Chapter 3

Ecosystems: What Are They and How Do They Work?

Chapter Outline

Key Concepts

3.1A The four major components of the earth's life-support system are the atmosphere (air), the hydrosphere (water), the geosphere (rock, soil, and sediment), and the biosphere (living things).
3.1B Life is sustained by the flow of energy from the sun through the biosphere, the cycling of nutrients within the biosphere, and gravity.
3.2A Some organisms produce the nutrients they need, others get the nutrients they need by consuming other organisms, and some recycle nutrients back to producers by decomposing the wastes and remains of other organisms.
3.2B Soil is a renewable resource that provides nutrients that support terrestrial plants and helps purify water and control the earth's climate.
3.3 As energy flows through ecosystems in food chains and webs, there is a decrease in the high-quality chemical energy available to organisms at each successive feeding level.
3.4 Matter, in the form of nutrients, cycles within and among ecosystems and the biosphere, and human activities are altering these chemical cycles.
3.5 Scientists use both field research, laboratory research, and mathematical and other models to learn about ecosystems and how much stress they can take.

Key Questions and Case Studies

CORE CASE STUDY

Tropical Rain Forests Are Disappearing

Tropical rainforests make up only 2% of the earth's land surface, but account for more than half of all biodiversity. Already more than half of this area has been destroyed, and degradation is increasing. This will cause a reduction in biodiversity, an increase in climate change, and changes in regional weather patterns.

3.1 How does the earth's life-support system work?

A. Earth's life support system consists of four main systems: the atmosphere (air), hydrosphere (water), geosphere (earth), and biosphere (living things).
    1. The atmosphere contains many layers:

a. The troposphere extends 17 km up and contains the air we breathe. About 1% is composed of greenhouse gases (water vapor, methane, and carbon dioxide), which absorb energy to warm the lower atmosphere.
b. The stratosphere lies 17–50 km above the troposphere and filters the sun's harmful radiation.

2. The hydrosphere consists of earth's water, found in liquid water, ice, and water vapor.
3. The geosphere consists of the earth's core, mantle, and crust.
4. The biosphere is where life is found.

B. Life on earth depends on three interconnected factors:
  1. The one-way flow of high-quality solar energy
  2. The cycling of nutrients
  3. Gravity

C. Solar energy reaches earth as electromagnetic waves in the form of visible light, UV radiation, and heat.

D. As solar radiation interacts with the earth, infrared radiation is produced. Greenhouse gases trap the heat and warm the troposphere. This natural greenhouse effect makes the planet warm enough to support life.
  1. Human activities add greenhouse gasses to the atmosphere, intensifying the greenhouse effect.

3.2 What are the major components of an ecosystem?

A. Ecosystems are composed of living (biotic) and nonliving (abiotic) components.
  1. Every organism occupies a trophic (feeding) level.
    a. Producers, or autotrophs, make their own food from compounds in the environment. Photosynthesis is the process by which plants take solar energy, carbon dioxide, and water to form energy rich sugars.
    b. Consumers, or heterotrophs, feed on other organisms.
      i. Herbivores (primary consumers) feed on plants.
      ii. Carnivores feed on animals.
      iii. Secondary consumers feed on herbivores
      iv. Tertiary consumers feed on other carnivores.
      v. Omnivores feed on both plants and animals.
      vi. Decomposers break down organic detritus (bacteria/fungi) into simpler inorganic compounds.
      vii. Detritivores feed on dead organic matter and break it down into smaller molecules.
    c. Ecosystems are composed of living (biotic) and nonliving (abiotic) components.

SCIENCE FOCUS 3.1

Many of the World's Most Important Organisms Are Invisible to Us

Microbes are pivotally important in terms of cycling matter, providing oxygen, and regulating the earth's temperature by removing carbon dioxide.

3.3 What happens to energy in an ecosystem?

A. Energy flow in a food web/chain decreases at each succeeding organism in a chain or web.
B. The dry weight of all organic matter within the organisms of a food chain/web is called biomass.
C. The greater the number of trophic levels in a food chain, the greater loss of usable energy.
D. The pyramid of energy flow visualizes the loss of usable energy through a food chain. The lower levels of the trophic pyramid support more organisms.
E. Production of biomass takes place at different rates among different ecosystems.

1. The rate of an ecosystem's biomass production is the gross primary productivity (GPP).
2. Some of the biomass must be used for the producers' own respiration. Net primary productivity (NPP) measures how fast producers can provide biomass needed by consumers in an ecosystem.
3. Ecosystems and life zones differ in their NPP.

H. The planet's NPP limits the numbers of consumers who can survive on earth.

3.4 What happens to matter in an ecosystem?

A. Nutrient cycles/biogeochemical cycles are global recycling systems that interconnect all organisms.
   1. These cycles include the carbon, oxygen, nitrogen, phosphorus, and water cycles.

B. The water/hydrologic cycle collects, purifies, and distributes the earth's fixed supply of water in a vast global cycle.

C. The water cycle is altered by man's activities.
   1. We withdraw large quantities of fresh water.
   2. We clear vegetation and increase runoff, reduce filtering and increase flooding.
   3. We increase flooding as we drain and alter wetlands.

SCIENCE FOCUS 3.2

Water's Unique Properties

Water has a unique set of properties. It is a liquid that changes temperature slowly. It takes a large amount of energy to evaporate because of hydrogen bonds. Liquid water can dissolve a variety of compounds. Water can adhere to solid surfaces, and it expands when it freezes.

D. The carbon cycle circulates through the biosphere.
   1. Human activities affect the carbon cycle.
      a. Harvesting fossil fuels for coal, oil, and natural gas
      b. Excess carbon dioxide in the atmosphere has contributed to global warming.
      c. Clearing carbon-absorbing vegetation from forests, especially tropical forests, faster than they can grow back

E. Nitrogen is recycled through the earth's systems by different types of bacteria.
   1. The nitrogen cycle converts nitrogen (N2) into compounds that are useful nutrients for plants and animals.
   2. Human activities affect the nitrogen cycle.
      a. In burning fuel, we add nitric oxide into the atmosphere; it can be converted to NO_2 gas and nitric acid, and it can return to the earth's surface as acid rain.
      b. Nitrous oxide that comes from livestock, wastes, and inorganic fertilizers we use on the soil can warm the atmosphere and deplete the ozone layer.
      c. We destroy forest, grasslands, and wetland and, thus, release large amounts of nitrogen into the atmosphere.
      d. We pollute aquatic ecosystems with agricultural runoff and human sewage.
      e. We remove nitrogen from topsoil with our harvesting, irrigating, and land-clearing practices.

F. The phosphorus cycle does not include the atmosphere. The major reservoir is terrestrial rock formations.
   1. Humans interfere with the phosphorous cycle in harmful ways.
      a. We mine phosphate rock to produce fertilizers and detergents.
      b. We cut down tropical forests and, thereby, reduce the phosphorus in tropical soils.
      c. Eroding topsoil moves large quantities of topsoil to aquatic systems, where it stimulates growth in algae.

3.5 How do scientists study ecosystems?

A. Ecologists do field research, observing and measuring the ecosystem structure and function.
B. New technologies such as remote sensing and geographic information systems (GISs) gather data that is fed into computers for analysis and manipulation of data.
C. Ecologists use tanks, greenhouses, and controlled indoor and outdoor chambers to study ecosystems (laboratory research). This allows control of light, temperature, CO2, humidity, and other variables.
D. Field and laboratory studies must be coupled together for a more complete picture of an ecosystem.
E. Systems analysis develops mathematical and other models that simulate ecosystems that are large and very complex and can't be adequately studied with field and laboratory research. This allows the analysis of the effectiveness of various alternate solutions to environmental problems and can help anticipate environmental surprises.

SCIENCE FOCUS 3.3

Planetary Boundaries

The Holocene (most of the past 10,000 years) has been a period of relatively stable climate and other environmental conditions following a glacial period. We are entering an Anthropocene era where humans have become major agents of change in the functioning of the earth's systems. Researchers estimated that we have exceeded four of the planetary boundaries. They are (1) disruption of the nitrogen and phosphorus cycles; (2) biodiversity loss from replacing biologically diverse forests and grasslands with simplified fields of single crops; 3) land system change from agriculture and urban development; (4) climate change from disrupting the carbon cycle.

INDIVIDUALS MATTER 3.1

Thomas E. Lovejoy— Forest Researcher and Biodiversity Educator

For several decades, conservation biologist and National Geographic Explorer Thomas E. Lovejoy has played a major role in educating scientists and the public about the need to understand and protect tropical forests. In 2012, he was awarded the Blue Planet Prize for his efforts to understand and sustain the earth's biodiversity.

Teaching Tips

Large Lecture Courses

Draw a diagram of a trophic pyramid on the board. Let the students suggest where the producers and consumers go on this diagram. Through Socratic questioning, direct them to the conclusion that consumer populations are limited by the amount of energy at the top of this pyramid. Then make the connection with food production and diet, allowing them to draw the conclusion that the best way to feed a growing human population is via a vegetarian diet.

Small Lecture Courses

Use the example of tropical rainforest deforestation to illustrate the impacts that alterations of an ecosystem can have on the carbon and hydrologic cycles. Break the class into groups to discuss the effects of alternate land uses, such as agriculture and grazing. Then reconvene the class for a brainstorming session on the blackboard. Focus on issues that have a truly global impact, such as carbon sinks and weather patterns, in addition to erosion and loss of biodiversity.

Key Terms

aerobic respiration
aquifer
atmosphere
autotrophs
biomass
biosphere
carbon cycle
carnivores
community
consumers
decomposers
detritus feeders
detritivores
ecology
ecosystem
food chain
food web
geosphere
greenhouse effect
gross primary productivity (GPP)
groundwater
herbivores
heterotrophs
hydrologic (water) cycle
hydrosphere
natural greenhouse effect
net primary productivity (NPP)
nitrogen cycle
nutrient (biogeochemical) cycles
omnivores
organism
photosynthesis
phosphorus cycle
population
primary consumers
producers
pyramid of energy flow
secondary consumers
soil
soil profile
stratosphere
surface runoff
tertiary consumers
trophic level
troposphere
weathering

Term Paper Research Topics

1. Sustaining ecosystems: the big picture.

2. Abiotic factors and range of tolerance: a comparison of terrestrial and aquatic limiting factors.

3. Biotic factors: a comparison of chemosynthesizers and photosynthesizers; lifestyles of detritivores.

4. Pyramid of energy and ecological efficiency: a comparison of ecological efficiency in different biomes.

5. Soil: the web of life in the soil, soil formation, and pioneer ecological succession; soils of your locale.

6. Cycles of matter: particular cycles of matter, clarifying chemical changes throughout the cycle; the processes of photosynthesis and respiration and how they connect autotrophic and heterotrophic organisms.

7. Energy flow: energy flow in a particular ecosystem; relationships among species in a particular ecosystem; comparison of the life of a specialist with that of a generalist.

8. Humans trying to work with ecosystems: composting; organic gardening; land reclamation; rebuilding degraded lands; tree-planting projects.

9. Methods used in ecological research: measuring net primary productivity and respiration rates; analyzing for particular chemicals in the air, water, and soil; computer modeling of ecological interrelationships.

10. Find groups focused on sustaining ecosystems and creating sustainable cities and societies in your area. Do their mission statements include the principles discussed in this chapter? Are other planks included as well?

Discussion Topics

1. Should we eat lower on the food chain?

2. Should we rely more on renewable sources of energy?

3. How do humans affect organisms at different levels of a pyramid of energy?

4. What are the advantages and disadvantages of different methods of studying ecosystems?

5. What sustains ecosystems? What services do ecosystems provide for humans? What can humans do to help sustain ecosystems?

6. To what extent should we disrupt and simplify natural ecosystems for our food, clothing, shelter, and energy needs and wants?

7. What do nature's cycles of matter suggest about landfills, incinerators, reducing consumption, and recycling?

8. Based on your current understanding of ecology, evaluate the emphasis of the United States on fossil fuels and nuclear power for energy production.

Activities and Projects

1. Organize a class trip to a natural area such as a forest, grassland, or estuary to observe the elements of ecosystem structure and function. Arrange for an ecologist or a naturalist to provide interpretive services.

2. Bring a self-sustaining terrarium or aquarium to class and explain the structure and function of this conceptually tidy ecosystem. Discuss the various things that can upset the balance of the ecosystem and describe what would happen if light, food, oxygen, or space were manipulated experimentally.

3. Find works of literature, art, and music that show human attachment to and destruction of natural ecosystems.

4. As a class exercise, have each student list the kinds and amounts of food he or she has consumed in the past 24 hours. Aggregate the results and compare them on a per capita basis with similar statistics derived from studies of dietary composition and adequacy in food-deficient nations. How many people with a vegetarian diet could subsist on the equivalent food value of the meat consumed by your class?

5. Have the students debate the argument that eating lower on the food chain is socially and ecologically more responsible, cheaper, and healthier. (It is helpful to do this around a time when fasting is common.) Also, look at the long-term picture: will eating low on the food chain sustain an exponentially growing human population indefinitely?

6. Define an ecosystem to study on campus. As a class project, analyze the abiotic and biotic components of the ecosystem. Draw webs and construct pyramids to show the relationships among species in the ecosystem. Project what might happen if pesticides were used in the ecosystem, if parts of the ecosystem were cleared for development, or if a coal-burning power plant were located upwind.

Attitudes and Values

1. Do you feel you are part of an ecosystem? What niche do you fill?

2. Do you hold any particular feelings for producers? Consumers? Decomposers?

3. How do you feel when you think of a coyote eating a rabbit? How do you feel when you think of humans eating hamburgers?

4. Do humans have a right to domesticate and eat other species?

5. Do you feel there will always be enough matter and energy for the survival of all individuals of all species? Will the carrying capacity of the Earth be expanded by new technologies? Will nature be able to continually absorb "waste-products" from human societies?

6. Do you feel any responsibility to protect natural ecosystems? Would you support the preservation of representative ecosystems? If so, on what basis?

Suggested Answers to End-of-Chapter Questions

Chapter Review

Core Case Study

1. What are three harmful effects of the clearing and degradation of tropical rain forests?
   - A reduction of the earth's vital biodiversity by destroying or degrading the habitats of many of the unique plant and animal species found in these forests, thereby causing their premature extinction.
   - An acceleration of global warming, and thus climate change, by eliminating large areas of trees faster than they can grow back, thereby degrading the forests' abilities to remove the greenhouse gas, carbon dioxide (CO_2), from the atmosphere.
   - A change in regional weather patterns in ways that can prevent the return of diverse tropical rain forests in cleared or degraded areas. Once this irreversible *ecological tipping point* is reached, tropical rain forests in such areas will become less-diverse tropical grasslands.

Section 3.1

2. What are the two key concepts for this section? Define and distinguish among the atmosphere, troposphere, stratosphere, hydrosphere, geosphere, and biosphere. What three interconnected factors sustain life on the earth? Describe the flow of energy to and from the earth. What is the greenhouse effect and why is it important?
   - Key concepts: The four major components of the earth's life-support system are the atmosphere (air), the hydrosphere (water), the geosphere (rock, soil, and sediment), and the biosphere (living things). Life is sustained by the flow of energy from the sun through the biosphere, the cycling of nutrients within the biosphere, and gravity.
   - The atmosphere is a thin spherical envelope of gases surrounding the earth's surface. Its inner layer, the troposphere, extends only about 17 kilometers (11 miles) above sea level at the tropics and about 7 kilometers (4 miles) above the earth's north and south poles. It contains the majority of the air that we breathe, consisting mostly of nitrogen (78% of the total volume) and oxygen (21%). The remaining 1% of the air includes water vapor, carbon dioxide, and methane, all of which are called greenhouse gases, which absorb and release energy that warms the lower atmosphere. Without these gases the earth would be too cold for the existence of life as we know it. Almost all of the earth's weather occurs within this layer.

The next layer, stretching 17–50 kilometers (11–31 miles) above the earth's surface, is called the stratosphere. Its lower portion holds enough ozone (O_3) gas to filter out most of the sun's harmful *ultraviolet (UV) radiation*. This global sunscreen allows life to exist on land and in the surface layers of bodies of water. The hydrosphere consists of all of the water on or near the earth's surface. It is found as *liquid water* (on the surface and underground), *ice* (polar ice, icebergs, and ice in frozen soil layers called *permafrost*), and *water vapor* in the atmosphere. The oceans, which cover about 71% of the globe, contain about 97% of the earth's water. The geosphere consists of the earth's intensely hot *core*, a thick *mantle* composed mostly of rock, and a thin outer *crust*. The biosphere consists of all of the parts of the atmosphere, hydrosphere, and geosphere where life is found.

- Three factors sustain the earth's life.
    - The *one-way flow of high-quality energy* from the sun, through living things in their feeding interactions, into the environment as low-quality energy (mostly heat dispersed into air or water at a low temperature), and eventually back into space as heat.
    - The *cycling of nutrients* (the atoms, ions, or molecules needed for survival by living organisms) through parts of the biosphere.
    - *Gravity* allows the planet to hold onto its atmosphere and helps to enable the movement and cycling of chemicals through the air, water, soil, and organisms.
- Energy flows from the sun to the earth. Some incoming radiation is reflected back to space, roughly half is absorbed by the earth's surface. This is re-radiated as heat, some of which escapes to space, the rest is absorbed by greenhouse gases and clouds in the atmosphere.
- The greenhouse effect is the warming of the troposphere by greenhouse gases absorbing heat. Greenhouse gases are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

Section 3.2

3. What is the key concept for this section? Define ecology. Define organism, population, community, and ecosystem, and give an example of each. Distinguish between the living and nonliving components in ecosystems and give two examples of each.
    - Key concept: Some organisms produce the nutrients they need, others get the nutrients they need by consuming other organisms, and some recycle nutrients back to producers by decomposing the wastes and remains of other organisms. Soil is a renewable resource that provides nutrients that support terrestrial plants and helps purify water and control the earth's climate.
    - Ecology is the biological science that studies how organisms, or living things, interact with one another and with their environment.
    - An organism is an individual living being, such as a human. A population is a group of individuals of the same species that live in the same place at the same time, such as a flock of geese. A community, or biological community, consists of all the populations of different species that live in a particular place, such as all of the organisms living on a farm.
    - The biosphere and its ecosystems are made up of living (biotic) and nonliving (abiotic) components. Nonliving components include water, air, nutrients, rocks, heat, and solar energy. Living components include plants, animals, and microbes.

4. What is a trophic level? Distinguish among producers (autotrophs), consumers (heterotrophs), decomposers, and detritus feeders and give an example of each. Summarize the processes of photosynthesis and explain how it provides us with food and the oxygen in the air that we breathe. Distinguish among primary consumers (herbivores), carnivores, secondary consumers, tertiary consumers, and omnivores, and give an example of each.
    - The trophic level, a *feeding level*, is the level assigned every type of organism in an ecosystem, depending on its source of food or nutrients.

- Producers, sometimes called autotrophs (self-feeders), make the nutrients they need from compounds and energy obtained from their environment through a process called photosynthesis, a tree for example.
- All organisms that are not producers are consumers, or heterotrophs ("other-feeders"), who cannot produce their own nutrients, a fox for example.
- Decomposers are consumers that release nutrients from the dead bodies of plants and animals and return them to the soil, water, and air for reuse by producers, mushrooms, for example.
- Detritus feeders feed on the wastes or dead bodies of other organisms. Examples are earthworms, some insects, and vultures.
- Photosynthesis is the process by which plants produce nutrients from solar energy. They convert carbon dioxide, water, and energy to glucose and oxygen.
- Primary consumers, or herbivores (plant eaters), are animals that eat producers, feeding mostly on green plants. Examples are caterpillars, deer, and zooplankton.
- Carnivores (meat eaters) are animals that feed on the flesh of other animals. Some carnivores such as spiders, robins, and tuna are secondary consumers that feed on the flesh of herbivores. Other carnivores such as tigers, hawks, and killer whales (orcas) are tertiary (or higher) consumers that feed on the flesh of other carnivores.
- Omnivores such as pigs, foxes, bears, and humans can eat plants and other animals.

5. Explain the importance of microbes. What is aerobic respiration? What two processes sustain ecosystems and the biosphere and how are they linked?
    - Microbes that decompose dead and decaying plant and animal materials are vital to all ecosystems. Their importance is often ignored, but without them life would not exist. They consist of many different types of bacteria and fungi that secrete enzymes that break down materials from other organisms into smaller components; this enables nutrients to be recycled through the ecosystem as they are taken up from the soil and water by the producers.
    - Producers use photosynthesis to convert CO_2 into complex carbohydrates such as glucose ($C_6H_{12}O_6$). Producers, consumers, and decomposers use the chemical energy stored in glucose and other organic compounds to fuel their life processes through the process of cellular respiration. In most cells, this energy is released by aerobic respiration, which uses oxygen to convert glucose (or other organic nutrient molecules) back into carbon dioxide and water. The net effect of the hundreds of steps in this complex process is represented by the following reaction: glucose +oxygen → carbon dioxide+water + energy. This linkage between *photosynthesis* in producers and *aerobic respiration* in producers, consumers, and decomposers circulates carbon in the biosphere. Oxygen and hydrogen—the other elements in carbohydrates—cycle almost in step with carbon.
    - Ecosystems and the biosphere are sustained through a combination of one-way energy flow from the sun through these systems and nutrient cycling of key materials within them—two important natural services that are components of the earth's natural capital.

6. What is soil? Explain how a mature soil forms. What is weathering? Why is soil such an important resource? What is a soil profile? Describe the four horizons in a mature soil. What does the color of topsoil tell us about its ability to grow crops? What three types of particles are found in soils?
    - Soil is a complex mixture of rock pieces and particles, mineral nutrients, decaying organic matter, water, air, and living organisms that support plant life, which, in turn, supports animal life. Soil formation begins when physical, chemical, and biological processes called weathering break down bedrock into small pieces. Decomposers and detritivores break down fallen leaves and wood and add organic matter and nutrients to the soil.
    - Soil is important because life on land depends upon soil.

- The major horizons in a mature soil are O (leaf litter), A (topsoil), B (subsoil), and C (weathered parent material), which build up over the parent material.
- The color of topsoil indicates how useful it is for growing crops or other plants. Black or dark brown topsoil is rich in nitrogen and organic matter. A gray, bright yellow, or red topsoil is low in organic matter and needs the addition of nitrogen to support most crops.
- Soils can include particles of three different sizes: very small clay particles, medium-size silt particles, and larger sand particles. The relative amounts of these different sizes and types of these mineral particles, the composition of organic materials, and the amount of space between the particles determine the texture of a soil.

Section 3.3

7. What is the key concept for this section? Define and distinguish between a food chain and a food web. Explain what happens to energy as it flows through the food chains and food webs. What is the pyramid of energy flow? Distinguish between gross primary productivity (GPP) and net primary productivity (NPP), and explain their importance. What are the two most productive land ecosystems and the two most productive aquatic ecosystems? What percentage of the world's NPP do humans use?
   - Key concept: As energy flows through ecosystems in food chains and webs, the amount of chemical energy available to organisms at each successive feeding level decreases.
   - A sequence of organisms, each of which serves as a source of food or energy for the next, is called a food chain. Organisms in most ecosystems form a complex network of interconnected food chains called a food web.
   - Each trophic level in a food chain or web contains a certain amount of biomass. In a food chain or web, chemical energy stored in biomass is transferred from one trophic level to another. With each transfer, some energy is lost as low-quality heat. As energy flows through ecosystems in food chains and webs, there is a decrease in the amount of chemical energy available to organisms at each succeeding feeding level.
   - The pyramid of energy flow assumes a 90% energy loss with each transfer in a food chain.
   - Gross primary productivity (GPP) is the *rate* at which an ecosystem's producers (usually plants) convert solar energy into chemical energy in the form of biomass found in their tissues. Net primary productivity (NPP) is the *rate* at which producers use photosynthesis to produce and store chemical energy *minus* the *rate* at which they use some of this stored chemical energy through aerobic respiration. The amount, or mass, of living organic material (*biomass*) that a particular ecosystem can support is determined by how much solar energy its producers can capture and store as chemical energy and by how rapidly they can do so.
   - The two most productive land ecosystems are swamps and marches, and the tropical rainforests. The two most productive aquatic ecosystems are estuaries, and lakes and streams.

Section 3.4

8. What is the key concept for this section? What happens to matter in an ecosystem? What is a nutrient cycle? Explain how nutrient cycles connect past, present, and future life. Describe the hydrologic cycle, or water cycle. What three major processes are involved in the water cycle? What is surface runoff? Define groundwater. What is an aquifer? What percentage of the earth's water supply is available to humans and other species as liquid freshwater? Summarize the unique properties of water. List three ways that human are altering the water cycle. Explain how clearing a rainforest can affect local weather and climate. Explain how human activities are affecting the water cycle.
   - Key concept: Matter, in the form of nutrients, cycles within and among ecosystems and the biosphere, and human activities are altering these chemical cycles.

- The elements and compounds that make up nutrients move continually through air, water, soil, rock, and living organisms within ecosystems in cycles called biogeochemical cycles (literally, life-Earth-chemical cycles), or nutrient cycles. Nutrient cycles connect past, present, and future forms of life. Some of the carbon atoms in your skin may once have been part of an oak leaf, a dinosaur's skin, or a layer of limestone rock. Your grandmother, George Washington, or a hunter—gatherer who lived 25,000 years ago may have inhaled some of the nitrogen (N_2) molecules you just inhaled.
- The hydrological cycle, or water cycle, collects, purifies, and distributes this supply of water.
- Water is necessary for life on the earth, and there is a fixed supply of it on our planet. Hydrogen bonds.
    - Exists as a liquid over a wide temperate range.
    - Stores a large amount of heat.
    - Dissolves a variety of compounds.
    - Filter's some UV rays from the sun.
    - Capillary action.
    - Expands when freezes.
    - Exists in all three phases at the Earth's surface
- The three major processes involved in the water cycle are evaporation, condensation, and precipitation.
- Surface runoff is water that flows over land in streams and rivers, which eventually carry it to lakes and oceans.
- Groundwater is water stored underground in aquifers. Aquifers are groundwater stored in layers of rock.
- Only about 0.024% of the earth's water supply is available to humans as liquid freshwater.
- We alter the hydrologic cycle by extracting water from streams, clearing vegetation, and altering wetlands.
- Large-scale loss of tropical rain forests can change regional weather patterns. Sometimes such changes can prevent the regrowth of rain forests in cleared or degraded areas.
- Humans withdraw freshwater from rivers, lakes, and aquifers at rates faster than natural processes can replace it. Second, humans clear vegetation from land for agriculture, mining, road building, and other activities, and cover much of the land with buildings, concrete, and asphalt. This increases water runoff and reduces infiltration that would normally recharge groundwater supplies. Third, we drain and fill wetlands for farming and urban development.

9. Describe the carbon, nitrogen, and phosphorus cycles, and explain how human activities are affecting each cycle. Summarize Thomas Lovejoy's role in protecting the world's tropical forests and protecting biodiversity.

- Various compounds of carbon circulate through the biosphere, the atmosphere, and parts of the hydrosphere. Carbon is cycled through the biosphere by a combination of photosynthesis by producers that removes CO_2 from the air and water, and aerobic respiration by producers, consumers, and decomposers that adds CO_2 in the atmosphere.
    - Human intervention in the carbon cycle centers upon the fact that humans, over millions of years, have converted carbon-containing fossil fuels such as coal, oil, and natural gas into products used for energy. In a few hundred years, we have extracted and burned huge quantities of fossil fuels that took millions of years to form. This has added large quantities of CO_2 to the atmosphere and altered the carbon cycle.
- Chemical forms of nitrogen are created in the nitrogen cycle by lightning, which converts N_2 to NH_3, and by specialized bacteria in topsoil. Other bacteria in topsoil and in the bottom sediments of aquatic systems convert NH_3 to NH_4^+ and nitrate ions (NO_3^-) that are taken up

by the roots of plants. The plants then use these forms of nitrogen to produce various proteins, nucleic acids, and vitamins. Animals that eat plants consume these nitrogen-containing compounds, as do detritus feeders and decomposers.

  - Humans intervene in the nitrogen cycle in several ways.
    - When we burn gasoline and other fuels, the resulting high temperatures convert some of the N_2 and O_2 in air to nitric oxide (NO). In the atmosphere, NO can be converted to nitrogen dioxide gas (NO_2) and nitric acid vapor (HNO_3), which can return to the earth's surface as damaging acid deposition, commonly called acid rain.
    - We add nitrous oxide (N_2O) to the atmosphere through the action of anaerobic bacteria on nitrogen-containing fertilizer or organic animal manure applied to the soil. This greenhouse gas can warm the atmosphere and take part in reactions that deplete stratospheric ozone, which keeps most of the sun's harmful ultraviolet radiation from reaching the earth's surface.
    - We alter the nitrogen cycle in aquatic ecosystems by adding excess nitrates (NO^{3-}) to these systems.
- The phosphorus (P) cycle moves phosphorous through water, the earth's crust, and living organisms. The major reservoir for phosphorus in this cycle is phosphate rocks that contain phosphate ions ($PO_4{}^{3-}$), which are an important plant nutrient. Phosphorus does not cycle through the atmosphere because few of its compounds exist as a gas. Phosphorus cycles more slowly than water, carbon, and nitrogen.
  - Human activities, including the removal of large amounts of phosphate from the earth to make fertilizer, disrupt the phosphorus cycle. By clearing tropical forests, we reduce phosphate levels in tropical soils. Eroded topsoil and fertilizer washed from fertilized crop fields, lawns, and golf courses carry large quantities of phosphate ions into streams, lakes, and oceans. There they stimulate the growth of producers such as algae and various aquatic plants, which can upset chemical cycling and other processes in bodies of water.
- Thomas E. Lovejoy has played a major role in educating scientists and the public about the need to understand and protect tropical forests. Some notable positions and achievements are: principal adviser for the public television series *Nature*; he has also written numerous articles and books on issues related to conserving biodiversity; in addition to teaching environmental science and policy at George Mason University, he has held several prominent posts, including director of the World Wildlife Fund's conservation program, president of the Society for Conservation Biology, and executive director of the U.N. Environment Programme (UNEP).

Section 3.5

10. What is the key concept for this section? Lit three ways in which scientists study ecosystems. Explain why we need much more basic data about the condition of the world's ecosystems. Distinguish between the Holocene era and the proposed Anthropocene era. What is a planetary boundary (ecological tipping point) and why are such boundaries important? List four boundaries that we may have been exceeded. What are this chapter's three big ideas? Explain how tropical rain forests (Core Case Study) showcase the functioning of the three scientific principles of sustainability.
    - Key concept: Scientists use both field research and laboratory research, as well as mathematical and other models, to learn about ecosystems.
    - Three approaches ecologists use to learn about ecosystems: field research, laboratory research, and ecosystem models.

- We need baseline data on the condition of the world's ecosystems to see how they are changing and to develop effective strategies for preventing or slowing their degradation.
- The Holocene era started approximately 10,000 years ago and has been a period of relatively stable climate and other environmental conditions following a glacial period. In the proposed Anthropocene era, humans are major agents of change in the functioning of the earth's life support system.
- A planetary boundary is also known as an ecological tipping point, beyond which it may not be possible for earth to recover. The ten planetary boundaries are as follows: The phosphorous cycle, ocean acidification, freshwater use, land use, ozone depletion, atmospheric aerosols, chemical pollution, biodiversity loss, carbon cycle climate change, and nitrogen cycle.
- We may have exceeded these four planetary boundaries: (1) disruption of the nitrogen and phosphorus cycles, mostly from greatly increased use of fertilizers to produce food; (2) biodiversity loss from replacing biologically diverse forests and grasslands with simplified fields of single crops; (3) land system change from agriculture and urban development; and (4) climate change from disrupting the carbon cycle, mostly by overloading it with carbon dioxide produced by the burning of fossil fuels.
- The three big ideas are as follows:
    - Life is sustained by the flow of energy from the sun through the biosphere, the cycling of nutrients within the biosphere, and gravity,
    - Some organisms produce the nutrients they need, others survive by consuming other organisms, and some recycle nutrients back to producer organisms.
    - Human activities are altering the flow of energy through food chains and webs and the cycling of nutrients within ecosystems and the biosphere.
- Producers within rain forests rely on solar energy to produce a vast amount of biomass through photosynthesis. Species living in the forests take part in, and depend on cycling of nutrients in the biosphere and the flow of energy through the biosphere. Tropical forests contain a huge and vital part of the earth's biodiversity, and interactions among species living in these forests help to control the populations of the species living there.

Critical Thinking

The following are examples of the material that should be contained in possible student answers to the end-of-chapter Critical Thinking questions. They represent only a summary overview and serve to highlight the core concepts that are addressed in the text. It should be anticipated that the students will provide more in-depth and detailed responses to the questions depending on an individual instructor's stated expectations.

1. How would you explain the importance of tropical rainforests (Core Case Study) to people who think that such forests have no connection to their lives?

   Students might focus on the role these forests play as carbon sinks, tying up carbon that might otherwise contribute to climate change. Additionally, the biodiversity in rainforests affects the lives of people around the world because of the medicines that have been discovered there, with the possible discovery of many more. And finally, weather patterns may be disrupted when the natural holding capacity of the forest is diminished and water simply runs off. Changes in equatorial weather patterns have global significance.
2. Explain why: (a) the flow of energy through the biosphere depends on the cycling of nutrients, and (b) the cycling of nutrients depends on gravity.

   a. The earth is closed to significant inputs of matter and has a fixed supply of nutrients that must be recycled to support life. Energy flows through living things in their feeding interactions, the basic components of which are recycled when plants photosynthesize, making molecules of sugars to be consumed.

b. Gravity holds the atmosphere close to the earth, and enables the cycling of chemicals through air, water, soil, and organisms.

3. Explain why microbes are so important. What are two ways in which they benefit your health or lifestyle? Write a brief description of what you think would happen to you if microbes were eliminated from the earth.

   Microbes that decompose dead and decaying plant and animal materials are vital to all ecosystems. Their importance is often ignored but without them life would not exist. They consist of many different types of bacteria and fungi that secrete enzymes that break down materials from other organisms into smaller components, and this enables nutrients to be recycled through the ecosystem as they are taken up from the soil and water by the producers. Two beneficial effects of microbes are their role in the recycling of matter and ensuring that there is no build-up of waste in the natural world. They are also used in the production of foods like cheese and yogurt. Life without microbes could not exist. As an example, there are more than 10,000 species of bacteria, fungi, and other microbes that live in or on our bodies. Many of them provide us with vital services. Bacteria in our intestinal tracts help break down the food we eat, and microbes in our noses help prevent harmful bacteria from reaching our lungs.

4. Make a list of the foods you ate for lunch or dinner today. Trace each type of food back to a particular producer species. Describe the sequence of feeding levels that led to your feeding.

   Student answers will vary but could include some of the following: if a student had a burger and fries for lunch, the bread can be traced back to wheat, the meat to cows and the grain that was fed to them, the lettuce and tomatoes to the original plants, and the fries to potatoes.

5. Use the second law of thermodynamics (see Chapter 2) to explain why many poor people in less-developed countries live on a mostly vegetarian diet.

   The second law of thermodynamics states that in any energy transformation, the energy quality will always decrease and we will end up with less-usable energy than we began with. Much of the degraded energy is lost in the form of heat. Energy is lost at each trophic level in a food chain by as much as 90%. The earth can support more people if they ate at a lower level on the food chain by consuming grains, vegetables, and fruits directly. If these crops are fed to animals and pass through another trophic level, more energy is lost in the process. From an economic perspective, it is also costlier to buy meat from cattle than it is to buy the grain that was used to feed them. People who live in rich developed countries can afford to live on a diet that is high in meat. However, people in poorer, less-developed countries cannot afford to buy meat and live primarily on a vegetarian diet. In doing so, they are behaving in a more energy efficient manner and, in many cases, a healthier one too.

6. How might your life and the lives of any children or grandchildren you might eventually have be affected if human activities continue to intensify the water cycle?

   If human activities continued to alter the water cycle, in places that grew hotter, the cycle could speed up and change global precipitation patterns, which in turn could affect the severity and frequency of storms, floods, and droughts. It could also enhance global warming by moving more water vapor into the atmosphere. An individual’s lifestyle could be affected by lack of water during droughts, too much water during floods causing landslides and mudslides, or increased exposure to disease causing organisms such as mosquitoes that reproduce in moist, humid climates that could result from increased rainfall in an area, in places that grew cooler,

7. What would happen to an ecosystem if: **(a)** all its decomposers and detritus feeders were eliminated, **(b)** all its producers were eliminated, or **(c)** all of its insects were eliminated? Could an ecosystem exist with producers and decomposers but no consumers? Explain.

   (a) The ecosystem would not be able to recycle matter, and wastes would build up. Eventually other species would die as no nutrients would be released for plant growth, etc. The ecosystem would be doomed to collapse.

   (b) The producers form the base of the food chain, and if they were removed then herbivores and subsequently carnivores would eventually die out as they both depend on the producers for the energy that sustains them. The ecosystem would also collapse in this scenario.

   (c) Ecosystem collapse is inevitable if all insects were removed. Pollination would cease and plant growth would be severely affected. Insects are intrinsically linked to two principles of sustainability (renewable solar energy and recycling of nutrients). Insects play a vital role in implementing these two scientific principles. If these parts of an ecosystem's function were removed, sustainability cannot be achieved and the ecosystem would become unbalanced and unstable.

   A fully functioning ecosystem is made up of producers, consumers, and decomposers all interacting with each other and the abiotic components of the environment. The greater the biodiversity of the ecosystem, the greater the balance, stability, and sustainability there is in the ecosystem. Could an ecosystem function with only producers and decomposers? Theoretically a plant could be grown and not eaten by any consumer, then die and be decomposed by bacteria and fungi. However, neither the producers nor the decomposers would function fully. Their role in the ecosystem would not be realized and the ecosystem would be out of balance. Consumers are vital to the sustainable functioning of the ecosystem, whether they are the animals that eat the producers, such as herbivores, or the animals that help decompose the producers, such as the detritus feeders. In order for a balanced ecosystem to exist, it needs all of the interacting components—producers, consumers, and decomposers.

8. If we have exceeded planetary boundaries for the nitrogen and phosphorus cycles, biodiversity loss, land change, and climate change by disrupting the carbon cycle, how might this affect (a) you, (b) any children you might have, and (c) any grandchildren you might have?

   Answers will vary, but generally, worsening effects will be felt by children and grandchildren.

Data Analysis

Recall that net primary productivity (NPP) is the rate at which producers can make the chemical energy that is stored in their tissues and that is potentially available to other organisms (consumers) in an ecosystem. In Figure 3.18, it is expressed as units of energy (kilocalories, or kcal) produced in a given area (square meters, or m^2) per year. Look again at Figure 3.18 and consider the differences in NPP among various ecosystems. Then answer the following questions:

1. What is the approximate NPP of a tropical rain forest in $kcal/m^2/yr$? Which terrestrial ecosystem produces about one-third of that rate? Which aquatic ecosystem has about the same NPP as a tropical rain forest?

- A tropical rain forest has an NPP of about 8,800 kcal/m2/yr. The northern coniferous forest (taiga) produces at about one-third of that rate. Estuaries produce at about the same rate.

2. Early in the 20th century, large areas of temperate forestland in the United States were cleared to make way for agricultural land. For each unit of this forest area that was cleared and replaced by farmland, about how much was NPP reduced?

    - For each square meter of land deforested, about 6,400 kcal/year were lost.

3. Why do you think deserts and grasslands have dramatically lower NPP than swamps and marshes?

    - Deserts and grasslands have fewer producers per unit area than swamps and marshes, which usually have several layers of plants in one given area.

4. About how many times higher is NPP in estuaries than it is in lakes and streams? Why do you think this is so?

    - Estuaries produce about four times as much as lakes and streams. Estuaries are large still bodies of water that support many layers of life. Lakes are small and cannot support as much, and streams are moving and cannot support as much.

<u>Answers to Google Earth Activity</u>

1. b
2. agricultural
3. true