

1

An Introduction to Environmental Science

Chapter Objectives

This chapter will help students:

- Define the term *environment*
- Describe natural resources and explain their importance to human life
- Characterize the interdisciplinary nature of environmental science
- Understand the scientific method and how science operates
- Diagnose and illustrate some of the pressures on the global environment
- Evaluate the concepts of sustainability and sustainable development

Lecture Outline

I. Our Island, Earth

- A. **Our environment** is the sum total of our surroundings.
 - 1. It includes both **biotic factors** and **abiotic factors**.
 - 2. The fundamental insight of environmental science is that we are part of the natural world and we are dependent on a healthy, functioning planet.
- B. **Environmental science** explores interactions between humans and our environment.
 - 1. Environmental science is the study of how the natural world works, how our environment affects us, and how we affect our environment.
- C. **Natural resources** are vital to our survival.
 - 1. Natural resources are the various substances and forces we need in order to survive.
 - 2. **Renewable natural resources** are virtually unlimited or can be replenished by the environment over short periods of time.
 - 3. **Nonrenewable natural resources** are in limited supply and are not

- replenished or are formed much more slowly than we use them.
4. Some renewable resources may turn nonrenewable if we deplete them too drastically.
- D. Human population growth has shaped our relationship with natural resources.
1. **The agricultural revolution** occurred around 10,000 years ago as humans transitioned from a hunter-gatherer lifestyle to an agricultural way of life.
 2. **The industrial revolution** began in the mid-1700s, shifting from a rural, agricultural life to an urban society powered by **fossil fuels**.
 3. **Thomas Malthus** and population growth
 - a. Malthus claimed that unless population growth was controlled, the number of people would outgrow the food supply.
 - b. He argued that a growing population would eventually be checked by famine, disease, or war.
 4. Paul Ehrlich and the “population bomb”
 - a. Ehrlich predicted that a rapidly increasing human population would bring widespread famine and civil strife.
 - b. He claimed that population control was the only way to avoid starvation and war.
 - c. Although his predictions have not come true yet, many who support his ideas predict a global food crisis in the near future.
- E. Resource consumption exerts social and environmental impacts.
1. Garrett Hardin and “The Tragedy of the Commons”
 - a. Hardin analyzed how people approach resource use.
 - b. Resources that are open to unregulated exploitation, the “commons,” will eventually be depleted.
 - c. He disputed the economic theory that individual self-interest, in the long term, serves the public.
 2. Wackernagel, Rees, and the ecological footprint
 - a. **The ecological footprint** expresses the environmental impact of an individual or a population in terms of the cumulative amount of land and water required to provide the raw materials consumed and to recycle the waste produced.
 - b. The ecological footprint is the sum of the amount of Earth’s surface “used” once all direct and indirect impacts are totaled.
 - c. Using these calculations, it is clear that we are depleting our resources about 30% faster than they are being replenished. “Overshoot” is the term that describes the actions of humans surpassing the productive capacity of the planet.
- F. Environmental science can help us avoid mistakes made by past civilizations.
1. The philosopher Plato commented on the deforestation and environmental destruction he observed in ancient Greece.

2. Contemporary social scientists including archaeologists, historians, and paleoecologists validate this trend.

II. The Nature of Environmental Science

- A. People vary in their perception of environmental problems.
 1. An environmental problem is any undesirable change in the environment.
 2. A person's age, gender, class, race, nationality, employment, and educational background can all affect whether he or she considers an environmental change a "problem."
 3. In other cases, different types of people may vary in their awareness of problems.
- B. Environmental science provides **interdisciplinary** solutions.
 1. **Environmental studies** are especially broad because they encompass the **natural sciences** and also many **social sciences**.
 2. An interdisciplinary approach to addressing environmental problems can produce effective and lasting solutions.
- C. Environmental science is not the same as **environmentalism**.
 1. Environmentalism is a social movement dedicated to protecting the natural world from undesirable changes brought about by human choices.
 2. Environmental science is the pursuit of knowledge about the environment, how it works, and our interactions with it.

III. The Nature of Science

1. Modern scientists describe **science** as a systematic process for learning about the world and testing our understanding of it.
 2. Environmental science is a dynamic yet systematic way of studying the world, and it is also the body of knowledge accumulated from this process.
- A. Scientists test ideas by weighing evidence.
 - B. **The scientific method** is the key element of science.
 1. It is a technique for testing ideas with observations and involves several assumptions and a series of interrelated steps.
 2. The assumptions are:
 - a. The universe functions in accordance with fixed natural laws.
 - b. All events arise from some cause and cause other events.
 - c. We can use our senses and reasoning abilities to detect and describe natural laws.
 3. The steps of the scientific method are:
 - a. Make observations.
 - b. Ask a question.
 - c. Develop a **hypothesis**. A hypothesis is an educated guess that explains a phenomenon or answers a scientific question.
 - d. Make **predictions**. A prediction is a specific statement that can be directly and unequivocally tested.

- e. Test the predictions. An **experiment** is an activity designed to test the validity of a hypothesis; it involves manipulating **variables**, or conditions that can change. The **independent variable** is the variable that the scientist manipulates, while the **dependent variable** is the one that depends upon the first variable.
 - f. Use **controlled experiments** by managing the variables. Have an unmanipulated point of comparison, called a **control**, and a manipulated **treatment**.
 - g. A **correlation** is a relationship among two or more variables.
 - h. Analyze and interpret results. **Data** are collected from experiments. Statistical tests are used to understand the significance of the data and the **probability** that a conclusion is true or untrue.
 - i. If repeated tests do not find a hypothesis to be untrue, then the conclusion is that the idea is supported. However, **alternative hypotheses** also need to be tested and ruled out.
- C. There are different ways to test hypotheses.
- 1. A **manipulative experiment** is an experiment in which the researcher actively chooses and manipulates the independent variable.
 - 2. When variables cannot be manipulated, a **natural experiment** is performed.
 - 3. **In ecology**, both manipulative and natural experiments are used. Ecology deals with the distribution and abundance of organisms and the interactions among organisms and with their abiotic environments.
 - 4. Observational studies and natural experiments can show correlation between variables but cannot prove that one variable causes a change in another variable.
- D. The scientific process does not stop with the scientific method.
- 1. Peer review, when other scientists examine and comment on an experiment, is an essential part of the scientific process.
 - 2. Scientists frequently present their work at professional conferences and in written publications.
 - 3. Sound science is based on doubt rather than on certainty and on repeatability rather than on one-time occurrence.
 - 4. If a hypothesis survives repeated testing by numerous research teams, it may be modeled and potentially be incorporated into a **theory**.
 - 5. A theory is a widely accepted, well-tested explanation of one or more cause-and-effect relationships that has been extensively validated by a large amount of research.
- E. Science may go through “**paradigm shifts**.”
- 1. A paradigm is a dominant view regarding a topic, based on the facts and experiments known at that time.
 - 2. Thomas Kuhn argued that science goes through periodic revolutions in which one dominant view is abandoned for another,

as more information becomes available.

IV. Sustainability and the Future of Our World

- A. Population and consumption lie at the root of many environmental changes.
 - 1. The ways we modify the environment have been influenced by the sudden rise in human population.
 - 2. Our consumption of resources rises even faster than our population growth.
- B. We face challenges in agriculture, pollution, energy, and **biodiversity**.
 - 1. Advancing technology has enabled us to grow more food per unit of land. Massive use of chemical fertilizers and pesticides and the resulting runoff and pollution, along with the widespread conversion of natural habitats, are some of the environmental costs of conventional agriculture.
 - 2. Artificial chemicals pollute land, water, and air.
 - 3. Political will is crucial if we are to address the looming specter of climate change. Our dependence on fossil fuels is the major cause.
 - 4. Overharvesting, the introduction of nonnative species, and habitat alteration cause serious problems with biodiversity, the number and diversity of living things, which is declining dramatically.
- C. Fortunately, potential solutions abound.
 - 1. Technological advances and new laws are decreasing pollution in some countries.
 - 2. Advances in conservation biology enable scientists and policymakers to work together to protect habitat and organisms.
 - 3. Recycling and renewable energy sources are increasing.
- D. Are things getting better or worse?
- E. **Sustainability** is a goal for the future.
 - 1. Sustainability means living within our resources such that they sustain us, and the rest of the Earth's biota, for the foreseeable future.
 - 2. **Sustainable development** is using renewable and nonrenewable resources in a way that satisfies current needs without compromising their availability in the future.

V. Conclusion

- A. The sustainable use of resources and the relationship between resource use and population are themes that you will encounter every day.
- B. Finding effective ways of living peacefully, healthily, and sustainably on our diverse and complex planet will require a thorough scientific understanding of both natural and social systems.
- C. It is important to keep in mind that identifying a problem is the first step in devising a solution to it.

4

From Chemistry to Energy to Life

Chapter Objectives

This chapter will help students:

Explain the fundamentals of environmental chemistry and apply them to real-world situations

Describe the molecular building blocks of living organisms

Differentiate among the types of energy and recite the basics of energy flow

Distinguish photosynthesis, respiration, and chemosynthesis, and summarize their importance to living things

Itemize and evaluate the major hypotheses for the origin of life on Earth

Outline our knowledge regarding early life and give supporting evidence for each major concept

Lecture Outline

- I. **Central Case: Bioremediation of the Exxon Valdez Oil Spill**
 - A. The tanker *Exxon Valdez* struck a reef on March 24, 1989, in Alaska's Prince William Sound and spilled 11 million gallons of crude oil.
 - B. Thousands of workers employed by Exxon, with government agencies and volunteers, tackled the spill with conventional methods.
 - C. Scientists used the opportunity to test a new way of cleaning up the spill by enlisting bacteria to naturally break down the oil in a process called **bioremediation**.
 1. Although the bacteria were presented with an abundant new food source, they were not immediately able to consume it because the oil contained too much carbon and not enough nitrogen and phosphorus.

2. Scientists applied a fertilizing mixture containing nitrogen and phosphorus.
3. Because there were many complicating factors, experts have debated how much the treatments sped up degradation.

II. Chemistry and the Environment

- A. Examine many environmental issues, and you will likely discover chemistry playing a central role; chemistry is also central to developing solutions.
- B. Chemistry is central to our understanding of water pollution, wastewater treatment, hazardous waste cleanup and disposal, atmospheric ozone depletion, how organisms synthesize food, and also, energy issues.
- C. Atoms and elements are the chemical building blocks.
 1. An **element** is a fundamental type of matter that cannot be broken down into substances with other properties.
 2. Matter may be transformed from one type of substance into others, but it cannot be created or destroyed. This principle is referred to as the **law of conservation of matter**.
 3. Elements are composed of **atoms**, the smallest components of an element that maintain the chemical properties of that element.
 4. Every atom has a nucleus of **protons** (positively charged particles) and **neutrons** (particles lacking electric charge); the *atomic number* of the element is the number of protons each atom contains, and the *mass number* is the combined number of protons and neutrons. An atom's nucleus is surrounded by negatively charged particles known as **electrons**, which balance the positive charge of the protons.
 5. Although all the atoms of an element have the same atomic number and the same number of protons, they may not contain the same number of neutrons; these atoms are called **isotopes**, and they have different mass numbers.
 6. Because isotopes differ slightly in mass, they also differ slightly in their behavior; researchers have used this to study many phenomena both in and out of the lab.
 7. Some isotopes shed subatomic particles (decay) and emit high-energy radiation as they do so; they are called **radioisotopes** and are radioactive.
 8. Each radioisotope decays at a particular rate called the **half-life**, or the amount of time it takes for one-half the atoms to give off radiation and decay.
 9. Atoms may also gain or lose electrons to become **ions**, which are electrically charged. An ion may consist of a single charged atom or be a combination of two or more atoms from one or more elements.
- D. Atoms bond to form molecules and compounds.
 1. Atoms can bond together in chemical reactions to form **molecules**, combinations of two or more atoms.
 2. If atoms in a molecule are composed of two or more different elements, the molecule is called a **compound**.

3. Atoms are held together in molecules by chemical bonds, ionic bonds, or covalent bonds.
 - a. When atoms in a molecule share electrons, they have a **covalent bond**.
 - b. If one atom exerts a greater pull, then one or more electrons may be transferred from an atom of one element to an atom of another element; this creates two oppositely charged ions and forms an **ionic bond**.
 - c. These associations of ions are not considered molecules, but instead are called **ionic compounds, or salts**.
 4. Elements, molecules, and compounds can come together without chemical bonding in a substance called a mixture.
- E. The chemical structure of the water molecule facilitates life.
1. The water molecule is a single oxygen atom that bonds to two hydrogen atoms at a 105-degree angle; the attraction of the oxygen for the electrons of the hydrogen atoms results in a polar molecule with slight charges.
 2. Because of the slight charge on each molecule, water molecules can adhere to one another in a special type of interaction called a *hydrogen bond*.
 3. Hydrogen bonding gives water the properties important to supporting life and stabilizing Earth's climate.
 4. Adding heat to water weakens the bonds, but does not initially speed molecular action. This capacity to resist change helps to stabilize systems from individual organisms to oceans.
- F. Hydrogen ions determine acidity.
1. Water molecules occasionally dissociate, forming a hydrogen ion (H^+) and a hydroxide ion (OH^-).
 2. Solutions in which the H^+ concentration is greater than the OH^- concentration are **acidic**, while solutions in which the OH^- concentration is greater than the H^+ concentration are **basic**.
 3. The **pH** scale was devised to quantify the acidity or basicity of solutions, and runs from 0 to 14, with 0 to 7 being acidic, 7 being neutral, and 7 to 14 being basic.
 4. The term "pH" comes from potential hydrogen.
- G. Matter is composed of organic and inorganic compounds.
1. **Organic compounds** consist of carbon atoms and, generally, hydrogen atoms that are joined together by covalent bonds, and may include other elements.
 2. **Hydrocarbons** contain only atoms of carbon and hydrogen.
 3. Bacteria used in bioremediation of petroleum spills degrade hydrocarbons into simpler molecules.
- H. Macromolecules are building blocks of life.
1. **Polymers** are long chains of repeated molecules, and three polymers—proteins, nucleic acids, and carbohydrates—play key roles as building blocks of life.
 2. Lipids are not considered polymers but are also fundamental to life. Four types of molecules—proteins, nucleic acids, carbohydrates, and lipids—are referred to as **macromolecules** because of their large size.

3. **Proteins** are made up of long chains of amino acids, each of which is made up of a central carbon linked to a hydrogen atom, an acidic carboxyl group (—COOH), a basic amine group (—NH_2), and an organic side chain unique to each type of amino acid. Proteins provide structure, transport substances, defend against invaders, carry messages, and promote certain chemical reactions.
 4. **Nucleic acids** are molecules that carry the hereditary information for organisms and direct the production of proteins.
 - a. **Deoxyribonucleic acid (DNA)** is a double-stranded spiral that contains the hereditary information.
 - b. **Ribonucleic acid (RNA)** is usually a single strand that contains information from a small portion of a DNA molecule and uses it to direct the building of proteins.
 - c. Regions of DNA that code for particular proteins that perform particular functions are called **genes**.
 5. **Carbohydrates** are organic compounds consisting of carbon, hydrogen, and oxygen atoms in the ratio of about 1 carbon to 2 hydrogen to 1 oxygen; they are used for energy and to build structures such as leaves, lobster shells, and fingernails.
 6. **Lipids** are a fourth type of macromolecule, but are not polymers and do not dissolve in water; they include fats, phospholipids, waxes, and steroids. Lipids are used for energy storage, membranes, and hormones.
- I. We create synthetic polymers.
1. Chemists work with the polymer concept and create polymers called plastics.
 2. Polyethylene, polypropylene, polyurethane, and polystyrene are just a few of the many synthetic polymers in our manufactured products today.
 3. The durability of natural polymers is reflected in the plastics created by humans. The durability of plastics makes life easier for us, but also creates pollution problems for humans and wildlife.
- J. Organisms use cells to compartmentalize macromolecules.
1. All living things are composed of **cells**, the most basic units of organization.
 2. Biologists classify organisms into two groups based on the structure of their cells.
 - a. **Eukaryotic** organisms have cells with **organelles** (internal structures that perform specific functions), including a nucleus.
 - b. **Prokaryotic** organisms are generally single-celled and lack organelles and a nucleus.

III. Energy Fundamentals

- A. **Energy** can change the position, physical composition, or temperature of matter.
1. There are two fundamental types of energy.

- a. **Potential energy** is the energy of position.
- b. **Kinetic energy** is the energy of motion.
2. **Chemical energy** is a special type of potential energy that is held in the bonds between atoms.
- B. Energy is always conserved . . .
 1. The **first law of thermodynamics** states that energy can change from one form to another, but cannot be created or lost.
- C. But energy changes in quality.
 1. The **second law of thermodynamics** states that energy tends to change from a more-ordered state to a less-ordered state.
 2. In every transfer of energy, some usable energy is lost; the degree of disorder in a substance, system, or process is called **entropy**.
 3. The order of an object or system can be increased through the input of additional energy from outside the system.
 4. In every transfer of energy some portion escapes. The degree to which we successfully capture energy is termed the **energy conversion efficiency** and is the ratio of useful output of energy to the amount that needs to be input.
- D. Light energy from the sun powers most living systems.
 1. The sun supplies energy to those organisms that are able to use it to produce their own food; they are **autotrophs**, or primary **producers**.
 2. Autotrophs turn light energy from the sun into chemical energy in a process called **photosynthesis**.
 3. In photosynthesis, sunlight powers a series of chemical reactions that convert water and carbon dioxide into sugars and oxygen, providing high-quality energy that the organism can use.
- E. Photosynthesis produces food for plants and animals.
- F. **Cellular respiration** releases chemical energy.
 1. The chemical energy created by photosynthesis can later be used by organisms in the process of cellular respiration.
 2. Cells use the reactivity of oxygen to convert glucose back into its original starting materials, water and carbon dioxide, and release energy to perform tasks within cells.
 3. This extraction of energy occurs in both autotrophs and **heterotrophs**, or **consumers**.
- G. Geothermal energy also powers Earth's systems.
 1. The gravitational pull of the moon causes tides, providing low-quality energy.
 2. A more significant additional energy source is the radiation from radioactive elements deep in the Earth; this heats the interior of the planet, causing volcanoes and hot water geysers, and producing **geothermal energy**.
- H. Hydrothermal vent communities utilize chemical energy instead of light energy.
 1. Hydrothermal vents are areas in the deep ocean from which jets of geothermally heated water emerge.
 2. Communities of living organisms at these locations depend on bacteria at the base of the food web; these bacteria fuel themselves by **chemosynthesis**, producing sugars.

IV. The Origin of Life

- A. Early Earth was a very different place.
- B. Several hypotheses have been proposed to explain life's origin.
 - 1. Primordial soup: The heterotrophic hypothesis
 - a. This is the idea that life evolved from a primordial soup of simple inorganic chemicals—carbon dioxide, oxygen, and nitrogen—dissolved in the ocean.
 - b. Lab experiments have provided evidence that the proposed process could work.
 - c. However, scientists since then have modified their ideas about early atmospheric conditions, so these experiments seem less likely to represent what actually happened.
 - 2. Seeds from space:
 - a. This is the idea that bacteria from space crashed to Earth on meteorites and started life here.
 - b. The Murchison meteorite, which fell in Australia in 1969, contained many amino acids.
 - c. This now called the **panspermia hypothesis**.
 - 3. Life from the depths: The chemoautotrophic hypothesis.
 - a. This is the idea that early life was formed in deep-sea vents where sulfur was abundant.
 - b. Some of the most ancient ancestors of today's life forms likely lived in extremely hot and wet environments.
- C. Self-replication and cell formation were crucial steps.
- D. The **fossil record** has taught us much about life's history.
 - 1. The earliest evidence of life on Earth comes from 3.5-billion-year-old rocks.
 - 2. Whether the first life arose from deep-sea vents, tidal pools, or comet craters, we know that life diversified into countless forms over Earth's long history, leading eventually to the planet full of life that we know today.
 - 3. **Fossils** are imprints of dead organisms in stone; fossils provide information about plants and animals in different time periods.
 - 4. The fossil record is the cumulative set of fossils worldwide.
 - a. The species living today are but a tiny fraction of all the species that have ever lived.
 - b. Earlier types of organisms changed, or evolved, into later ones.
 - c. The number of species existing at any one time has increased through history.
 - d. There have been several episodes of mass extinction, or simultaneous loss of great numbers of species.
 - e. Many organisms present early in history were smaller and simpler than modern organisms.

- E. Present-day organisms and their genes also help us decipher life's history.

V. Conclusion

- A. Deciphering how life originated depends in part on understanding energy, energy flow, and chemistry.
- B. Energy and chemistry are tied to nearly every significant process in environmental science.
- C. Chemistry can be a tool for finding solutions to environmental problems.

5

Evolution, Biodiversity, and Population Ecology

Chapter Objectives

This chapter will help students:

Explain the process of natural selection and cite evidence for this process

Describe the ways in which evolution influences biodiversity

Discuss reasons for species extinction and mass extinction events

List the levels of ecological organization

Outline the characteristics of populations that help predict population growth

Assess logistic growth, carrying capacity, limiting factors, and other fundamental concepts in population ecology

Identify efforts and challenges involved in the conservation of biodiversity

Lecture Outline

- I. Central Case: Striking Gold in a Costa Rican Cloud Forest

- A. Local residents in Costa Rica's mountainous Monteverde region told of an elusive golden toad that appeared only in the early rainy season.
- B. In 1964, Dr. Jay M. Savage and his colleagues encountered hundreds of golden toads during an expedition.
- C. The newly discovered species went extinct 25 years later when global climate change caused drying of the forest.

II. Evolution as the Wellspring of Earth's Biodiversity

- A. Natural selection shapes organisms and diversity.
 - 1. Biological **evolution** consists of genetic change in organisms across generations.
 - 2. **Natural selection** is the process by which traits that enhance survival and reproduction are passed on more frequently to future generations, altering the genetic makeup of populations through time.
 - 3. In 1858, **Charles Darwin** and **Alfred Russell Wallace** each independently proposed the concept of natural selection as a mechanism for evolution and as a way to explain the great variety of living things.
 - a. Individuals of the same species vary in their characteristics.
 - b. Organisms produce more offspring than can possibly survive.
 - c. Some offspring may be more likely than others to survive and reproduce.
 - d. Characteristics that give certain individuals an advantage in surviving and reproducing might be inherited by their offspring.
 - e. These characteristics would tend to become more prevalent in the population in future generations.
 - 4. A trait that promotes success is called an **adaptive trait**, or an **adaptation**.
- B. Natural selection acts on genetic variation.
 - 1. Accidental changes in DNA are called **mutations** and can range from the addition, deletion, or substitution of single nucleotides to the insertion or deletion of large sections of DNA.

2. Most mutations have little effect; some are deadly; a few are beneficial.
 3. Sexual reproduction generates variation as organisms reproduce through sex; they mix, or recombine, their genetic material so that a portion of each parent's genome is included in the genome of the offspring.
- C. Evidence of natural selection is all around us.
1. This process of selection conducted under human direction is termed **artificial selection**.
- D. Evolution generates biological diversity.
1. **Biological diversity**, or **biodiversity**, is the sum total of all organisms in an area, taking into account the diversity of species, the diversity of populations within a community, and the diversity of communities within an ecosystem.
 2. A **species** is a population whose members share certain characteristics and can freely breed with one another and produce fertile offspring.
- E. **Speciation** produces new types of organisms.
1. When populations of the same species are kept separate, their individuals no longer come in contact, so their genes no longer mix.
 2. If there is no contact, the mutations that occur in one population cannot spread to the other.
- F. Populations can be separated in many ways.
- G. Life's diversification results from numerous speciation events.
- H. Speciation and extinction together determine Earth's biodiversity.
- I. Some species are more vulnerable to extinction than others.
1. Generally, **extinction** occurs when environmental conditions change rapidly or severely enough that a species cannot genetically adapt to the change.
 2. Some species are vulnerable because they are **endemic**, occurring in only a single place on the planet.
- J. Earth has seen several episodes of mass extinction.
1. There have been five **mass extinction events** at widely spaced intervals in Earth's history that have wiped out anywhere from 50 to 95% of Earth's species each time.
- K. The sixth mass extinction is upon us.

III. Levels of Ecological Organization

- A. Ecology is studied at several levels.
 - 1. Life occurs in a hierarchy of levels, from the atoms, molecules, and cells up through the **biosphere**, which is the cumulative total of living things on Earth and the areas they inhabit
 - 2. A group of organisms of the same species that live in the same area is a **population**, and species are often composed of multiple populations.
 - 3. **Communities** are made up of multiple interacting species that live in the same area.
 - 4. **Ecosystems** encompass communities and the abiotic (nonliving) material and forces with which their members interact.
 - 5. **Population ecology** investigates how individuals within a species interact with one another.
 - 6. **Community ecology** focuses on interactions among species.
 - 7. **Ecosystem ecology** studies living and nonliving components of systems.
- B. Habitat, niche, and degree of specialization are important in organismal ecology.
 - 1. The specific environment in which an organism lives is its **habitat**.
 - 2. Each organism has patterns of **habitat use**.
 - 3. A species' **niche** reflects its use of resources and its functional role in a community.
 - 4. Species with very specific requirements are said to be **specialists**.
 - 5. Those with broad tolerances, able to use a wide array of habitats or resources, are **generalists**.

IV. Population Ecology

- A. Populations exhibit characteristics that help predict their dynamics.
 - 1. **Population size** is the number of individual organisms present at a given time.
 - 2. **Population density** is the number of individuals in a population per unit area.

3. **Population distribution**, or **population dispersion**, is the spatial arrangement of organisms within a particular area.
 4. A population's **sex ratio** is its proportion of males to females.
 5. **Age distribution**, or **age structure**, describes the relative numbers of organisms of each age within a population.
 6. **Birth** and **death rates** measure the number of births and deaths per 1,000 individuals for a given time period. The likelihood of death varies with age; this can be graphically shown in **survivorship curves**.
- B. Populations may grow, shrink, or remain stable.
1. Population growth or decline is determined by births, deaths, **immigration** into an area, and **emigration** away from an area.
 2. The **growth rate** equals the crude birth rate plus the immigration rate minus the crude death rate plus the emigration rate.
- C. Unregulated populations increase by exponential growth.
1. When a population increases by a fixed percentage each year, it is said to undergo **exponential growth**.
- D. **Limiting factors** restrain population growth.
1. Every population is eventually contained by limiting factors, which are physical, chemical, and biological characteristics of the environment.
 2. The interaction of the limiting factors determines the **carrying capacity**.
 3. The **logistic growth curve** shows a population that increases sharply at first and then levels off as it is affected by limiting factors.
- E. Carrying capacities can change.
1. Limiting factors are diverse and complex, and help keep population levels below carrying capacity.
 2. Some organisms can alter their environment to reduce environmental resistance and increase carrying capacity.
 3. Humans have appropriated immense proportions of the planet's resources and in the process have reduced the carrying capacities for many other organisms.

- F. The influence of some factors on population depends on population density.
 - 1. The influence of **density-dependent** factors waxes and wanes according to population density.
 - 2. **Density-independent** factors are not affected by population density.
- G. Biotic potential and reproductive strategies vary from species to species.
 - 1. Species that devote large amounts of energy and resources to caring for a few offspring are said to be **K-selected**, because their populations tend to stabilize over time at or near their carrying capacity.
 - 2. Species that are **r-selected** have high biotic potential and devote their energy and resources to producing as many offspring as possible in a relatively short time.
 - 3. K is an abbreviation for carrying capacity, and species that are K-selected species are ones that tend to stabilize over time at or near the carrying capacity.
- H. Changes in populations influence the composition of communities.

V. The Conservation of Biodiversity

- A. Social and economic factors affect species and communities.
 - 1. Costa Rica took steps to protect its environment.
 - 2. Tourists now visit Costa Rica for **ecotourism**.

VI. Conclusion

- 1. Speciation and extinction help determine Earth's biodiversity.
- 2. Many human activities are playing a role in biodiversity loss.

6

Species Interactions and Community Ecology

Chapter Objectives

This chapter will help students:

Compare and contrast the major types of species interactions

Characterize feeding relationships and energy flow, using them to construct trophic levels and food webs

Distinguish characteristics of a keystone species

Characterize the process of succession and the debate over the nature of communities

Perceive and predict the potential impacts of invasive species in communities

Explain the goals and the methods of ecological restoration

Describe and illustrate the terrestrial biomes of the world

Lecture Outline

- I. **Central Case: Black and White, and Spread All Over: Zebra Mussels Invade the Great Lakes**
 - A. The pollution-fouled waters of Lake Erie and the other Great Lakes shared by Canada and the United States became gradually cleaner in the years following the Clean Water Act of 1970.

- B. Then the zebra mussel arrived, a native to western Asia and eastern Europe.
- C. The zebra mussel's larval stage is well adapted for long-distance dispersal, and it has encountered none of the predators, competitors, and parasites that evolved to limit its population growth in the Old World.
- D. Zebra mussels can clog up water intake pipes, damage boat engines, degrade docks, foul fishing gear, and sink buoys that ships use for navigation.
- E. Zebra mussels also have severe impacts on the ecological systems they invade. Among the most significant impacts, is their ability to take large quantities of food (phytoplankton) needed by native molluscs for food.
- F. Most recently, the zebra mussel is being displaced by the quagga mussel. Scientists do not yet understand the complex interactions driving the change. The quagga has a larger niche than any native mussels or even the zebra mussel.

II. Species Interactions

- 1. The most prominent interactions are competition, predation, parasitism, herbivory, and mutualism.
- A. **Competition** can occur when resources are limited.
 - 1. Competitive interactions can take place among members of the same species (*intraspecific competition*), or among members of two or more different species (*interspecific competition*).
 - 2. *Competitive exclusion* occurs when one species excludes the other from resource use entirely.
 - 3. Competing species that live side by side at a certain ratio of population sizes may reach a stable equilibrium point—*species coexistence*.
 - 4. Coexisting species that use the same resources tend to minimize competition by using only a portion of the total array of resources—their niche, or ecological role in the community—that they are capable of using.
 - a. The full niche of a species is called its **fundamental niche**.
 - b. An individual that plays only part of its role because of competition or other species interactions is said to be displaying a **realized niche**.

5. Over time, competing species may evolve to use slightly different resources or to use their shared resources in different ways; this is **resource partitioning**.
 - a. Because species limit their resource use, over time, character displacement may occur as they evolve physical characteristics that reflect their reliance on a particular portion of the resource.
- B. Several types of interactions are exploitative.
 1. Exploitation occurs when one member of an interaction exploits another for its own gain.
- C. Predators kill and consume prey.
 1. **Predation** is the process by which an individual of one species, a *predator*, hunts, captures, kills, and consumes an individual of another species, its *prey*.
 2. Predation can sometimes drive population dynamics, causing cycles in population sizes.
 3. Predation also has evolutionary ramifications—more adept predators will leave more and healthier offspring, leading to the evolution of adaptations that make them better hunters. The same selective pressure acts on prey species, who evolve defenses against being eaten.
- D. Parasites exploit living hosts.
 1. **Parasitism** is a relationship in which one organism, the *parasite*, depends on another, the *host*, for nourishment or some other benefit while simultaneously doing the host harm.
 2. Many parasites live in close contact with their hosts, such as disease pathogens, tapeworms, ticks, and lamprey.
 3. Other types of parasites are free-living and come into contact with their hosts only infrequently (e.g., nest parasites such as cuckoos and cowbirds).
 4. Some parasites cause little harm, but others may kill their hosts.
 5. Hosts and parasites can become locked in a duel of escalating adaptations called the *evolutionary arms race*.
- E. Herbivores exploit plants.
 1. **Herbivory** occurs when animals feed on the tissues of plants.
- F. Mutualists help one another.

1. **Mutualism** is a relationship in which two or more species benefit from interaction with one another.
 2. Many mutualistic relationships—like many parasitic relationships—occur between organisms that live in close physical contact; this is called **symbiosis**.
 3. Free-living organisms such as bees and flowers also engage in mutualism in the process of pollination.
- G. Some interactions have no effect on some participants.
1. **Amensalism** is a relationship in which one organism is harmed and the other is unaffected.
 2. **Commensalism** occurs when one organism benefits and the other is unaffected.

III. Ecological Communities

- A. Energy passes among **trophic levels**.
1. As organisms feed on one another, energy moves through the community, from one rank in the feeding hierarchy, or trophic level, to another.
 2. Producers, or autotrophs (“self-feeders”), comprise the first trophic level.
 - a. Producers include terrestrial green plants, cyanobacteria, and algae, and all of them capture solar energy and use photosynthesis to produce sugars.
 - b. The chemosynthetic bacteria of hot springs and deep-sea hydrothermal vents use geothermal energy in a similar way to produce food.
 3. Organisms that consume producers (e.g., deer and grasshoppers) are known as *primary consumers*. Most of them consume plants and are called *herbivores*.
 4. The third level consists of *secondary consumers*, which prey on primary consumers. Predators that feed at higher trophic levels are known as *tertiary consumers* (e.g., hawks eat rodents that ate grasshoppers).
 5. Secondary and tertiary consumers are *carnivores* because they eat animals.
 6. Animals that eat both plant and animal food are *omnivores*.

7. *Detritivores* and *decomposers* consume nonliving organic matter.
- B. Energy, biomass, and numbers decrease at higher trophic levels.
1. At each trophic level, most of the energy that organisms use is lost through respiration.
 2. The first trophic level (producers) contains a large amount of energy, while the second (primary consumers) contains less energy—only that amount gained from consuming producers.
 3. The third trophic level (secondary consumers) contains still less energy, and higher trophic levels (tertiary consumers) contain the least.
 4. A general rule of thumb is that each trophic level contains just 10% of the energy of the trophic level below it, although the actual proportion can vary greatly.
 5. This pattern can be visualized as a pyramid, and generally also holds for the numbers of organisms at each trophic level, with fewer organisms existing at higher trophic levels than at lower trophic levels.
 6. This same pyramid-like relationship also often holds true for biomass; the sheer number of prey relative to predators means that prey biomass will likely be greater overall than predator biomass.
 7. Humans can decrease their ecological footprint by eating lower on the pyramid—choosing vegetarianism or reducing meat consumption that takes more energy from the trophic pyramid than a plant-centered diet would.
- C. **Food webs** show feeding relationships and energy flow.
1. A food web is a visual map of feeding relationships and energy flow, showing the many paths by which energy passes among organisms as they consume one another.
- D. Some organisms play bigger roles in communities than others.
1. A **keystone species** is a species that has a particularly strong or far-reaching impact.
 2. Large-bodied secondary or tertiary consumers are often considered keystone species.

3. Some species attain keystone species status not through what they eat, but by physically modifying the environment.
- E. Communities respond to disturbance in different ways.
1. A community that resists change and remains stable despite disturbance is said to show **resistance** to the disturbance.
 2. Alternatively, a community may show **resilience**, meaning that it changes in response to disturbance but later returns to its original state.
 3. Human activities are among the major forces of disturbance in ecological communities today.
- F. **Succession** follows severe disturbance.
1. If a disturbance is severe enough to eliminate all or most of the species in a community, the affected site will undergo a somewhat predictable series of changes that ecologists call succession.
 - a. **Primary succession** follows a disturbance so severe that no vegetation or soil life remains from the community that previously occupied the site. In primary succession, a biotic community is built essentially from scratch.
 - 1) Pioneer species, such as lichens, are the first to arrive.
 - 2) Lichens secrete acid, starting the process of soil formation.
 - 3) New, larger organisms arrive, establish themselves, and pave the way for more new species, where eventually a climax community becomes established.
 - b. **Secondary succession** begins when a disturbance dramatically alters an existing community but does not destroy all living things or all organic matter in the soil.
 2. At terrestrial sites, primary succession takes place after a bare expanse of rock, sand, or sediment becomes newly exposed. Species that arrive first and colonize the new substrate are referred to as **pioneer species**.
 3. In the traditional view of succession, the transitions between stages of succession eventually lead to a *climax community*, which

remains in place with little modification until some disturbance restarts succession.

4. Today, ecologists recognize that succession is far more variable and less predictable. Its stages blur into one another and vary from place to place, with certain stages sometimes being skipped entirely.
- G. How cohesive are communities?
1. Frederick Clements promoted the view that communities are cohesive entities whose members remain associated over time and space.
 2. Henry Gleason maintained that each species responds independently to its own limiting factors, and that species can join or leave communities without greatly altering their composition.
 3. Today, ecologists side largely with Gleason, although they see validity in aspects of both ideas.
- H. Invasive species pose new threats to community stability.
1. An **invasive species** is a non-native organism that arrives in a community from elsewhere, spreads, and becomes dominant, with the potential to substantially alter a community.
 2. In case after case, managers are finding that controlling and eradicating invasive species are so difficult and expensive that preventive measures represent a much better investment.
 3. In most cases, ecologists view invasive species as having overall negative impacts on ecosystems. In rare cases, non-native species like the honeybee provide important economic benefits to agriculture and ornamental crops.
- I. Altered communities can be restored to their former condition.
1. Efforts to restore areas to a more pristine habitat are known as **ecological restoration**.
 2. The practice of ecological restoration is informed by the science of **restoration ecology**, with research into the history of an area, as well as an understanding of its “presettlement” condition.
 3. Ecological restoration is often time consuming and expensive. A restored system may not match the diversity of the original landscape. It is better to protect natural landscapes from degradation.

IV. Earth's Biomes

1. A **biome** is a major regional complex of similar communities—a large ecological unit recognized primarily by its dominant plant type and vegetation structure.
- A. Biomes are groupings of communities that cover large geographic areas.
1. A biome depends on many abiotic factors, but is determined largely by climate—temperature and precipitation.
 2. Scientists often use **climate diagrams**, or **climatographs**, to depict annual patterns and monthly averages of temperature and precipitation.
 3. Each biome encompasses a variety of communities that share similarities (e.g., oak-hickory, beech-maple, and pine-oak forests are all temperate deciduous forests).
- B. We can divide the world into roughly ten terrestrial biomes.
1. **Temperate deciduous forest** is found in eastern North America and is characterized by broadleaf trees that lose their leaves in the fall.
 2. Moving westward from the Great Lakes, we find **temperate grasslands** that were once widespread but have now been mostly converted to agricultural land.
 3. **Temperate rainforest** is found in the Pacific Northwest and is a forest type known for its high biodiversity and potential to produce large volumes of commercially important products.
 4. **Tropical rainforest** is found in regions near the equator, and is characterized by high rainfall year-round, uniformly warm temperatures, high biodiversity, and lush vegetation.
 5. Tropical areas that are warm year-round but where rainfall is lower overall and highly seasonal give rise to **tropical dry forest**, or tropical deciduous forest.
 6. Dry tropical areas across large stretches of Africa, South America, India, and Australia are **savannas**—regions of grasslands interspersed with clusters of trees.

7. **Desert** is the driest biome on Earth, and much of the rainfall occurs during isolated storms. Deserts are not always hot, but they have low humidity and relatively little vegetation to insulate them. Temperatures, therefore, may vary widely from day to night and across seasons.
 8. **Tundra** is nearly as dry as desert, but is located in cold regions at very high latitudes along the northern edges of Russia, Canada, and Scandinavia. Little daylight in winter and lengthy, cool days in summer result in a landscape of lichens and low, scrubby vegetation without trees.
 9. The northern coniferous forest, or **boreal forest**, often called *taiga*, develops in cooler, drier regions than temperate rainforests. Taigas stretch in a broad band across much of Canada, Alaska, Russia, and Scandinavia.
 10. **Chaparral** is found in areas of Mediterranean climate, and consists of densely thicketed evergreen shrubs.
- C. Altitude creates patterns analogous to latitude.
D. Aquatic systems also show biome-like patterns.

V. Conclusion

- A. The natural world is so complex that we can visualize it in many ways and at various scales.
- B. Dividing the world's communities into major types, or biomes, is informative at the broadest geographic scales.
- C. Understanding how communities function at more local scales requires an understanding of how species interact with one another.
- D. Increasingly, humans are altering communities.

7

Environmental Systems and Ecosystem Ecology

Chapter Objectives

This chapter will help students:

Describe the nature of environmental systems

Define ecosystems and evaluate how living and nonliving entities interact in ecosystem-level ecology

Compare and contrast how carbon, phosphorus, nitrogen, and water cycle through the environment

Explain how plate tectonics and the rock cycle shape the earth beneath our feet

Lecture Outline

- I. **Central Case: The Gulf of Mexico's "Dead Zone"**
 - A. In 2002, the dead zone grew to its largest size ever—22,000 square km (8,500 square miles).
 - B. The dead zone is a region in the Gulf of Mexico so depleted of oxygen that it cannot support marine organisms, a condition called **hypoxia**.
 - C. The change from productive fishery to dead zone has occurred in the last 30 years. The spread of the hypoxic zone threatens the Gulf's fishing industry, one of the most productive fisheries in the United States.
 - D. Scientists studying the dead zone have determined that fertilizer runoff from midwestern farms is a major cause.

- E. Other important causes include urban runoff, industrial discharge, fossil fuel combustion, and municipal sewage.

II. Earth's Environmental Systems

- A. Systems show several defining properties.
 - 1. A system is a network of relationships among a group of parts, elements, or components that interact with and influence one another through the exchange of energy, matter, and/or information.
 - 2. Systems receive input, process it, and produce output.
 - 3. Sometimes a system's output can serve as input to that same system in a circular process called a **feedback loop**.
 - a. In a **negative feedback loop**, output driving the system in one direction acts as input that moves the system in the other direction.
 - b. In a **positive feedback loop**, the output drives the system further toward one extreme.
 - 4. The inputs and outputs of a complex natural system often occur simultaneously, keeping the system constantly active. If they are in balance, it is called a **dynamic equilibrium**.
 - 5. Processes in dynamic equilibrium contribute to **homeostasis**, where the tendency of the system is to maintain stable internal conditions.
 - 6. It is difficult to fully understand systems by focusing on their individual components because systems can show **emergent properties**, characteristics that are not evident in the system's components.
 - 7. Systems rarely have well-defined boundaries, so deciding where one system ends and another begins can be difficult.
 - 8. A **closed system** is isolated and self-contained, having no interactions with other systems. This does not occur in nature but is a useful way to begin considering a simple version of a system.
 - 9. An **open system** exchanges energy, matter, and information with other systems. All systems on Earth are open systems.

- B. Understanding the dead zone requires considering Mississippi River and Gulf of Mexico systems together.
 - 1. Hypoxia in the Gulf of Mexico stems from excess nitrogen from the Mississippi River watershed.
 - 2. Excess nutrients are present in runoff from fertilized agricultural fields, animal manure, crop residues, sewage, and industrial and automobile emissions.
 - 3. The nutrients reach the Gulf, where they boost the growth of microorganisms; this provides food for bacterial decomposers, which flourish.
 - 4. The decomposers use the oxygen in the water; other organisms, such as fish and shrimp, suffocate and die.
 - 5. The process of nutrient enrichment, algal bloom, bacterial increase, and ecosystem deterioration is called **eutrophication**.
- C. Environmental systems may be perceived in various ways.
 - 1. The **atmosphere** is comprised of the air surrounding our planet.
 - 2. The **hydrosphere** encompasses all water in surface bodies, underground, and in the atmosphere.
 - 3. The **lithosphere** is everything that is solid earth beneath our feet.
 - 4. The **biosphere** consists of the sum total of all the planet's living organisms, or biotic components, and the abiotic portions of the environment with which they interact.

III. Ecosystems

- A. **Ecosystems** are systems of interacting living and nonliving entities.
 - 1. An ecosystem describes all interacting organisms and abiotic factors that occur in a particular place at the same time.
 - 2. Energy for most ecosystems is input from the sun and is converted to biomass by producers through photosynthesis. Net Primary Production can be measured by the energy or the organic matter stored by plants after they have metabolized enough for their own maintenance.
 - 3. Most materials cycle within an ecosystem.

4. Ecosystem outputs include energy (often as heat), water, and waste products from plants and animals. Autotrophs (green plants) produce food, while heterotrophs (animals) consume plants and other animals.
 5. Ecosystems that produce large amounts of biomass are considered to have high net primary productivity.
 6. The absence of one or more critical nutrient molecule or element can limit net primary productivity.
- B. Landscape ecologists study geographic areas with multiple ecosystems.
1. **Landscape ecology** is the broad-scale study of how landscape structure affects the abundance, distribution, and interactions of organisms.
 2. An **ecotone** is a transitional zone where two or more ecosystems meet; it contains some elements from each ecosystem.
 3. Landscapes are composed of an array of spatial units called **patches** spread in a mosaic throughout the area. Depending on an ecologist's research focus, patches can be ecosystems, communities, or habitat for specific species.
- C. Energy is converted to **biomass**.
1. Autotrophs capture the sun's energy through photosynthesis. This is **gross primary production**.
 2. After autotrophs use some of their acquired energy for their own metabolism, the remainder is used to generate biomass. This amount is the **net primary production**.
 3. The rate at which biomass is generated is called **productivity**. Ecosystems with rapid biomass production have high **net primary productivity**.
- D. Nutrients can limit ecosystem productivity.
1. **Nutrients** are elements and compounds that organisms consume and require for survival.
 2. In natural ecosystems, some nutrients always run off land into oceans. This nutrient input causes high primary productivity in nearshore waters along continents.
 3. When human activities, such as farms, cities, and industry, increase this nutrient load, then

eutrophication and hypoxia often occur. This creates dead zones.

IV. **Biogeochemical Cycles**

- A. Nutrients circulate through ecosystems in biogeochemical cycles.
 - 1. Nutrients move through the environment in cycles called **nutrient cycles** or **biogeochemical cycles**.
 - 2. Most nutrients travel through the atmosphere, hydrosphere, and lithosphere and from one organism to another, moving between pools, or reservoirs, remaining in a reservoir for a residence time.
 - 3. Nutrient movement between reservoirs is called flux; the rates of flux can change over time. Flux typically involves negative feedback loops that promote dynamic equilibrium.
 - 4. Human activity has changed some flux rates.
- B. The **carbon cycle** circulates a vital organic nutrient.
 - 1. Carbon is an ingredient in carbohydrates, fats, proteins, bones, cartilage, and shells of all living things.
 - 2. The carbon cycle describes the routes carbon takes through the environment.
 - 3. Through photosynthesis, producers pull carbon dioxide out of the atmosphere to produce oxygen and carbohydrates.
 - 4. During respiration, producers, consumers, and decomposers break down carbohydrates to produce carbon dioxide and water.
- C. Humans are shifting carbon from the lithosphere to the atmosphere.
 - 1. As we mine fossil fuel deposits and cut or burn vegetation, we remove carbon from reservoirs and increase the flux into the atmosphere.
 - 2. This ongoing flux of carbon into the atmosphere is a major force behind global climate change.
 - 3. Atmospheric scientists remain baffled by the “missing carbon sink,” the roughly 1-2 billion metric tons of carbon unaccounted for that we anticipate should be in the atmosphere due to fossil fuel combustion and deforestation.
- D. The **phosphorus cycle** involves mainly lithosphere and ocean.

1. The element phosphorus is a key component of DNA, RNA, ATP, and cell membranes.
 2. Phosphorus is primarily found in rocks, soil, sediments and oceans; the weathering of rocks releases phosphates into water at a very low rate of flux.
 3. The phosphorus cycle has no appreciable atmospheric component.
 4. Concentrations of available phosphorus in the environment are very low; this is often a limiting factor for producers.
- E. We affect the phosphorus cycle.
1. We mine rocks for phosphorus to make fertilizers, and our sewage discharge and agricultural runoff are high in phosphates.
 2. These additions to the available reservoir of phosphorus in water and soil can cause rapid increases in biomass and eutrophication and hypoxia in waterways.
- F. The nitrogen cycle involves specialized bacteria.
1. Nitrogen makes up 78% of the atmosphere and is the sixth most abundant element on Earth.
 2. The **nitrogen cycle** involves chemically inert nitrogen gas, which most living organisms cannot use. This makes the atmosphere the major reservoir for nitrogen.
 3. Lightning, highly specialized bacteria, and human technology are the only ways to fix nitrogen into compounds usable by living organisms.
 4. Nitrogen is frequently a limiting factor for producers and therefore limits populations of consumers, including humans.
 5. There are two ways that inert nitrogen gas becomes “fixed” so that plants can use it—nitrogen fixation and nitrification.
 - a. **Nitrogen fixation** occurs through lightning or **nitrogen-fixing bacteria** that live in mutualistic relationships with many leguminous plants.
 - b. **Nitrification** occurs through specialized free-living bacteria.
 - c. **Denitrifying bacteria** converts nitrates in soil or water to gaseous nitrogen.
- G. Humans have greatly influenced the nitrogen cycle.

1. Nitrogen fixation has always been a bottleneck, limiting the flux of nitrogen out of the atmospheric reservoir.
 2. The **Haber-Bosch process** allows humans to synthesize ammonia, accelerating its flux into other reservoirs within the cycle.
 3. Burning forests and fields and fossil fuels all increase the amount of atmospheric nitrogen, as does bacterial decomposition of animal wastes from feedlots.
 4. Strategies to limit the amount of damage caused by excess nutrients in the waterways are not successful at this time.
- H. The **hydrologic cycle** influences all other cycles.
1. The oceans are the main reservoir, holding 97% of all water on Earth. Less than 1% of planetary water is usable by humans.
 2. Water moves into the atmosphere via **evaporation** and **transpiration**. It returns to the surface as **precipitation**, most of which flows into water bodies as **runoff**.
 3. Some precipitation and surface water soaks down to recharge underground reservoirs known as **aquifers**. This is **groundwater**, and its depth underground is the **water table**.
- I. Our impacts on the hydrologic cycle are extensive.
1. We have dammed rivers and created reservoirs, increasing evaporation.
 2. We have changed vegetation patterns, increasing runoff and erosion and decreasing recharge.
 3. Irrigation, industry, and other human uses have depleted aquifers and increased evaporation.
 4. Atmospheric pollutants have changed the chemical nature of precipitation.
 5. Water shortages are giving rise to conflicts throughout the world and are predicted to increase.

V. Geological Systems: How Earth Works

- A. The **rock cycle** is a fundamental environmental system.
1. Over geological time, rocks are heated, cooled, broken down, and reassembled in the rock cycle.
 2. Rocks that form when **magma** cools are called **igneous rock**. When magma is spewed from a volcano, it is known as **lava**.

3. **Sedimentary rock** is formed when dissolved minerals seep through **sediment** layers and crystallize and bind particles together in the process called **lithification**.
 4. When great heat or pressure is exerted on rock, it is transformed into **metamorphic rock**; marble and slate are examples.
 5. Understanding the rock cycle helps us appreciate soil formation and conservation, and conservation of fossil fuels and other natural resources.
- B. **Plate tectonics** shapes Earth's geography.
1. Earth's surface consists of the **crust, mantle, and core**. Earth's internal heat causes the mantle to flow, pushing rock up and down.
 2. In the distant past all the landmasses on the plates joined into a supercontinent called *Pangaea*.
 3. New crust is formed where two plates are pushed apart at **divergent plate boundaries**.
 4. When two plates meet, they may slip and grind alongside one another, forming a **transform plate boundary**.
 5. When two plates collide at **convergent plate boundaries**, uplift or **subduction** can result.

VI. Conclusion

- A. Approaching questions holistically by taking a systems approach is helpful in environmental science.
- B. The case of the Gulf of Mexico's hypoxic zone provides evidence that systems thinking can lead the way to solutions.
- C. Renewable solar energy, nutrient recycling, dynamic equilibrium, and negative feedback loops are all hallmarks of unperturbed ecosystems that have survived the test of time.
- D. Our industrialized civilization is very young in comparison; we should consider taking lessons in sustainability from these older, successful ecosystems.

8

Human Population

Chapter Objectives

This chapter will help students:

Assess the scope of human population growth

Evaluate how human population, affluence, and technology affect the environment

Explain and apply the fundamentals of demography

Outline and assess the concept of demographic transition

Describe how wealth and poverty, the status of women, and family planning programs affect population growth

Characterize the dimensions of the HIV/AIDS epidemic

Lecture Outline

I. Central Case: One-Child Policy

- A. The People's Republic of China is the world's most populous nation, home to one-fifth of the 6.5 billion people living on Earth at the start of 2006.
- B. Under Mao Zedong's leadership, improved food production and distribution and better medical care allowed China's population to swell, causing environmental problems.
- C. The government instituted a population-control program in the 1970s.
 1. The program started with education and outreach efforts encouraging people to marry

- later and have fewer children, and increasing the accessibility of contraceptives and abortion.
2. In 1979 the government decided to institute a system of rewards and punishments, enforcing a one-child limit per family.
 3. In 1984, the policy was relaxed, exempting rural areas and certain minorities, thus minimizing opposition.
- D. China's growth rate is down to 0.6%; however, there have been unintended consequences of the program, such as widespread killing of female infants and an unbalanced sex ratio.

II. Human Population Growth: Baby 6 Billion and Beyond

- A. The human population is growing nearly as fast as ever.
1. The human population has doubled since 1964. There are approximately 6.7 billion humans living on the planet today.
 2. Since 1975 the world's population has added one billion humans every 12 years.
 3. Most of human population growth is occurring in developing countries where economic hardships exist and the governments are ill-equipped to deal with increasing citizens requiring services.
- B. Is population growth really a "problem"?
1. Our ongoing burst of population growth has resulted from technological innovations, improved sanitation, better medical care, increased agricultural output, and other factors that have led to a decline in death rates, particularly a drop in infant mortality.
 2. There are many people today who deny that population growth is a problem.
 3. Under the Cornucopian view, resource depletion as a consequence of greater numbers of people is not a problem if new resources can be found to replace the depleted resources.
 4. Environmental scientists argue that not all resources are replaceable by others once they are depleted, and that few resources are actually created by humans.
 5. Even if resource substitution could enable indefinite population growth, could we

- maintain the quality of life that we would desire, or would our descendants have less space, less food, and less material wealth than the average person does today?
6. Many governments have found it difficult to let go of the notion that population growth increases a nation's economic, political, and military strength.
- C. Population is one of several factors that affect the environment.
1. The **IPAT model** represents how humans' total impact (I) results from the interaction among three factors—population (P), affluence (A), and technology (T): $I = P \times A \times T$.
 2. A sensitivity factor (S) can be added to the equation to denote how sensitive a given environment is to human pressures: $I = P \times A \times T \times S$.
 3. Impact can generally be boiled down to either pollution or resource consumption.
 4. Modern-day China shows how all elements of the IPAT formula can combine to result in tremendous environmental impact in very little time.

III. Demography

- A. Demography is the science of human population.
1. The principles of population ecology apply to humans.
 2. Like other organisms, humans have a carrying capacity set by environmental limitations on our population growth.
 3. Estimates of the human carrying capacity have ranged greatly—from 1–2 billion people living prosperously in a healthy environment to 33 billion living in extreme poverty in a degraded world without natural areas.
- B. Demography is the study of human population.
1. The application of population ecology principles to the study of statistical change in human populations is the focus of the social science of **demography**.
 2. Population size is the absolute number of individuals.
 3. People are very unevenly distributed over the globe.

- a. This uneven distribution means that certain areas bear far more environmental impact than others.
- b. At the same time, areas with low population density are often vulnerable to environmental impacts. The reason they have low populations may be that they are sensitive and cannot support many people.
4. Age structure diagrams show the relative sizes of each age group in a population and are especially valuable to demographers in predicting future dynamics of a population.
5. The ratio of males to females, the sex ratio, can also affect population dynamics.
 - a. The naturally occurring sex ratio in human populations at birth features a slight preponderance of males.
 - b. In China, selective abortion of female fetuses has skewed the natural sex ratio.
- C. Population growth depends on the rates of birth, death, immigration, and emigration.
 1. In today's world, immigration and emigration are playing an increasingly large role because of the flow of refugees.
 2. Since 1970, growth rates in many countries have been declining and the global growth rate has declined, partially because of a steep drop in birth rates.
- D. A population's total fertility rate influences population growth.
 1. The **total fertility rate (TFR)** is the average number of children born per female member of a population during her lifetime.
 2. **Replacement fertility** is the TFR that keeps the size of a population stable; for humans, it is 2.1.
 3. A lower infant mortality rate has reduced people's tendency to conceive many children in order to ensure that at least some survive.
 4. Many other social factors play a role in reducing the emphasis on child rearing.
 5. The **natural rate of population change** is the change due to birth and death rates alone, excluding migration.
- E. Some nations have experienced a change called the demographic transition.

1. **Life expectancy** is the average number of years that an individual in a particular age group is likely to continue to live.
 2. **Demographic transition** is a theoretical model of economic and cultural change that explains the trend of declining death rates and birth rates that occurs when nations become industrialized.
 3. The first stage, the **pre-industrial stage**, is characterized by conditions in which both death rates and birth rates are high.
 4. In the next stage, the **transitional stage**, death rates decline and birth rates remain high.
 5. The **industrial stage** creates employment opportunities, particularly for women, causing the birth rate to fall.
 6. In the final stage, the **post-industrial stage**, both birth rates and death rates remain low and populations stabilize or decline slightly.
 7. Natural resource managers warn that despite technological advances, the Earth does not contain enough resources for existing and future generations to maintain a standard of living equal to developed countries.
- F. Is the demographic transition a universal process?
1. This transition has occurred in many European countries, the United States, Canada, Japan, and several other developed nations over the past 200–300 years.
 2. It may or may not apply to all of the developing countries depending on their culture, especially if they place greater value on childbirth or grant women fewer freedoms.

IV. Population and Society

- A. Civil Rights for women greatly affects population growth rates.
1. Drops in TFR have been most noticeable in countries where women have gained improved access to contraceptives and education, particularly family-planning education.
 2. Unfortunately, many women still lack the information and personal freedom of choice to allow them to make their own decisions about when to have children and how many to have.

3. In societies in which women are freer to make reproductive decisions, fertility rates have fallen, and the children are better cared for, healthier, and better educated.
- B. Population policies and family-planning programs are working around the globe.
1. The government of Thailand has relied on an education-based approach to family planning that has reduced birth rates and slowed population growth.
 2. India was the first country to implement population control measures. After strident policies of the 1970s led to the downfall of the government, newer policies now focus on education, family planning services, and incentives/disincentives to better manage the nation's population that is expected to overtake China as the most populated nation.
 3. Brazil, Mexico, Iran, Cuba, and many other developing countries have instituted active programs consisting of population reduction targets, incentives, education, contraception, and reproductive health care.
 4. In 1994, the United Nations hosted a conference in Cairo on population and development, at which 179 nations endorsed a platform calling for all governments to offer universal access to reproductive health care within 20 years.
 5. Despite the successes of family planning internationally, the United States has often declined to fund family-planning efforts by the United Nations. For example, canceling this funding was one of George W. Bush's first acts upon becoming U.S. president in 2001.
- C. Poverty is strongly correlated with population growth.
- D. Consumption from affluence creates environmental impact.
1. Individuals in affluent societies leave a larger "ecological footprint."
- E. The wealth gap and population growth contribute to violent conflict.
1. In 1999, the richest 20% of the world's people used 86% of the world's resources, and had over 80 times the income of the poorest 20%.

- F. HIV/AIDS is a major influence on populations in parts of the world.
 - 1. Of the 38 million people around the world infected with HIV/AIDS in 2004, 25 million lived in the nations of sub-Saharan Africa.
 - 2. The AIDS epidemic is unleashing a variety of demographic changes.
 - 3. Premature deaths, of both infants and young adults, are reducing the average life expectancy in African nations.
- G. Severe demographic changes have social, political, and economic repercussions.
 - 1. Everywhere in sub-Saharan Africa, AIDS is undermining the ability of developing countries to make the transition to modern technologies because it is removing many of the youngest and most productive members of society.
 - 2. Governments of AIDS-infected countries are experiencing *demographic fatigue*.

V. Conclusion

- A. Although global populations are still growing, the rate of growth has decreased nearly everywhere.
- B. There has been progress in expanding rights for women worldwide. In addition to the clear ethical progress of this development, it also helps to slow population growth.
- C. True sustainability demands that we stabilize our population size in time to avoid destroying the natural systems that support our economies and societies.

9

Soil and Agriculture

Chapter Objectives

This chapter will help students:

Explain the importance of soils to agriculture, and describe the impacts of agriculture on soils

Outline major historical developments in agriculture

Delineate the fundamentals of soil science, including soil formation and the properties of soil

State the causes and predict the consequences of soil erosion and soil degradation

Recite the history and explain the principles of soil conservation

Lecture Outline

I. Central Case: No-Till Agriculture in Southern Brazil

- A. In southernmost Brazil, decades of farming had used up the soil's fertility and caused erosion.
- B. In the 1990s, Brazil's farmers adopted no-tillage farming.
- C. With less soil eroding away and more organic material being added to it, the soil could hold more water and was better able to support crops.
- D. No-till farming reduced costs to farmers who now used less labor and less fuel.

II. Soil: The Foundation for Feeding a Growing Population

- A. Increasing food production sustainably is necessary if we are to feed the world's rising human population.
 - 1. **Agriculture** is the practice of cultivating soil, producing crops, and raising livestock for human use and consumption.
 - 2. As the human population increases, so does the amount of **cropland** and other resources devoted to agriculture, which currently covers 38% of Earth's land surface.
 - 3. **Rangeland**, or pasture, is the land used for livestock.
 - 4. Healthy **soil** is a mix of rock, organic matter, water, gases, nutrients, and microorganisms.
- B. As population and consumption increase, soils are being degraded.
- C. Agriculture began to appear around 10,000 years ago.
 - 1. **Traditional agriculture** needed human and animal muscle power, hand tools, and simple machines.
- D. Industrialized agriculture is newer still.
 - 1. The industrial revolution introduced large-scale fossil fuel combustion and mechanization, leading to industrialized agriculture.
 - 2. For maximum efficiency, the new agriculture required the uniform planting of a single crop, or **monoculture**.
 - 3. The **green revolution** applied technology to boost crop yields in developing nations.

III. Soil as a System

- A. Soil formation is slow and complex.
 - 1. **Parent material** is the base geological material in a location. It may be composed of volcanic deposits, glacial deposits, sediments from wind or water, or bedrock.
 - 2. The **weathering** of parent material is the first step in the formation of soil.
 - 3. Weathering takes place through the physical, chemical, and biological processes that break down rocks and minerals.
 - 4. **Erosion**, the process of moving soil from one area to another, may contribute to the formation of soil in one locality even as it depletes topsoil from another.
- B. A soil "profile" consists of distinct layers known as "horizons."

1. Soils from different locations differ, but soil from any given location can nonetheless be divided into recognizable layers, or **horizons**.
 2. The cross section from bedrock to surface is the **soil profile**.
 3. Many soil profiles contain an uppermost layer consisting mostly of organic matter; this layer is designated the **O horizon** (O for organic).
 4. Just below the O horizon in a typical soil profile is the **A horizon (topsoil)**, which consists of mostly inorganic mineral components with some organic matter and humus.
 5. Unsustainable agricultural practices can cause degradation and loss of topsoil. This depletes the soil's fertility over time.
 6. Beneath the A horizon lies the **E horizon**, also known as the zone of eluviation.
 7. **Leaching** picks up particles in the soil and transports them elsewhere, generally downward.
 8. Materials leached from the A and E horizons are carried down into the layer beneath them, the **B horizon** (subsoil).
 9. The **C horizon**, beneath the B horizon, contains rock particles that are larger and less weathered than the layers above.
 10. The C horizon sits directly above the **R horizon**, which is also known as the parent material, or **bedrock**.
- C. Soil can be characterized by color, texture, structure, pH, and cation exchange.
1. U.S. soil scientists have classified soils into 12 major groups, based largely on the processes thought to form them.
 2. Soil color is an indicator of soil composition and sometimes soil fertility.
 3. Soil texture is determined by the size of particles and is the basis on which the USDA assigns soils to one of three general categories:
 - a. **Clay** consists of particles less than 0.002 mm in diameter.
 - b. **Silt** consists of particles 0.002–0.05 mm in diameter.
 - c. **Sand** is particles 0.05–2 mm in diameter.
 - d. Soil with an even mix of these particle sizes is called **loam**.

4. Soil structure is a measure of the arrangement of sand, silt, or clay particles into clumps, or aggregates.
 5. Soil pH is the degree of acidity or alkalinity, which influences its ability to support plant growth.
 6. Soil particles that are negatively charged hold positively charged nutrient ions called cations. Calcium, magnesium, and potassium cations are a good measure of soil fertility. Clay and organic soils tend to have efficient cation exchange. Acidic soils have less exchange of cations.
- D. Regional differences in soil traits can affect agriculture.

IV. Soil Degradation: Problems and Solutions

- A. Erosion can degrade ecosystems and agriculture.
- B. Soil erodes by various mechanisms.
 1. These include wind erosion and four types of water erosion: splash, sheet, rill, and gully.
- C. Soil erosion is a global problem.
- D. Arid land may lose productivity by desertification.
 1. **Desertification** is a loss of more than 10% productivity due to soil erosion, soil compaction, forest removal, **overgrazing**, drought, **salinization**, climate change, depletion of water sources, or an array of other factors.
- E. The Dust Bowl was a monumental event in the United States.
 1. Large-scale cultivation of the southern Great Plains of the United States, combined with a drought in the 1930s, led to dust storms, destroying the land and affecting human health in the **Dust Bowl**.
- F. The Soil Conservation Service pioneered measures to slow soil degradation.
 1. **Conservation districts** within each county promoted soil-conservation practices.
- G. Farmers can protect soil against degradation in various ways.
 1. **Crop rotation** is the practice of alternating the kind of crop grown in a particular field from one season or year to the next.
 2. **Contour farming** consists of plowing furrows along the natural contours of the land.
 3. The planting of alternating bands of different crops across a slope is called **intercropping**.

4. **Terracing**, cutting level platforms into hillsides, is used on extremely steep terrain.
 5. **Shelterbelts** are rows of trees that are planted along the edges of fields to break the wind.
 6. With conservation, or reduced, tillage, plowing is bypassed as an approach to soil conservation.
- H. Protecting and restoring plant cover is the theme of most erosion-control practices.
- I. Irrigation has boosted productivity but has also caused long-term soil problems.
1. Crops that require a great deal of water can be grown with **irrigation**, artificial provision of water.
 2. Soils too saturated with water may experience waterlogging, which damages both soil and roots.
 3. An even more frequent problem is salinization, the buildup of salts in surface soil layers.
- J. Salinization is easier to prevent than to correct.
- K. Agricultural fertilizers boost crop yields but can be overapplied.
1. Nutrient depletion creates a need for **fertilizers** containing nutrients.
 2. **Inorganic fertilizers** are mined or synthetically manufactured mineral supplements.
 3. **Organic fertilizers** consist of natural materials.
- L. Grazing practices and policies can contribute to soil degradation.
- M. Forestry, too, has impacts on soils.
- N. A number of U.S. and international programs promote soil conservation.

V. Conclusion

- A. Many policies enacted and practices followed in the United States and worldwide have been quite successful in reducing erosion.
- B. Many challenges remain; better technologies and wider adoption of soil conservation techniques are needed to avoid a food crisis.

10

Agriculture, Biotechnology, and the Future of Food

Chapter Objectives

This chapter will help students:

- Explain the challenge of feeding a growing human population
- Identify the goals, methods, and environmental impacts of the “green revolution”
- Categorize the strategies of pest management
- Discuss the importance of pollination
- Describe the science behind genetically modified food
- Evaluate controversies and the debate over genetically modified food
- Ascertain approaches for preserving crop diversity
- Assess feedlot agriculture for livestock and poultry
- Weigh approaches in aquaculture
- Evaluate sustainable agriculture

Lecture Outline

I. Central Case: Possible Transgenic Maize in Oaxaca, Mexico

- A. Corn is a staple grain of the world’s food supply, and today Oaxaca, Mexico, is a world center of biodiversity for maize, with many native varieties, or *cultivars*.
- B. In 2001, Mexican scientists found DNA in Oaxacan farmers’ maize that seemed to match genes from genetically modified corn.
 1. To genetically engineer crops, scientists extract genes from the DNA of one organism and transfer them into the DNA of another organism of a different species.

2. The genes are called **transgenes**, and the new organisms are **transgenic** plants.
- C. Two researchers collected samples of wild maize and their lab analyses revealed traces of DNA from genetically engineered corn.
- D. Their findings were published in *Nature*, but the findings were disputed and, bowing to criticism, *Nature* stated that the study should never have been published.
- E. Further research has confirmed their findings.
- F. The question is how genetically modified crops may affect people and the environment.

II. The Race to Feed the World

- A. Agricultural production has outpaced population increase so far.
 1. Agricultural scientists and policymakers pursue a goal of **food security**, the guarantee of an adequate, reliable, and available food supply to all people at all times.
 2. Starting in the 1960s, a number of doomsayers predicted widespread starvation and catastrophic failure of agricultural systems.
 3. Instead, we have achieved dramatic increases in our carrying capacity, in part by increasing our ability to produce food.
 4. This has occurred because we have devoted more energy (especially fossil fuel energy) to agriculture; increased the use of irrigation, fertilizer, and pesticides; increased the amount of cultivated land; and developed (through crossbreeding and genetic engineering) more productive crop and livestock varieties.
- B. We face undernourishment, overnutrition, and malnourishment.
 1. While some people do not have access to enough food to stay healthy, others are affluent enough to consume far more than is healthy.
 - a. Those who are **undernourished** receive less than 90% of their daily caloric needs.
 - b. Those who suffer from **overnutrition** receive too many calories each day.
 2. The quantity of food a person eats is important for health, but the quality of food is important as well. **Malnutrition** is a shortage of nutrients the body needs, and it can occur in both undernourished and overnourished individuals.
 3. One-fifth of the world's people live on less than \$1 per day, and over half live on less than \$2 per day, according to the World Bank.
 4. *Kwashiorkor* results from a high-starch diet with little protein.
 5. *Marasmus* is caused by a combination of protein deficiency and lack of calories.
- C. The "**green revolution**" led to dramatic increases in agricultural production.
 1. Farmers in the United States had been dramatically increasing their yields using new methods and technology, and many people saw this as a way to end starvation in developing nations.

2. The transfer of technology to the developing world began in 1940 when a specially bred wheat species was introduced to Mexico.
 3. Some varieties of crops yielded three or four times as much per acre as did the older varieties.
- D. The green revolution has caused the environment both benefit and harm.
1. Developing countries imported the methods of industrialized agriculture such as the use of synthetic fertilizers, chemical pesticides, irrigation, and heavy equipment.
 2. This high-input agriculture was dramatically successful at allowing farmers to harvest more corn, wheat, rice, and soybeans from each hectare of land.
 3. From 1900 to 2000, humans expanded the world's total cultivated area by 33%, yet increased energy inputs into agriculture by 80 times.
 4. The green revolution techniques have had negative consequences for biodiversity and mixed consequences for crop yields. The intensive use of water, fossil fuels, and chemical fertilizers and pesticides has had extensive negative impacts in terms of pollution, salinization, and desertification.
 5. The planting of *monocultures*, large expanses of single crop types, has made planting and harvesting more efficient, but has reduced biodiversity and caused increased susceptibility of an entire crop to disease, pathogens, or insect pests. This brings the risk of catastrophic failure.
 6. Monocultures have also contributed to a narrowing of the human diet. This has nutritional dangers as well as biodiversity dangers.

III. Pests and Pollinators

1. Throughout the history of agriculture, pests have taken advantage of our clustering of food plants into agricultural fields.
 2. A *pest* is any organism that damages crops that are valuable to us, and a *weed* is any plant that competes with our crops. These are subjective categories defined entirely by our own economic interests.
- A. Many thousands of chemical **pesticides** have been developed and applied.
1. Poisons that target pest organisms are called pesticides. Over 900 million pounds of the active ingredients of pesticides are applied in the United States each year.
- B. Pests evolve resistance to pesticides.
- C. **Biological control** pits one organism against another.
1. Biological control, or **biocontrol**, operates on the principle that “the enemy of one’s enemy is one’s friend.” We find natural enemies, or predators, of a species we consider a pest and introduce them to an area where the pests are a problem.
- D. Biological control agents themselves may become pests.
1. Scientists argue over the relative benefits and risks of biocontrol measures.

2. A widespread modern biocontrol effort has been the use of ***Bacillus thuringiensis* (Bt)**, a naturally occurring soil bacterium that produces a protein that kills many caterpillars and the larvae of some flies and beetles.
- E. Integrated pest management combines biocontrol and chemical methods.
1. Integrated pest management (IPM) uses numerous techniques, including biocontrol, chemicals, population monitoring, habitat alteration, crop rotation, transgenic crops, alternative tillage methods, and mechanical pest removal.
- F. We depend on insects to pollinate many of our crops.
1. **Pollination** is the process by which male sex cells of a plant (pollen) fertilize female sex cells of the same species of plant; it is the botanical version of sexual intercourse.
 2. While our staple grain crops are grasses that are wind-pollinated, many of our other crops depend on insects for pollination.
- G. Conservation of pollinators is vital.
1. North American farmers today are dependent on European honeybees for much of their pollination. Parasitic mites have been devastating the hives of these bees in recent years.
 2. Native pollinators are often more effective than European honeybees, but they are kept from plants by the more aggressive honeybees.
 3. All insect pollinators are vulnerable to the vast arsenal of insecticides that are applied to crops in modern agriculture.
 4. There are ways that everyone can help to maintain populations of pollinating insects. Planting flowering plants that nourish pollinating insects and providing nesting sites for native bees can help to maintain a diverse community of insects.

IV. Genetic Modification of Food

- A. Genetic modification of organisms depends on **recombinant DNA**.
1. **Genetic engineering** is any process whereby scientists directly manipulate an organism's genetic material in the lab by adding, deleting, or changing segments of DNA.
 2. **Genetically modified (GM) organisms** are organisms that have been genetically engineered using recombinant DNA technology, developed in the 1970s by scientists studying the *Escherichia coli* bacterium.
 3. When scientists use recombinant DNA technology to develop new varieties of crops, they often can introduce the recombinant DNA directly into a plant cell and then regenerate an entire plant.
 4. The creation of transgenic organisms is one type of **biotechnology**, the material application of biological science to create products derived from organisms.
- B. Genetic engineering is like, and unlike, traditional agricultural breeding.
1. The genetic modification of organisms by humans is nothing new.

2. However, the new techniques mix genes of different species in the lab, involving experiments with genetic material apart from the organism.
- C. Biotechnology is transforming the products around us.
- D. What are the impacts of GM crops?
1. Some feared the new foods might be dangerous. Others were concerned that transgenes might escape and pollute ecosystems and damage nontarget organisms. Others worried that pests would evolve resistance to the supercrops and become “superpests,” or that transgenes would be transferred from crops to other plants, ruining the integrity of native races of crops.
 2. We still don’t know the answers to these questions, and some say that we should adopt the **precautionary principle** and not undertake a new action until the ramifications of that action are well understood.
 3. Studies thus far have shown no clear answers to questions about the impacts of GM crops.
- E. Debate over GM foods involves more than science.
1. Ethical issues have played a large role in the debate over GM foods because the idea of “tinkering” with the food supply seems dangerous or morally wrong.
 2. The perceived lack of control over one’s own food has caused concern about the domination of the global food supply by a few large businesses.
 3. So far GM crops have not lived up to their promise of feeding the world’s hungry.
 - a. Most crops have been engineered to express pesticidal properties or herbicide tolerance—the herbicides are often manufactured and sold by the same companies.
 - b. Crops with traits that might benefit poor farmers in developing countries have not been developed, perhaps because corporations have less economic incentive to do so.
 4. Public relations has played a role.
 - a. In Canada, Monsanto has been engaged in a high-publicity battle with a third-generation Saskatchewan farmer, Percy Schmeiser.
 - b. European consumers have expressed widespread unease about possible risks of GM technologies.
 - c. Transnational spats between Europe and the United States will surely affect the future direction of agriculture.
 - d. Some countries are approving GM crops, with China aggressively expanding the use of transgenic crops, while other nations refuse to allow any GM foods or seeds within their borders. Zambia refused United States food aid during a drought in 2002, worried that farmers would plant some of the GM corn seed rather than eat it and that GM corn would then establish itself within the country.

V. Preserving Crop Diversity

- A. Crop diversity provides insurance against failure.

1. Monoculture cropping places food systems at risk should one catastrophic event wipe out the entire crop variety.
2. Wild and domestic relatives of crop plants contain genes that can reinvigorate crops by conferring disease, pest, or drought resistance.
3. Because accidental interbreeding can decrease the diversity of local variants, scientists argue that we need to protect areas like Oaxaca.
4. Many fruit and vegetable crops in the United States have decreased in diversity by 90% in less than a century.
5. A primary cause of this loss of biodiversity is that market forces have discouraged diversity in the appearance of fruits and vegetables.

B. Seed banks are living museums for seeds.

1. In seed banks, or **gene banks**, institutions store seeds from crop varieties, keeping them in cold, dry conditions to encourage long-term viability.
2. Large seed banks include the U.S. National Seed Storage Laboratory, the Royal Botanic Garden's Millennium Seed Bank in Britain, Seed Savers Exchange in Iowa, and the Wheat and Maize Improvement Center (CIMMYT) in Mexico.

VI. Feedlot Agriculture: Livestock and Poultry

A. Consumption of animal products is growing.

1. The world population of domesticated animals raised for food tripled between 1961 and 2000. Most of these animals are chickens.
2. Per capita meat consumption around the world nearly doubled between 1950 and 2000.

B. High consumption has led to feedlot agriculture.

1. **Feedlots**, or factory farms, are operations in which animals are housed in huge warehouses or pens where energy-rich food is provided to the animals living at extremely high densities.
2. Animals that are densely concentrated in feedlots will not contribute to overgrazing and soil degradation.
3. Waste from feedlots can emit strong odors, and can pollute surface water and groundwater.
4. Feedlot impacts can be minimized when properly managed.

C. Our food choices are also energy choices.

1. The lower in the food chain our food sources are, the greater the proportion of the sun's energy we put to use as food, and the more people Earth can support.
2. Producing eggs and chicken meat requires the least space and water, while producing beef requires the most.
3. Such differences make clear that when we choose what to eat, we are also indirectly choosing how to make use of resources such as land and water.

VII. Aquaculture

1. Raising fish and shellfish on "fish farms" in controlled environments is **aquaculture**; it may be the only way to meet

the demand for these foods because most fisheries are overharvested.

- A. Aquaculture brings a number of benefits.
 - 1. Aquaculture provides a reliable source of protein for developing countries.
 - 2. On a small scale, aquaculture is sustainable and is compatible with other activities.
 - 3. On a large scale, aquaculture helps improve a nation's food security.
 - 4. Aquaculture reduces fishing pressures on wild stocks.
 - 5. Aquaculture relies far less on fossil fuels than do fishing vessels, and is very energy-efficient.
 - 6. Aquaculture provides a safer work environment than does commercial fishing.
- B. Aquaculture has negative environmental impacts.
 - 1. The dense concentrations of farmed animals can increase the incidence of disease and necessitates the use of antibiotics.
 - 2. Aquaculture can also produce large amounts of waste, both from the organisms being farmed and from uneaten feed.
 - 3. The escape of farmed animals into the environment can have negative consequences including spreading disease, outcompeting native species, and introducing new genetic material to a native population.

VIII. Sustainable Agriculture

- 1. **Sustainable agriculture** is farming that does not deplete soils faster than they form and does not reduce the amount of healthy soil, clean water, and genetic diversity essential to long-term crop and livestock production.
 - 2. *Low-input agriculture* is farming that uses smaller amounts of pesticides, fertilizers, growth hormones, water, and fossil fuel energy than is used in industrial agriculture.
 - 3. Food growth practices that use no synthetic fertilizers or pesticides are often termed **organic agriculture**.
- A. Organic agriculture is on the increase.
 - 1. In 1990, the U.S. Congress passed the Organic Food Production Act that established national standards for organic products and facilitated the sale of organic food.
 - 2. Long viewed as a small niche market, the market for organic foods is on the rise, although it accounts for only 1% of food expenditures.
 - 3. Production is increasing along with demand, although organic agriculture takes up less than 1% of cultivated land worldwide.
 - 4. These trends have been fueled by the desire of many consumers to reduce health risks in their diets and to support improving environmental quality.
 - 5. Government initiatives have also spurred the growth of organic farming.
 - B. Locally supported agriculture is growing.
 - 1. Farmers' markets are more numerous as consumers rediscover the joys of fresh, locally grown produce.

2. The average food product sold in U.S. supermarkets travels at least 1,400 miles between the farm and the shelf, and is often chemically treated to preserve freshness and color.
- C. Cuba has embraced organic agriculture.
1. Cuba suffered economic and agricultural upheaval upon the dissolution of the Soviet Union because it lost 75% of its imports.
 2. With far less oil available, farmers began growing food closer to cities and even within them.
 3. In addition, Cuban farmers are now using oxen and integrated pest management.
- D. Organic and sustainable agriculture will likely need to play a large role in our future.

IX. Conclusion

- A. Many of the intensive agricultural practices discussed have substantial negative environmental impacts, but have positive impacts as well.
- B. It is certain that if we are to support nine billion people we must make a shift to more sustainable agriculture.
- C. The extent to which individuals, governments, and corporations will be able to put their own interests and agendas in perspective to work together toward a sustainable future remains to be seen.

11

Biodiversity and Conservation Biology

Chapter Objectives

This chapter will help students:

- Characterize the scope of biodiversity on Earth
- Describe ways to measure biodiversity
- Contrast background extinction rates and periods of mass extinction
- Evaluate the primary causes of biodiversity loss
- Specify the benefits of biodiversity
- Assess conservation biology and its practice
- Explain island biogeography theory and its application to conservation biology
- Compare and contrast traditional and more innovative biodiversity conservation efforts

Lecture Outline

- I. Central Case: Saving the Siberian Tiger**
 - A. Up until the past 200 years, tigers roamed widely across the Asian continent from Turkey to northeast Russia to Indonesia.
 - B. Of the tigers that still survive in small pockets of their former range, those in the subspecies known as the Siberian tiger are the largest cats in the world.
 - C. For thousands of years, the Siberian tiger coexisted with the native people of what is today the Russian Far East, who equated the tiger with royalty and viewed it as a guardian.

- D. The Russians who moved into and exerted control over the region in the early to mid-20th century had no cultural traditions that expressed respect for the animal, leading to the decline of the species.
- E. International conservation groups began to get involved, working with Russian biologists to try to save the dwindling tiger population.
- F. Today, the Siberian tiger population is up to roughly 330 to 370, and 600 more survive in zoos around the world. However, 40% of the tiger's habitat has disappeared in the last decade.

II. Our Planet of Life

- A. What is **biodiversity**?
 - 1. **Biological diversity**, or biodiversity, is the sum total of all organisms in an area.
 - 2. Biodiversity takes into account the diversity of species, their genes, their populations, and their communities.
- B. Biodiversity encompasses several levels of life's organization.
 - 1. **Species diversity** is expressed in terms of the number or variety of species in the world or in a particular region.
 - a. Taxonomists, the scientists who classify species, use an organism's physical appearance and genetic makeup to determine to which species it belongs.
 - b. Speciation, the generation of new species, adds to species diversity, while extinction decreases species diversity.
 - c. Biodiversity exists below the species level in the form of subspecies.
 - 2. **Genetic diversity** encompasses the differences in DNA composition among individuals within a given species.
 - a. Whether genetic diversity is extremely minor or great enough to warrant subspecies status, such diversity has repercussions for the well-being of a species in at least two major ways.
 - b. First, as a species becomes adapted to local environmental conditions, its genetic diversity may decrease.
 - c. In the long term, species with more genetic diversity have better chances of persisting, because their built-in variation better enables them to cope with environmental change.
 - 3. Ecosystem diversity, community diversity, habitat diversity, and landscape diversity are all ways to view biodiversity.
- C. Measuring biodiversity is not easy.
- D. You may be able to help measure biodiversity where you live.
- E. Global biodiversity is not distributed evenly.

III. Biodiversity Loss and Species Extinction

- A. Extinction occurs when the last member of a species dies and the species ceases to exist; in contrast, the extinction of a certain population from a given area, but not the entire species globally, is called **extirpation**.
- B. Extinction is a natural process.

1. Most extinctions preceding the appearance of humans have occurred one by one, at a rate that paleontologists refer to as the **background rate of extinction**.
- C. Earth has experienced five previous **mass extinction** episodes.
- D. Humans set the sixth mass extinction in motion years ago.
- E. Current extinction rates are much higher than normal.
 1. To keep track of the current status of endangered species, the World Conservation Union (IUCN) maintains the **Red List**.
- F. Biodiversity loss involves more than extinction.
- G. There are several major causes of biodiversity loss:
 1. Habitat alteration
 2. Invasive species
 3. Pollution
 4. Overharvesting
 5. Climate change
- H. Causes of biodiversity loss can be difficult to determine.

IV. Benefits of Biodiversity

- A. Biodiversity provides ecosystem services free of charge.
- B. Biodiversity helps maintain ecosystem function.
- C. Biodiversity enhances food security.
- D. Biodiversity provides traditional medicines and high-tech pharmaceutical products.
- E. Biodiversity provides economic benefits through tourism and recreation.
- F. People value and seek out connections with nature.
 1. E. O. Wilson described the phenomenon of **biophilia**, “the connections that human beings subconsciously seek with the rest of life.”
- G. Do we have an ethical responsibility to prevent species extinction?

V. Conservation Biology: The Search for Solutions

- A. **Conservation biology** arose in response to biodiversity loss.
 1. Conservation biology is a scientific discipline devoted to understanding the factors, forces, and processes that influence the loss, protection, and restoration of biological diversity.
- B. Conservation biologists work at multiple levels.
- C. Island biogeography theory is a key component of conservation biology.
 1. Much of modern conservation biology is based on the **equilibrium theory of island biogeography**.
 2. Island biogeography is best understood at the landscape level. Species richness is explained by size (of the island or patch of habitat) and immigration and emigration affect total number of species in an area.
 3. The number of species is expected to double as the island (or patch) size increases ten times.
- D. Should endangered species be the focus of conservation efforts?
 1. Currently, the primary legislation for protecting biodiversity in the United States is the **Endangered Species Act (ESA)**.

- E. Single-species approaches include **captive breeding**, reintroduction efforts, and cloning.
 1. Zoos and botanical gardens have become centers for the captive breeding of endangered species, so that large numbers of individuals can be raised and then reintroduced into the wild.
 2. Examples of successful reintroduction programs include wolves in Yellowstone National Park and Siberian tigers in China.
- F. Some species act as “umbrellas” for protecting habitat and communities.
- G. International conservation efforts include widely signed treaties.
 1. The 1973 **Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)** protects endangered species by banning the international transport of their body parts.
 2. In 1992, the leaders of many nations agreed to the **Convention on Biological Diversity**, a treaty outlining the importance of conserving biodiversity, using it sustainably, fairly distributing its benefits, and committing signatory nations to conserving this diversity.
- H. **Biodiversity hotspots** pinpoint areas of high diversity.
 1. Biodiversity hotspots are areas that support an especially great diversity of species, particularly species that are **endemic** to the area.
- I. **Community-based conservation** is increasingly popular.
 1. Many conservation biologists actively engage local people in efforts to protect the land and wildlife in their own backyards, in an approach called community-based conservation.
- J. Innovative economic strategies are being employed.

VI. Conclusion

- A. The erosion of biological diversity threatens to result in a mass extinction event equivalent to the major ones of the geological past.
- B. The primary causes of biodiversity loss include habitat alteration, invasive species, pollution, overharvesting, and global climate change.
- C. Many conservation biologists are rising to the challenge with traditional and innovative strategies to save endangered species and their habitats.
- D. Earth’s biologically diverse communities of plants and animals are part of the natural capital of the planet. From natural capital, flow ecosystem services. We need ecosystem services for our own good. It is in the best interests of humans and all other life to protect biological diversity.

12

Resource Management, Forestry, Land Use, and Protected Areas

Chapter Objectives

This chapter will help students:

Identify the principles, goals, and approaches of resource management

Summarize the ecological roles and economic contributions of forests, and outline the history and scale of forest loss

Explain the fundamentals of forest management, and describe the major methods of harvesting timber

Analyze the scale and impacts of agricultural land use

Identify major federal land management agencies and the lands they manage

Recognize types of parks and reserves, and evaluate issues involved in their design

Lecture Outline

I. Central Case: Battling Over the Last Big Trees at Clayoquot Sound

- A. The largest act of civil disobedience in Canadian history occurred on Vancouver Island, British Columbia, in 1993, over forest management. Protesters chose direct action to block logging roads and chain themselves to gates across access points. Of the 12,000 protesters, 850 were arrested.
- B. Opponents of **clear-cutting**, the removal of all the trees from an area, were trying to protect the forests of Clayoquot Sound, which is one of the largest undisturbed stands of temperate rainforest left on the planet.
- C. When the government halted clear-cutting at Clayoquot Sound, they found that ecotourism dollars surpassed logging as an important local economic force—the trees were worth more standing than cut down.
- D. The United Nations designated the site an international biosphere reserve, encouraging land protection and sustainable development.
- E. In recent years the government has reversed its logging regulations, and new logging companies are harvesting in areas near park and biosphere reserve boundaries.
- F. As long as our demand for lumber, paper, and forest products keeps increasing, pressures will keep building on the remaining forests on Vancouver Island and around the world.

II. Resource Management

- 1. **Resource management** is the practice of harvesting resources in ways that do not deplete them.
- A. Several natural resources are vital to us.
 - 1. Soils, particularly topsoil, are of direct importance to us because they support the plants we grow for food and fiber, and thus play a central role in agriculture.
 - 2. Each of us depends directly on freshwater, so assuring a dependable supply of drinking water is a life-or-death issue. Freshwater also is necessary for agriculture and for waterways and wetlands.
 - 3. Wildlife and fisheries management is important to maintaining properly functioning ecosystems, as well as to preventing the decline of the

organisms that we harvest for food, materials, and medicines.

4. Range managers are responsible for regulating ranching on public lands, and advise ranchers on sustainable grazing practices on private lands.
 5. Although we rely on mineral resources, we do not manage their extraction as we do with the aforementioned resources.
 - a. Minerals are nonrenewable resources, so the mining industry has no built-in incentive to conserve.
 - b. Instead, it benefits by extracting as much as it can as fast as it can, and then moving on to new sites once extraction at existing sites has become too inefficient to be profitable.
 - c. Mining removes vegetation, causes erosion, and produces acidic runoff that poisons area waterways.
 - d. Public pressure and government legislation are important in minimizing environmental impacts from the mining and smelting of minerals.
- B. Managers have tried to achieve **maximum sustainable yield**.
1. The maximum amount of resource extraction possible without depleting the resource from one harvest to the next is known as the maximum sustainable yield.
 2. While this approach produces large amounts of short-term products, reexamining the overall ecosystem impacts of this management system indicate that long-term health and productivity of the system will be impaired if maximum sustainable yield principles are followed.
- C. Today many managers pursue **ecosystem-based management**.
1. Ecosystem-based management attempts to manage the harvesting of resources in ways that minimize impacts on the ecosystems and ecological processes that provide the resource.
- D. **Adaptive management** evolves and improves.
1. Systematically testing different management approaches with the aim of improving methods as time goes on, including changing practices in

midstream if necessary, is the basis of adaptive management.

2. Monitoring the impact of management practices is an essential component of adaptive management. Science, not politics, should be the final judge of these practices.

III. Forest Management

1. **Forestry** balances the importance of forests as ecosystems with civilization's demand for wood products.
 - A. Forests are ecologically valuable.
 1. Most of the world's forests occur as boreal forest and tropical rainforest. Forests cover roughly 30% of the Earth's surface.
 2. Because of their structural complexity and ability to provide many niches for forest organisms, forests comprise some of the richest ecosystems for biodiversity.
 3. Much of a forest's diversity resides in the forest floor, where the soil is generally nourished by leaf litter and many soil organisms are present to decompose plant materials and cycle nutrients.
 4. Forest systems provide many vital ecosystem services such as stabilizing soil, preventing erosion, regulating the hydrologic cycle, lessening flooding, purifying water, storing carbon, releasing oxygen, and moderating climate.
 - B. Forest products are economically valued.
 1. Wood fuels our fires, keeps us warm and well fed, and provides housing and paper.
 2. Most commercial logging today takes place in Canada, Russia, and other nations that hold large expanses of boreal forest, and in tropical countries with large amounts of rainforest, such as Brazil.
 3. In the United States most logging takes place on land both private and public, primarily in the conifer forests of the West and the pine plantations of the South.
 4. There is growing awareness that forests also provide other "products" like watershed protection, protection for biological diversity, and "social services" such as recreation,

education, and protection of culturally important sites.

- C. Demand for wood has led to **deforestation**.
 - 1. We have cleared forests for millennia to use wood for fuel, to make paper, or to make way for agriculture.
 - 2. Deforestation has altered ecosystems and has caused soil degradation, population declines, and species extinctions.
 - 3. Deforestation has occurred on all continents, and in some cases has helped to bring entire civilizations to ruin.
 - 4. Today, forests are being felled at the fastest rates in the tropical rainforests of Latin America and Africa.
- D. The growth of the United States and Canada was fed by deforestation.
 - 1. Deforestation for timber and farmland propelled the growth of the United States throughout the population's phenomenal expansion across the continent over the past 400 years.
 - 2. By the early 20th century, very little virgin timber was left in the lower 48 U.S. states. The largest trees found in eastern North America, and even most redwoods in California, are **second-growth** trees—all that remains after the old-growth timber was cut.
 - 3. The fortunes of loggers have risen and fallen with the availability of big trees.
- E. Deforestation is proceeding rapidly in many developing nations.
 - 1. Today's advanced technology allows developing countries to exploit their resources even faster than had occurred in North America. Deforestation is occurring rapidly in places such as Brazil and Indonesia.
 - 2. Developing nations are often desperate for economic development, and so impose few or no restrictions on logging.
 - 3. Many of the short-term economic benefits are being reaped by international corporations that log the timber, export it, and move on.
- F. Fear of a "timber famine" spurred establishment of national forests.
 - 1. The depletion of the eastern forests spurred the formation of a system of forest reserves—the U.S.

national forest system, managed by the U.S. Forest Service—that covers over 8% of the nation's land area.

- G. Timber is extracted from public and private lands.
 - 1. Timber is extracted from publicly held forests in the U.S. and Canada by private timber companies and not by the governments of these nations. Government employees plan and manage timber sales, and build roads to provide access for the loggers who sell the timber for profit.
 - 2. Most timber harvesting in the United States today is on private land.
 - 3. Despite the slower pace of harvest from public and private forests, second-growth forests returning postharvest lack many of the characteristics of the original forests in terms of diversity, function, and structure.
- H. Plantation forestry has grown.
 - 1. Tree plantations with **even-aged** monocultures are planted and cut all at once, and then the land is replanted.
 - 2. Because there are few species and little age variation, plantations have little biodiversity in the organisms that live there.
 - 3. It is important that some harvesting methods maintain **uneven-aged** stands, with a mix of ages and species, to more closely resemble a natural forest.
- I. Timber is harvested by several methods.
 - 1. Clear-cutting is the easiest and most cost-efficient method in the short term, but it has the greatest impacts on ecosystems.
 - 2. The *seed-tree* approach leaves small numbers of mature and vigorous seed-producing trees to reseed the logged area.
 - 3. The *shelterwood* approach leaves small numbers of mature trees to provide shelter for new seedlings.
 - 4. All of these methods still lead to even-aged stands.
 - 5. Selection systems cut only some trees at any one time, with the stand remaining mostly intact between harvests. Either individual trees or small patches of trees are cut at any one time.

- J. Public forests may be managed for recreation and ecosystems.
 - 1. Many people debate whether the Forest Service has in fact managed the forests sustainably. They want forests managed as ecological entities, not as croplands for trees.
 - 2. The Forest Service has nominally been guided by a policy of **multiple use**, meaning that the national forests are to be managed for recreation, wildlife habitat, mineral extraction, and other uses.
 - 3. In 1976 Congress passed the **National Forest Management Act**, mandating that renewable resource management plans be made for every national forest, based explicitly on the concepts of multiple use and sustained yield.
 - 4. The Forest Service has developed new programs to manage wildlife and endangered species, including nongame species.
 - 5. The **new forestry** approaches call for timber cuts that explicitly mimic natural disturbances.
- K. Fire policy has also stirred controversy.
 - 1. For over a century, the Forest Service and other land management agencies have suppressed fire whenever and wherever it has broken out.
 - 2. Research now shows that many ecosystems depend on fire—for seed germination, to keep the understory clear, and to maintain both plant and animal biodiversity.
 - 3. Fire suppression increases the likelihood of catastrophic fires that damage forests, destroy human property, and threaten human lives.
 - 4. To reduce fuel load and improve the health and safety of forests, the Forest Service and other agencies have in recent years sponsored **prescribed burns**, or **controlled burns**—burning areas of forest under carefully controlled conditions.
 - 5. In the wake of the 2003 California fires, the U.S. Congress passed the Healthy Forests Restoration Act, which encourages prescribed burns and **salvage logging**, the physical removal of small trees, underbrush, and dead trees by timber companies.
 - 6. Dead trees have enormous value to the forest, providing homes and food for many organisms,

and timber removal operations on recently burned land can cause severe erosion and soil damage. Therefore, many critics of the Healthy Forests Restoration Act say it increases commercial logging in national forests and does little to reduce catastrophic fires near populated areas. Recent studies also show that the salvage logging also impairs the regeneration of healthy forests. It also decreases oversight and public participation.

- L. Sustainable forestry is gaining ground.
 - 1. Several organizations examine timber company practices and offer **sustainable forestry certification** to products produced using sustainable methods.

IV. Agricultural Land Use

- 1. Agriculture now covers more of the planet's surface than does forest.
- 2. In theory, the marketplace should discourage farming with intensive methods that degrade land if such practices are not profitable, but agriculture in many countries is supported by massive subsidies.
- A. Wetlands have been drained for farming.
 - 1. Many of today's crops grow on the sites of former wetlands that have been drained.
 - 2. Today, less than half the original wetlands in the lower 48 states and southern Canada remain.
 - 3. Today we have a Wetland Reserve Program offering subsidies to landowners who refrain from developing wetland areas.
- B. Livestock graze one-fourth of the Earth's land surface.
 - 1. As severe as its ecological impacts have proven to be, cropland agriculture uses less than half the land taken up by livestock grazing.
 - 2. Human use of rangeland does not exclude its use by wildlife or its continued functioning as a grassland ecosystem.
 - 3. Most U.S. rangelands are federally owned and managed by the **Bureau of Land Management (BLM)**.
- C. Land use in the American West might have been better managed.

1. Land uses such as grazing, farming, and timber harvesting need not have strongly adverse impacts.
2. Most land to the west of the 100th meridian receives less than 50 cm of rain per year, making it too arid for nonirrigated agriculture.
3. The ideas of John Wesley Powell were too revolutionary for the entrenched political interests and the prevailing misconception that the West was a utopia for frontier settlement.
4. For agriculture and forestry, debates continue today over how to best utilize land and manage resources.

V. Parks and Reserves

- A. Why have we created parks and reserves?
 1. Many people believe that enormous, beautiful, or unusual features should be protected.
 2. Protected areas offer recreational value to tourists, hikers, fishermen, hunters, and others.
 3. Protected areas offer utilitarian benefits such as clean drinking water and buffers against floods.
 4. Parks have been created as a way to make use of sites lacking economically valuable material resources.
 5. A park or reserve is widely viewed as a kind of Noah's Ark—an island or habitat that can maintain species that might otherwise disappear.
- B. Federal parks and reserves began in the United States.
 1. The striking scenery of the American West impelled the U.S. government to create the world's first **national parks**, publicly held lands protected from extraction and development but open to the public for nature appreciation and recreation.
 2. The National Park Service (NPS) was created in 1916 to administer the growing system of parks and monuments, which today comprises 388 sites totaling 32 million hectares.
 3. A **national wildlife refuge** is another type of protected area and is managed by the U.S. Fish and Wildlife Service.
- C. **Wilderness areas** have been established on various federal lands.

1. Areas of existing federal lands may be designated wilderness areas, meaning that they are off-limits to any kind of development but are open to hiking, nature study, and other activities with minimal impact on the land.
- D. Not everyone supports land set-asides.
1. The restriction of activities in wilderness areas has helped generate opposition to the land protection policies of the U.S. government.
 2. The drive to extract more resources, obtain greater local control of lands, and obtain greater access for motorized recreation is epitomized by the **wise-use** movement.
 3. Debate between environmental groups and wise-use spokespeople has been vitriolic, each claiming the other is repressive.
- E. Nonfederal entities also protect land.
1. Efforts to set aside land and the debates over such decisions at the federal level are paralleled at the state and local levels.
 2. Each U.S. state has agencies that manage land and resources on state lands, as do many counties and municipalities.
 3. Some land conservation is also accomplished by private nonprofit groups such as **land trusts**, local and regional organizations that preserve lands valued by their members.
- F. Parks and reserves are increasing internationally.
1. Many nations have established national park systems and are benefiting from ecotourism as a result.
 2. Many of the world's protected areas are so-called *paper parks*, protected on paper but not in reality.
 3. Some types of protected areas fall under national sovereignty but are designated or protected by the United Nations, such as the *world heritage sites* and *transboundary parks* that overlap national borders.
 4. **Biosphere reserves** are tracts of land with exceptional biodiversity that couple preservation with sustainable development to benefit the local people. They are designated by UNESCO following application by local stakeholders.

- G. The design of parks and reserves has important consequences for biodiversity.
 - 1. Often it is not the outright destruction of habitat that threatens species, but the fragmentation of habitat.
 - 2. Because habitat fragmentation is an important issue for biodiversity conservation, conservation biologists debate the **SLOSS dilemma** (single large or several small).
 - 3. A related issue is whether **corridors** of protected land are important for allowing animals to travel between islands of habitat.

VI. Conclusion

- A. Managing natural resources is necessary for resources like timber, which can be either responsibly and sustainably managed or carelessly exploited and overharvested.
- B. Public forests today are managed not only for timber production, but also for recreation, wildlife habitat, and ecosystem integrity.
- C. Meanwhile, public support for preservation of natural lands has resulted in national parks, wilderness areas, and other forms of reserves, both in North America and abroad.
- D. These trends are positive ones because the preservation and conservation of land and resources is essential if we wish our society to be sustainable and to thrive in the future.

14

Environmental Health and Toxicology

Chapter Objectives

This chapter will help students:

Identify the major types of environmental health hazards and explain the goals of environmental health

Describe the types, abundance, distribution, and movement of synthetic and natural toxicants in the environment

Discuss the study of hazards and their effects, including case histories, epidemiology, animal testing, and dose-response analysis

Assess risk assessment and risk management

Compare philosophical approaches to risk

Describe policy and regulation in the United States and internationally

Lecture Outline

I. Central Case: Alligators and Endocrine Disruptors at Lake Apopka, Florida

- A. In 1985, Louis Guillette discovered bizarre reproductive problems in American alligators in Lake Apopka.
- B. He developed the hypothesis that certain chemical contaminants in Lake Apopka were disrupting the endocrine system of alligators during development in the egg.
- C. Guillette and his co-workers found that Lake Apopka alligators had abnormally low hatchling rates starting in the years after a pesticide spill. The lake also received high levels of chemical runoff from agriculture.
- D. Guillette's results showed that atrazine and nitrates act as endocrine disruptors, causing smaller penises and lower testosterone levels in juvenile male alligators.

- E. Many scientists suspect that chemical contaminants could be affecting people just as they have alligators.

II. Environmental Health

1. The study and practice of **environmental health** assess environmental factors that influence human health and quality of life.
- A. Environmental hazards can be physical, chemical, biological, or cultural.
 1. Physical hazards are processes that occur naturally in our environment and can pose health hazards. These include discrete events such as earthquakes, fires, floods, and droughts, and also include ongoing natural phenomena such as ultraviolet radiation from the sun, which can cause sunburn and skin cancer.
 2. Chemical hazards include many of the synthetic chemicals that our society produces, such as disinfectants and pesticides, and also include chemicals produced naturally by organisms.
 3. Biological hazards result from ecological interactions among organisms, such as becoming sick from a virus, bacterial infection, or other pathogen. If this illness can spread to other humans, then it is an **infectious disease**, also called *communicable* or *transmissible disease* (e.g., malaria, cholera, flu).
 4. Cultural hazards result from where we live, our socioeconomic status, our occupation, or our behavioral choices. Choosing to smoke, poor diet, and living in proximity to toxic waste are all cultural hazards.
 - B. Disease is a major focus of environmental health.
 1. Many major killers such as cancer, heart disease, and respiratory disorders have genetic bases but are also influenced by environmental factors.
 2. Malnutrition can foster a wide variety of illnesses, as can poverty, poor hygiene, lifestyle choices, and lack of exercise.
 3. Infectious disease involves a pathogen that attacks us directly, or an infection may occur through a vector.
 4. In order to predict and prevent infectious disease, experts deal with the often-complicated interrelationships among technology, land use, and ecology.
 5. Increased human mobility achieved through globalization has made diseases like avian flu a potential global epidemic. Other diseases like tuberculosis and malaria are becoming more drug resistant.
 6. Through habitat alteration and climate change, tropical diseases are moving further from the equator and will put more people at risk of infection.
 - C. Environmental health hazards exist indoors as well as outdoors.
 1. Indoor environmental health threats include radon, lead poisoning, and asbestos.
 2. A recently recognized hazard is a group of chemicals known as polybrominated diphenyl ethers (PBDEs). These chemicals

appear to be endocrine disruptors, affecting thyroid hormones in animals, and have been banned in Europe.

- D. **Toxicology** is the study of poisonous substances.
1. Toxicology studies the effects of poisonous substances on humans and other organisms.
 2. A **toxicant**, or toxic agent, must be compared to other substances to determine the *toxicity*, or the degree of harm that it can inflict.
 3. With toxins, “the dose makes the poison” means that the quantity received is an important factor in the damage done.
 4. **Environmental toxicology** deals specifically with toxic substances that come from or are discharged into the environment, and includes the study of health effects on humans, other animals, and ecosystems.

III. Toxic Agents in the Environment

- A. Synthetic chemicals are ubiquitous in our environment.
1. Thousands of synthetic chemicals have been manufactured and many have found their way into soil, air, and water.
 2. Every one of us carries traces of numerous industrial chemicals in our bodies.
 3. Very few of these chemicals have been tested for harmful effects.
- B. *Silent Spring* began the public debate over pesticides.
1. Rachel Carson was a naturalist, author, and government scientist.
 2. Using scientific studies, medical case histories, and other data, she showed that DDT and artificial pesticides in general were hazardous to people, wildlife, and the environment.
 3. Carson’s book was a bestseller and generated significant social changes in views and actions toward the environment.
 4. The United States manufactures and exports DDT to countries that still use it, especially for mosquito control. Certain species of mosquitoes are vectors for malaria, which is considered to be a greater risk than the toxic effects of the pesticide.
- C. Toxicants come in several different types.
1. **Carcinogens** are chemicals or types of radiation that cause cancer.
 2. **Mutagens** are chemicals that cause mutations in the DNA of organisms.
 3. Chemicals that cause harm to the unborn are called **teratogens**.
 4. **Allergens** overactivate the immune system, causing an immune response when one is not necessary.
 5. **Neurotoxins** assault the nervous system.
 6. **Endocrine disruptors** are toxicants that interfere with the *endocrine system*.
- D. Endocrine disruption may be widespread.
1. The idea that synthetic chemicals might be altering the hormones of animals was presented in the 1996 book *Our Stolen Future*.
 2. One common type of endocrine disruptor involves the feminization of male animals.

3. To date, endocrine effects have been most widely found in nonhuman animals, but scientists attribute the striking drop in sperm counts among men worldwide to endocrine disruptors.
 4. Because the endocrine system is geared to respond to minute concentrations of hormones in the bloodstream, it may be especially vulnerable to effects from environmental contaminants.
- E. Endocrine disruption research has generated debate.
1. Manufacturers of herbicides would lose many millions of dollars if their products were banned or restricted.
 2. Many everyday household plastic products contain bisphenol-A, an estrogen mimic, but the plastic industry protests that the chemical is safe despite research showing birth defects in lab mice.
- F. Toxicants may concentrate in surface water or groundwater.
1. Water runoff often carries low amounts of toxicants from large areas of land and concentrates them in small volumes of surface water.
 2. Many chemicals are soluble in water, and thus are very accessible to organisms. This is why aquatic animals such as fish, frogs, and stream invertebrates are especially good indicators of pollution.
- G. Airborne toxicants can travel widely.
- H. Some toxicants persist for a long time.
1. DDT and PCBs have long persistence times, while Bt toxin has a very short persistence time.
 2. Some toxicants have breakdown products that are just as toxic as the original chemical, or more so (e.g., DDT breaks down into DDE, a highly persistent and toxic compound).
 3. Toxicants remain in the environment because they are designed to persist. Some plastics, for example, were developed because they resist breakdown.
- I. Toxicants may accumulate and move up the food chain.
1. Fat-soluble toxicants such as DDT and DDE are absorbed and stored in fatty tissues and may build up in animals in a process called **bioaccumulation**.
 2. Toxicants that bioaccumulate in the tissues of one organism may then be transferred to other organisms in the food chain, in a process called **biomagnification**.
 3. An example is polar bears in arctic Norway that are suffering from PCB contamination because of biomagnification, resulting in high cub mortality.
- J. Not all toxicants are synthetic.
1. Chemical toxicants also exist naturally in the environment around us and in the foods we eat.
 2. Scientists have actively debated just how much risk is posed by natural toxicants.

IV. Studying Effects of Hazards

- A. Wildlife studies use careful observations in the field and the lab.

- B. Human studies rely on case histories, epidemiology, and animal testing.
 - 1. Much knowledge has been gained by studying sickened individuals directly, a *case history* approach.
 - 2. **Epidemiological studies** involve large-scale comparisons among groups of people, usually contrasting a group known to have been exposed to some toxicant with a group that has not.
 - 3. The advantages of epidemiological studies are their realism and ability to enable relatively accurate predictions about risk; the drawbacks include the length of time it takes to obtain results and the inability to address possible effects of new products.
 - 4. Manipulative experiments are needed to truly nail down causation. However, this is not possible with human subjects, so animals are substituted.
- C. Dose-response analysis is a mainstay of toxicology.
 - 1. The standard method of testing lab animals in toxicology is called dose-response analysis.
 - 2. The *dose* is the amount of toxicant the test animal receives, and the *response* is the type or magnitude of negative effects the animal exhibits as a result. The response is generally quantified by measuring the proportion of animals exhibiting negative effects.
 - 3. Once a **dose-response curve** is plotted, scientists can calculate a convenient shorthand gauge of a substance's toxicity—the amount of toxicant it takes to kill half the population of study animals used (**LD₅₀**).
 - 4. Nonlethal health effects are determined by the level of toxicant at which 50% of the population is affected (**ED₅₀**).
 - 5. Common sense suggests that the greater the dose, the stronger the response will be. However, sometimes responses occur only above a certain dose, called the **threshold** dose.
 - 6. Sometimes responses decrease with dose. Some dose-response curves are U-shaped, J-shaped, or shaped like an inverted U; these curves appear to apply to endocrine disruptors.
 - 7. Knowing the shape of the dose-response curve is important for predicting effects. For some toxicants like endocrine disruptors, the “U” shaped curve indicates impact at very low concentrations.
- D. Individuals vary considerably in their response to hazards.
- E. The type of exposure can affect the response.
 - 1. The toxicity of many substances varies according to whether the exposure is in high amounts for short periods of time—**acute exposure**—or in lower amounts over long periods of time—**chronic exposure**.
 - 2. Acute exposure is easier to recognize but chronic exposure is more common, and is more difficult to detect and diagnose.
- F. Mixes may be more than the sum of their parts.
 - 1. Interactive impacts may arise when toxicants are mixed together, and when these impacts are more than or different from the simple sum of their constituent effects; these are called **synergistic effects**.

2. Traditionally, environmental health has tackled the effects of single hazards one at a time, and single-substance tests have received priority. This is changing, but scientists will never be able to test all possible combinations.

V. Risk Assessment and Risk Management

- A. **Risk** is expressed in terms of probability.
 1. Exposure to a toxin causes some probability of harm, a statistical chance that damage will result. The probability depends on the toxin, its strength, the frequency and duration of the encounter, the sensitivity of the organism, and other factors.
- B. Our perception of risk may not match reality.
- C. **Risk assessment** analyzes risk quantitatively.
 1. Risk assessment involves the scientific study of toxicity and the likely extent of the exposure.
 2. Risk assessment studies are often performed by scientists associated with the industries that manufacture toxicants, which in many people's minds may undermine the objectivity of the process.
- D. **Risk management** combines science and other social factors.
 1. In most developed nations, risk management is handled largely by federal agencies.
 2. Scientific assessments of risk are considered in light of economic, social, and political needs and values.

VI. Philosophical and Policy Approaches

- A. Two approaches exist for determining safety.
 1. One approach is to assume that substances are harmless until shown to be harmful—the *innocent-until-proven-guilty* approach. This approach encourages technological innovation but may put some dangerous substances into wide use.
 2. The other approach is to assume that substances are harmful until shown to be harmless. This enables us to identify toxicants before they are released into the environment, but may also impede technological and economic advances.
- B. Philosophical approaches are reflected in policy.
 1. Most nations follow a blend of the two approaches.
 2. At present, European nations follow the precautionary principle.
 3. The United States largely follows the innocent-until-proven-guilty approach.
 4. In the United States, the tracking and regulation of synthetic chemicals is shared among several federal agencies.
 5. The EPA also regulates diverse chemicals under the Toxic Substances Control Act (TSCA).
 - a. TSCA was the first law to require screening of substances before they entered the marketplace.
 - b. Many public health and environmental advocates view TSCA as being too weak.
 - c. Industry's critics say chemical manufacturers should be made to bear the burden of proof for the safety of their products before they market them.

- C. The EPA regulates pesticides and other substances.
 - 1. The registration process involves risk assessment and risk management.
 - 2. Critics say the process allows hazardous chemicals to be approved if they offer enough economic benefits.
- D. Toxicants are regulated internationally.
 - 1. In 2004, an international treaty, the Stockholm Convention, was ratified by over 140 nations. The convention aims first to end the use and release of 12 persistent organic pollutants (POPs) called the “dirty dozen.” It appears to be on its way to ratification.
 - 2. In 2007 the European Union’s REACH (registration, evaluation, authorization and restriction of chemicals) program went into effect. The burden of proof for chemical safety shifted from governments to industry. REACH will also test previously authorized chemicals for toxicity and 1,500 chemicals could become restricted.
 - 3. These new regulations are expected to cost as much as \$5 billion, but the benefits to public health are estimated to be \$67 billion.

VII. Conclusion

- A. International agreements such as the Stockholm Convention represent a hopeful sign that governments will act to protect the world’s people, wildlife, and ecosystems from harm by toxic chemicals and other environmental hazards.
- B. A society’s philosophical approach to risk management will determine what policy decisions are made.

15

Freshwater Resources: Natural Systems, Human Impact, and Conservation

Chapter Objectives

This chapter will help students:

Explain the importance of water and the hydrologic cycle to ecosystems, human health, and economic pursuits

Delineate freshwater distribution on Earth

Describe major types of freshwater ecosystems

Discuss how we use water and alter freshwater systems

Assess problems of water supply and propose solutions to address freshwater depletion

Assess problems of water quality and propose solutions to address water pollution

Explain how wastewater is treated

Lecture Outline

I. Central Case: Plumbing the Colorado River

- A. In January 2003, the U.S. government cut off 15% of California's water supply from the Colorado River.
- B. The Colorado River begins in the Rocky Mountains, travels through the Grand Canyon, crosses the border into Mexico, and empties into the Gulf of California, draining 637,000 km² of southwestern North America.
- C. The waters of the Colorado River irrigate 7% of U.S. cropland; provide drinking water to over 30 million people; provide flood control, recreation, and hydroelectric power; keep hundreds of golf

courses green in the desert; and fill the swimming pools and fountains of Las Vegas casinos. Very little, if any, actually reaches the ocean.

- D. For over 80 years, the seven states along the Colorado have attempted to divide the river's water among themselves, guided by the Colorado River Compact they signed in 1922.
 - 1. California has been permitted to exceed its allotment because the other states did not use their full shares.
 - 2. In 2000, the federal government pressured California to lower its usage by about 15%, gradually over 15 years.
 - 3. By 2007, the reservoirs were only half full and the seven states were forced to revisit the agreement.
- E. Several states sought variances in the amount of entitled water due to continued drought conditions and predicted droughts.
 - 1. California worked hard to get agricultural districts, which controlled most of the water, to sell part of their shares, but the Imperial Irrigation District backed out.
 - 2. In 2007, Las Vegas chose a controversial plan to mine groundwater from below the scenic Great Basin desert. Critics fear the plan will undermine the fragile desert ecology of the region.
 - 3. With growing human population, the western desert states will continue to challenge the capacity of water districts in that region.

II. Freshwater Systems

- A. Of all the water on Earth, only 2.5% is considered **freshwater**. Most of that is tied up in glaciers and ice caps.
- B. Water moves in the hydrologic cycle.
- C. Rivers and streams wind through landscapes.
 - 1. Bodies of actively flowing water comprise one major class of freshwater ecosystem.
 - 2. As streams flow downhill, they join one another and eventually form larger water channels, or rivers.
 - 3. Due to their size and power, rivers shape the landscape through which they run.
 - 4. A river may shift its course over time; areas that are periodically flooded are within the **floodplain**.
- D. Lakes and ponds are also ecologically diverse systems.
 - 1. The region ringing the edge of a water body is the **littoral zone**.
 - 2. The bottom of a lake or pond is the **benthic zone**.
 - 3. The shallow waters away from shore are termed the **limnetic zone**, where light enters and supports phytoplankton, which in turn supports zooplankton.
 - 4. Deeper in open water, where the sunlight does not reach, is the **profundal zone**, which lacks plant life.
- E. Wetlands include marshes, swamps, and bogs.
 - 1. Systems that combine elements of freshwater and dry land are enormously rich and productive.

2. All types of wetlands are extremely valuable to wildlife, and all types have been extensively drained and filled, largely for agriculture.
- F. Groundwater plays key roles in the hydrologic cycle.
1. Groundwater is contained in **aquifers**—porous, spongelike formations of rock, sand, or gravel that hold water.
 2. The water table is the boundary between the upper layer, or zone of aeration, and the lower layer, or zone of saturation, which is completely filled with water.
 3. There are two broad categories of aquifers—**confined aquifers**, also known as **artesian aquifers**, which are under pressure, and **unconfined aquifers**.
- G. Water is unequally distributed across Earth’s surface.

III. How We Use Water

- A. Water supplies our households, agriculture, and industry.
1. Most uses of water are **consumptive use**, in which water is removed from a particular body of water and is not returned to it.
 2. **Nonconsumptive use** of water does not remove, or only temporarily removes, water from an aquifer or surface water body.
- B. Inefficient irrigation wastes water.
- C. We are depleting groundwater.
1. Sometimes as aquifers lose water, the substrate becomes weaker, and subsidence occurs, locally and suddenly, in the form of **sinkholes**.
- D. We divert—and deplete—surface water to suit our needs.
- E. Will we see a future of water wars?
1. Many predict that water’s role in regional conflicts will increase as human population continues to grow in water-poor areas.
- F. Dikes and levees are meant to control floods.
- G. We have erected thousands of **dams**.
- H. China’s Three Gorges Dam is the world’s largest.
- I. Some dams are now being removed.
1. By removing dams and letting rivers flow free, we can restore riparian ecosystems, reestablish economically valuable fisheries, and reintroduce river recreation.
 2. Many dams have aged and are in need of costly repairs or have outlived their economic usefulness.

IV. Solutions to Freshwater Depletion

- A. Solutions can address supply or demand.
- B. **Desalination** “makes” more freshwater.
1. The best-known technological approach to generate freshwater is desalination, or desalinization—the removal of salt from seawater or other water of marginal quality.
 2. One method of desalination mimics the hydrologic cycle by hastening evaporation from allotments of ocean water with heat and then condensing the vapor—essentially distilling freshwater.

3. Another method involves forcing water through membranes to filter out salts; the most common process is called reverse osmosis.
- C. Agricultural demand can be reduced.
1. Farmers can use technology to improve efficiency in a number of ways, including lining irrigation canals to prevent leaks and leveling fields to minimize runoff.
 2. Techniques to increase irrigation efficiency include low-pressure spray irrigation, which sprays water downward toward plants, and drip irrigation systems, which target individual plants and introduce water directly onto the soil.
 3. Choosing crops to match the land and climate in which they are being farmed can save huge amounts of water.
 4. Selective breeding and genetic modification produce crop varieties that require less water.
- D. We can lessen residential, municipal, and industrial use in many ways.
1. We can reduce our household water use by installing low-flow faucets, showerheads, washing machines, and toilets.
 2. Automatic dishwashers use less water than washing dishes by hand.
 3. Watering lawns at night minimizes water loss from evaporation.
 4. Replacing water-intensive lawns with native plants adapted to your region's natural precipitation patterns saves the most water.
 5. *Xeriscaping*, landscaping using plants adapted to arid conditions, has become a popular approach in much of the U.S. Southwest.
 6. Manufacturers have shifted to processes that use less water and, in doing so, have reduced their costs.
 7. Finding and patching leaks in pipes has saved some cities and companies large amounts of water—and money—once they have invested in the search.
 8. Recycling wastewater for suitable uses is another water conservation practice; it can be made suitable for irrigation and for some industrial uses.
 9. Governments in both Arizona and England are capturing excess surface runoff during their rainy seasons and pumping it into aquifers, thus making more efficient use of their available water supply.
- E. Various economic solutions to water conservation are being debated.
1. Many economists have suggested market-based strategies for achieving sustainability in water use.
 - a. Ending government subsidies of inefficient practices.
 - b. Letting water become a commodity whose price reflects the true costs of its extraction.
 2. Others worry that making water a fully priced commodity would make it less available to the world's poor and increase the gap between rich and poor.
 3. Because industrial use of water can be 70 times more profitable than agricultural use, market forces alone could favor uses that would benefit wealthy and industrialized people, companies, and nations at the expense of the poor and less industrialized.

4. The privatization of water supplies has been tried in hope of increasing efficiency, but many people worry that firms have little incentive to allow equitable access to water for rich and poor alike.
5. Decentralization of control over water, from the national level to the local level, may help conserve water.

V. Freshwater Pollution and Its Control

- A. Water pollution comes from **point sources** and from diffuse **nonpoint sources**.
 1. The term **pollution** describes any matter or energy released into the environment that causes undesirable impacts on the health and well-being of humans or other organisms.
 2. Regardless of its source, water pollution exists in many forms and can cause diverse impacts on aquatic ecosystems and human health.
- B. Pathogens and waterborne diseases are a biological form of water pollution.
 1. Many disease-causing organisms survive in surface water, and some enter inadequately treated drinking water supplies via human and animal waste.
 2. As our understanding of these pathogens found in water has advanced, we have developed several strategies for reducing risks they pose:
 - a. Treating sewage to remove pathogens.
 - b. Using chemical or other means to disinfect drinking water.
 - c. A variety of hygienic measures, including personal hygiene and the cleanliness of food production, processing, and distribution.
- C. Nutrient pollution can cause eutrophication.
- D. Toxic chemicals pollute our waterways.
- E. Sediment can be a pollutant.
- F. Even heat and cold can pollute.
- G. Scientists use several indicators of water quality.
 1. Physical, chemical, and biological properties of water are all measured to characterize its quality.
 2. The important chemical properties include nutrient concentrations, pH, hardness, and dissolved oxygen content.
 3. Scientists also classify water according to three physical characteristics: turbidity, color, and temperature.
- H. Groundwater pollution is a serious problem.
- I. There are many sources of groundwater pollution.
 1. A variety of chemicals that are toxic at high concentrations, including aluminum, fluoride, nitrates, and sulfates, occur naturally in groundwater.
 2. Industrial, agricultural, and urban wastes—from heavy metals to petroleum products to industrial solvents to pesticides—can leach through soil and seep into aquifers.
 3. Pathogens and other pollutants can also enter groundwater through improperly designed wells.

4. Some aquifer contamination results from the intentional pumping of wastes below ground.
5. Leakage from underground storage tanks is another major contributor to groundwater pollution.
6. Agriculture also contributes to groundwater pollution:
 - a. Nitrate from fertilizers.
 - b. Pesticides.
 - c. Pathogens.
7. Manufacturing industries and military sites have been heavy polluters through the years.
 - a. Near St. Louis, the U.S. Army operated the world's largest facility to produce trinitrotoluene (TNT); by-products have seeped into the drinking water for miles around.
 - b. At one of the best-known Superfund sites, the Hanford Nuclear Reservation in Washington State, vast quantities of radioactive waste have seeped into groundwater, some of it with a half-life of a quarter-million years.
 - c. A 17-year study revealed that VOCs such as MTBE and chloroform from manufactured products and industrial processes were found in 20% of the wells sampled.
- J. Legislative and regulatory efforts have already helped reduce pollution.
- K. Drinking water is treated before it reaches your tap.
- L. It is better to prevent pollution than to mitigate it after it occurs.

VI. Wastewater and Its Treatment

- A. **Wastewater** refers to water that has been used by people in some way.
- B. Municipal wastewater treatment involves several steps.
 1. In rural areas the most popular solution is **septic systems**, where wastewater runs to an underground septic tank, solids and oils are separated from the water, and the water goes to a drain field.
 2. In more populated areas, municipal sewer systems carry wastewater to centralized treatment locations.
 - a. The wastewater is screened to remove large debris.
 - b. **Primary treatment** then removes contaminants in settling tanks; solids, grit, and particulates settle to the bottom, while greases and soils float to the surface.
 - c. In **secondary treatment**, the water is aerated, and aerobic bacteria degrade the organic pollutants.
 - d. Several other steps may be performed, including further settling, chlorination, or carbon filters.
- C. Artificial wetlands can aid the treatment process.

VII. Conclusion

- A. Citizen action, government legislation and regulation, new technologies, economic incentives, and public awareness are all enabling us to confront the problems with quantity and quality of freshwater.
- B. We have grown to take freshwater for granted, yet it is only a minuscule percentage of the entire hydrosphere.

C. There is reason to hope that we may yet attain sustainability in our water usage.