water on Earth is constant--there is no loss or gain of it. And only a small portion of

a)



b)

c)

Figure 1–2. (a) Everything in this shopping cart comes from soil. (b) Sod house, stick built house, green earth house—all from soil. (c) Clothed in mud or elegant dress—all from soil. Read the label on your shirt and think about how the textile comes from soil. Cotton? Silk? Polyester? Rayon? Wool?

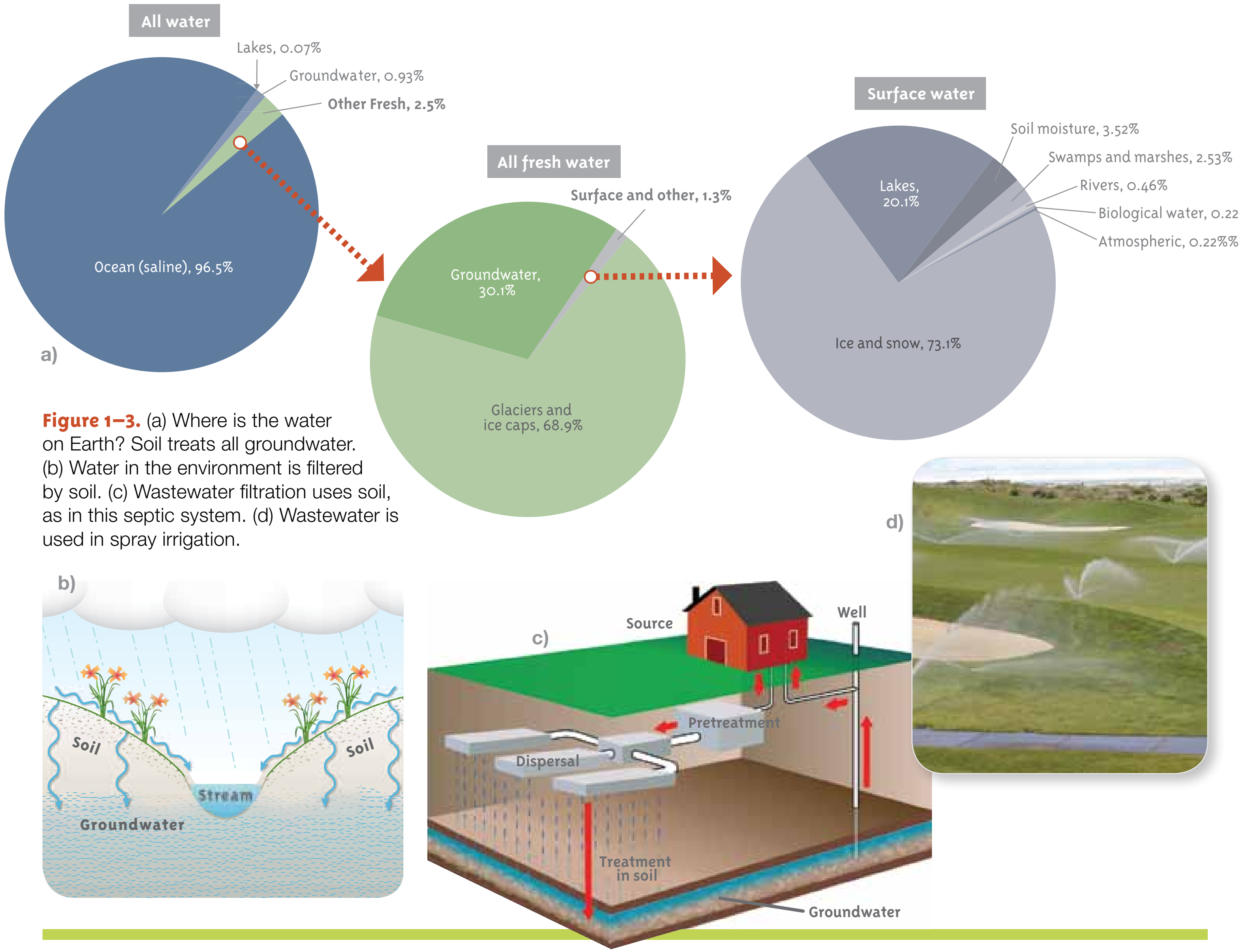


Figure 1–3. (a) Where is the water on Earth? Soil treats all groundwater. (b) Water in the environment is filtered by soil. (c) Wastewater filtration uses soil, as in this septic system. (d) Wastewater is used in spray irrigation.

that finite amount (approximately 1%) of water is usable for drinking (figure 1–3). How does this water remain clean enough for us to drink? You might think it's because we treat it before we drink it. While this is true in many urban or suburban areas, many people worldwide get their drinking water from groundwater. This groundwater is often not treated before people drink it. Instead, it is treated by the soil. As water infiltrates and percolates through soil, the soil's chemical, biological, and physical properties clean the water by removing contaminants. This means that soil is perhaps the largest single water (and wastewater) treatment plant in the world. Soil helps keep water clean by filtering it. We'll learn more about the role of soil in water cycling in chapter 2.

We've seen how soils are essential to plants, by providing many of the nutrients that plants need. Where the supply of nutrients is too low for *crops* to grow we add nutrients to ensure growth and a reliable food supply. Soils store the nutrients until the plant needs them. Soil acts as a nutrient reservoir for plant growth and survival. Soil also provides critical support for plant roots, preventing the plant from falling down or washing away. Soil also acts as a sponge to hold water. Plant roots take up water, allowing the plant to grow and photosynthesize.

In addition to its environmental roles relating to food and water, soil also plays a role in construction. Properties of soil are important to consider when constructing roads and buildings that will last. In particular some soils will shrink and swell because of changes in the amount of water present (figure 1–4). Engineers must identify these and other soil properties to properly design structures (figure 1–4).

Beyond our food, fiber, and shelter, soils are intimately involved in construction and water treatment. Now that we understand how important soil is to our lives, we can consider how much of this precious resource we have.

HOW MUCH SOIL IS ON EARTH?

Surprisingly, there is not that much soil on Earth, yet it is one of the most important natural resources. **As the world population increases, the finite soil resource must provide enough food, fiber, and shelter for the world.**

Relatively speaking, how much productive soil do we have?

The earth has approximately 149 million square kilometers (58 million square miles) of land area (figure 1–5). Of this, deserts and ice sheets account for about 31% and forests another 31%. The remaining 38% is considered agricultural land, but 26% is in permanent pasture, used only to produce feed for livestock, such as cattle, sheep, and goats. Only about 12% of Earth's land surface is used to produce food and fiber (cotton) for human consumption. Of that, just over 1% is perennial cropland primarily used for orchards and vineyards. The remaining 11% is considered *arable* land, which is capable of sustaining annual crops. In the United States, about 23% of the land is in deserts or mountain ranges, 33% is in forests, 26% is rangeland used for grazing, and 18% of the land is used for producing crops.

Since 1961 the global amount of land in annual crops has varied between 9.5% and 11%. In the same period, the world

Figure 1–4. (a) Houses and roads are damaged when soils shrink and swell. (b) Buildings in permafrost can shift when the soils thaw and refreeze. (c) Road construction sometimes involves bringing in sand and removing poor local soil. (d) Interceptor drains are used to divert water from foundations. (e) Construction on organic soils requires special engineering to ensure stability. (f) Septic systems in mounds are used to avoid high water tables.

d)

a)

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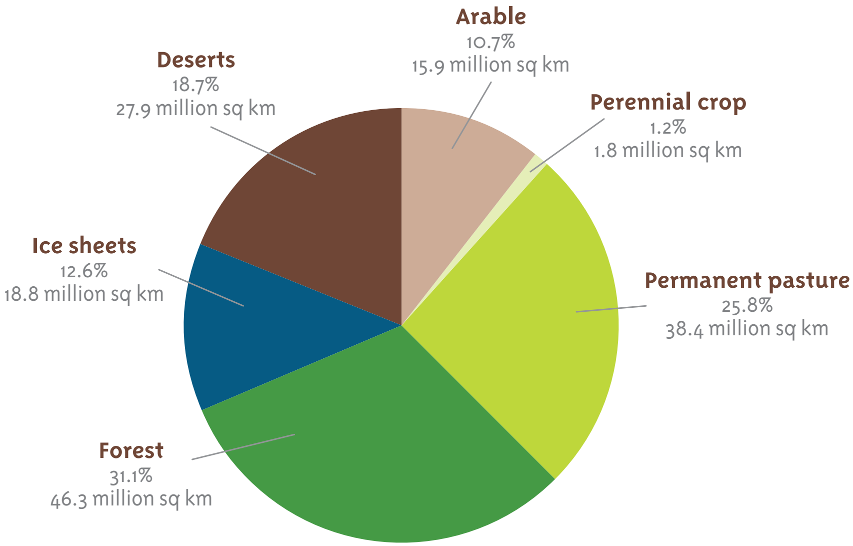


Figure 1–5. Comparison of total area on Earth in various land uses.

average of arable land per person has decreased from 0.37 hectares per person in 1961 to 0.20 hectares in 2012. (Note that a hectare, or 10,000 square meters, is approximately 2.5 acres, and one acre is 43,560 square feet). Nor is the arable land evenly distributed. In East Asia and the Pacific, less than 0.10 hectare per person is available, while Africa has about 0.20 hectares and North America has about 0.61 hectares. As the human population grows, arable land comes under increasing pressure to produce more food per hectare. Some countries don't have the economic strength to buy fertilizers, better seed, and other inputs required to increase yields, or they lack the means or water supply to irrigate, so they look for more land to produce crops. But converting other land into food production poses problems.

Many of the world's forests are in areas that are too cold to produce food crops. Others are in steep areas or shallow soils over bedrock. Removing the trees from these soils leads to rapid *erosion* and loss of productivity. Other forests are in high rainfall regions with acid soils requiring many amendments and careful management to maintain productivity. The capital to purchase the inputs and management expertise in some of these regions is limited.

Deserts are fragile ecosystems that receive too little precipitation to grow crops. Grazing lands (permanent pasture) are often in semiarid regions, and are highly susceptible to drought. Plowing such lands to produce food already led to one Dust Bowl in North America in the 1930s (see chapters 6 and 8) and is having similar impacts in Asia and Africa now. Some soils in deserts and semiarid regions have so much salt in them that plant growth is limited.

Irrigation can increase crop yields and decrease drought risk for crop production in arid and semiarid regions. However, water supplies are becoming more limiting in both quantity and quality. Overall, less than 1% of the arable land in the world is irrigated. About 5.5% of arable land in the United States is irrigated, while more than 50% of the arable land in Pakistan, South Korea, and Bangladesh is irrigated. Worldwide approximately 40% of all food crops are irrigated.

Medieval alchemists considered there to be four elements: earth, air, fire, and water. You can think of these as soil, air, sunlight, and water (figure 1–6), the four items critical to life on Earth. We know we cannot spin gold out of the four medieval elements, but we do need these four things to support something more valuable: all life as we know it.

Earth as an Apple

Grasping land in terms of acres, hectares, square miles, or square kilometers may be hard to fully comprehend. Another way to consider the relative amount of arable land is to imagine Earth as an apple. Cut the apple into four equal parts and discard three parts (75%)—that represents the oceans of the world. The fourth part (25%) represents the land area. Cut the "land area" part in half, leaving two parts each equal to one eighth (12.5%) of the total apple. Discard one of the parts as it represents the deserts, wetlands, and polar areas where people do not live.

The remaining part (12.5%) represents the areas where people live, but not all of it is used for producing food. Cut this remaining part (12.5%) into four pieces. Each remaining slice represents about one thirty-second (1/32, or 3.125%) of the original apple. Three of these one thirty-second sections represent areas of the world that are too rocky, too wet, too hot, or where soils are too poor for growing food, as well as urban areas. Thus, only one thin slice of apple (3.125%) is suitable for food production. But also consider this: soil is present only at the very surface of the earth, so peel that last slice. The thin apple peel represents the soil where all our food, fiber, and shelter come from. Each year more and more of that thin sliver is lost from production, yet the human population continues to grow (see the end of this chapter and chapter 6). This makes it more and more important to take proper care of the soil we have.

Figure 1–6. A modern view of the alchemists' four elements we cannot live without.

WHAT IS SOIL?

Realizing the importance of soil and how little there is, we need to briefly make sure we all know what *soil* is (figure 1–7). First and foremost, **soil is not dirt.** Dirt is the stuff under your fingernails; it is what you sweep up off the floor; it is unwanted and unnecessary. Soil, on the other hand, is essential for life, so soil is not dirt! Dirt may be soil out of place, just as a weed is a plant out of place. For example, a rose in a cornfield, while beautiful, is a weed; a corn plant in a rose garden is also a weed. So when you track mud (wet soil) inside, you are putting the soil in a place it is not wanted. At that point it becomes dirt.

If soil is not dirt what is it? There are several definitions.... Perhaps the simplest is that soil is a living, *dynamic* resource at the surface of the earth. To expand that definition, soil is

> *a natural, three-dimensional body at the Earth's surface. It is capable of supporting plants and has properties resulting from the effects of climate and living matter acting on earthy parent material, as conditioned by relief and by the passage of time.*

Worldwide tens of thousands of different soils occur on every continent and virtually anywhere plant life can set roots. An understanding of the environment requires an understanding of soil—what it is, how it is formed, what it is made of, and how it is used. Soil serves as a repository of many geological and climatic events that have occurred in its location. It is a window to the past, but it can also serve as a view of the future as its properties relate to how we can and should manage this finite resource.

Now consider a handful of soil. At first it may seem lifeless and solid, but in reality soils are teaming with life and contain pockets of air and water. There are four components to every soil: minerals, organic matter (living and dead), water, and air. The minerals and organic matter make up the solid phase. The water and air make up the pore space. A typical handful of soil contains 50% pore space, 45–50% minerals and 0–5% organic matter (figure 1–8). These components will be discussed in detail in the next chapter. Soil as a whole is affected by four basic processes, discussed next.

BASIC SOIL PROCESSES

That same handful of soil is dynamic and responds to its environment. A great number of processes take place in the soil, but they can be grouped together under four major categories: *additions*, *losses*, *transformations*, and *translocations* (figure 1–9). Each of these is briefly defined in the following paragraphs.

Figure 1–7. What is the difference between soil and non-soil? Non-soil includes dirt on the floor, sand dunes in deep desert, barren rock areas, and surface materials at extreme elevations. Think about where the soil is in the world around you—in an agricultural field, lawns, parks, and gardens in urban areas, as in New York's Central Park. There is even soil in the Artic and Antarctic desert, subaqueous soil with eel grass and seaweed, and where trees appear to grow straight out of rock.

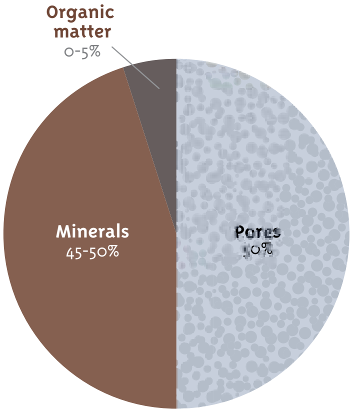


Figure 1–8. Percentages of each component of soil: mineral, pore space (filled with air and/or water), and organic matter.

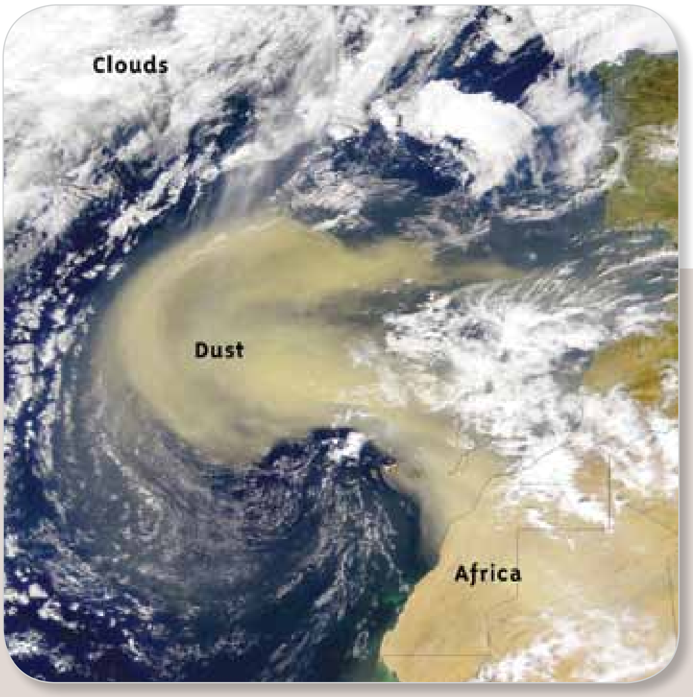
Figure 1–9. The four essential processes of soil: additions, losses, translocations, and transformations.

Additions are easy to understand. They consist of materials deposited on the soil from above, as well as materials moved in with groundwater, such as salts. Obvious examples are additions of leaf litter as trees shed their leaves, or additions of organic material as plants and plant roots die. Also obvious are additions of mineral material from flooding, landslides, and other geologic events. Perhaps not so obvious is the nearly constant addition of atmospheric dust to the soil surface. Some of this dust can travel long distances and is important to the overall fertility of a region. Rainfall is also an addition.

Losses are also rather obvious. Erosion is a major form of soil loss. Loss can also occur as nutrients are taken up by plants,

Across the Seas

One of Africa's biggest "exports" is soil from the Sahara Desert. Whipped up by winds and carried into the atmosphere, fine particles of desert soil can travel across the entire Atlantic Ocean. The dust sometimes causes hazy skies in the southeastern United States and is even credited with adding needed nutrients to the soils of the Amazon rainforests.



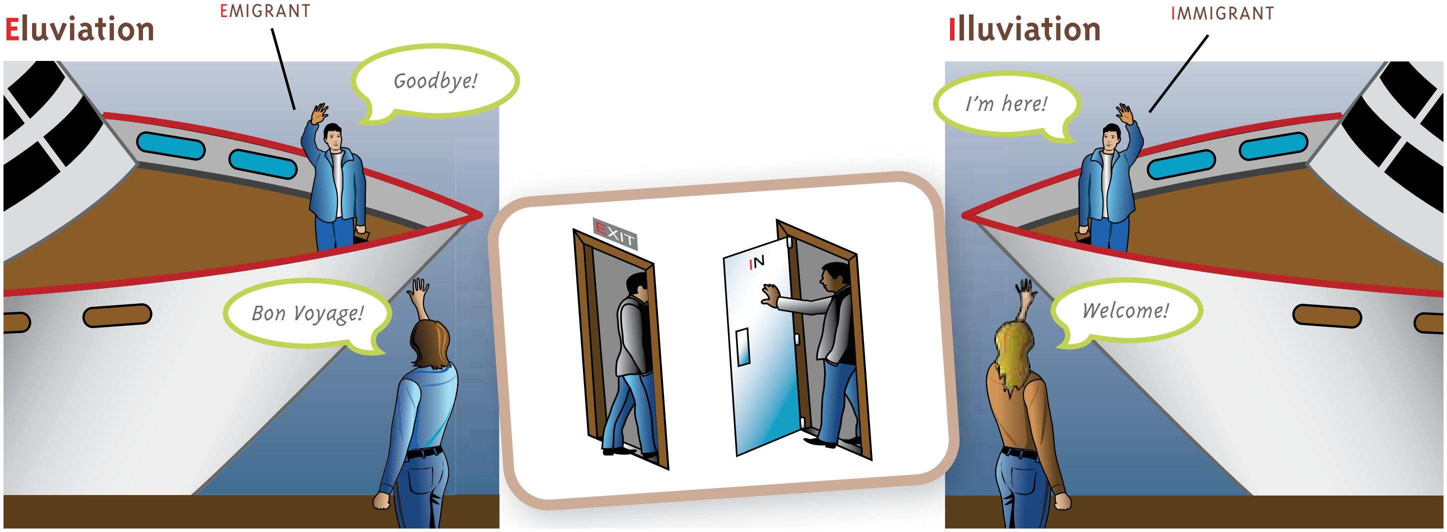


Figure 1–10. Illuviation and eluviation can be understood with these metaphors—the first letter of these words will help you remember! **E**luviation is like **e**migration, leaving your country or origin to go to a new country. **I**lluviation is like **i**mmigration into a new country. **E**xit is leaving a room, as **e**luviation is material exiting the horizon. **I**n is moving into a new room, as **i**lluviation is material moving **i**nto a zone below.

and plants are harvested and removed. As minerals and nutrients move through soil into groundwater or out of the plants' rooting zone, this too is considered a loss.

Translocations are similar to losses in that they involve movement of materials. Translocation differs in that the material is not removed from the soil; instead, it moves from one location to another. This internal movement is referred to as *illuviation* and *eluviation*. Eluviation removes material from a zone. Illuviation moves material into a zone. In other words, eluviation is material exiting, while illuviation is material entering (figure 1–10).

Understanding transformations takes a little more thought. Soils are dynamic—that means they are constantly changing, and biological, chemical, and physical transformations are part of this. For example, leaf litter falling on soil eventually decomposes. This decomposition is a transformation process. Likewise as rocks weather to soil, this too is a transformation process. The initial minerals in the rock are transformed to clays in the soils over time. One mineral can be transformed to another without additions of materials.

The cumulative processes that act on a soil depend on a range of environmental factors, which in turn shape the world's different biomes, discussed next.

SOILS AND BIOMES

Ecologists group large geographic regions with similar environments and distinctive plant and animal communities into biomes (figure 1–11). The major terrestrial biomes include savanna and temperate grasslands, tropical and temperate rainforests, boreal and temperate forests, arctic and alpine tundra, deserts, shrublands, and wetlands. Each biome comprises several ecosystems. For example, temperate grasslands may be short, mixed, or tallgrass prairies.

The environmental factors influencing biomes include latitude, the general climate and topography of the region, and soil. Soil is the foundation of every terrestrial ecosystem.

Each biome has soils with characteristics unique to it. Soil is more than just weathered mineral particles of different sizes. Even a handful of soil is home to more organisms than people living on Earth, as we will learn in chapter 3. Most of these organisms are too small to be seen without a microscope. Microbes consume dead plant and animal tissues to get energy and nutrients. When more nutrients are available than the microbes need, the surplus nutrients are released into the soil. These nutrients are available to support new plant growth, which in turn support animals.

Many plants and animals either prefer, or are adapted to, specific types of soils within a biome. These connections among soils and biomes run both ways; the soil influences the biome, and the biome affects the soil found in it. These relations among soils and biomes will be explored in greater detail in chapter 7.

POPULATION GROWTH AND SOIL

People have exerted a huge influence on biomes over time. We are converting natural biomes into urban lands and cultivated lands (both forests and farms) (figure 1–12). As population growth continues we use more of our soil resources. Human population growth since 1950 (figure 1–13) has caused

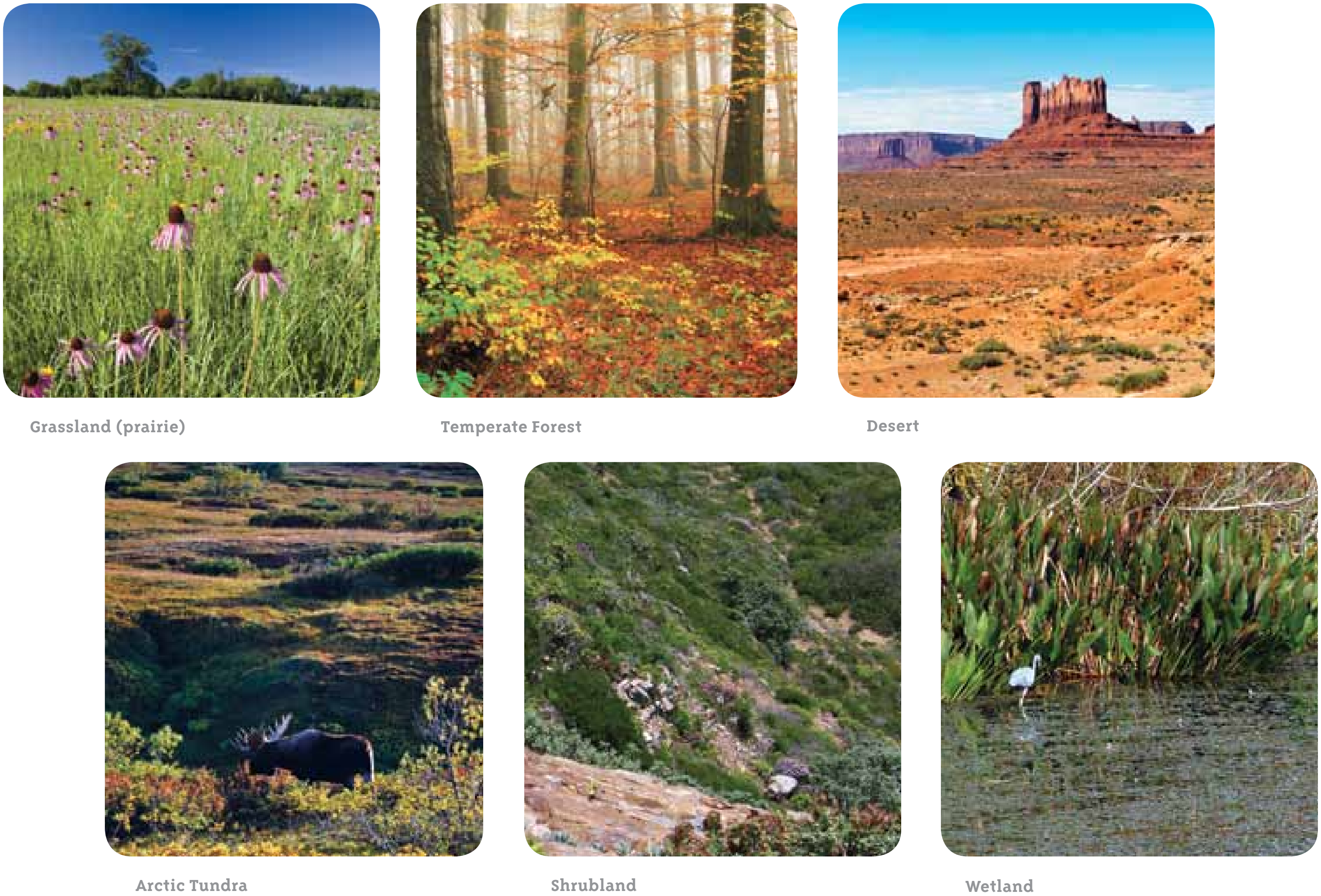


Figure 1–11. Earth's biomes include savanna and temperate grasslands (prairie), temperate and boreal forests, tropical and temperate rainforests, deserts, shrublands, alpine and arctic tundra, shrublands and wetlands. These are merely examples. Can you think of a forest that looks different than this one? How about a different desert?

rapidly growing demands for food, water, timber, fiber, and fuel. These demands are affecting ecosystems more extensively than in any comparable time in human history. Approximately 12% (1.55 billion hectares) of total world land area and 32% of agricultural (arable) land (4.93 billion hectares) is currently cropland (table 1–1). The remaining 3.38 billion hectares of agricultural land, primarily (90%) in Latin America and sub-Saharan Africa, is in forests, permanent pasture, and other non-crop uses. To expand cropland into these 3.38 billion hectares, farmers face large costs because of the poor soil fertility, shallow soils, low rainfall, and other limitations. Furthermore, loss of biodiversity, soil, and other factors affect ecosystem functions, such as maintaining water and air quality.

Since the early 1960s, the world annual population growth rate has dropped to slightly over 1% (figure 1–13). While annual growth rates in all nations are projected to decrease by 2050, rates in developing nations will still be approximately sixfold higher (0.5%) than those in industrialized nations (−0.1%) (table 1–2). In developing countries, most of the decline in population growth rates is projected to result from improvements in education, economic development, and agricultural productivity, primarily in South and East Asia, where nearly 50% of the world's population resides. In sub-Saharan Africa where poverty, suppressed economic opportunity, and low agricultural productivity persist, absolute populations are projected to more