CHAPTER 3
ECOSYSTEMS: WHAT ARE THEY AND HOW DO THEY WORK?

Outline

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

A. The earth's life-support system has four major components.
   1. The **atmosphere** is the thin membrane of air around the planet.
      a. The troposphere is the air layer about 4–11 miles above sea level. It contains greenhouse gases that absorb and release energy which warms the inner layer of the atmosphere.
      b. The stratosphere lies above the troposphere between 11–31 miles; it filters out the sun's harmful radiation.
   2. The **hydrosphere** consists of the earth's water, found in liquid water, ice, and water vapor.
   3. The **geosphere** is the hot core, a thick mantle, and thin crust.
   4. The **biosphere** includes parts of the atmosphere, hydrosphere, and geosphere.

B. Three factors sustain the earth's life:
   1. One-way flow of high-quality energy.
   2. Cycling of nutrients.
   3. Gravity.

3.2 What are the major components of an ecosystem?

A. Ecologists study interactions in nature.
   1. Ecology focuses on how organisms interact with each other and with their non-living environment. They study interactions within and among these following levels of organization:
      a. Population is a group of individuals of the same species living in a particular place.
      b. Community is populations of different species living in a particular place, and potentially interacting with each other.
      c. Ecosystem is a community of different species interacting with one another and with their nonliving environment of matter and energy.
      d. Biosphere is parts of the earth's air, water, and soil where life is found.

B. Ecosystems have several important components.
   1. Every organism belongs to a particular trophic level depending on its source of nutrients.
   2. Producers, or autotrophs, use photosynthesis to make nutrients from components in the environment.
   3. Consumers get their nutrients by feeding on other organisms or their remains.
   4. Consumers can be herbivores (feed on plants), carnivores (feed on animals) or omnivores (feed on both plants and animals).
   5. Consumers can be primary, secondary, or tertiary consumers, depending upon their trophic level.
   6. Decomposers (bacteria/fungi) break down organic detritus into simpler inorganic compounds.
   7. Detritivores (detritus feeders) feed on waste or dead bodies.
   8. Producers, consumers, and decomposers utilize chemical energy stored in organic molecules. In most cells, this energy is released by aerobic respiration.

C. Soil is the foundation of life on land.
   1. Soil is a complex mixture that supports plant life, which, in turn, supports animal life.
   2. Soil purifies water, supplies nutrients for plant growth and help control the earth's climate.
   3. A soil profile is a cross-sectional view of soil horizon, or horizontal layer.
   4. Humus helps make soil fertile.
   5. Soil is a renewable resource that is renewed very slowly.

3.3 What happens to energy in an ecosystem?

A. Energy flows through ecosystems in food chains and food webs.
   1. A food chain is a sequence of organisms, each of which serves as a source of nutrients and energy for the next organisms. Organisms are assigned to trophic levels in a food chain.

2. A food web is a series of interconnected food chains. Food webs occur in most ecosystems. Organisms are also assigned to trophic levels in food webs.
   a. Producers belong to the first trophic level.
   b. Primary consumers belong to the second trophic level.
   c. Secondary consumers belong to the third trophic level.
   d. Tertiary consumers belong to the fourth trophic level.
   e. Detritivores and decomposers process detritus from all trophic levels.

B. Usable energy decreases with each link in a food chain or web.
1. There is less high-quality energy available to organisms at each succeeding feeding level because when chemical energy is transferred from one trophic level to the next, about 90% of the energy is lost as heat.

C. Some ecosystems produce plant matter faster than others do.
1. The rate of an ecosystem's producers converting energy into biomass is the gross primary productivity (GPP).
2. Some of the biomass must be used for the producers' own respiration. Net primary productivity (NPP) is the rate that producers use photosynthesis to store biomass minus the rate at which they use energy for aerobic respiration. NPP measures how fast producers can provide biomass needed by consumers in an ecosystem.
3. Ecosystems and aquatic life zones differ in their NPP. The three most productive systems are swamps and marshes, tropical rain forests, and estuaries. The three least productive are tundra, desert scrub, and extreme desert.

3.4 What happens to matter in an ecosystem?

A. Nutrients cycle within and among ecosystems.
1. Elements and compounds move through air, water, soil, rock, and living organisms in biogeochemical, or nutrient, cycles.

B. The water cycle (hydrologic cycle).
1. Solar energy evaporates water; the water returns as precipitation (rain or snow), goes through organisms, goes into bodies of water, and evaporates again.
2. Water is filtered and partly purified as it moves through the hydrological cycle.
3. Water can be stored as ice in glaciers or in underground aquifers.
4. Unique properties of water include that it:
   a. Is held together by hydrogen bonds.
   b. Exists as a liquid over a wide temperate range.
   c. Stores a large amount of heat.
   d. Requires a large amount of energy to be evaporated.
   e. Dissolves a variety of compounds.
   f. Filter's some UV rays from the sun.
   g. Can move through capillary action.
   h. Expands when freezes.
   i. Exists in all three phases at the Earth's surface.
5. Humans alter the water cycle in three ways:
   a. Withdrawing freshwater at faster rates than nature can replenish it.
   b. Clearing vegetation which increases runoff and decreases replenishment of groundwater supplies.
   c. Draining wetlands which interferes with flood control.

C. The carbon cycle.
1. Carbon is the basic building block of carbohydrates, fats, proteins, DNA, and other compounds.
2. Carbon circulates through the biosphere, hydrosphere, and atmosphere.
3. Producers, consumers, and decomposers circulate carbon in the biosphere.
4. Fossil fuels contain carbon.
5. Humans are altering atmospheric carbon dioxide mostly by our use of fossil fuels and our destruction of the carbon-absorbing vegetation.

D. The nitrogen cycle: bacteria in action.
1. Nitrogen gas (N_2), which makes up 78% of the atmosphere, cannot be used directly by most living organisms.
2. Nitrogen-fixing bacteria convert N_2 into compounds that are useful nutrients for plants and animals.

3. The nitrogen cycle includes the following steps:
    a. Specialized bacteria convert gaseous nitrogen to ammonia in nitrogen fixation.
    b. Specialized bacteria convert ammonia in the soil to nitrite ions and nitrate ions; the latter is used by plants as a nutrient. This process is nitrification.
    c. Decomposer bacteria convert detritus into ammonia and water-soluble salts in ammonification.
    d. In denitrification, anaerobic bacteria in soggy soil and bottom sediments of water areas convert NH_3 and NH_4^+ back into nitrite and nitrate ions, then into nitrogen gas and nitrous oxide gas, which are released into the atmosphere.
4. Human activities have more than doubled the annual release of nitrogen from the land into the rest of the environment, mostly from the greatly increased use of inorganic fertilizers to grow crops. This excessive input of nitrogen into the air and water contributes to pollution and other problems.

E. The phosphorus cycle.
1. Phosphorus circulates through water, Earth's crust, and living organisms in the phosphorus cycle. Phosphorus does not cycle through the atmosphere.
2. The major reservoirs of phosphorus on Earth are rock formations and ocean bottom sediments.
3. Phosphorus is transferred by food webs and is an important component of many biological molecules.
4. Phosphorus is often the limiting factor for plant growth.
5. Human activity removes phosphate from the earth to make fertilizer and reduces phosphate levels in tropical soils by clearing forests. Phosphate-rich runoff from the land can produce huge populations of algae, which can upset chemical cycling and other processes

3.5 How do scientists study ecosystems?

A. Some scientists study nature directly.
1. Field research involves making direct measurements and observations of ecosystems in natural settings.
2. Remote sensing devices can gather data on the earth's surface that can be converted into usable forms by geographic information systems (GIS), such as computerized maps of an area that are used to examine forest cover, water resources, air pollution emissions, coastal changes, and changes in global sea temperatures.

B. Some scientists study ecosystems in the laboratory.
1. Ecologists use tanks, greenhouses, and controlled indoor and outdoor chambers to study ecosystems in laboratory research. This allows control of light, temperature, CO_2, humidity, and other variables.

C. We need to learn more about the health of the world's ecosystems.
1. Mathematical models and computer simulations can help scientists understand large and very complex systems.
2. Simulations are no better than the data and assumptions used to develop models.
3. We need more baseline data about components and physical and chemical conditions in order to determine how well the ecosystem is functioning and anticipate how best to prevent harmful environmental changes.

D. Three big ideas:
1. The flow of energy from the sun through the biosphere, the cycling of nutrients, and gravity, sustains life.
2. Some organisms are producers. Others are consumers and still others live on the remains of organisms.
3. Human activities alter the chemical cycling of nutrients and energy flow.

Concepts

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

CONCEPT 3.1A The four major components of the earth's life-support system are the atmosphere (air), the hydrosphere (water), the geosphere (rock, soil, sediment), and the biosphere (living things).

1. Distinguish among the following terms: *atmosphere, troposphere, stratosphere, hydrosphere, geosphere,* and *biosphere.*

CONCEPT 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.

1. Briefly describe how the sun, nutrient cycles, and gravity sustain life on the earth. Compare the flow of matter and the flow of energy through the biosphere.

3.2 What are the major components of an ecosystem?

CONCEPT 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 organisms.

1. Distinguish between producers and consumers. List and distinguish four types of consumers. Distinguish among scavengers, detritus feeders, and decomposers.
2. Define *abiotic component of an ecosystem*. List three important physical factors and three important chemical factors that have large effects on ecosystems.
3. Define *biotic component of an ecosystem*. Distinguish between producers and consumers. List and distinguish four types of consumers. Distinguish among scavengers, detritus feeders, and decomposers.
4. Discuss the importance of decomposers and detritivores in nutrient cycling.
5. Define aerobic respiration. Draw a connection between photosynthesis and aerobic respiration.

CONCEPT 3.2B Soil is a renewable resource that provides nutrients that support terrestrial plants and helps purify water and control the earth's climate.

1. Define soil, soil profile, horizon, and humus.

3.3 What happens to energy in an ecosystem?

CONCEPT 3.3 As energy flows through ecosystems in food chains and webs, the amount of high-quality chemical energy available to organisms at each succeeding feeding level decreases.

1. Distinguish among trophic levels and give examples of organisms at the primary, secondary, and tertiary trophic level. Describe food chain and food web and how the two differ.
2. Apply the second law of energy to food chains and pyramids of energy, which describe energy flow in ecosystems.
3. Distinguish between gross primary productivity (GPP) and net primary productivity (NPP). Evaluate which ecosystems show the highest average net primary productivity and which contribute most to global net primary productivity.

3.4 What happens to matter in an ecosystem?

CONCEPT 3.4 Matter, in the form of nutrients, cycles within and among ecosystems and the biosphere, and human activities are altering these cycles.

1. Briefly describe the hydrologic cycle. Distinguish among the following: evaporation, transpiration, precipitation and runoff. Describe the storage of water in glaciers and aquifers.
2. Name and describe five types of biogeochemical cycles. Apply the law of conservation of matter to biogeochemical cycles, which describe the flow of matter.
3. Summarize the major ways humans affect each biogeochemical cycle.

3.5 How do scientists study ecosystems?

CONCEPT 3.5 Scientists use both field research and laboratory research, as well as mathematical and other models, to learn about ecosystems and how much stress they can take.

1. Briefly describe the distinguishing features of three approaches ecologists use to learn about ecosystems: field research, laboratory research, and simulations analysis.

Key Terms

abiotic	biotic	decomposers
aerobic respiration	carbon cycle	detritus feeders
anaerobic respiration	carnivores	detrivores
aquifers	cell	ecologist
atmosphere	community	ecology
atom	condensation	Ecosystem modeler
biosphere	consumers	ecosystem

evaporation
fermentation
food chain
food web
geosphere
GIS analyst
greenhouse effect
greenhouse gases
gross primary productivity GPP
groundwater
herbivores
heterotrophs
hydrologic cycle
hydrosphere
infiltration
molecule
net primary productivity NPP
nitrogen cycle
nutrient cycles
nutrients
omnivores
organisms
phosphorus cycle
photosynthesis
percolation
population
precipitation
primary consumers
producers
pyramid of energy flow
remote sensing analyst
runoff
secondary consumers
soil
soil profile
stratosphere
surface runoff
tertiary consumer
transpiration
trophic level
troposphere
water cycle

Teaching Tips

Draw relationships to the Core Case Study regarding the rainforest and their essential role in global sustainability.

- Begin by asking students what they know about rainforests, especially any specific species, and ask them to bring in pictures of different rainforest species including microbes. Also ask if anyone has seen any media clips on the rainforests.
- Make a list of rainforest species in one column and a list of native species in a second column. Discuss some differences in number and type of species found in the rainforest and your community. Draw relationship arrows showing connections—like bee to flowers to fruit to birds to soil—and start discussing nutrient cycles.

Ask each individual student to sketch/photo and label themselves in their habitat (home/school/work) then produce a list of how they depend on and impact their environment. They can use the text's labels (producer, primary consumer, secondary consumer, and decomposer).

- Produce a home refrigerator/freezer inventory and specify for two or three items where the food came from and the food's nutritional value.
- List a few material items in their habitat and specify what they were made from and where they were produced.
- Discuss the importance of water. Demonstrate clear containers of hot, room temperature, and cold (optional ice) water dissolving sugar. Discuss water as a universal solvent, its three states, and its ability to hold heat.
- Itemize a typical meal for students. Ask students to find where each item came from, for example, if breakfast, where did the eggs come from. Have students find out how the food came to their table, whether by truck, railroad, and at what environmental cost. Ask them if the items could be bought locally, for example at a farmer's market, or grown at home, and compare the environmental impact

Discussion Topics

1. How does the human body utilize biotic and abiotic materials? Describe the specific elements and compounds our bodies need.

2. How does energy drive the nutrient cycles? Where does the energy come from and what happens to the energy?

3. Explain and give local examples of how nature cycles matter. Suggest how landfills, incinerators, reducing consumption, and recycling work with these cycles.

4. Explore how field and laboratory methods used in ecological research help increase our understanding of our world by examining data that measures net primary productivity and respiration rates; analyzes for particular

chemicals in the air, water, and soil; studies relationships among species/populations; or applies computer modeling of ecological interrelationships.

Activities and Projects

1. Organize a class trip or a virtual field trip (Google Earth) 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 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. Have your students debate the issue of saving the rainforests from a social, economic, and ecological perspective. Are there indigenous societies living in the rainforests that are being displaced? Will sustaining the current rainforest be enough? Make suggestions and support these suggestions.

5. Define an ecosystem to study on campus. As a class project, analyze the abiotic and biotic components of the ecosystem. Draw food webs 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.

Attitude and Vales Assessment

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

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

3. Do you feel there will always be enough matter and energy for the survival of all individuals of all species? Will nature be able to continually absorb "waste products" from human societies?

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

5. Should you do anything to preserve the rainforests?

6. Why would anyone embrace a stewardship philosophy?

Laboratory Skills

Wells, Edward. *Lab Manual for Environmental Science.* 2009. Lab #5: Food Webs.

Additional Videos

Animals: New Species Discovered in Papua New Guinea (online video from Discovery News, 2010)
http://news.discovery.com/videos/animals-new-species-discovered-in-papua-new-guinea.html

New Species Found at Great Barrier (online video from National Geographic, 2009) http://video.nationalgeographic.com/video/player/news/animals-news/great-barrier-census-wcvin.html

Journey to Planet Earth (DVD from PBS, 2003)
http://www.pbs.org/journeytoplanetearth/

The Living Planet—A Portrait of the Earth (hosted by David Attenborough, four discs, 1984)
This series discusses the biomass and life in a variety of ecosystems.
http://www.amazon.com/Living-Planet-Portrait-Earth/dp/B0000ADXEB/ref=cm_cr_pr_product_top

Web Resources

Food Webs
Interactive exploration of terrestrial and aquatic food webs.
http://www.gould.edu.au/foodwebs/kids_web.htm

The Hydrologic Cycle
Interactive exploration of various phases of the water cycle.
http://polaris.umuc.edu/cvu/envm/hydro/hydro.html

The Carbon Cycle
Additional information about the carbon cycle.
http://chemistry.about.com/od/geochemistry/ss/carboncycle.htm

Digital Integration

Correlation to Global Environment Watch

Aquifers
Carbon Markets
Ecosystems
Greenhouse Gas Emissions
Organic Agriculture and Organic Foods
Ozone Depletion

Correlation to Explore More

Ecology

Suggested Answers to End of Chapter Questions

Answers will vary but these represent phrases from this chapter. The following are examples of the material that should be included in possible student answers to the end of chapter 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.

Review

Core Case Study

1. What are three harmful effects resulting from the clearing and degradation of tropical rain forests? See page 46.

- It will reduce 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.

- It will help to accelerate 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.
- It will change 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 effec**t and why is it important?

    a. The two key concepts for this section are:
        i) CONCEPT 3.1A The four major components of the earth's life-support system are the atmosphere (air), the hydrosphere (water), the geosphere (rock, soil, sediment), and the biosphere (living things).
        ii) CONCEPT 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.
    b. Define and distinguish:
        i) The **atmosphere** is a thin spherical envelope of gases surrounding the earth's surface.
        ii) The **troposphere** is the inner layer of the atmosphere, extending 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%). Almost all of the earth's weather occurs within this layer.
        iii) The **stratosphere** is the second layer of the atmosphere, extending to 17–50 kilometers (11–31 miles) above the earth's surface. Its lower portion contains ozone (O_3) gas that filters out most of the sun's harmful ultraviolet radiation. This global sunscreen allows life to exist on land and in the surface layers of bodies of water.
        iv) 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.
        v) The **geosphere** consists of the earth's intensely hot *core*, a thick *mantle* composed mostly of rock, and a thin outer *crust*.
        vi) The **biosphere** consists of the parts of the atmosphere, hydrosphere, and geosphere where life is found.
    c. Three interconnected factors that sustain life on earth.
        i) 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 (Figure 3.3).
        ii) The *cycling of nutrients* (the atoms, ions, or molecules needed for survival by living organisms) through parts of the biosphere.
        iii) *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.
    d. Solar energy flows to the earth. About one-third of the incoming solar radiation is reflected back into space by clouds, particles in the atmosphere, and the earth's surface. Another fifth of the incoming radiation is absorbed by ozone in the lower stratosphere and clouds and water vapor in the troposphere. Most of the remaining half of incoming solar radiation is absorbed by land and water on the earth's surface.
    e. Water vapor, carbon dioxide, and methane are greenhouse gases found in the troposphere. They 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.

Section 3.2

3. What are the two key concepts for this section? Define **ecology**. Define **organism**, **population**, **community**, and **ecosystem**, and give an example of each.

a. Two key concepts are:
   i) CONCEPT 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.
   ii) CONCEPT 3.2B Soil is renewable resource that provides nutrients that support terrestrial plants and helps purify water and control the earth's surface.
b. Define **ecology**.
   i) **Ecology** is the science that focuses on how organisms interact with one another and with their nonliving environment of matter and energy.
c. Define **organism**, **population**, and **community** and give an example of each.
   i) An **organism** is an individual living being. A deer is an organism.
   ii) **Populations** are groups of individuals of the same species living in a particular place. A herd of deer living in a valley in a population.
   iii) A **community** is all the populations of different organisms living in a particular place. All of the organisms living in a valley is a community.
   iv) **Ecosystems** are communities of organisms interacting with one another and with the physical environment of matter and energy in which they live.

4. Distinguish between the living and nonliving components in ecosystems and give two examples of each.
   a. Abiotic: consists of nonliving components such as water, air, nutrients, rocks, heat, and solar energy.
   b. Biotic: consists of living biological components—plants, animals, and microbes.

5. What is a trophic level? Distinguish among **producers**, **consumers**, **decomposers**, and **detritus feeders (detritivores)**, and give an example of each. Summarize the process of **photosynthesis**. Distinguish among **primary consumers (herbivores)**, **carnivores**, **secondary consumers**, **tertiary consumers,** and **omnivores** and give an example of each.
   a. The trophic level, or feeding level, is the level assigned to every type of organism in an ecosystem, depending on its source of food or nutrients.
   b. Distinguish among **producers (autotrophs), consumers (heterotrophs), decomposers,** and **detritus feeders (detritivores)**, and give an example of each.
      i) **Producers** make the nutrients they need from compounds and energy obtained from their environment through a process called photosynthesis. Trees and algae are producers.
      ii) All organisms that are not producers are **consumers**, or **heterotrophs** and cannot produce their own nutrients. A fox is a consumer.
      iii) **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 are decomposers.
      iv) **Detritus feeders**, or **detritivores**, feed on the wastes or dead bodies of other organisms, called detritus. Examples are earthworms, and some insects.
   c. Process of photosynthesis –
      i) Producers, such as plants, use the process of photosynthesis to capture solar energy that falls on their leaves and use this energy to combine carbon dioxide and water to form energy rich organic molecules. The molecules produced, such as glucose, store the chemical energy plants need. The overall reaction for photosynthesis is: carbon dioxide + water + solar energy → glucose + oxygen

6. Explain the importance of microbes. What is aerobic **respiration (fermentation)**? What two processes sustain ecosystems and the biosphere and how are they linked? Define soil and soil profile. What are soil horizons. What is humus and how does it relate to fertile soil?
   a. Microbes that decompose dead and decaying plant and animal materials are vital to all ecosystems. They 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.
   b. Producers, consumers, and decomposers use the chemical energy stored in glucose and other organic compounds to fuel their life processes. In most cells, this energy is released by aerobic respiration, which uses oxygen to convert organic molecules back into carbon dioxide and water. The overall reaction for aerobic respiration is: glucose + oxygen → carbon dioxide + water + energy.
   c. 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.

d. **Soil** is a complex mixture that consists of rock particles, mineral nutrients, decaying organic matter, water, air, and living organisms that support life.
e. Soil has many horizontal layers or **horizons**. A cross-sectional view of the horizon is called a **soil profile.**
f. **Humus** is a mixture of partially decomposed plant and animal remains. An abundance of humus and a thick topsoil are characteristics of fertile soil that produces high crop yields.

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 a food chains and a food web. What is a **pyramid of energy flow**?
   a. CONCEPT 3.3 As energy flows through ecosystems in food chains and webs, the amount of high-quality chemical energy available to organisms at each succeeding feeding level decreases.
   b. A food chain is a sequence of organisms, each of which serves as a source of food or energy for the next. Organisms in most ecosystems form a complex network of interconnected food chains called a food web.
   c. 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, considerable 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. Graphically, the energy loss at each trophic level is called the **pyramids of energy flow**.
8. Distinguish between GPP and NPP and explain their importance. What are the two most productive land ecosystems and the two most productive aquatic ecosystems?
   a. 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.
   b. 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.
   c. The two most productive:
      i. Land ecosystems—swamps; marshes
      ii. Aquatic ecosystems—Estuaries; lakes and streams

Section 3.4

9. 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. Summarize the unique properties of water. Describe the hydrologic cycle, or water cycle. Describe the **hydrologic cycle**, or **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. Explain how human activities are affecting the water cycle. Describe the **carbon, nitrogen**, and **phosphorus cycles**, and explain how human activities are affecting each cycle.
   a. CONCEPT 3.4 Matter, in the form of nutrients, cycles within and among ecosystems and the biosphere, and human activities are altering these chemical cycles.
   b. A **nutrient cycle**—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, or nutrient cycles.
   c. How nutrient cycles connect past, present, and future—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, rock star Bono, or a hunter–gatherer who lived 25,000 years ago may have inhaled some of the same nitrogen molecules that you just inhaled.
   d. The **hydrological cycle**, or **water cycle**, collects, purifies, and distributes this supply of water, as shown in figure 3.15. Its three major processes are evaporation, precipitation, and transpiration.
   e. Most precipitation falling on terrestrial ecosystems becomes **surface runoff**. This water flows into streams, rivers, lakes, wetlands, and oceans, from which it can evaporate to repeat the cycle. Some precipitation seeps into the upper layers of soils where it is used by plants, and some evaporates from the soils back into the atmosphere. Some precipitation also sinks through soil into underground layers of rock, sand, and gravel called **aquifers**, where it is stored as **groundwater**. Some precipitation is converted to ice that is stored in glaciers, usually for long periods of time. Over land, about 90% of the water that reaches the

atmosphere evaporates from the surfaces of plants, through a process called transpiration, and from the soil.

f. Only about 0.024% of the earth's vast water supply is available to humans and other species as liquid freshwater in accessible groundwater deposits and in lakes, rivers, and streams. The rest is too salty for us to use, is stored as ice, or is too deep underground to extract at affordable prices.
g. Unique properties of water include that water:
    i. Is held together by hydrogen bonds.
    ii. Exists as a liquid over a wide temperate range.
    iii. Stores a large amount of heat.
    iv. Requires a large amount of energy to be evaporated.
    v. Dissolves a variety of compounds.
    vi. Filter's some UV rays from the sun.
    vii. Can move through capillary action.
    viii. Expands when freezes.
    ix. Exists in all three phases at the earth's surface
h. Humans alter the water cycle in three ways:
    i. Withdrawing freshwater at faster rates than nature can replenish it.
    ii. Clearing vegetation which increases runoff and decreases replenishment of groundwater supplies.
    iii. Draining wetlands which interferes with flood control.
i. Carbon is the basic building block of the carbohydrates, fats, proteins, DNA, and other organic compounds necessary for life. It circulates through the biosphere, the atmosphere, and parts of the hydrosphere, in the carbon cycle shown in Figure 3.16. Humans are altering atmospheric carbon dioxide mostly by our use of fossil fuels and our destruction of the carbon-absorbing vegetation.
j. Nitrogen is a crucial component of proteins, many vitamins, and nucleic acids such as DNA. See Figure 3.17. Human activities have more than doubled the annual release of nitrogen from the land into the rest of the environment, mostly from the greatly increased use of inorganic fertilizers to grow crops. This excessive input of nitrogen into the air and water contributes to pollution and other problems.
k. Phosphorus circulates through water, the earth's crust, and living organisms in the phosphorus cycle, depicted in Figure 3.17. Human activity removes large amounts of phosphate from the earth to make fertilizer and reduces phosphate levels in tropical soils by clearing forests. Topsoil that is eroded from fertilized crop fields, lawns, and golf courses carries large quantities of phosphate ions into streams, lakes, and oceans. There they stimulate the growth of producers such as algae and various aquatic plants. Phosphate-rich runoff from the land can produce huge populations of algae, which can upset chemical cycling and other processes.

Section 3.5

10. What is the key concept for this section? Describe three ways scientists study ecosystems. Explain why we need much more basic data about the structure and condition of the world's ecosystems. Distinguish between the Holocene and Anthropocene eras. List four planetary boundaries that scientists have identified. Which three of these boundaries have already been exceeded, according to these scientists? What are this chapter's *three big ideas*? How are the three **scientific principles of sustainability** showcased in tropical rain forests?
    a. CONCEPT 3.5 Scientists use both field research and laboratory research, and mathematical and other types of models, to learn about ecosystems and how much stress they can take.
    b. Three approaches ecologists use to learn about ecosystems: field research, laboratory research, and ecosystem models.
    c. We need more baseline ecological data about living components and physical and chemical conditions in order to evaluate ecosystems are functioning, to see how they are changing, and to develop effective strategies for preventing or slowing their degradation.
    d. Holocene is a period of relatively stable climate and other environmental conditions following a long glacial period. Since the industrial revolution began around 1750, we have entered an era called the Anthropocene. In this new era, humans have become major agents of change in the functioning of the earth's life-support system.
    e. Answers can include the following planetary boundaries:
        i. Disruption of the nitrogen and phosphorus cycles (exceeded)
        ii. Biodiversity loss (exceeded)
        iii. Land system change (exceeded)
        iv. Climate change (exceeded)

   v. Freshwater use
   vi. Ocean acidification
   vii. Ozone depletion in the stratosphere
   viii. Fine-particle air pollution
   ix. Pollution from chemicals
f. Here are this chapter's *three big ideas:*
   i. Life is sustained by the flow of energy from the sun through the biosphere, the cycling of nutrients within the biosphere, and gravity.
   ii. Some organisms produce the nutrients they need, others survive by consuming other organisms, and some recycle nutrients back to producer organisms.
   iii. Human activities are altering the flow of energy through food chains and webs and the cycling of nutrients within ecosystems and the biosphere.
g. 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 sustain these complex ecosystems.

Critical Thinking

1. How would you explain the importance of tropical rainforests (**Core Case Study**) to people who think that such forests have no connections with 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. And finally, weather patterns may be disrupted when the natural holding capacity of the forest is diminished and water simply runs off.

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, starting with photosynthesis, in which plants make sugar molecules that are available for consumption by other organisms.
   (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; 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. Two harmful effects of microbes are that they can cause diseases that can be detrimental to an individual's health, and they can cause food to decay and be rendered unfit for human consumption.

If microbes were eliminated, waste would pile up and not be available as nutrients.

4. Make a list of the food 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. The bread is from producers but the beef from primary consumers.

5. Use the second law of thermodynamics (see Chapter 2, p. 38) 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 could 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 therefore 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 have be affected if human activities as a whole continue to intensify the water cycle?

   Answers may vary but it's important to realize that humans are intervening in the natural working of the water cycle in two important ways: (1) polluting water and (2) using more water than is being recharged.
   The earth cannot obtain any additional water. The outcome of these two human interventions is that fresh, clean water will not be as available in the future. Some of the issues of water scarcity being experienced in developing countries will come to be present in developed countries.

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

   (a) If all decomposers were eliminated, no decay would take place. There would be an abundance of dead plants and animals, leaving little room for living ones. Also, the Earth would be deprived of access to nutrients that are provided by the breakdown of organic material.
   (b) If all producers were eliminated, there would be nothing living. Consumers rely on the nutritive material which is the result of photosynthesis.
   (c) If there were no consumers, the gas exchange that provides carbon dioxide necessary for plants and exhaled by consumers would not exist. This exchange is a complementary function.

8. Describe how exceeding each of the planetary boundaries—*disruption of the nitrogen and phosphorous cycles biodiversity loss, land system change,* and *climate change*—might affect **(a)** you, **(b)** any child you might have, and **(c)** any grandchild you might have.

With all of the planetary boundaries, time will only intensify the long-range and possibly disastrous effects. The danger lies in the fact that we could trigger abrupt and long-lasting or irreversible environmental changes that could seriously degrade the earth's life-support system.

Doing Environmental Science

Students are encouraged to visit a nearby terrestrial ecosystem or aquatic life zone in order to identify major producers, primary and secondary consumers, detritus feeders, and decomposers. Students are then guided to take notes and describe one example of each. Subsequently, students are asked to make a simple sketch showing how the organisms are related in a food chain or food web and think of two ways in which the food chain or food web can be disrupted. Students are tasked with writing a report summarizing their research and conclusions. Answers will vary.

Global Environment Watch Exercise

Go to your MindTap course to access the GREENR database. Using the "Basic Search" box at the top of the page, search for *Nitrogen Cycle* and look for information how humans are affecting the nitrogen cycle. Specifically look for impacts on the atmosphere and human health from emissions of nitrogen oxides, and look for the harmful ecological effects of the runoff of nitrate fertilizers into rivers and lakes. Make a list of these impacts and use this information to review your daily activities. Find three things that you do regularly that contribute to these impacts.

Answers will vary but could include:
(1) Burning fuel—ways to contribute include driving a car, using electric appliances, purchasing goods that required energy to be produced.
(2) Using inorganic fertilizers—ways to contribute include purchasing food that is not grown organically, fertilizing the garden or lawn, and improper maintenance of septic systems.

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 3.14, it is expressed as units of energy (kilocalories, or *kcal*) produced in a given area (square meters, or m^2) over a period of time (a year). Look again at Figure 3.14 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?
   - Approximately 9,000

   Which terrestrial ecosystem produces about one-third of that rate?
   - Savannah

   Which aquatic ecosystem has about the same NPP as a tropical rain forest?
   - Swamps and marshes

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 NPP was lost?
   - 5,600

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

4. About how many times more NPP do estuaries produce, compared to lakes and streams? Why do you think this is so?
   - About four times more
   - Estuaries are more biodiverse than lakes and streams