The Principles of Ecology

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CHAPTER 1 The Principles of Ecology

CHAPTER OUTLINE

These brilliant red "feathers" are actually animals called tube worms. They live in an extreme environment on the deep ocean floor, thousands of meters below the water's surface. Their world is always very cold and completely dark. Without sunlight, photosynthesis is not possible. So what do organisms eat at these depths? Tube worms depend on chemosynthetic microorganisms that live inside them for food. In this and other ways, tube worms have adapted to the extreme conditions of their environment.

All organisms must adapt to their environment in order to survive. This is true whether they live in water or on land. Most environments are not as extreme as the deep ocean where tube worms live. But they all have conditions that require adaptations. In this chapter, you will read about a wide variety of environments and the organisms that live in them.

Courtesy of Nicolle Rager Fuller, National Science Foundation. www.nsf.gov/news/special_reports/sfs/popup/life_vc_tubeworms.htm. Public Domain.

1.1 The Science of Ecology

Lesson Objectives

- Distinguish between abiotic and biotic factors.
- Define ecosystem and other ecological concepts.
- Describe how energy flows through ecosystems.
- Explain how food chains and webs model feeding relationships.
- Identify trophic levels in a food chain or web.

Vocabulary

- abiotic factor
- biomass
- biotic factor
- carnivore
- chemoautotroph
- competitive exclusion principle
- decomposer
- detritivore
- detritus
- ecology
- food chain
- food web
- habitat
- herbivore
- niche
- omnivore
- photoautotroph
- saprotroph
- scavenger
- trophic level

Introduction

Ecology is the study of how living things interact with each other and with their environment. It is a major branch of biology, but has areas of overlap with geography, geology, climatology, and other sciences. This lesson introduces fundamental concepts in ecology, beginning with organisms and the environment.

Organisms and the Environment

Organisms are individual living things. Despite their tremendous diversity, all organisms have the same basic needs: energy and matter. These must be obtained from the environment. Therefore, organisms are not closed systems. They depend on and are influenced by their environment. The environment includes two types of factors: abiotic and biotic.

1. **Abiotic factors** are the nonliving aspects of the environment. They include factors such as sunlight, soil, temperature, and water.
2. **Biotic factors** are the living aspects of the environment. They consist of other organisms, including members of the same and different species.

The Ecosystem

An ecosystem is a unit of nature and the focus of study in ecology. It consists of all the biotic and abiotic factors in an area and their interactions. Ecosystems can vary in size. A lake could be considered an ecosystem. So could a dead log on a forest floor. Both the lake and log contain a variety of species that interact with each other and with abiotic factors. Another example of an ecosystem is pictured in **Figure** 1.1.

FIGURE 1.1
Desert Ecosystem. What are some of the biotic and abiotic factors in this desert ecosystem?

When it comes to energy, ecosystems are not closed. They need constant inputs of energy. Most ecosystems get energy from sunlight. A small minority get energy from chemical compounds. Unlike energy, matter is not constantly added to ecosystems. Instead, it is recycled. Water and elements such as carbon and nitrogen are used over and over again.

Niche

One of the most important concepts associated with the ecosystem is the niche. A **niche** refers to the role of a species in its ecosystem. It includes all the ways that the species interacts with the biotic and abiotic factors of the environment. Two important aspects of a species' niche are the food it eats and how the food is obtained. Look at **Figure** 1.2. It shows pictures of birds that occupy different niches. Each species eats a different type of food and obtains the food in a different way.

Habitat

Another aspect of a species' niche is its habitat. The **habitat** is the physical environment in which a species lives and to which it is adapted. A habitat's features are determined mainly by abiotic factors such as temperature and rainfall. These factors also influence the traits of the organisms that live there.

Competitive Exclusion Principle

A given habitat may contain many different species, but each species must have a different niche. Two different species cannot occupy the same niche in the same place for very long. This is known as the **competitive exclusion principle**. If two species were to occupy the same niche, what do you think would happen? They would compete with one another for the same food and other resources in the environment. Eventually, one species would be likely to outcompete and replace the other.

Flow of Energy

Energy enters ecosystems in the form of sunlight or chemical compounds. Some organisms use this energy to make food. Other organisms get energy by eating the food.

Producers

Producers are organisms that produce food for themselves and other organisms. They use energy and simple inorganic molecules to make organic compounds. The stability of producers is vital to ecosystems because all organisms need organic molecules. Producers are also called autotrophs. There are two basic types of autotrophs: photoautotrophs and chemoautotrophs.

1. **Photoautotrophs** use energy from sunlight to make food by photosynthesis. They include plants, algae, and certain bacteria (see **Figure** 1.3).
2. **Chemoautotrophs** use energy from chemical compounds to make food by chemosynthesis. They include some bacteria and also archaea. Archaea are microorganisms that resemble bacteria.

Consumers

Consumers are organisms that depend on other organisms for food. They take in organic molecules by essentially "eating" other living things. They include all animals and fungi. (Fungi don't really "eat"; they absorb nutrients from other organisms.) They also include many bacteria and even a few plants, such as the pitcher plant in **Figure** 1.4. Consumers are also called heterotrophs. Heterotrophs are classified by what they eat:

- **Herbivores** consume producers such as plants or algae. They are a necessary link between producers and other consumers. Examples include deer, rabbits, and mice.
- **Carnivores** consume animals. Examples include lions, polar bears, hawks, frogs, salmon, and spiders. Carnivores that are unable to digest plants and must eat only animals are called obligate carnivores. Other carnivores can digest plants but do not commonly eat them.

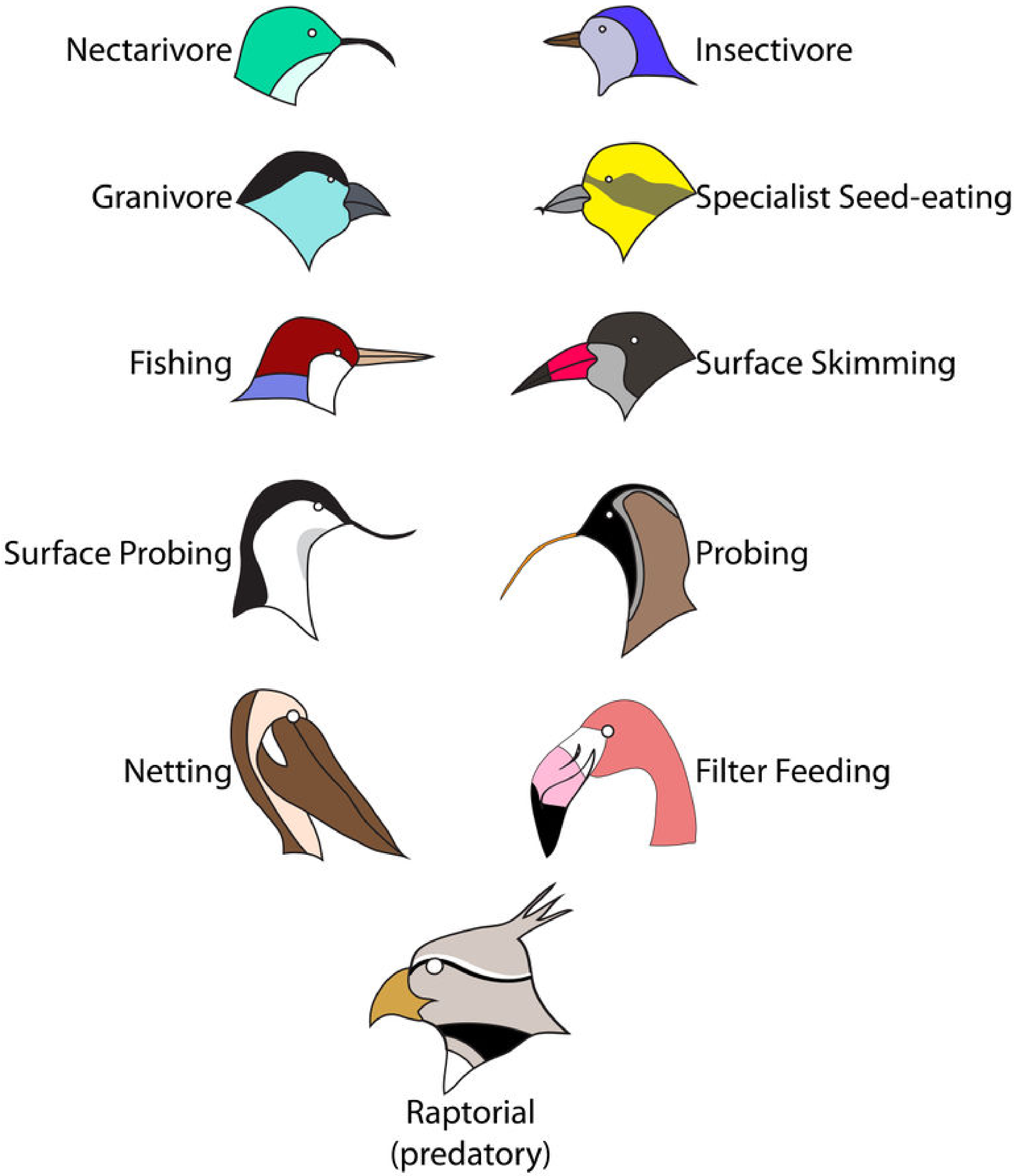

FIGURE 1.2

Bird Niches. Each of these species of birds has a beak that suits it for its niche. For example, the long slender beak of the nectarivore allows it to sip liquid nectar from flowers. The short sturdy beak of the granivore allows it to crush hard, tough grains.

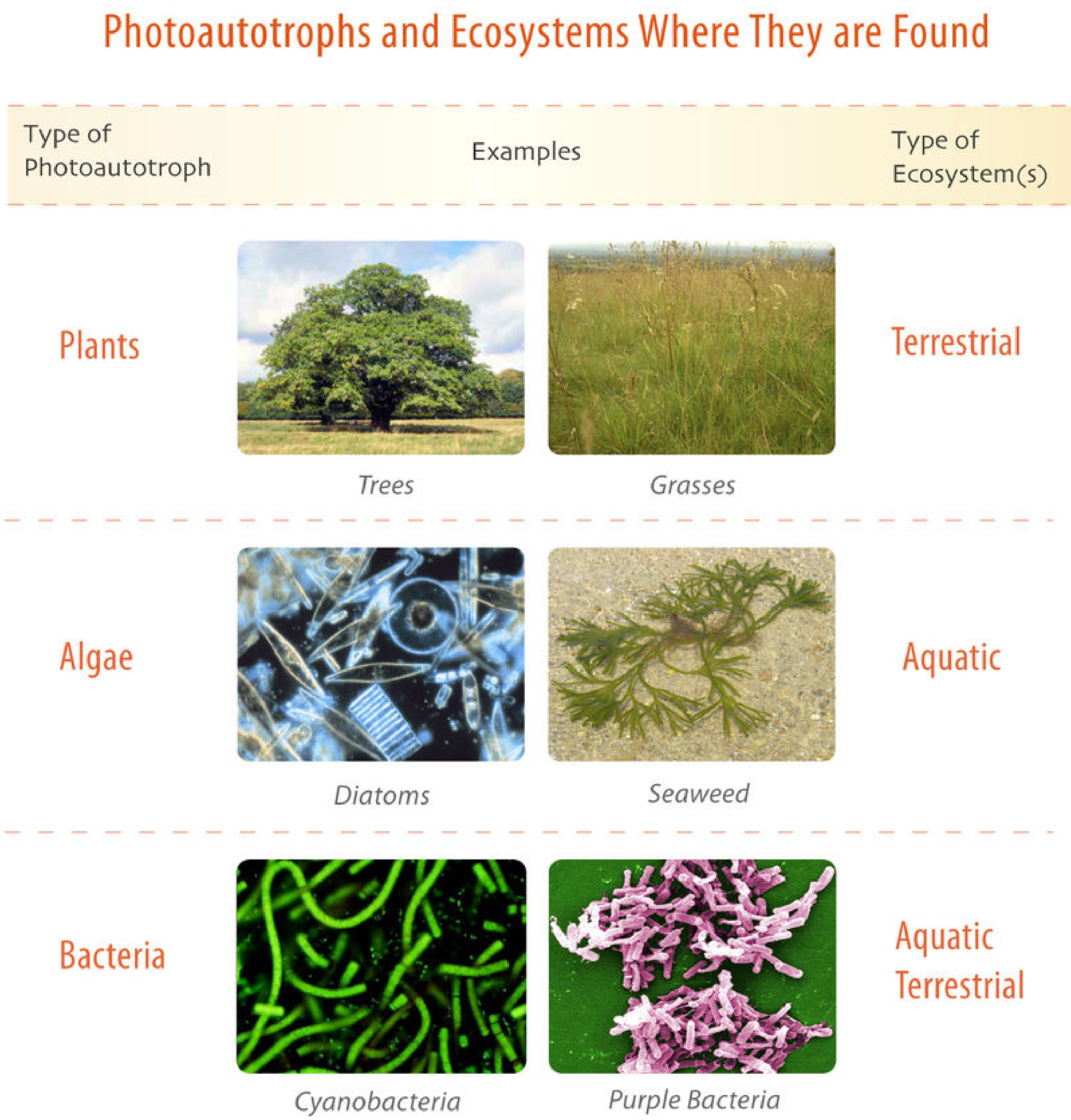

FIGURE 1.3
Different types of photoautotrophs are important in different ecosystems.

- **Omnivores** consume both plants and animals. They include humans, pigs, brown bears, gulls, crows, and some species of fish.

FIGURE 1.4

Pitcher Plants. Virtually all plants are producers. The pitcher plant is an exception. It consumes insects. It traps them in a sticky substance in its "pitcher." Then it secretes enzymes that break down the insects and release nutrients. Which type of consumer is a pitcher plant?

Decomposers

When organisms die, they leave behind energy and matter in their remains. **Decomposers** break down the remains and other wastes and release simple inorganic molecules back to the environment. Producers can then use the molecules to make new organic compounds. The stability of decomposers is essential to every ecosystem. Decomposers are classified by the type of organic matter they break down:

- **Scavengers** consume the soft tissues of dead animals. Examples of scavengers include vultures, raccoons, and blowflies.
- **Detritivores** consume **detritus**—the dead leaves, animal feces, and other organic debris that collects on the soil or at the bottom of a body of water. On land, detritivores include earthworms, millipedes, and dung beetles (see **Figure** 1.5). In water, detritivores include "bottom feeders" such as sea cucumbers and catfish.
- **Saprotrophs** are the final step in decomposition. They feed on any remaining organic matter that is left after other decomposers do their work. Saprotrophs include fungi and single-celled protozoa. Fungi are the only organisms that can decompose wood.

FIGURE 1.5

Dung Beetle. This dung beetle is rolling a ball of feces to its nest to feed its young.

KQED: Banana Slugs: The Ultimate Recyclers

One of the most beloved and iconic native species within the old growth redwood forests of California is the Pacific Banana Slug. These slimy friends of the forest are the ultimate recyclers. Feeding on fallen leaves, mushrooms or even dead animals, they play a pivotal role in replenishing the soil. QUEST goes to Henry Cowell Redwoods State Park near Santa Cruz, California on a hunt to find *Ariolomax dolichophallus*, a bright yellow slug with a very big personality. See http://www.kqed.org/quest/television/science-on-the-spot-banana-slugs-unpeeled for more information.

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Food Chains and Food Webs

Food chains and food webs are diagrams that represent feeding relationships. They show who eats whom. In this way, they model how energy and matter move through ecosystems.

Food Chains

A **food chain** represents a single pathway through which energy and matter flow through an ecosystem. An example is shown in **Figure** 1.6. Food chains are generally simpler than what really happens in nature. Most organisms consume—and are consumed by—more than one species.

A musical summary of food chains can be heard at http://www.youtube.com/watch?v=TE6wqG4nb3M (2:46).

Food Webs

A **food web** represents multiple pathways through which energy and matter flow through an ecosystem. It includes many intersecting food chains. It demonstrates that most organisms eat, and are eaten, by more than one species. Examples are shown in **Figures** 1.7 and 1.8.

Trophic Levels

The feeding positions in a food chain or web are called **trophic levels**. The different trophic levels are defined in **Table** 1.1. Examples are also given in the table. All food chains and webs have at least two or three trophic levels. Generally, there are a maximum of four trophic levels.

TABLE 1.1: Trophic Levels

Trophic Level	Where It Gets Food	Example
1st Trophic Level: Producer	Makes its own food	Plants make food

TABLE 1.1: (continued)

Trophic Level	Where It Gets Food	Example
2nd Trophic Level: Primary Consumer	Consumes producers	Mice eat plant seeds
3rd Trophic Level: Secondary Consumer	Consumes primary consumers	Snakes eat mice
4th Trophic Level: Tertiary Consumer	Consumes secondary consumers	Hawks eat snakes

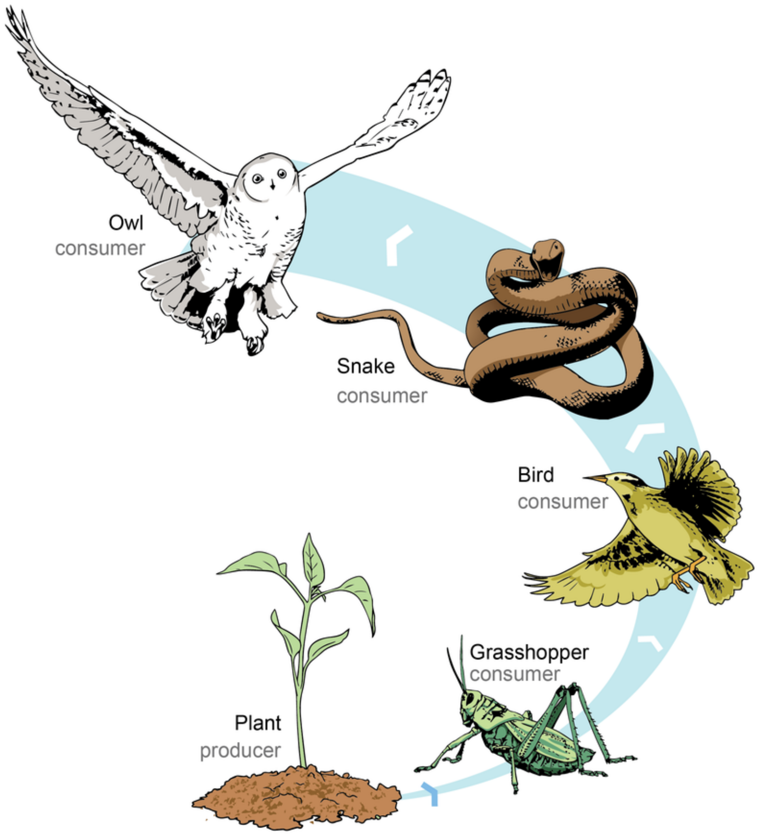

FIGURE 1.6
This food chain includes producers and consumers. How could you add decomposers to the food chain?

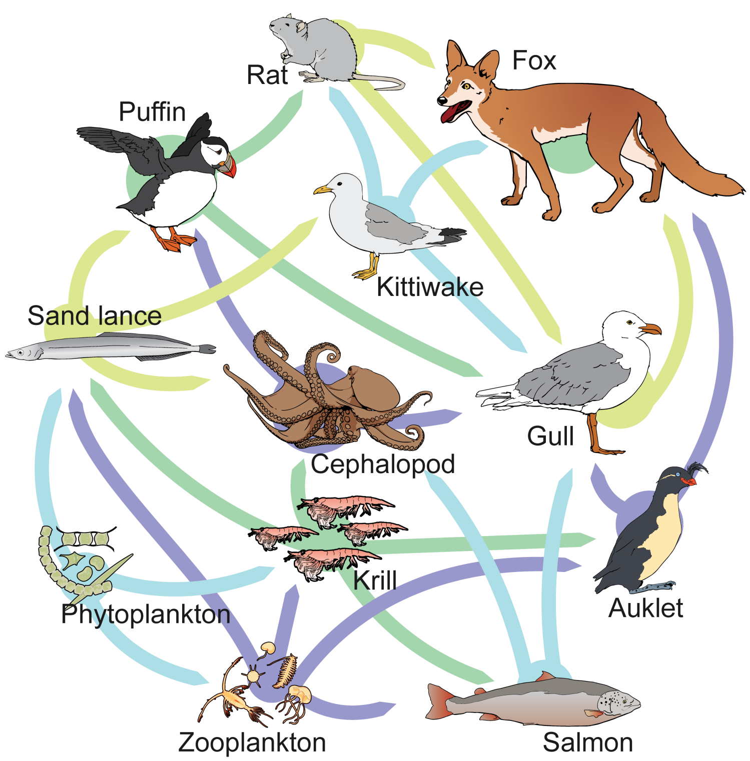

FIGURE 1.7
Food Web. This food web consists of several different food chains. Which organisms are producers in all of the food chains included in the food web?

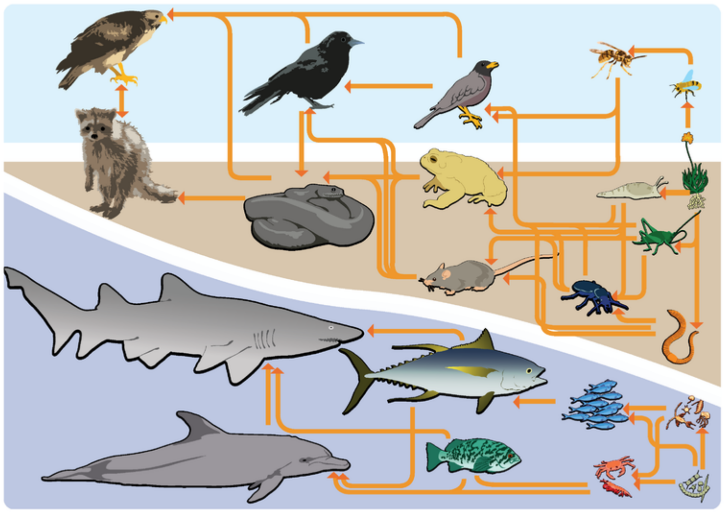

FIGURE 1.8
Examples of food webs.

Many consumers feed at more than one trophic level. Humans, for example, are primary consumers when they eat plants such as vegetables. They are secondary consumers when they eat cows. They are tertiary consumers when they eat salmon.

Trophic Levels and Energy

Energy is passed up a food chain or web from lower to higher trophic levels. However, only about 10 percent of the energy at one level is available to the next level. This is represented by the pyramid in **Figure** 1.9. What happens to the other 90 percent of energy? It is used for metabolic processes or given off to the environment as heat. This loss of energy explains why there are rarely more than four trophic levels in a food chain or web. Sometimes there may be a fifth trophic level, but usually there's not enough energy left to support any additional levels.

Energy pyramids are discussed at http://www.youtube.com/watch?v=8T2nEMzk6_E (1:44).

Trophic Levels and Biomass

With less energy at higher trophic levels, there are usually fewer organisms as well. Organisms tend to be larger in size at higher trophic levels, but their smaller numbers result in less biomass. **Biomass** is the total mass of organisms at a trophic level. The decrease in biomass from lower to higher levels is also represented by **Figure** 1.9.

Lesson Summary

- Ecology is the study of how living things interact with each other and with their environment. The environment includes abiotic (nonliving) and biotic (living) factors.
- An ecosystem consists of all the biotic and abiotic factors in an area and their interactions. A niche refers to the role of a species in its ecosystem. A habitat is the physical environment in which a species lives and to which it is adapted. Two different species cannot occupy the same niche in the same place for very long.
- Ecosystems require constant inputs of energy from sunlight or chemicals. Producers use energy and inorganic molecules to make food. Consumers take in food by eating producers or other living things. Decomposers

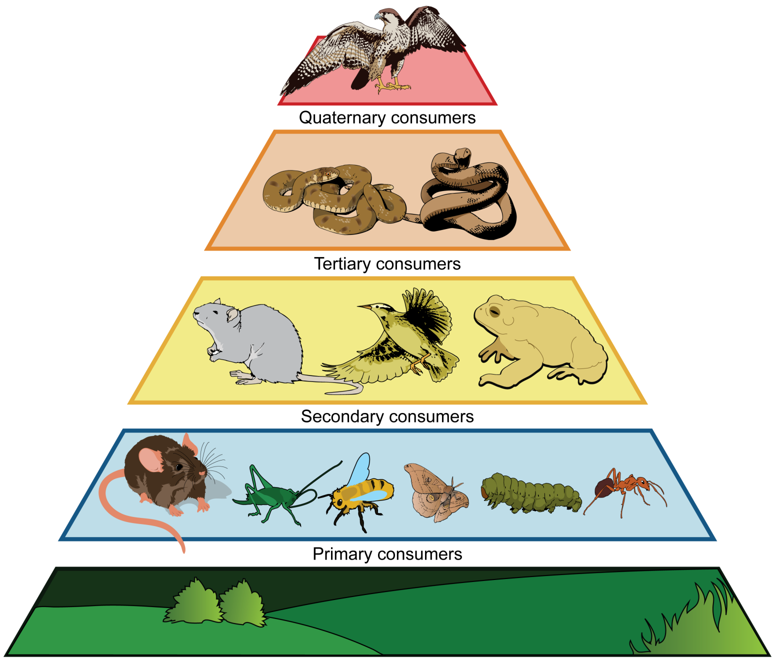

FIGURE 1.9

Ecological Pyramid. This pyramid shows how energy and biomass decrease from lower to higher trophic levels. Assume that producers in this pyramid have 1,000,000 kilocalories of energy. How much energy is available to primary consumers?

break down dead organisms and other organic wastes and release inorganic molecules back to the environment.

- Food chains and food webs are diagrams that represent feeding relationships. They model how energy and matter move through ecosystems.
- The different feeding positions in a food chain or web are called trophic levels. Generally, there are no more than four trophic levels because energy and biomass decrease from lower to higher levels.

Lesson Review Questions

Recall

1. Define biotic and abiotic factors of the environment. Give an example of each.

2. How do ecologists define the term *ecosystem*?

3. State the competitive exclusion principle.

4. Identify three different types of consumers. Name an example of each type.

5. Describe the role of decomposers in food webs.

Apply Concepts

6. Draw a terrestrial food chain that includes four trophic levels. Identify the trophic level of each organism in the food chain.

Think Critically

7. Compare and contrast the ecosystem concepts of niche and habitat.
8. What can you infer about an ecosystem that depends on chemoautotrophs for food?
9. Explain how energy limits the number of trophic levels in a food chain or web.

Points to Consider

In this lesson, you learned how matter is transferred through food chains and webs. Producers make food from inorganic molecules. Other organisms consume the producers. When organisms die, decomposers break down their remains and release inorganic molecules that can be used again by producers. In this way, matter is recycled by the biotic factors in ecosystems.

- Do you think that abiotic factors in ecosystems might also play a role in recycling matter? In what way?
- What abiotic factors might be involved in recycling matter? For example, what abiotic factors might be involved in recycling water?

1.2 Recycling Matter

Lesson Objectives

- Define biogeochemical cycles.
- Describe the water cycle and its processes.
- Give an overview of the carbon cycle.
- Outline the steps of the nitrogen cycle.

Vocabulary

- aquifer
- biogeochemical cycle
- carbon cycle
- condensation
- evaporation
- exchange pool
- groundwater
- nitrogen cycle
- nitrogen fixation
- precipitation
- reservoir
- runoff
- sublimation
- transpiration
- water cycle

Introduction

Where does the water come from that is needed by your cells? Or the carbon and nitrogen that is needed to make your organic molecules? Unlike energy, matter is not lost as it passes through an ecosystem. Instead, matter is recycled. This recycling involves specific interactions between the biotic and abiotic factors in an ecosystem.

Biogeochemical Cycles

The chemical elements and water that are needed by organisms continuously recycle in ecosystems. They pass through biotic and abiotic components of the biosphere. That's why their cycles are called **biogeochemical cycles**. For example, a chemical might move from organisms (*bio*) to the atmosphere or ocean (*geo*) and back to organisms again. Elements or water may be held for various periods of time in different parts of a cycle.

- Part of a cycle that holds an element or water for a short period of time is called an **exchange pool**. For example, the atmosphere is an exchange pool for water. It usually holds water (in the form of water vapor) for just a few days.
- Part of a cycle that holds an element or water for a long period of time is called a **reservoir**. The ocean is a reservoir for water. The deep ocean may hold water for thousands of years.

The rest of this lesson describes three biogeochemical cycles: the water cycle, carbon cycle, and nitrogen cycle.

The Water Cycle

Water on Earth is billions of years old. However, individual water molecules keep moving through the water cycle. The **water cycle** is a global cycle. It takes place on, above, and below Earth's surface, as shown in **Figure** 1.10.

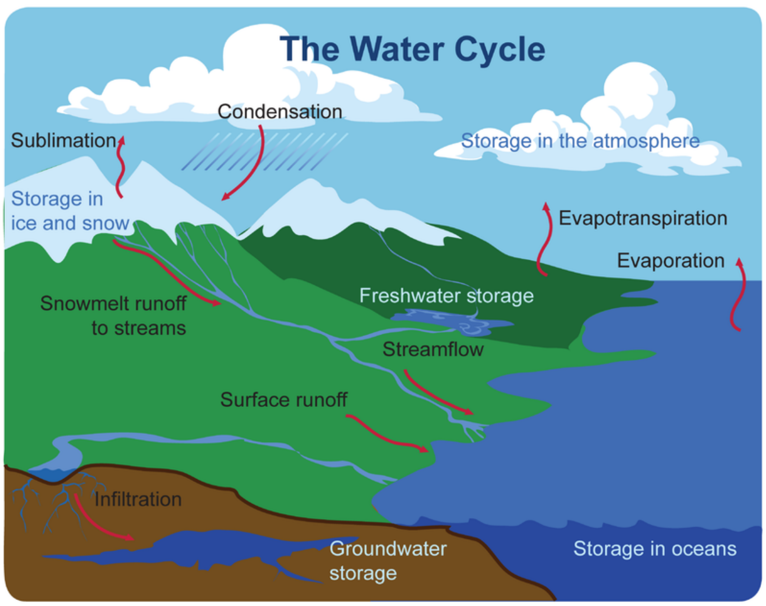

FIGURE 1.10
Like other biogeochemical cycles, there is no beginning or end to the water cycle. It just keeps repeating.

During the water cycle, water occurs in three different states: gas (water vapor), liquid (water), and solid (ice). Many processes are involved as water changes state in the water cycle.

Evaporation, Sublimation, and Transpiration

Water changes to a gas by three different processes:

1. **Evaporation** occurs when water on the surface changes to water vapor. The sun heats the water and gives water molecules enough energy to escape into the atmosphere.
2. **Sublimation** occurs when ice and snow change directly to water vapor. This also happens because of heat from the sun.
3. **Transpiration** occurs when plants release water vapor through leaf pores called stomata (see **Figure** 1.11). The water is a product of photosynthesis.

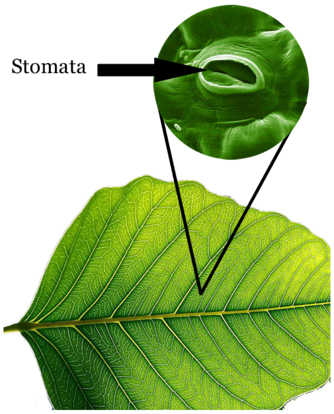

FIGURE 1.11
Plant leaves have many tiny stomata. They release water vapor into the air.

Condensation and Precipitation

Rising air currents carry water vapor into the atmosphere. As the water vapor rises in the atmosphere, it cools and condenses. **Condensation** is the process in which water vapor changes to tiny droplets of liquid water. The water droplets may form clouds. If the droplets get big enough, they fall as **precipitation**—rain, snow, sleet, hail, or freezing rain. Most precipitation falls into the ocean. Eventually, this water evaporates again and repeats the water cycle. Some frozen precipitation becomes part of ice caps and glaciers. These masses of ice can store frozen water for hundreds of years or longer.

Groundwater and Runoff

Precipitation that falls on land may flow over the surface of the ground. This water is called **runoff**. It may eventually flow into a body of water. Some precipitation that falls on land may soak into the ground, becoming **groundwater**. Groundwater may seep out of the ground at a spring or into a body of water such as the ocean. Some groundwater may be taken up by plant roots. Some may flow deeper underground to an **aquifer**. This is an underground layer of rock that stores water, sometimes for thousands of years.

The water cycle is demonstrated at http://www.youtube.com/watch?v=iohKd5FWZOE (4:00).

The *Water Cycle Jump* can be viewed at http://www.youtube.com/watch?v=BayExatv8lE (1:31).

KQED: Tracking Raindrops

We all rely on the water cycle, but how does it actually work? Scientists at University of California Berkeley are embarking on a new project to understand how global warming is affecting our fresh water supply. And they're doing it by tracking individual raindrops in Mendocino and north of Lake Tahoe. See http://www.kqed.org/quest/television/tracking-raindrops for more information.

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The Carbon Cycle

Flowing water can slowly dissolve carbon in sedimentary rock. Most of this carbon ends up in the ocean. The deep ocean can store carbon for thousands of years or more. Sedimentary rock and the ocean are major reservoirs of stored carbon. Carbon is also stored for varying lengths of time in the atmosphere, in living organisms, and as fossil fuel deposits. These are all parts of the **carbon cycle**, which is shown in **Figure** 1.12.

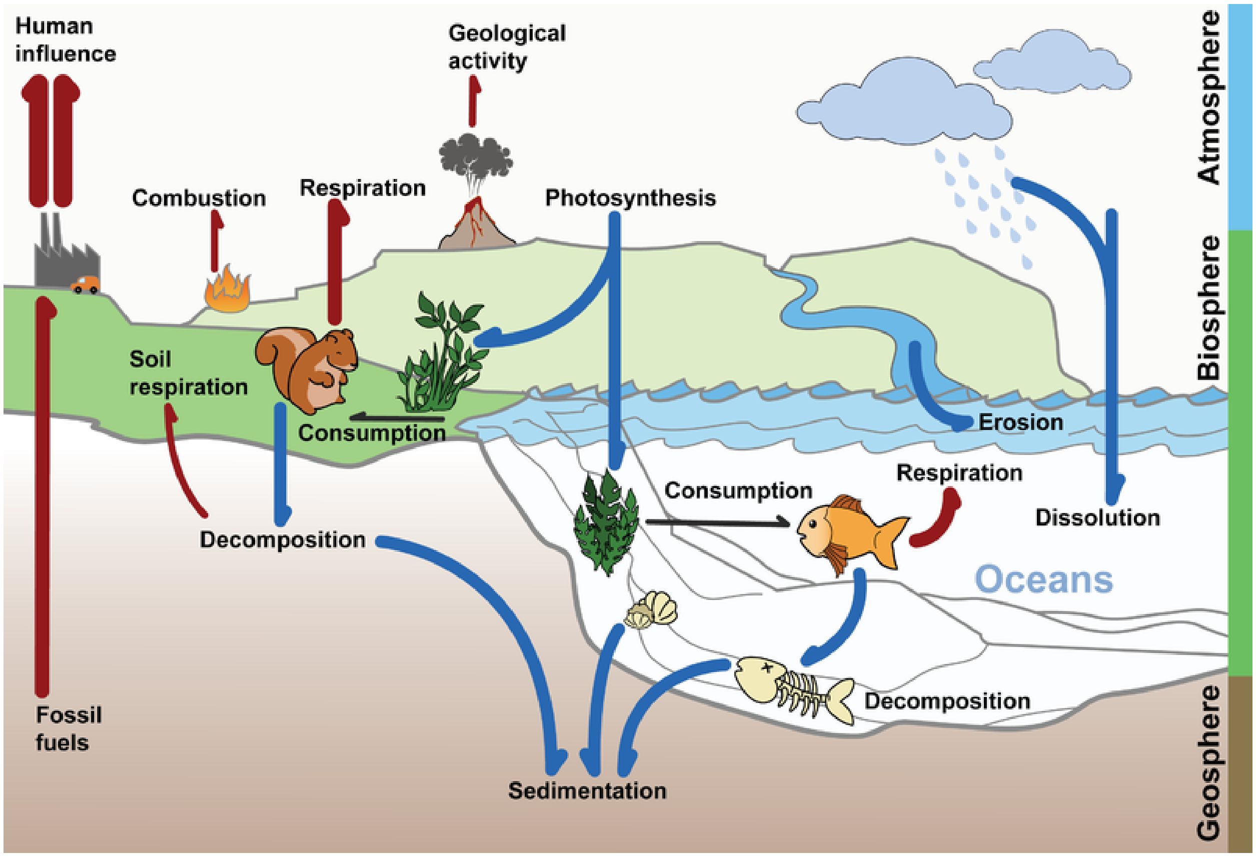

FIGURE 1.12

The Carbon Cycle. Carbon moves from one reservoir to another in the carbon cycle. What role do organisms play in this cycle?

The carbon cycle is discussed in the following video: http://www.youtube.com/watch?v=0Vwa6qtEih8 (1:56).

Carbon cycles quickly between organisms and the atmosphere. Cellular respiration releases carbon into the atmosphere as carbon dioxide. Carbon is also released when organisms decompose. Human actions, such as the burning of fossil fuels, also release carbon into the atmosphere. Natural processes, such as volcanic eruptions, release carbon from magma into the atmosphere. Warm ocean waters also release carbon, whereas cold ocean water dissolves carbon from the atmosphere. Photosynthesis (autotrophs) removes carbon dioxide from the atmosphere and uses it to make organic compounds. Carbon cycles far more slowly through geological processes such as sedimentation. Runoff, rivers and streams dissolve carbon in rocks and carry it to the ocean. Sediments from dead organisms may form fossil fuels or carbon-containing rocks. Carbon may be stored in sedimentary rock for millions of years.

The Nitrogen Cycle

Nitrogen makes up 78 percent of Earth's atmosphere. It's also an important part of living things. Nitrogen is found in proteins, nucleic acids, and chlorophyll. The **nitrogen cycle** moves nitrogen through the abiotic and biotic parts of ecosystems. **Figure** 1.13 shows how nitrogen cycles through a terrestrial ecosystem. Nitrogen passes through a similar cycle in aquatic ecosystems.

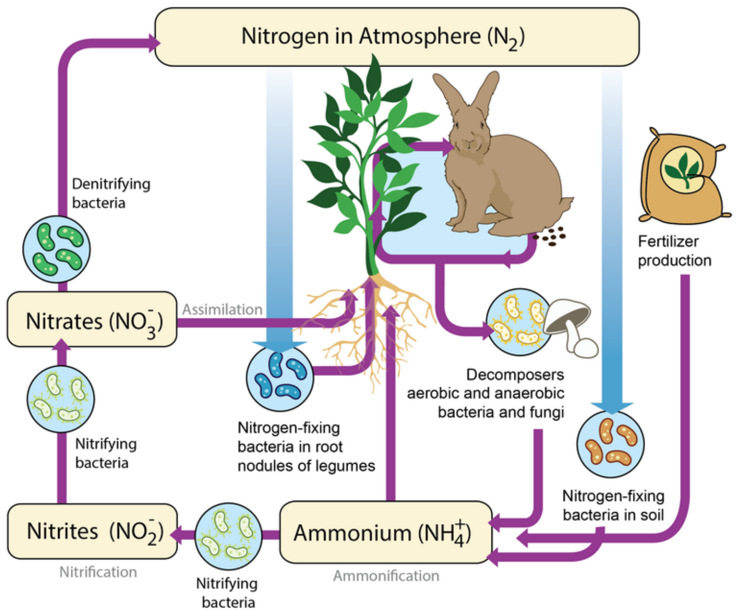

FIGURE 1.13
Nitrogen Cycle in a Terrestrial Ecosystem. Nitrogen cycles between the atmosphere and living things.

Plants cannot use nitrogen gas from the air to make organic compounds for themselves and other organisms. The nitrogen gas must be changed to a form called nitrates, which plants can absorb through their roots. The process of changing nitrogen gas to nitrates is called **nitrogen fixation**. It is carried out by nitrogen-fixing bacteria. The bacteria live in soil and roots of legumes, such as peas.

When plants and other organisms die, decomposers break down their remains. In the process, they release nitrogen in the form of ammonium ions. Nitrifying bacteria change the ammonium ions into nitrates. Some of the nitrates are used by plants. Some are changed back to nitrogen gas by denitrifying bacteria.

The nitrogen cycle is discussed at http://www.youtube.com/watch?v=pdY4I-EaqJA (5:08).

Lesson Summary

- Chemical elements and water are recycled through biogeochemical cycles. The cycles include both biotic and abiotic parts of ecosystems.
- The water cycle takes place on, above, and below Earth's surface. In the cycle, water occurs as water vapor, liquid water, and ice. Many processes are involved as water changes state in the cycle. The atmosphere is an exchange pool for water. Ice masses, aquifers, and the deep ocean are water reservoirs.
- In the carbon cycle, carbon passes among sedimentary rocks, fossil fuel deposits, the ocean, the atmosphere, and living things. Carbon cycles quickly between organisms and the atmosphere. It cycles far more slowly through geological processes.

- The nitrogen cycle moves nitrogen back and forth between the atmosphere and organisms. Bacteria change nitrogen gas from the atmosphere to nitrogen compounds that plants can absorb. Other bacteria change nitrogen compounds back to nitrogen gas, which re-enters the atmosphere.

Lesson Review Questions

Recall

1. What is a biogeochemical cycle? Name an example.
2. Identify and define two processes by which water naturally changes from a solid or liquid to a gas.
3. Define exchange pool and reservoir, and identify an example of each in the water cycle.
4. State three ways that carbon dioxide enters Earth's atmosphere.
5. List all the ways that a single tree may be involved in the carbon cycle.

Apply Concepts

6. Assume you are a molecule of water. Describe one way you could go through the water cycle, starting as water vapor in the atmosphere.

7. Read the following passage, then apply information from the lesson to explain why the farmer plants peas:

A farmer has three fields in which she grows corn for market. Every year, she plants one of the fields with peas, even though she cannot make as much money selling peas as she can selling corn. She rotates the fields she plants with peas so that each field is planted with peas every 3 years.

Think Critically

8. Compare and contrast biological and geological pathways of the carbon cycle.
9. Explain why bacteria are essential parts of the nitrogen cycle.

Points to Consider

In this lesson, you read how matter is recycled through ecosystems. Ecosystems vary in the amount of matter they can recycle. For example, rainforests can recycle more matter than deserts.

- Consider the abiotic and biotic factors of a rainforest and desert. How might they be different?
- Why do you think a rainforest can recycle more matter than a desert?

1.3 Biomes

Lesson Objectives

- Identify and describe terrestrial biomes.
- Give an overview of aquatic biomes.

Vocabulary

- aphotic zone
- aquatic biome
- climate
- dormancy
- estuary
- freshwater biome
- growing season
- intertidal zone
- marine biome
- photic zone
- phytoplankton
- terrestrial biome
- wetland
- zooplankton

Introduction

If you look at the two pictures in **Figure** 1.14, you will see very few similarities. The picture on the left shows a desert in Africa. The picture on the right shows a rainforest in Australia. The desert doesn't have any visible plants, whereas the rainforest is densely packed with trees. What explains these differences?

FIGURE 1.14

Sahara Desert in northern Africa (left). Rainforest in northeastern Australia (right). Two very different biomes are pictured here. Both are found at roughly the same distance from the equator.

The two pictures in **Figure** 1.14 represent two different biomes. A biome is a group of similar ecosystems with the same general abiotic factors and primary producers. Biomes may be terrestrial or aquatic.

Terrestrial Biomes

Terrestrial biomes include all the land areas on Earth where organisms live. The distinguishing features of terrestrial biomes are determined mainly by climate. Terrestrial biomes include tundras, temperate forests and grasslands, chaparral, temperate and tropical deserts, and tropical forests and grasslands.

Terrestrial Biomes and Climate

Climate is the average weather in an area over a long period of time. Weather refers to the conditions of the atmosphere from day to day. Climate is generally described in terms of temperature and moisture.

Temperature falls from the equator to the poles. Therefore, major temperature zones are based on latitude. They include tropical, temperate, and arctic zones (see **Figure** 1.15). However, other factors besides latitude may also influence temperature. For example, land near the ocean may have cooler summers and warmer winters than land farther inland. This is because water gains and loses heat more slowly than does land, and the water temperature influences the temperature on the coast. Temperature also falls from lower to higher altitudes. That's why tropical zone mountain tops may be capped with snow.

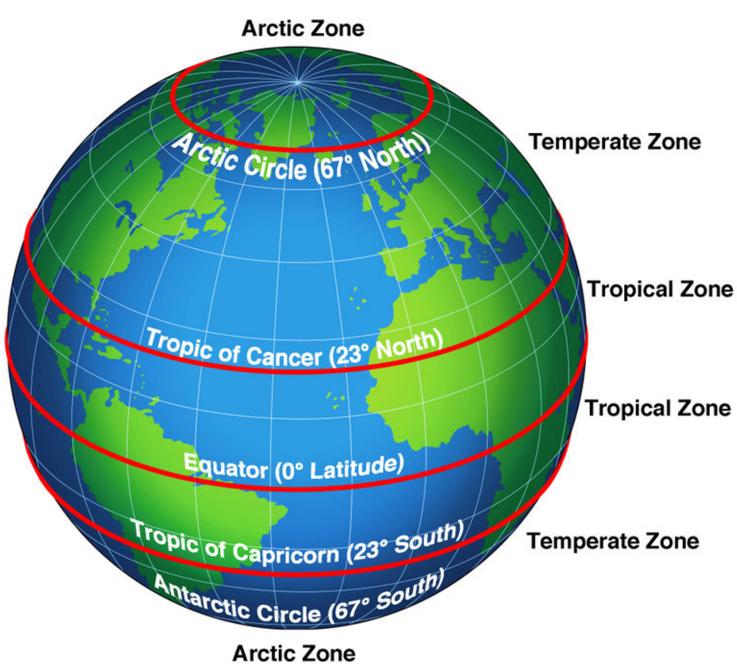

FIGURE 1.15
Temperature Zones. Temperature zones are based on latitude. What temperature zone do you live in?

In terms of moisture, climates can be classified as arid (dry), semi-arid, humid (wet), or semi-humid. The amount of moisture depends on both precipitation and evaporation.

Climate and Plant Growth

Plants are the major producers in terrestrial biomes. They have five basic needs: air, warmth, sunlight, water, and nutrients. How well these needs are met in a given location depends on the growing season and soil quality, both of which are determined mainly by climate.

- The **growing season** is the period of time each year when it is warm and wet enough for plants to grow. The growing season may last all year in a hot, wet climate but just a few months in a cooler or drier climate.
- Plants grow best in soil that contains plenty of nutrients and organic matter. Both are added to soil when plant litter and dead organisms decompose. Decomposition occurs too slowly in cold climates and too quickly in hot, wet climates for nutrients and organic matter to accumulate. Temperate climates usually have the best soil for plant growth.

Climate and Biodiversity

Because climate determines plant growth, it also influences the number and variety of other organisms in a terrestrial biome. Biodiversity generally increases from the poles to the equator. It is also usually greater in more humid climates. This is apparent from the desert and rainforest biomes pictured in **Figure** 1.14.

Climate and Adaptations

Organisms evolve adaptations that help them survive in the climate of the biome where they live. For example, in biomes with arid climates, plants may have special tissues for storing water (see **Figure** 1.16). The desert animals pictured in **Figure** 1.17 also have adaptations for a dry climate.

FIGURE 1.16
Aloe Plant and Barrel Cactus. The aloe plant on the left stores water in its large, hollow leaves. The cactus plant on the right stores water in its stout, barrel-shaped stems.

In biomes with cold climates, plants may adapt by becoming dormant during the coldest part of the year. **Dormancy** is a state in which a plant slows down cellular activities and may shed its leaves. Animals also adapt to cold temperatures. One way is with insulation in the form of fur and fat. This is how the polar bears in **Figure** 1.18 stay warm.

FIGURE 1.17
Gila Monster and Kangaroo Rat. The Gila monster's fat tail is an adaptation to its dry climate. It serves as a storage depot for water. The kangaroo rat has very efficient kidneys. They produce concentrated urine, thus reducing the amount of water lost from the body.

FIGURE 1.18
Polar Bears. Thick fur and a layer of blubber keep polar bears warm in their Arctic ecosystem. Why do you think their fur is white? Why might it be an adaptation in an Arctic biome?

Survey of Terrestrial Biomes

Terrestrial biomes are classified by climatic factors and types of primary producers. The world map in **Figure** 1.19 shows where 13 major terrestrial biomes are found.

The following figures summarize the basic features of major terrestrial biomes. Think about how its biodiversity and types of plants and animals relate to its climate. For example, why do you think there are no amphibians or reptiles in tundra biomes? (Hint: Amphibians and reptiles cannot maintain a constant body temperature. Instead, they have about the same temperature as their surroundings.)

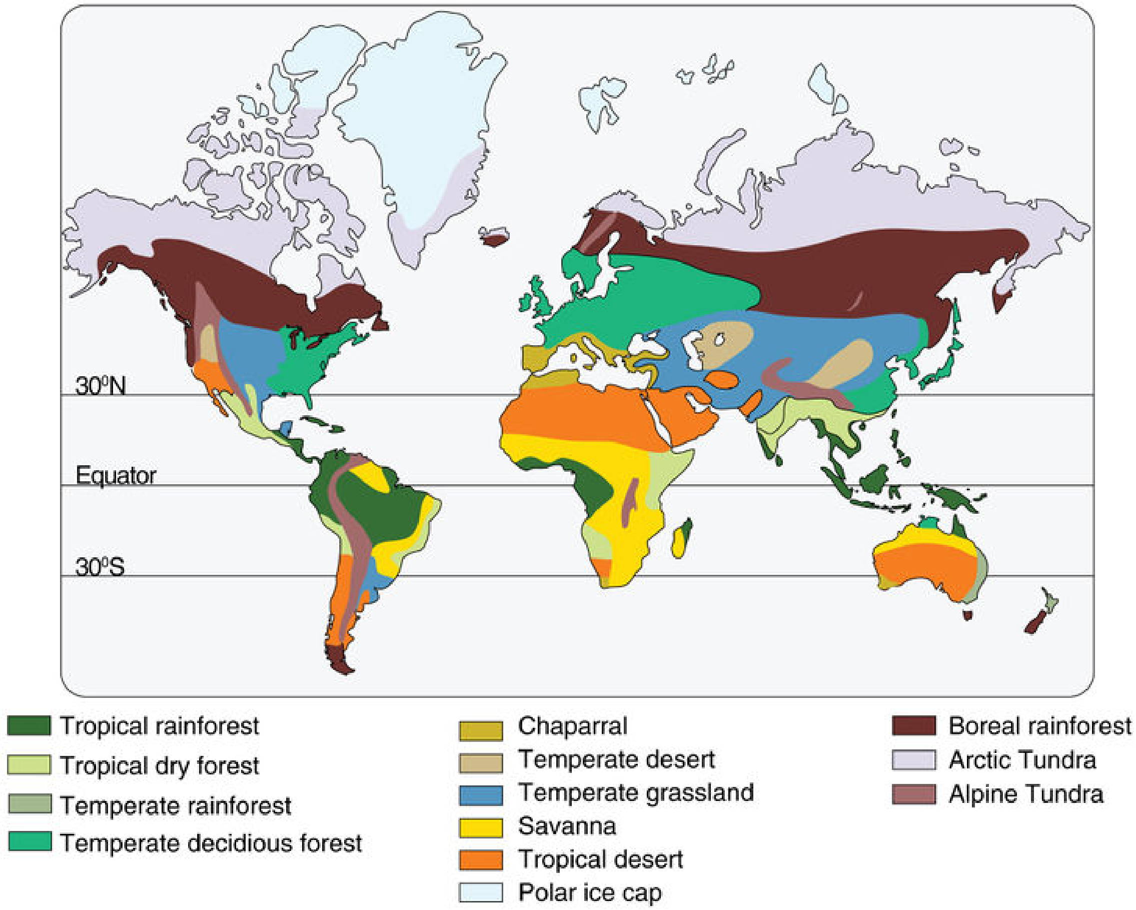

FIGURE 1.19

Worldwide Distribution of Terrestrial Biomes. This map shows the locations of Earth's major terrestrial biomes.

Boreal forest in central (inland) Alaska, United States

Boreal Forest

Other names: Taiga, northern conifer forest
Climate: Subarctic, semi-arid
Growing season: Short
Soil quality: Poor

Biodiversity: Low

Plants: Conifers such as cedar, spruce, pine, and fir; mosses and lichens

Animals: Insects; birds (mainly in summer); no amphibians or reptiles; mammals such as rodents, rabbits, minks, raccoons, bears, and moose; caribou (winter only)

Temperate deciduous forest in Pennsylvania, eastern United States

Temperate Deciduous Forest

Other names: Temperate hardwood forest, temperate broadleaf forest
Climate: Temperate, semi-humid
Growing season: Medium
Soil quality: Good

Biodiversity: High

Plants: Broadleaf deciduous trees such as beech, maple, oak, and hickory; ferns, mosses, and shrubs; many herbaceous plants

Animals: Insects, amphibians, reptiles, and birds; mammals such as mice, chipmunks, squirrels, raccoons, foxes, deer, black bears, bobcats, and wolves

Temperate grassland in Nebraska, midwestern United States

Temperate Grassland

Other names: Prairie, outback, pampa, steppe
Climate: Temperate, semi-arid
Growing season: Medium
Soil quality: Excellent

Biodiversity: Medium-high

Plants: Grasses; other herbaceous plants; no trees

Animals: Invertebrates such as worms and insects; amphibians, reptiles, and birds; mammals such as mice, prairie dogs, rabbits, foxes, wolves, coyotes, bison, and antelope; kangaroo (only in Australia)

Chaparral in southern California, United States

Chaparral

Other names: Mediterranean scrub forest
Climate: Temperate, semi-arid
Growing season: Medium
Soil quality: Poor

Biodiversity: Low-medium

Plants: Shrubs and small trees such as scrub oak and scrub pine

Animals: Insects, reptiles, and birds; mammals such as rodents and deer

Desert in southern California, United States

Desert

Climate: Temperate or tropical, arid
Growing season: Varies
Soil quality: Very poor

Biodiversity: None-low

Plants: Plants adapted to dryness, such as cacti, sagebrush, and mesquite; virtually no plants if extremely arid

Animals: Insects, reptiles, and birds; mammals such as rodents and coyotes

Tropical rainforest in Ecuador, South America

Tropical Rainforest

Climate: Tropical, humid
Growing season: Year-round
Soil quality: Excellent

Biodiversity: Very high

Plants: Tall flowering, broadleaf evergreen trees; vines and epiphytes; few plants on forest floor

Animals: Insects, amphibians, reptiles, and birds; mammals such as monkeys, sloths, leopards, jaguars, pigs, and tigers

Elephant grazing in its grassland ecosystem.

Tropical Grassland

Other names: Savanna
Climate: Tropical, semi-arid
Growing season: Year-round
Soil quality: Poor

Biodiversity: Low-medium

Plants: Grasses, scattered clumps of trees

Animals: Insects, reptiles, and birds; mammals such as zebras, giraffes, antelopes, lions, cheetahs, and hyenas

Aquatic Biomes

Terrestrial organisms are generally limited by temperature and moisture. Therefore, terrestrial biomes are defined in terms of these abiotic factors. Most aquatic organisms do not have to deal with extremes of temperature or moisture. Instead, their main limiting factors are the availability of sunlight and the concentration of dissolved oxygen and nutrients in the water. These factors vary from place to place in a body of water and are used to define **aquatic biomes**.

Aquatic Biomes and Sunlight

In large bodies of standing water, including the ocean and lakes, the water can be divided into zones based on the amount of sunlight it receives:

1. The **photic zone** extends to a maximum depth of 200 meters (656 feet) below the surface of the water. This is where enough sunlight penetrates for photosynthesis to occur. Algae and other photosynthetic organisms can make food and support food webs.
2. The **aphotic zone** is water deeper than 200 meters. This is where too little sunlight penetrates for photosynthesis to occur. As a result, food must be made by chemosynthesis or else drift down from the water above.

These and other aquatic zones in the ocean are identified in **Figure** 1.20.

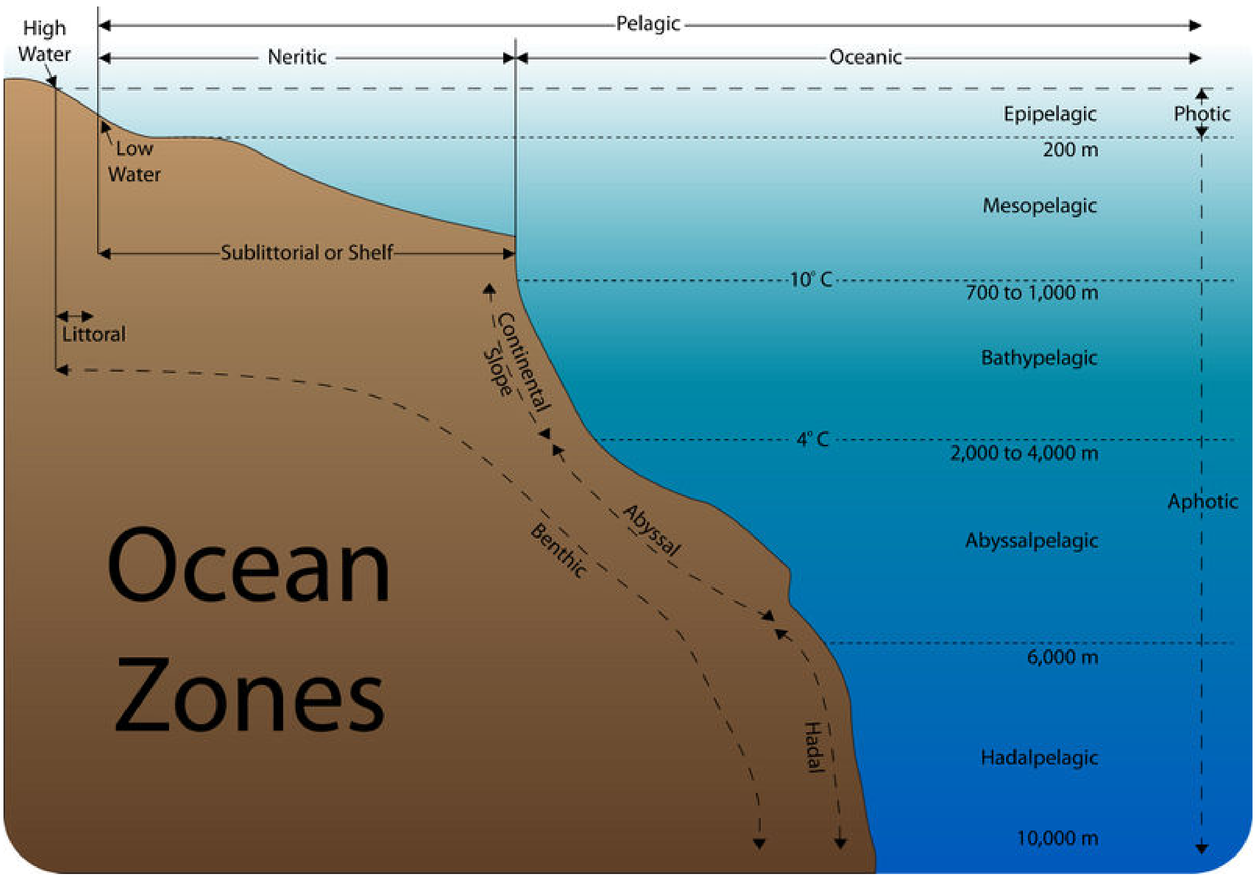

FIGURE 1.20
The ocean is divided into many different zones, depending on distance from shore and depth of water.

Aquatic Biomes and Dissolved Substances

Water in lakes and the ocean also varies in the amount of dissolved oxygen and nutrients it contains:

1. Water near the surface of lakes and the ocean usually has more dissolved oxygen than does deeper water. This is because surface water absorbs oxygen from the air above it.
2. Water near shore generally has more dissolved nutrients than water farther from shore. This is because most nutrients enter the water from land. They are carried by runoff, streams, and rivers that empty into a body of water.

3. Water near the bottom of lakes and the ocean may contain more nutrients than water closer to the surface. When aquatic organisms die, they sink to the bottom. Decomposers near the bottom of the water break down the dead organisms and release their nutrients back into the water.

Aquatic Organisms

Aquatic organisms generally fall into three broad groups: plankton, nekton, and benthos. They vary in how they move and where they live.

1. Plankton are tiny aquatic organisms that cannot move on their own. They live in the photic zone. They include phytoplankton and zooplankton. **Phytoplankton** are bacteria and algae that use sunlight to make food. **Zooplankton** are tiny animals that feed on phytoplankton.
2. Nekton are aquatic animals that can move on their own by "swimming" through the water. They may live in the photic or aphotic zone. They feed on plankton or other nekton. Examples of nekton include fish and shrimp.
3. Benthos are aquatic organisms that crawl in sediments at the bottom of a body of water. Many are decomposers. Benthos include sponges, clams, and anglerfish like the one in **Figure** 1.21. How has this fish adapted to a life in the dark?

FIGURE 1.21

Anglerfish. This anglerfish lives between 1000 and 4000 meters below sea level. No sunlight penetrates to this depth. The rod-like structure on its face has a glow-in-the-dark tip. It is covered with microorganisms that give off their own light. The fish wiggles the structure like a worm to attract prey. In the darkness, only the rod-like worm is visible.

Marine Biomes

Anglerfish live in the ocean. Aquatic biomes in the ocean are called **marine biomes**. Organisms that live in marine biomes must be adapted to the salt in the water. For example, many have organs for excreting excess salt. Two ocean zones are particularly challenging to marine organisms: the intertidal zone and the deep ocean.

The **intertidal zone** is the narrow strip along the coastline that is covered by water at high tide and exposed to air at low tide (see **Figure** 1.22). There are plenty of nutrients and sunlight in the intertidal zone. However, the water is constantly moving in and out, and the temperature keeps changing. These conditions require adaptations in the organisms that live there, such as the barnacles in **Figure** 1.23.

Organisms that live deep in the ocean must be able to withstand extreme water pressure, very cold water, and complete darkness. However, even here, thriving communities of living things can be found. Organisms cluster around hydrothermal vents in the ocean floor. The vents release hot water containing chemicals that would be toxic to most other living things. The producers among them are single-celled chemoautotrophs. They make food using energy stored in the chemicals. The tube worms in this chapter's opening photo depend on these chemoautotrophs for food.

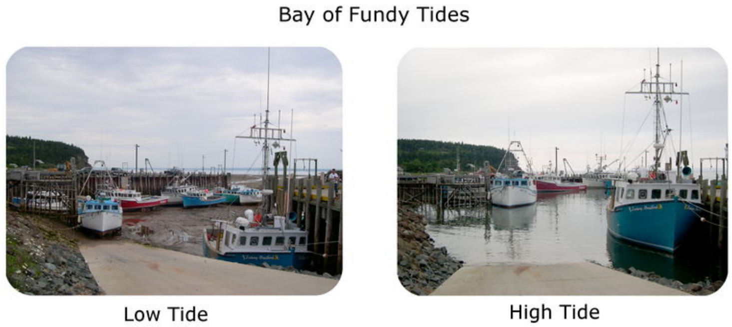

FIGURE 1.22
These pictures show the intertidal zone of the Bay of Fundy, on the Atlantic coast in Maine. Can you identify the intertidal zone from the pictures?

FIGURE 1.23
Barnacles. Barnacles secrete a cement-like substance that anchors them to rocks in the intertidal zone.

Monitoring Marine Protected Areas

Is overfishing an important issue? What would happen if fish populations dwindled? Marine Protected Areas are no-fishing zones that have recently been established up and down the California coast, in the hope of allowing fish to breed, grow large, and replenish state waters. Scientists monitor these areas to determine if this process is working. See http://science.kqed.org/quest/video/one-fish-two-fish-monitoring-marine-protected-areas/ for additional information.

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Freshwater Biomes

Freshwater biomes have water that contains little or no salt. They include standing and running freshwater biomes. Standing freshwater biomes include ponds and lakes. Lakes are generally bigger and deeper than ponds. Some of the water in lakes is in the aphotic zone where there is too little sunlight for photosynthesis. Plankton and plants (such as the duckweed in **Figure** 1.24) are the primary producers in standing freshwater biomes.

FIGURE 1.24
The pond on the left has a thick mat of duckweed plants. They cover the surface of the water and use sunlight for photosynthesis. The cattails on the right grow along a stream bed. They have tough, slender leaves that can withstand moving water.

Running freshwater biomes include streams and rivers. Rivers are usually larger than streams. Streams may start with runoff or water seeping out of a spring. The water runs downhill and joins other running water to become a stream. A stream may flow into a river that empties into a lake or the ocean. Running water is better able to dissolve oxygen and nutrients than standing water. However, the moving water is a challenge to many living things. Algae and plants (such as the cattails in **Figure** 1.24) are the primary producers in running water biomes.

Wetlands

A **wetland** is an area that is saturated with water or covered by water for at least one season of the year. The water may be freshwater or salt water. Wetlands are extremely important biomes for several reasons:

- They store excess water from floods.
- They slow down runoff and help prevent erosion.
- They remove excess nutrients from runoff before it empties into rivers or lakes.
- They provide a unique habitat that certain communities of plants need to survive.
- They provide a safe, lush habitat for many species of animals, so they have high biodiversity.

KQED: Restoring Wetlands

More than 100,000 acres of wetlands are being restored in the Northern California Bay Area, but how exactly do we know what to restore them to? Historical ecologists are recreating San Francisco Bay wetlands that existed decades ago. To learn more, see http://science.kqed.org/quest/video/wetlands-time-machine/ .

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For more than 100 years, south San Francisco Bay has been a center for industrial salt production. Now federal and state biologists are working to restore the ponds to healthy wetlands for fish and other wildlife. Salt marshes are rich habitats that provide shelter and food for many species, some of which are endangered or threatened. See http://www.kqed.org/quest/television/from-salt-ponds-to-wetlands for additional information.

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KQED: San Francisco Bay: A Unique Estuary

An **estuary** is a partly enclosed coastal body of water with one or more rivers or streams flowing into it, and with a free connection to the ocean. Estuaries can be thought of as the most biologically productive regions on Earth, with very high biodiversity. Estuaries are zones where land and sea come together, and where fresh and salt water meet.

The San Francisco Bay is one of the great estuaries of the world. See http://www.youtube.com/watch?v=clZz2OjE5n0 for further information.

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KQED: Studying Aquatic Animals

Oceans cover more than 70 percent of our planet yet they make up one of the least explored regions on Earth. Who better to unlock the mysteries of the ocean than marine animals themselves? Marine scientists have been tagging and tracking sharks, leatherback turtles and other sea life to learn more about marine ecosystems. Through the Tagging of Pacific Predators program (TOPP), scientists hope to both assess and explain the migration routes, ecosystems and diversity of our oceans' species.

Beginning in 2000, scientists from the National Oceanic and Atmospheric Administration, Stanford University and the University of California, Santa Cruz combined to form TOPP. As part of TOPP, researchers attach satellite tags to elephant seals, white sharks, giant leatherback turtles, bluefin tuna, swordfish and other marine animals. The tags collect information, such as how deep each animal dives, the levels of ambient light (to help determine an animal's location) and interior and exterior body temperature. Some tags also collect information about the temperature, salinity and depth of the water surrounding an animal to help scientists identify ocean currents. The tags send the data to a satellite, which in turn sends the data the scientists. They use this information to create maps of migration patterns and discover new information about different marine ecosystems. The information collected by TOPP offers rare insights into the lives of marine animals. Without TOPP, that information would otherwise remain unknown. With TOPP, scientists are developing a working knowledge of the particular migration routes animals take, as well as the locations of popular breeding grounds and the environmental dangers faced by different species. TOPP has shed light on how we can better protect the leatherback turtle and other endangered species.

See http://www.kqed.org/quest/television/tagging-pacific-predators- for more information.

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Lesson Summary

- Terrestrial biomes are determined mainly by climate. Climate influences plant growth, biodiversity, and adaptations of land organisms. Terrestrial biomes include tundras, temperate forests and grasslands, chaparral, temperate and tropical deserts, and tropical forests and grasslands.
- Aquatic biomes are determined mainly by sunlight and concentrations of dissolved oxygen and nutrients in the water. Aquatic organisms are either plankton, nekton, or benthos. Marine biomes are found in the salt water of the ocean. Freshwater biomes include standing and running water biomes. Wetlands are extremely important biomes. They may have freshwater or salt water.

Lesson Review Questions

Recall

1. What is climate? How does it differ from weather?

2. What is a rain shadow?

3. How does climate influence plant growth?

4. Identify two types of tundra and where they are found.

5. In which biome are you most likely to find grasses, zebras, and lions?

6. What is the photic zone of the ocean?

Apply Concepts

7. Compare the data for Seattle and Denver in **Table** 1.2. Seattle is farther north than Denver. Why is Seattle warmer?

TABLE 1.2: Seattle versus Denver

City, State	Latitude (°N)	Altitude (ft above sea level)	Location (relative to ocean)	Average Low Temperature in January (°F)
Seattle, Washington	48	429	Coastal	33
Denver, Colorado	41	5183	Interior	15

8. If you were to design a well-adapted desert animal, what adaptations would you give it to help it survive in its desert biome?

Think Critically

9. Explain the relationship between biodiversity and climate in terrestrial biomes.

10. Compare and contrast plankton, nekton, and benthos.

11. A developer wants to extend a golf course into a wetland. Outline environmental arguments you could make against this plan.

Points to Consider

You read in this lesson that wetlands have high biodiversity.

- In general, what abiotic factors do you think contribute to high biodiversity?
- Do you think Earth's biodiversity is increasing or decreasing? Why?

Major terrestrial biomes:

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