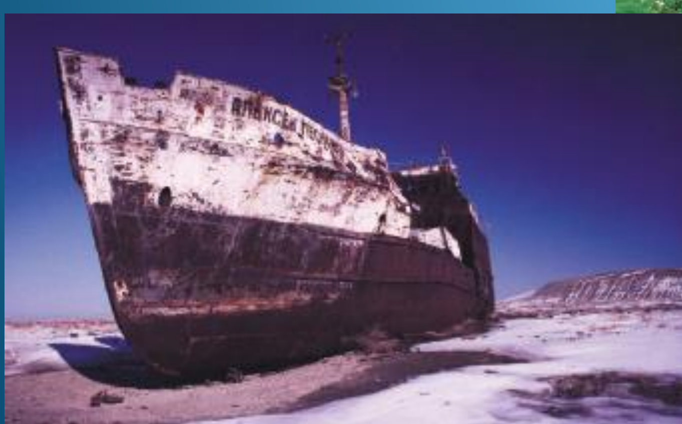
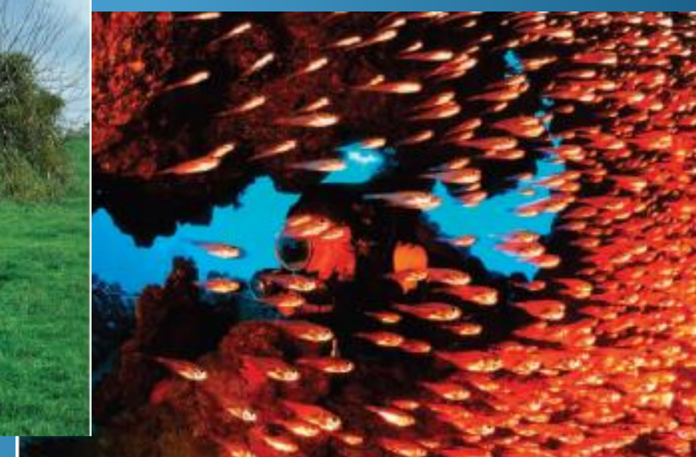
Course title:
Introduction to Environmental Sciences

Lecturer: Dr. Hossein Moradi





Department of Natural Resources
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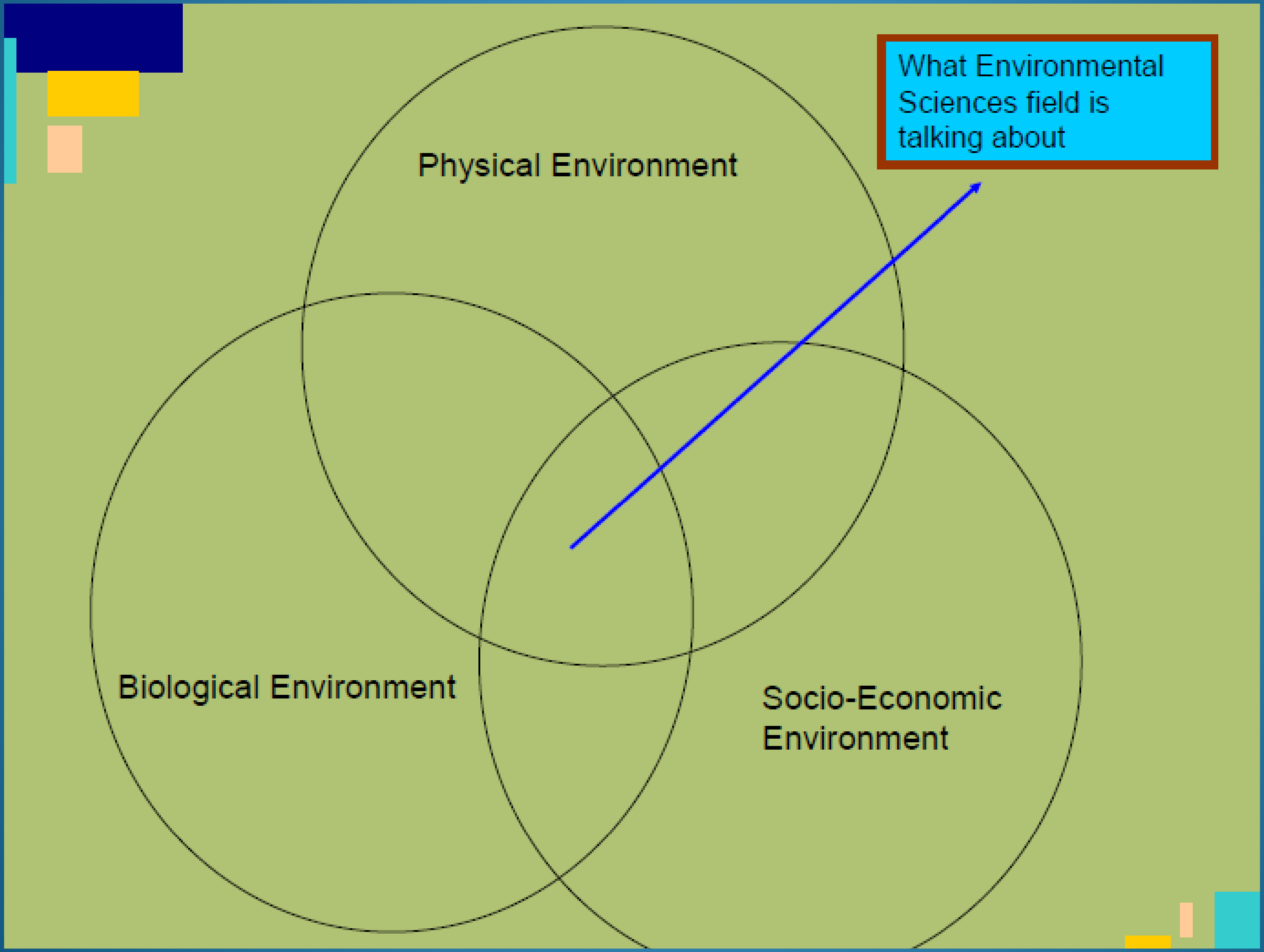
The **environment** is everything around us, or as the famous physicist Albert Einstein put it, “The environment is everything that isn’t me.” It includes the living and the nonliving things (air, water, and energy) with which we interact in a complex web of relationships that connect us to one another and to the world we live in.

Environmental science: an *interdisciplinary* study of how humans interact with the living and nonliving parts of their environment.


What Environmental Sciences field is talking about
Physical Environment
Biological Environment
Socio-Economic Environment

The aim of Environmental Sciences:

1- To understand the natural processes (both physical and biological) that operate in the world

2- To appreciate the role that technology plays in our society and its capacity to alter natural processes as well as solve problems caused by human impact

3- Helping to understand the complex social processes that characterize human populations

In another way:

The three goals of environmental science are:

- *to learn how nature works,*
- *to understand how we interact with the environment,*
- and *to find ways to deal with environmental problems and to live more sustainably.*

Environmental science involves:

- Biology?
- Law?
- Sociology?
- Economics?
- Physics?
- Chemistry?
- Agriculture?
- Philosophy?
- Earth science?
- Computers?
- Engineering?
- politics?

It integrates information and ideas from the *natural sciences* such as biology, chemistry, and geology; the *social sciences* such as geography, economics, and political science; and the *humanities* such as philosophy and ethics.

A short history of life

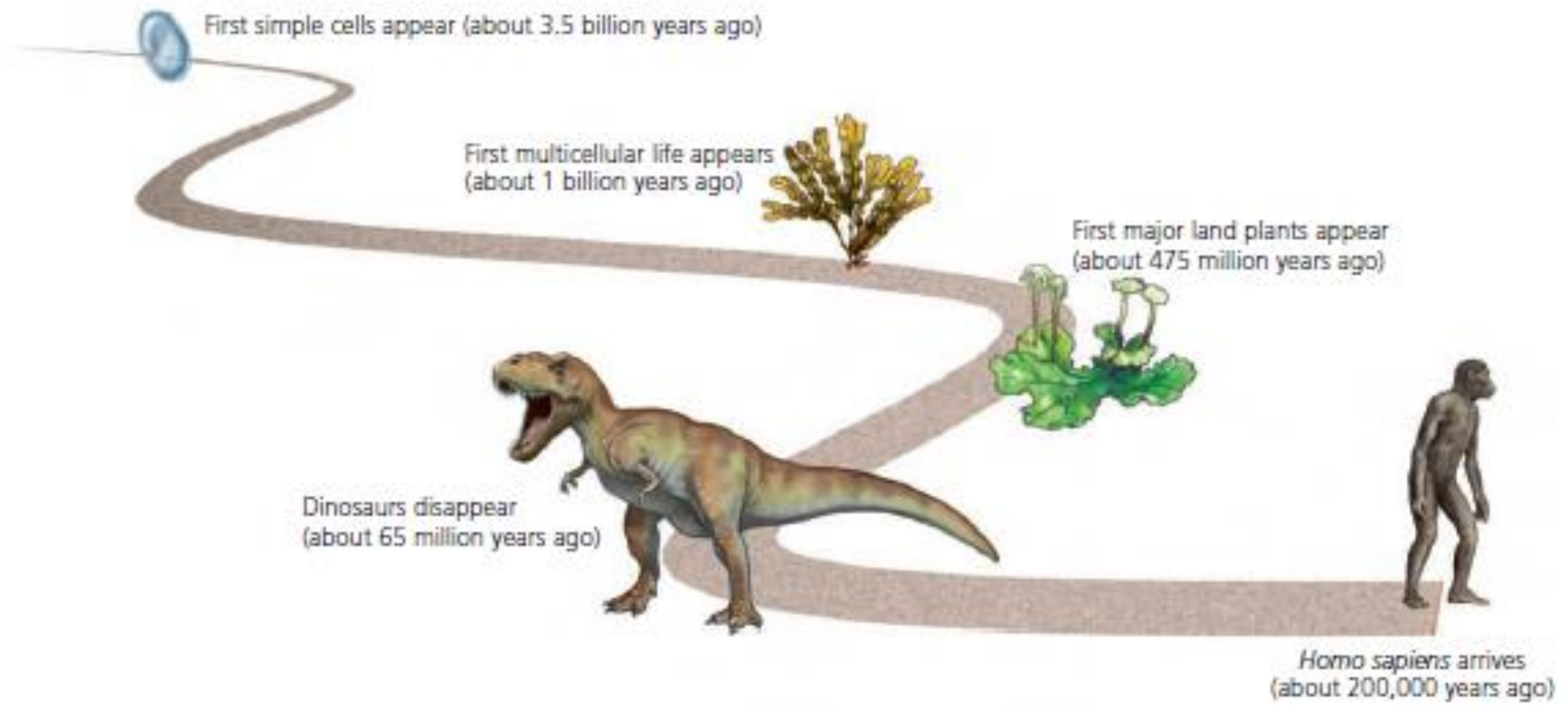


Figure 1-2 Here, the span of *Homo sapiens sapiens'* time on earth is compared with that of all life beginning about 3.5 billion years ago. If the length of this time line were 1 kilometer (0.6 miles), humanity's time on earth would occupy roughly the last 3 one-hundredths of a millimeter. That is less than the diameter of a hair on your head—compared with 1 kilometer of time.

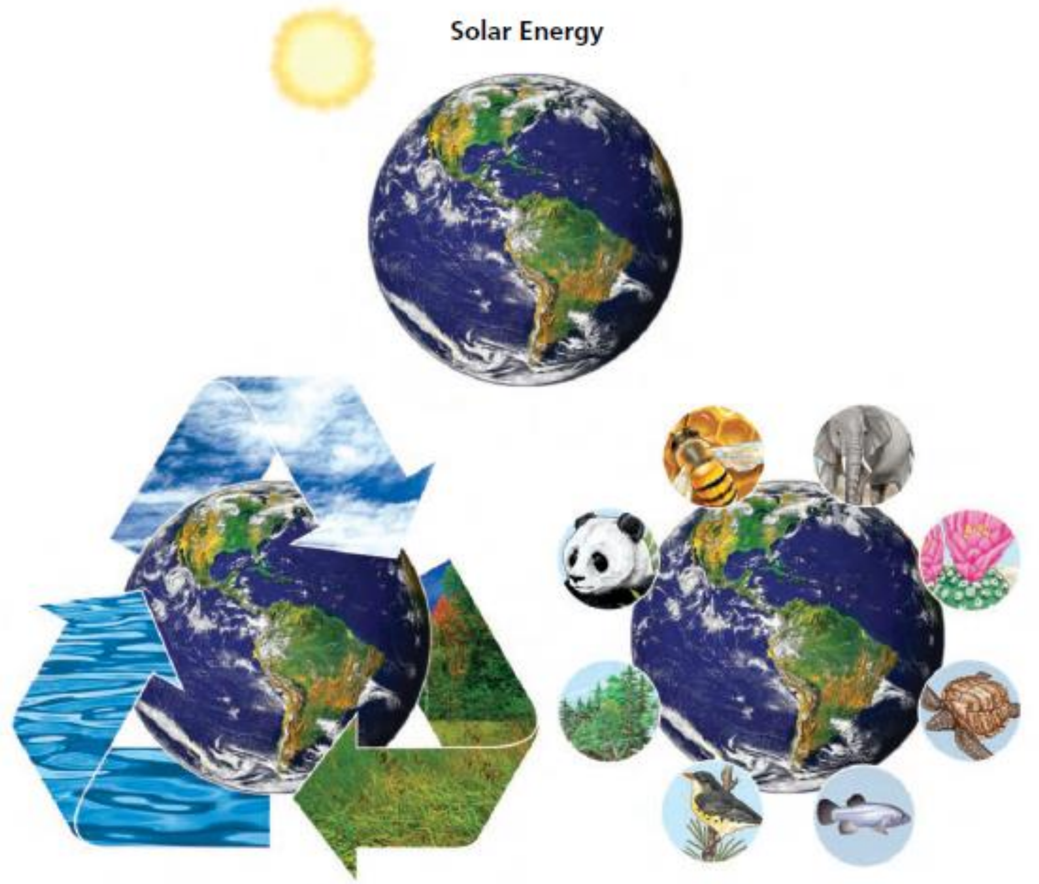


Figure 1-3 **Three principles of sustainability:** We derive these three interconnected principles of sustainability from learning how nature has sustained a huge variety of life on the earth for at least 3.5 billion years, despite drastic changes in environmental conditions (**Concept 1-1A**).

To learn how to live more sustainably and thus more wisely, we need to find out how life on the earth has sustained itself. Our research leads us to believe that in the face of drastic environmental changes, there are three overarching themes relating to the long-term sustainability of life on this planet: ***solar energy***, ***biodiversity***, and ***chemical cycling***.

• **Reliance on solar energy:** The sun warms the planet and supports *photosynthesis*—a complex chemical process used by plants to provide the *nutrients*, or chemicals that most organisms need in order to stay alive and reproduce. Without the sun, there would be no plants, no animals, and no food. The sun also powers indirect forms of solar energy such as wind and flowing water, which we can use to produce electricity.

• **Biodiversity** (short for *biological diversity*): This refers to the astounding variety of organisms, the natural systems in which they exist and interact (such as deserts, grasslands, forests, and oceans), and the natural services that these organisms and living systems provide free of charge (such as renewal of topsoil, pest control, and air and water purification). Biodiversity also provides countless ways for life to adapt to changing environmental conditions. Without it, most life would have been wiped out long ago.

• **Chemical cycling:** Also referred to as **nutrient cycling**, this circulation of chemicals from the environment (mostly from soil and water) through organisms and back to the environment is necessary for life. Natural processes keep this cycle going, and the earth receives no new supplies of these chemicals. Thus, for life to sustain itself, these nutrients must be cycled in this way, indefinitely. Without chemical cycling, there would be no air, no water, no soil, no food, and no life.

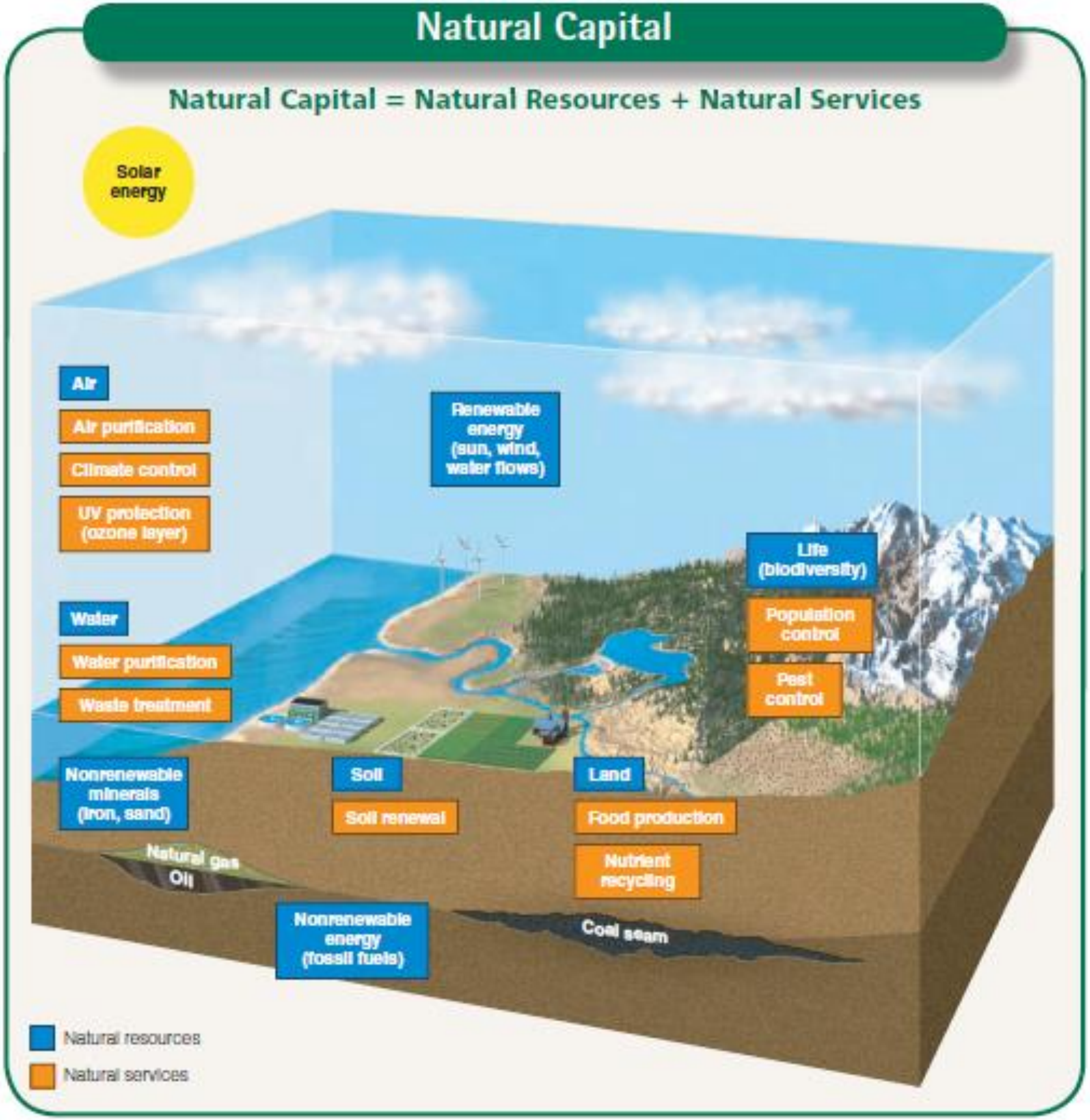


Figure 1-4 These key *natural resources* (blue) and *natural services* (orange) support and sustain the earth's life and human economies (**Concept 1-1A**).

Some Resources Are Renewable and Some Are Not

Renewables
resource, as long as we do not use it up faster than nature can renew it. Examples include forests, grasslands, fish populations, freshwater, fresh air, and fertile topsoil.

Non-Renewables
Include *energy resources* (such as coal and oil), *metallic mineral resources* (such as copper and aluminum), and *nonmetallic mineral resources* (such as salt and sand).

Experts Have Identified Four Basic Causes of Environmental Problems

According to a number of environmental and social scientists, the major causes of pollution, environmental degradation, and other environmental problems are:

- **population growth,**
- **wasteful and unsustainable resource use,**
- **poverty,**
- **and failure to include the harmful environmental costs of goods and services in their market prices**

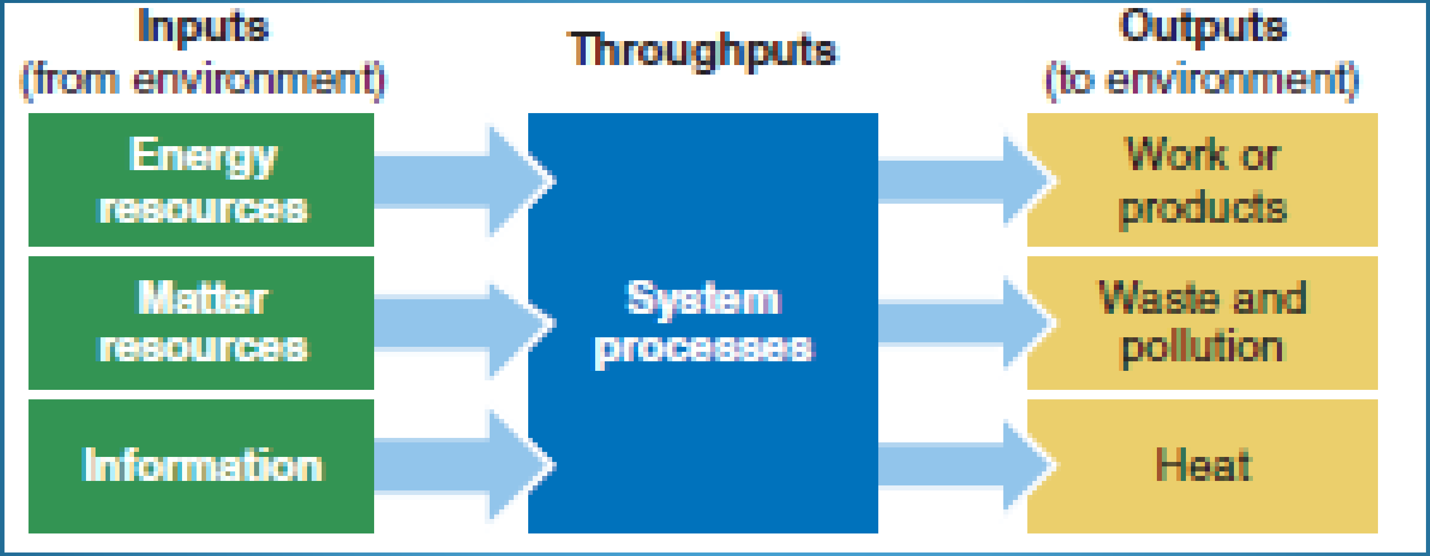
What Are Systems and How Do They Respond to Change?

A **system** is a set of components that function and interact in some regular way. The human body, a river, an economy, and the earth are all systems.

Most systems have the following key components: **inputs** from the environment, **flows** or **throughputs** of matter and energy within the system, and **outputs** to the environment

▶ CONCEPT 2-5 Systems have inputs, flows, and outputs of matter and energy, and feedback can affect their behavior.

Systems Respond to Change through Feedback Loops

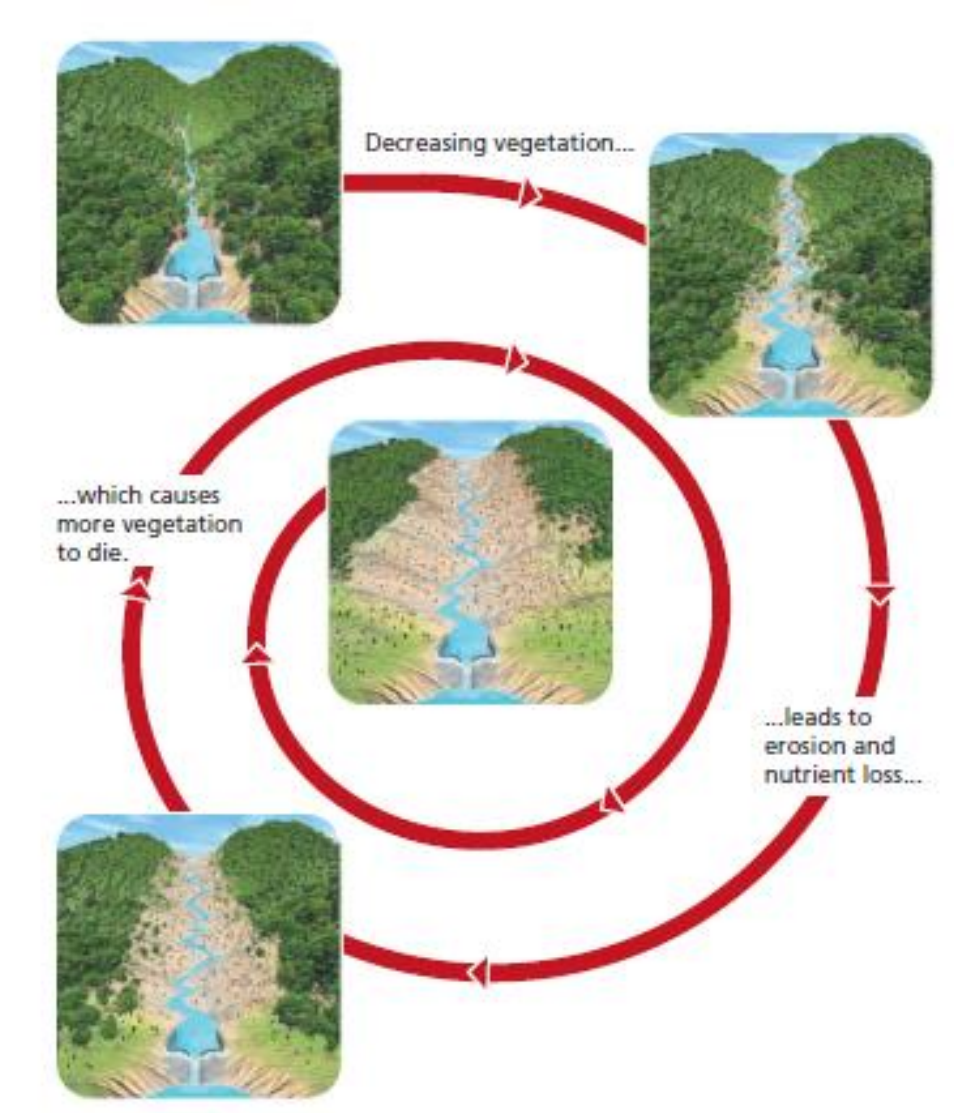


This diagram illustrates a greatly simplified model of a system. Most systems depend on inputs of matter and energy resources, and outputs of wastes, pollutants, and heat to the environment.

A system can become unsustainable if the throughputs of matter and energy resources exceed the abilities of the system's environment to provide the required resource inputs and to absorb or dilute the resulting wastes, pollutants, and heat.

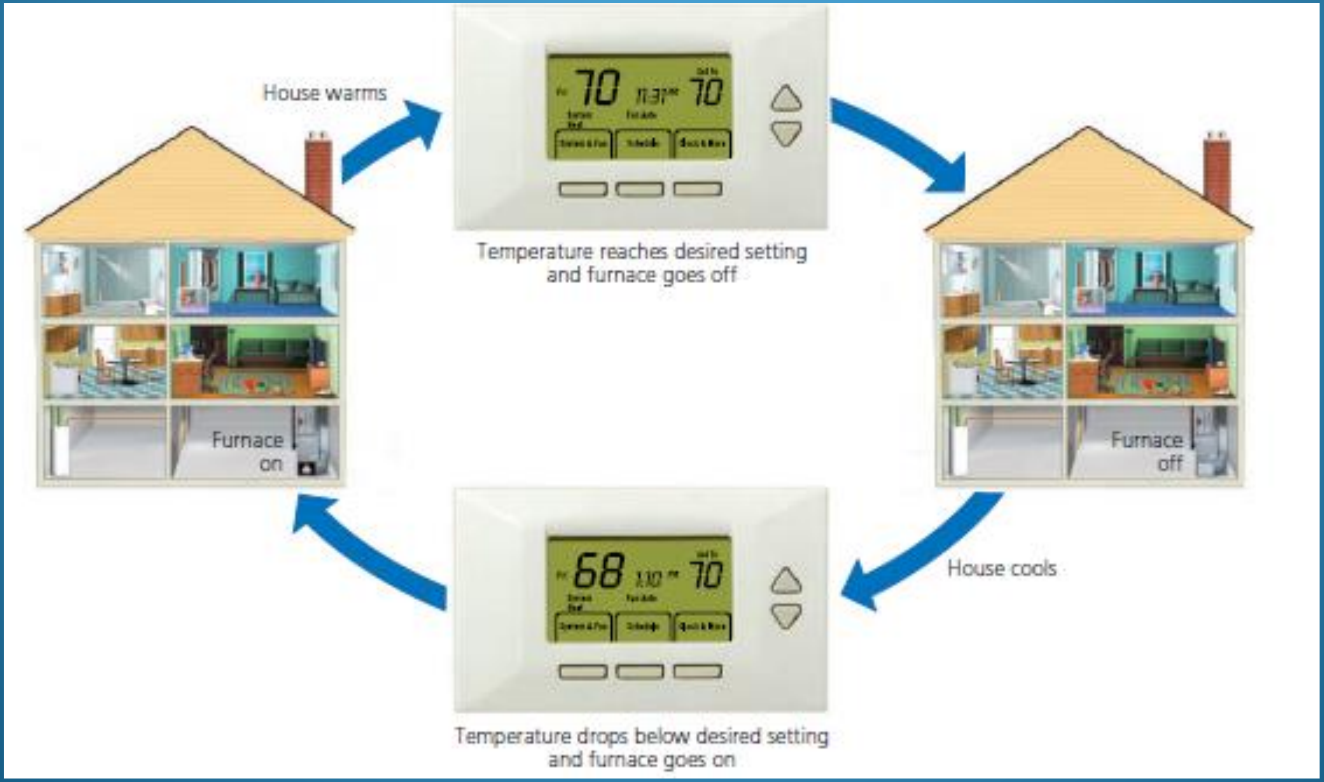
Most systems are affected in one way or another by **feedback**, any process that increases (**positive feedback**) or decreases (negative feedback) a change to a system . Such a process, called a **feedback loop**, occurs when an output of matter, energy, or information is fed back into the system as an input and leads to changes in that system. Note that, unlike the human brain, most systems do not consciously decide how to respond to feedback. Nevertheless, feedback can affect the behavior of systems.

A **positive feedback loop** causes a system to change further in the same direction.



Such accelerating positive feedback loops are of great concern in several areas of environmental science. One of the most alarming is the melting of polar ice, which has occurred as the temperature of the atmosphere has risen during the past few decades. As that ice melts, there is less of it to reflect sunlight, and more water that is exposed to sunlight. Because water is darker than ice, it absorbs more solar energy, making the polar areas warmer and causing the ice to melt faster, thus exposing more water.

A **negative**, or **corrective**, **feedback loop** causes a system to change in the opposite direction from which is it moving. A simple example is a thermostat, a device that controls how often and how long a heating or cooling system runs.



An important example of a negative feedback loop is the recycling and reuse of some resources such as aluminum and copper. For example, an aluminum can is an output of a mining and manufacturing system. When we recycle the can, that output becomes an input. This reduces the amount of aluminum ore that we must mine and process to make aluminum cans. It also reduces the harmful environmental impacts from mining and processing the aluminum ore.

It Can Take a Long Time for a System to Respond to Feedback

A complex system will often show a time delay, or a lack of response during a period of time between the input of a feedback stimulus and the system's response to it.

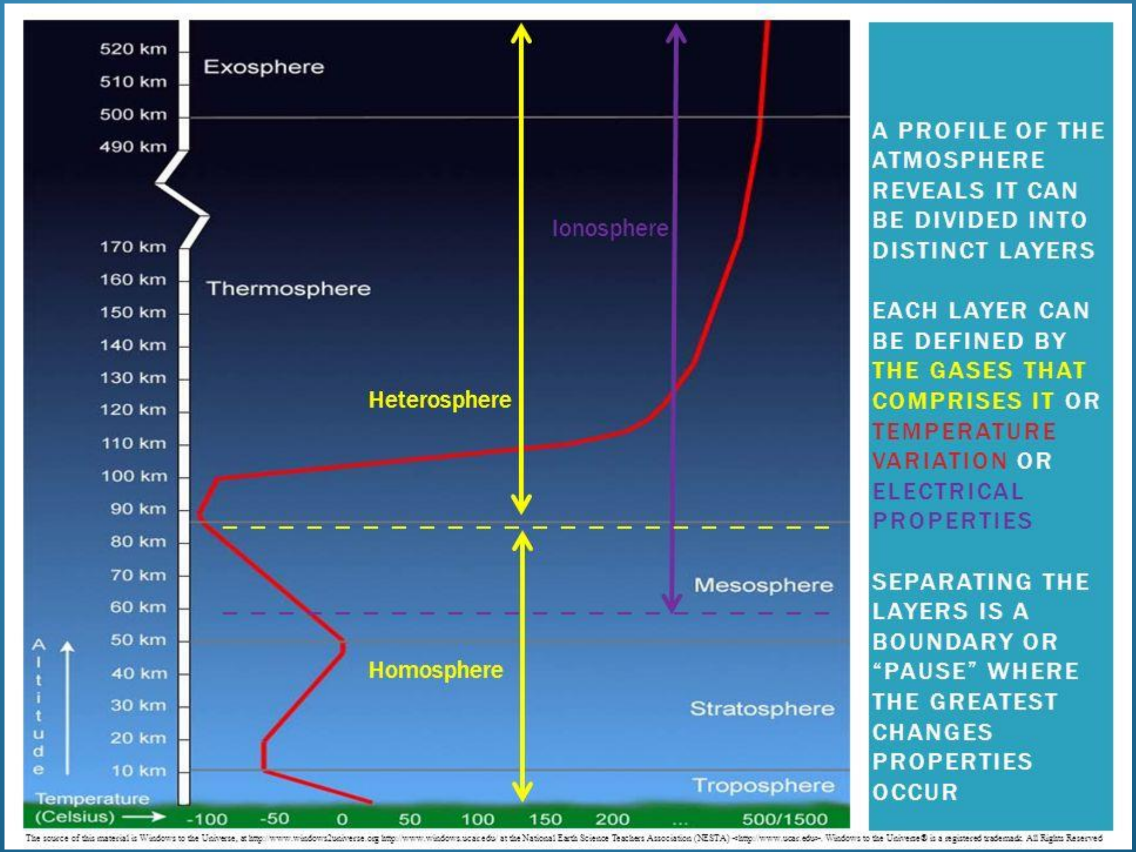
Earth's Life-Support System Has Four Major Components

The **earth's life-support system** consists of four main spherical systems that interact with one another—the atmosphere (air), the hydrosphere (water), the geosphere (rock, soil, and sediment), and the biosphere (living things)

Atmosphere

The **atmosphere** is a thin spherical envelope of gases surrounding the earth's surface. Its inner layer, the **troposphere**, extends only about 17 kilometers (11 miles) above sea level at the tropics and about 7 kilometers (4 miles) above the earth's north and south poles. It contains air that we breathe, consisting mostly of nitrogen (78% of the total volume) and oxygen (21%). The remaining 1% of the air includes water vapor, carbon dioxide, and methane, all of which are called **greenhouse gases**, which absorb and release energy that warms the lower atmosphere. Without these gases, the earth would be too cold for the existence of life as we know it. Almost all of the earth's weather occurs within this layer.

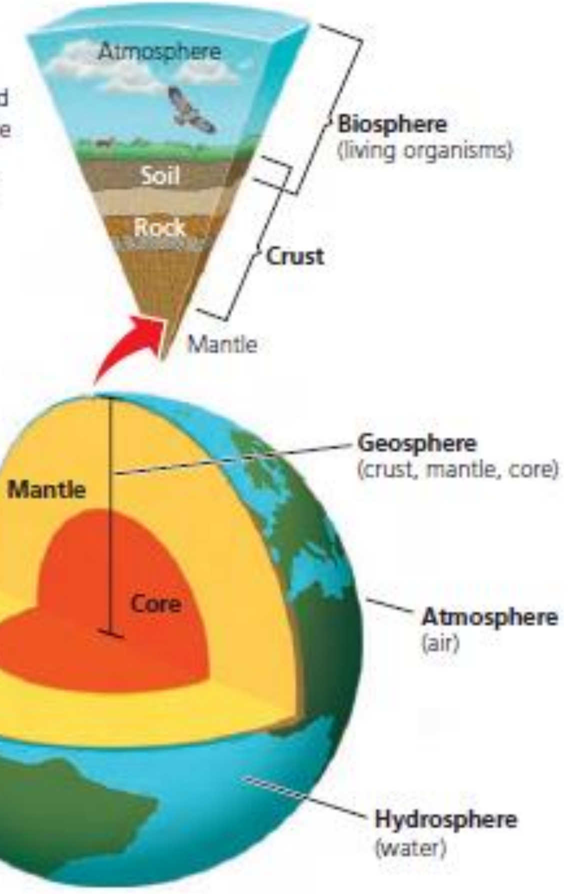
The next layer, stretching 17–50 kilometers (11–31 miles) above the earth's surface, is called the **stratosphere**. Its lower portion holds enough ozone (O_3) gas to filter out about 95% of the sun's harmful *ultraviolet (UV) radiation*. This global sunscreen allows life to exist on land and in the surface layers of bodies of water.



The **hydrosphere** consists of all of the water on or near the earth's surface. It is found as *water vapor* in the atmosphere, *liquid water* on the surface and underground, and *ice*—polar ice, icebergs, glaciers, and ice in frozen soil layers called *permafrost*. The oceans, which cover about 71% of the globe, contain about 97% of the earth's water.

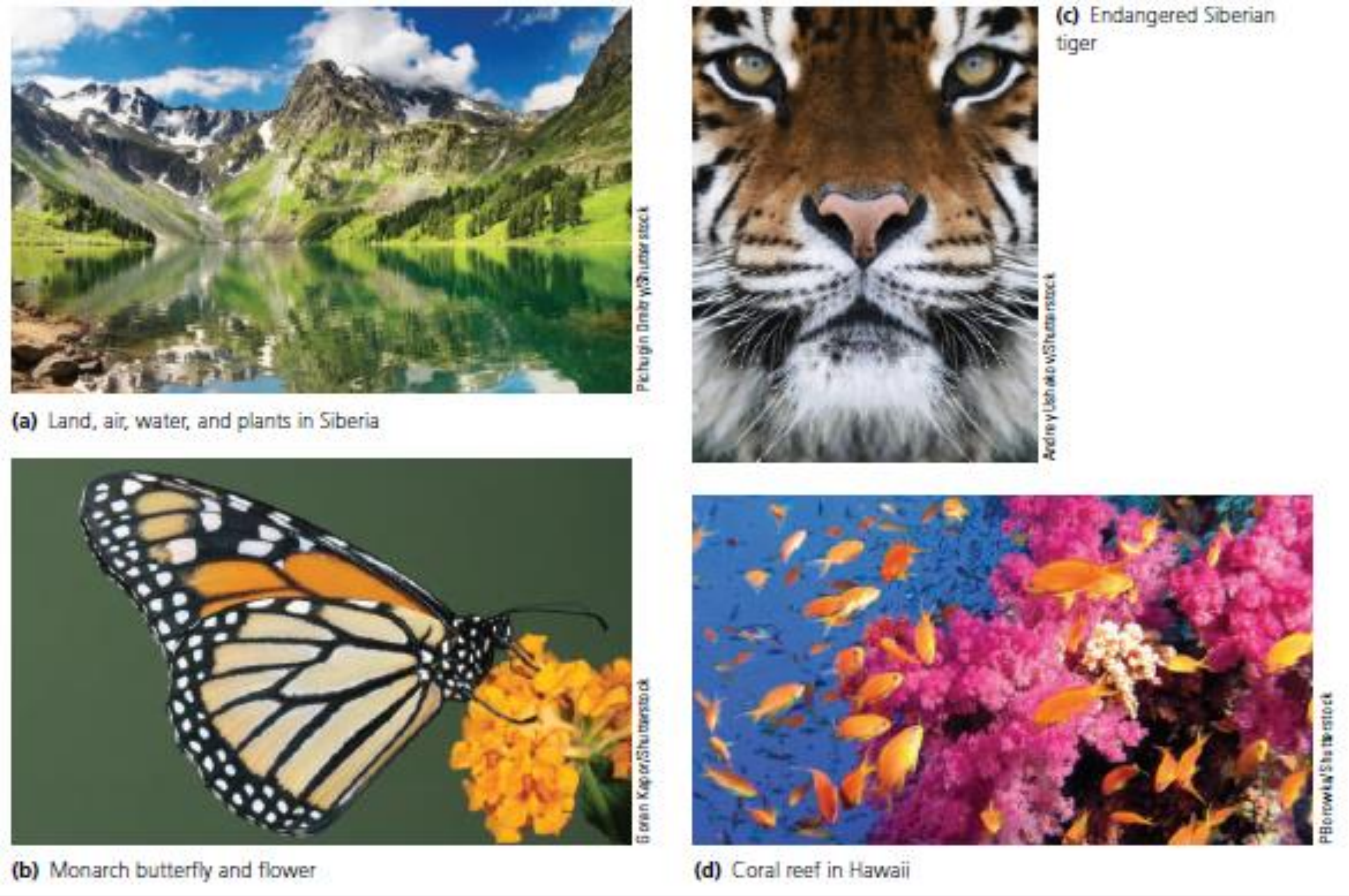
The **geosphere** consists of the earth's intensely hot *core*, a thick *mantle* composed mostly of rock, and a thin outer *crust*. Most of the geosphere is located in the earth's
interior. Its upper portion contains nonrenewable fossil fuels and minerals that we use, as well as renewable soil chemicals (nutrients) that organisms need in order to live, grow, and reproduce.

Figure 3-2 **Natural capital:** This diagram illustrates the general structure of the earth, showing that it consists of a land sphere (*geosphere*), an air sphere (*atmosphere*), a water sphere (*hydrosphere*), and a life sphere (*biosphere*) (**Concept 3-1A**).



The **biosphere** consists of the parts of the atmosphere, hydrosphere, and geosphere where life is found.

If the earth were an apple, the biosphere would be no thicker than the apple's skin. *One important goal of environmental science is to understand the interactions that occur within this thin layer of air, water, soil, and organisms.*

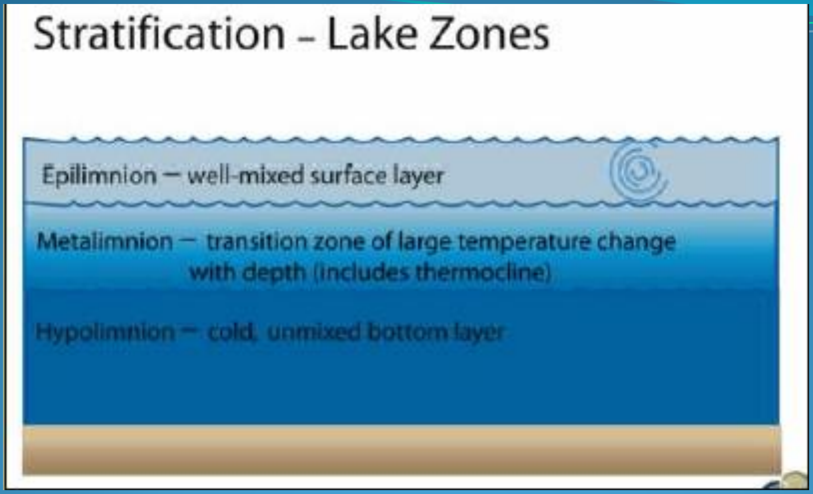


(a) Land, air, water, and plants in Siberia

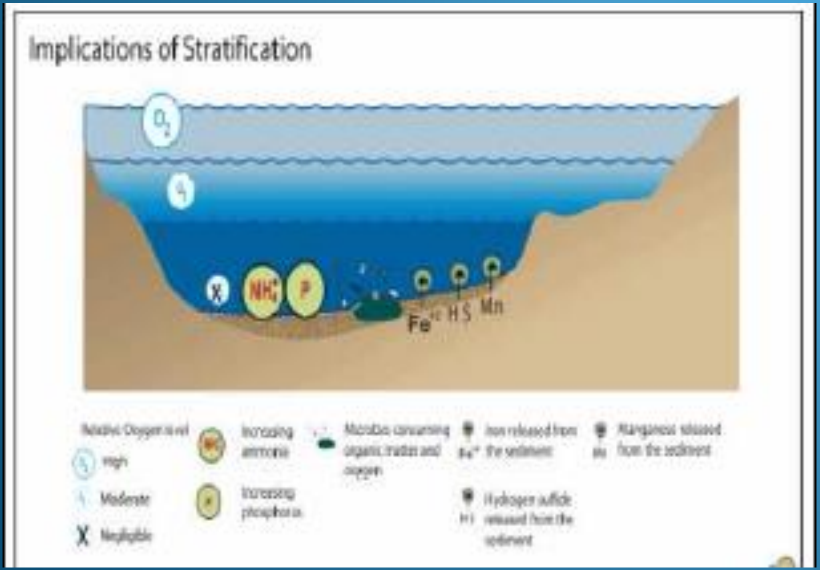
(b) Monarch butterfly and flower

(c) Endangered Siberian tiger

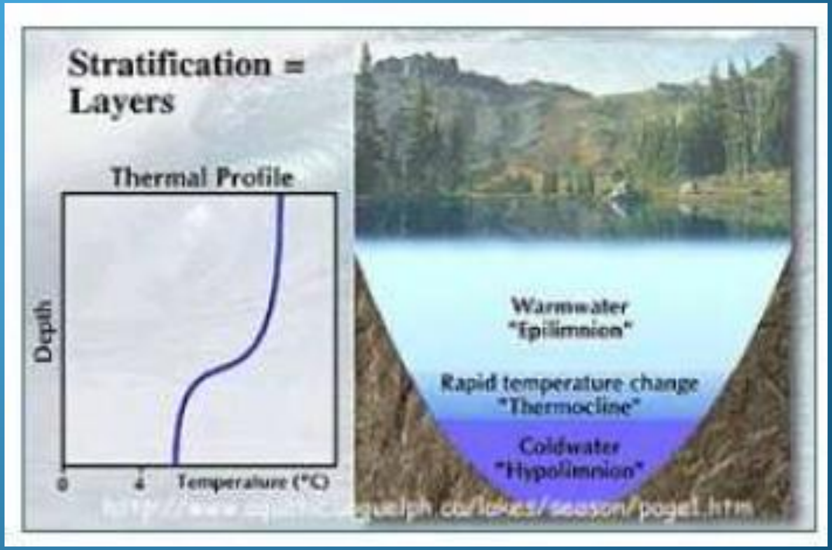
(d) Coral reef in Hawaii



Stratification – Lake Zones
Epilimnion – well-mixed surface layer
Metalimnion – transition zone of large temperature change with depth (includes thermocline)
Hypolimnion – cold, unmixed bottom layer



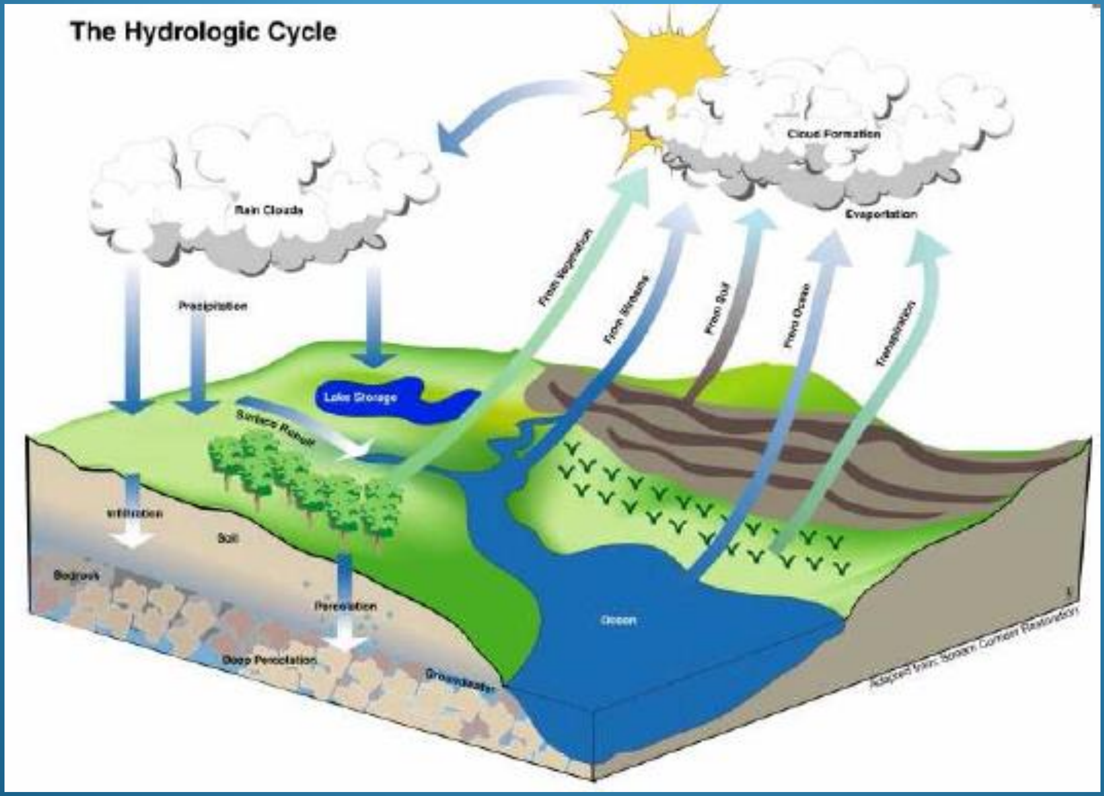
Implications of Stratification
O_2
NH_4^+
P
Fe
H S
Mn
Moderate
Negligible
Increasing ammonia
Increasing phosphorus

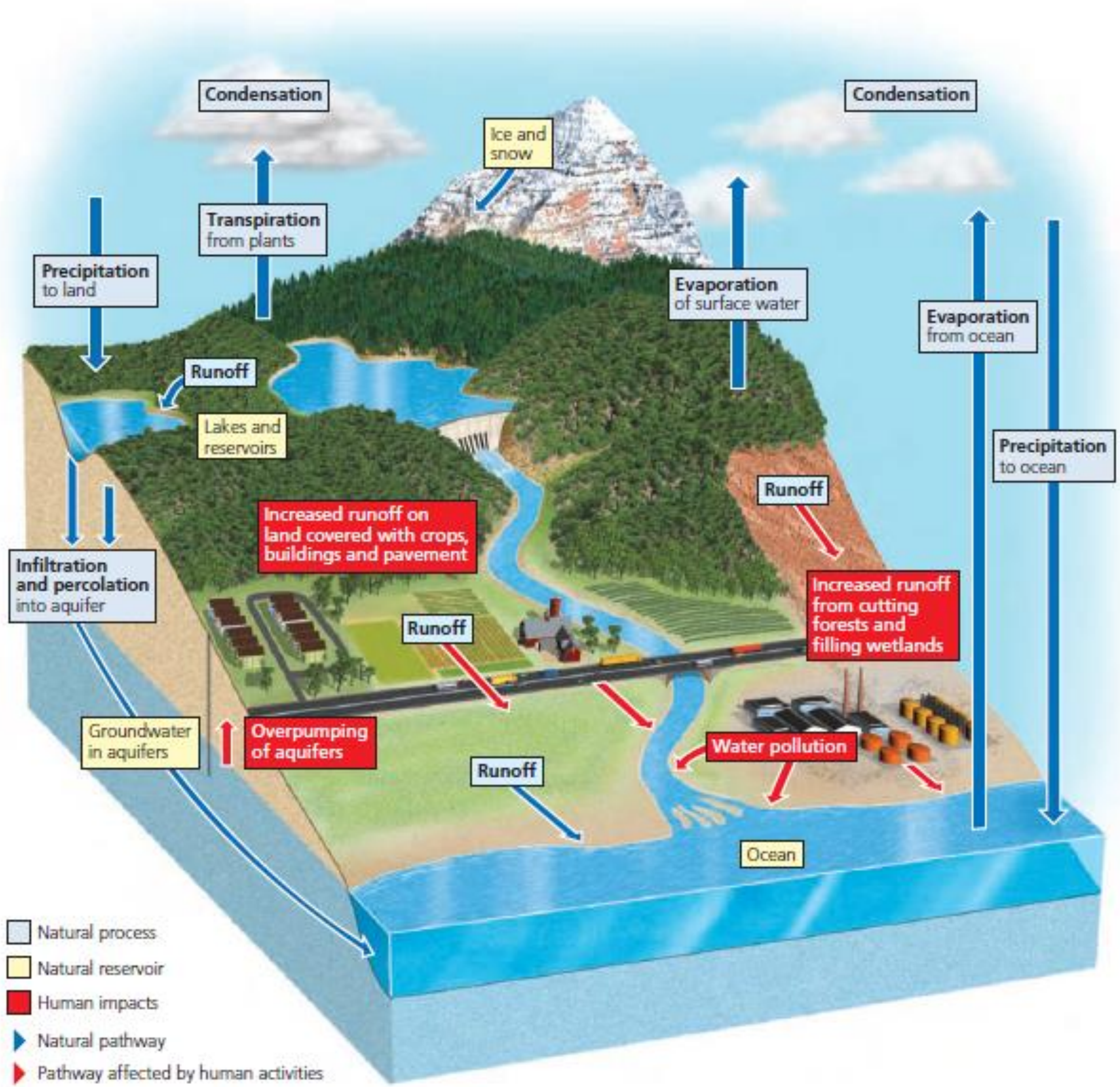


Stratification = Layers
Thermal Profile
Depth
0
4
Temperature (°C)
Warmwater "Epilimnion"
Rapid temperature change "Thermocline"
Coldwater "Hypolimnion"

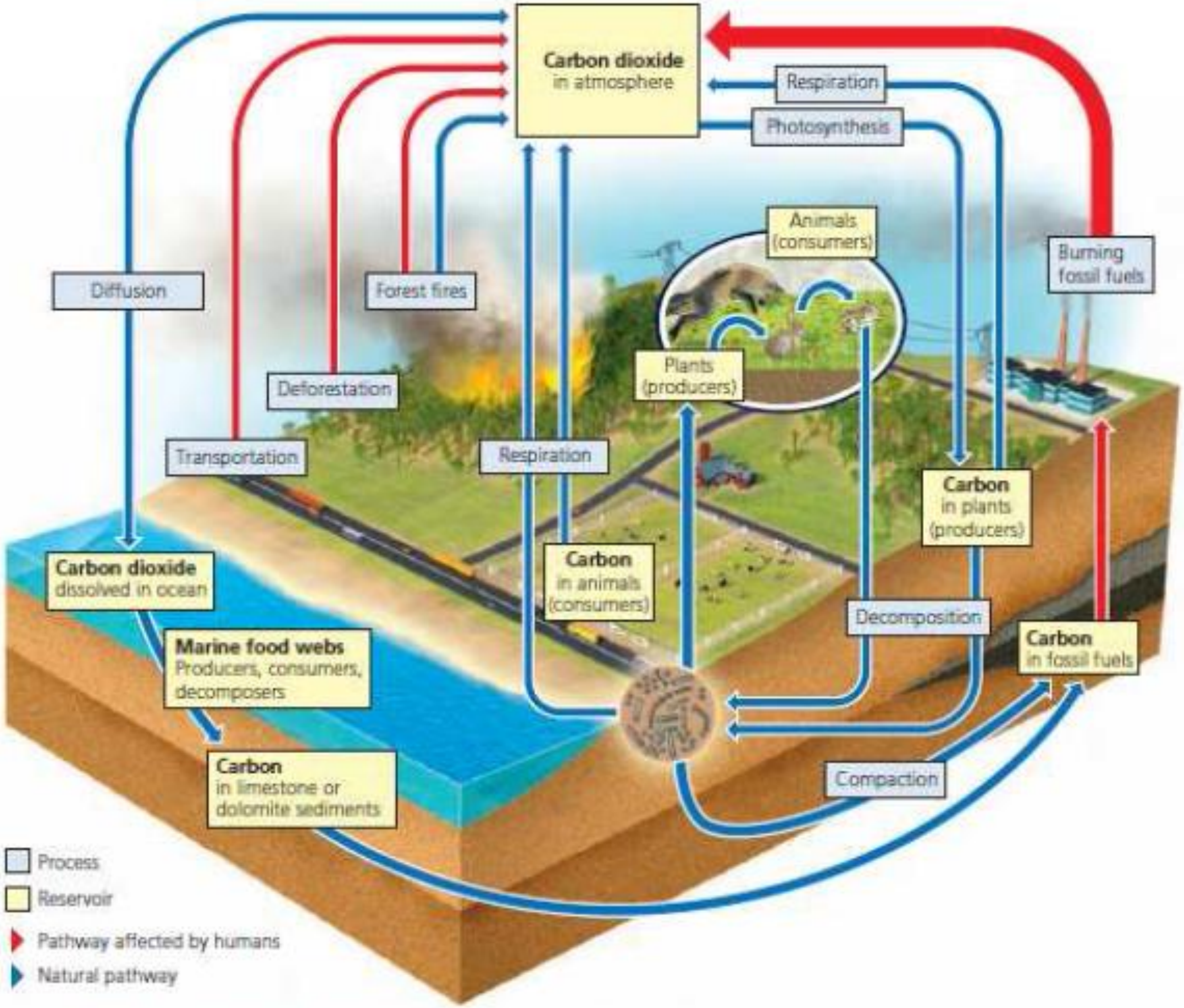
Would you believe that a dinosaur could have once used your last drink of water?

Water on earth today has been here for millions of years. Because of the **water cycle**, water moves from the earth to the air to the earth again. It changes from solid to liquid to gas, over and over again.

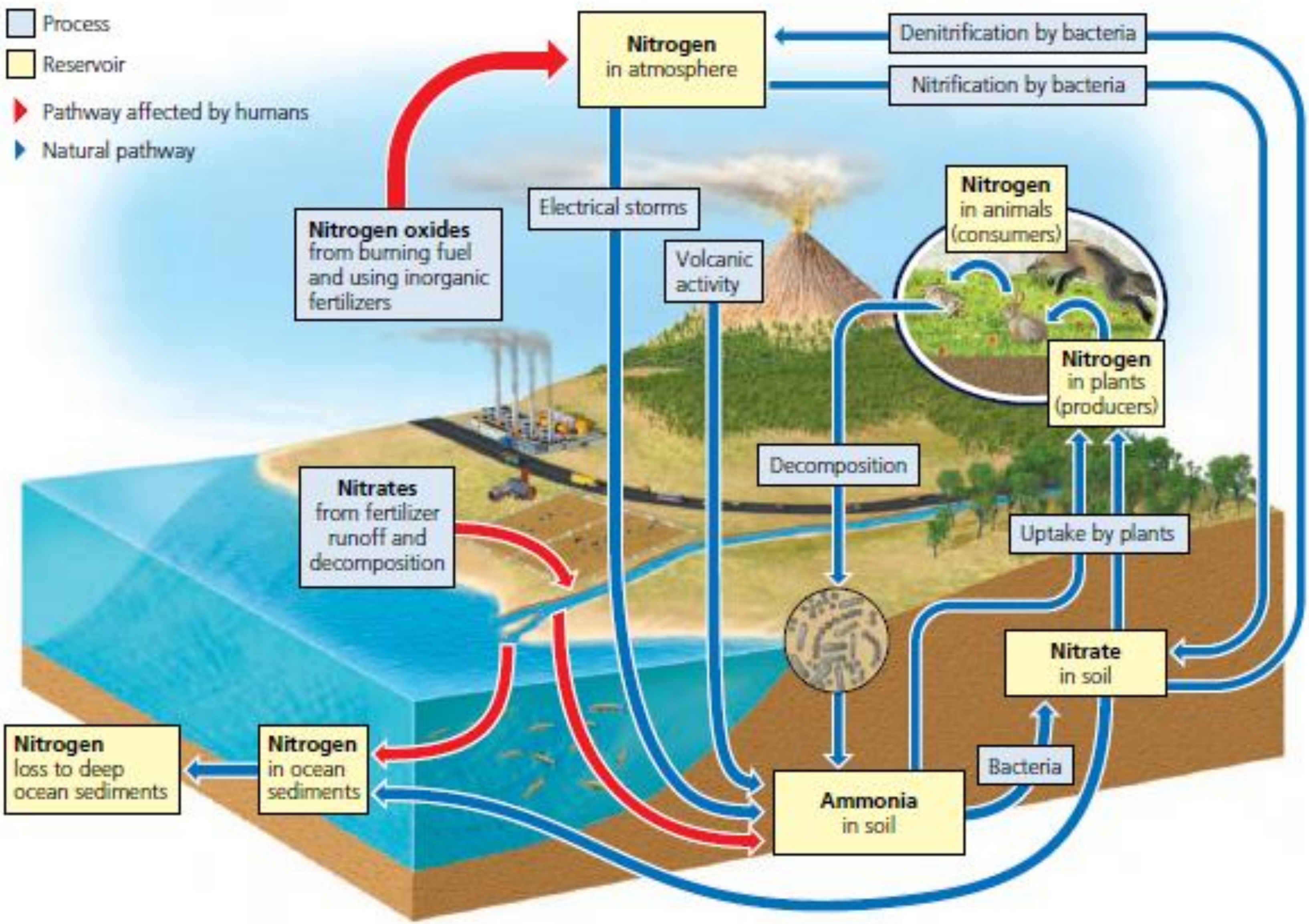




CENGAGENOW™ **Active Figure 3-16** **Natural capital:** This diagram is a simplified model of the *water cycle*, or *hydrologic cycle*, in which water circulates in various physical forms within the biosphere. Major harmful impacts of human activities are shown by the red arrows and boxes. *See an animation based on this figure at* CengageNOW. **Question:** What are three ways in which your lifestyle directly or indirectly affects the hydrologic cycle?



CENGAGENOW™ **Active Figure 3-19** **Natural capital:** This simplified model illustrates the circulation of various chemical forms of carbon in the global *carbon cycle*, with major harmful impacts of human activities shown by the red arrows. *See an animation based on this figure at* CengageNOW. **Question:** What are three ways in which you directly or indirectly affect the carbon cycle?



CENGAGENOW™ **Active Figure 3-20** **Natural capital:** This diagram is a simplified model of the circulation of various chemical forms of nitrogen in the *nitrogen cycle* in a terrestrial ecosystem, with major harmful human impacts shown by the red arrows. *See an animation based on this figure at* CengageNOW. **Question:** What are three ways in which you

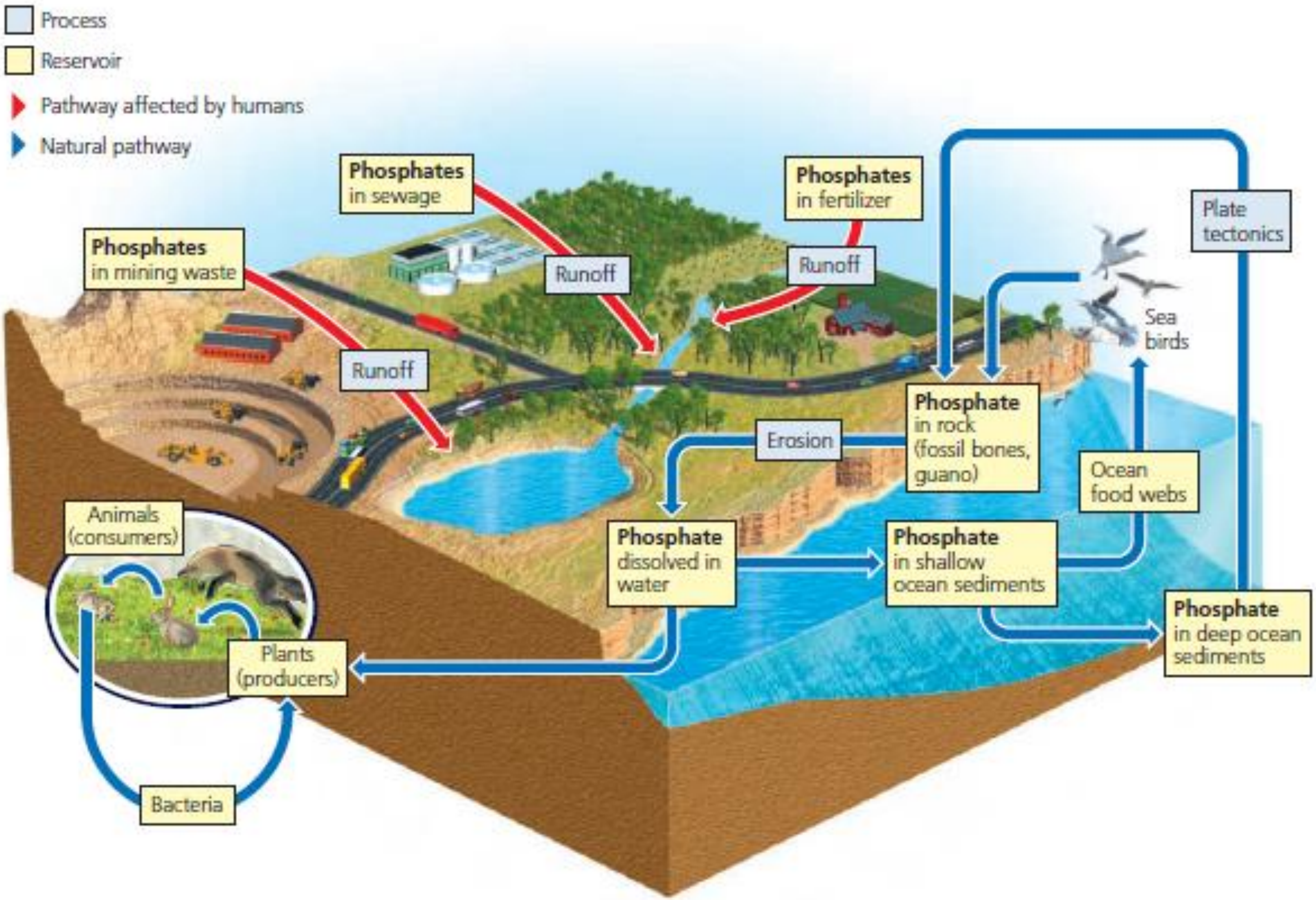
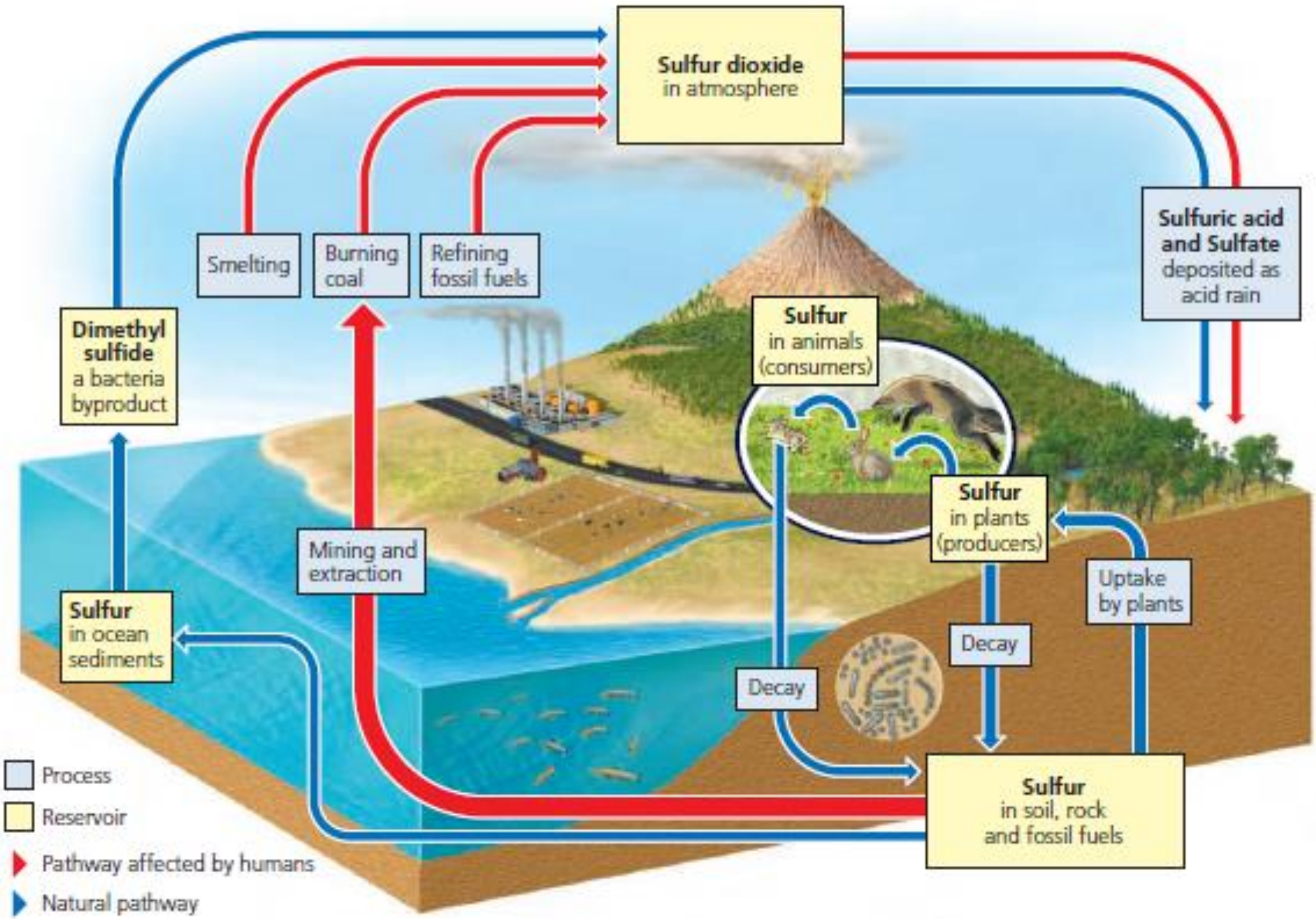
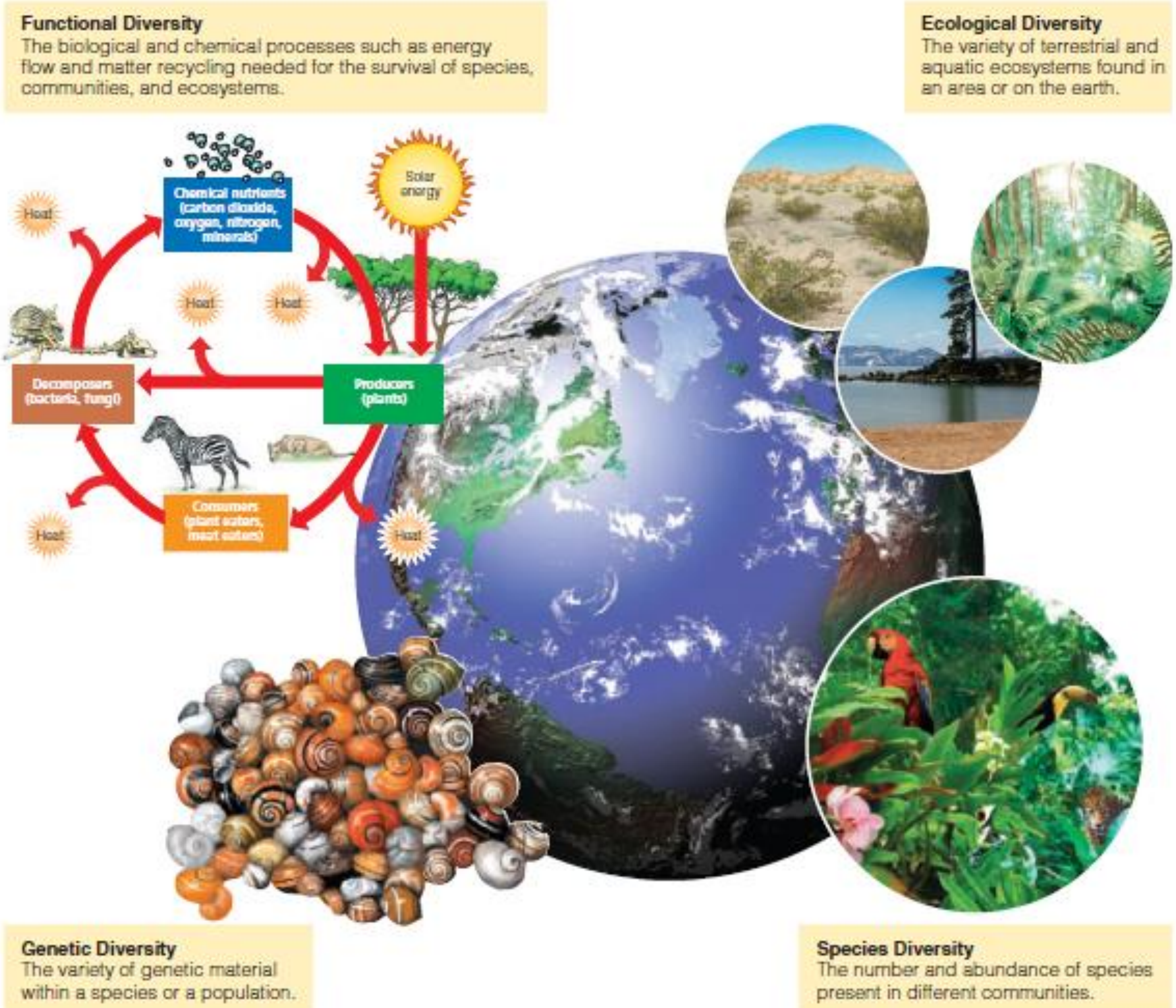


Figure 3-21 Natural capital: This is a simplified model of the circulation of various chemical forms of phosphorus (mostly phosphates) in the *phosphorus cycle*, with major harmful human impacts shown by the red arrows. **Question:** What are three ways in which you directly or indirectly affect the phosphorus cycle?



CENGAGENOW™ **Active Figure 3-22** **Natural capital:** This is a simplified model of the circulation of various chemical forms of sulfur in the *sulfur cycle*, with major harmful impacts of human activities shown by the red arrows. *See an animation based on this figure at* CengageNOW. **Question:** What are three ways in which your lifestyle directly or indirectly affects the sulfur cycle?



CENGAGENOW™ **Active Figure 4-2** **Natural capital:** This diagram illustrates the major components of the earth's *biodiversity*—one of the earth's most important renewable resources and a key component of the planet's natural capital (see Figure 1-4, p. 9). *See an animation based on this figure at* CengageNOW. **Question:** What role do you play in such degradation?

Habitat: The space that the organism inhabits, the place where it lives (its address)

Species: is a population of organisms in which the individuals ae potentially able to interbreed and produce fertile offspring.

Individual organisms are members of a species.

Two points:

1- not all the members reproduce

2- not all the offspring are the fetile

How Do Species Interact?

Species Interact in Five Major Ways
Ecologists identify five basic types of interactions between species as they share limited resources such as food, shelter, and space:

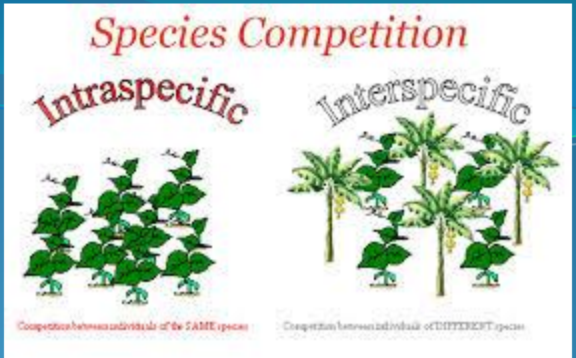
• **Interspecific competition** occurs when members of two or more species interact to gain access to the same limited resources such as food, water, light, and space.

• **Predation** occurs when a member of one species (the *predator*) feeds directly on all or part of a member of another species (the *prey*).

• **Parasitism** occurs when one organism (the *parasite*) feeds on another organism (the *host*), usually by living on or in the host.

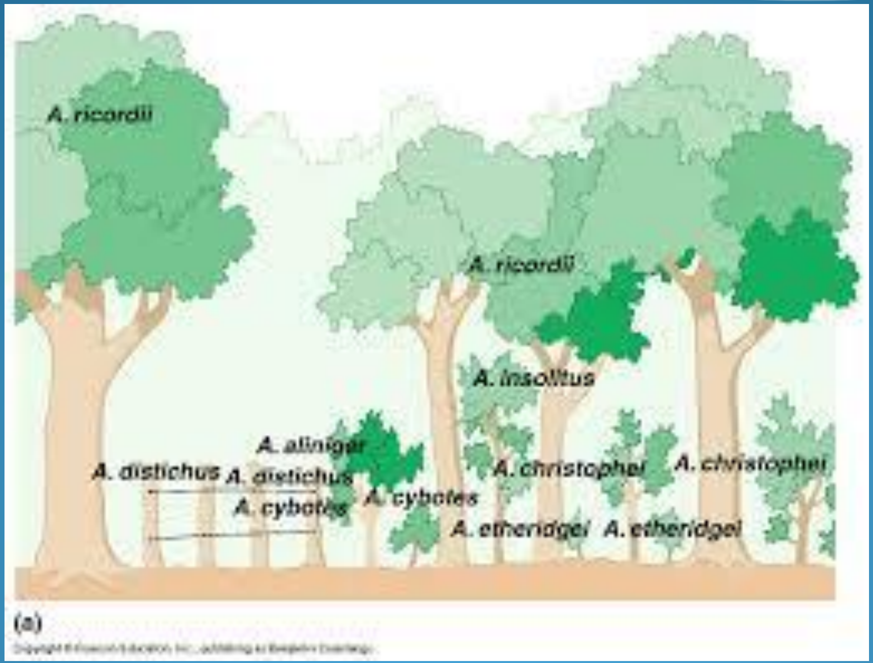
• **Mutualism** is an interaction that benefits both species by providing each with food, shelter, or some other resource.

• **Commensalism** is an interaction that benefits one species but has little or no effect on the other


Species Competition
Intraspecific
Interspecific
Competition between individuals of the SAME species
Competition between individuals of DIFFERENT species

Resource partitioning: Some Species Evolve Ways to Share Resources to reduce the competition

Figure 5-3 *Specialist species of honeycreepers:* Through natural selection, different species of honeycreepers developed specialized ecological niches that reduced competition between these species. Each species has evolved a specialized beak to take advantage of certain types of food resources.


A. ricordii
A. ricordii
A. insolitus
A. aliniger
A. distichus
A. distichus
A. cybotes
A. cybotes
A. christophei
A. christophei
A. etheridgei
A. etheridgei
(a)

Predation

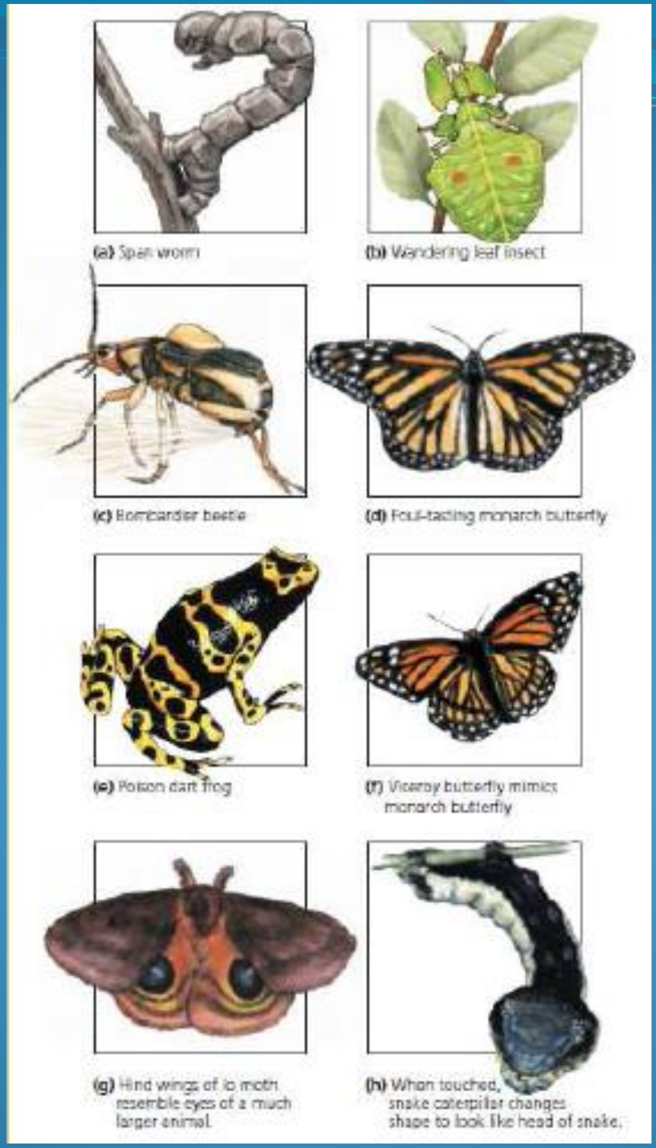
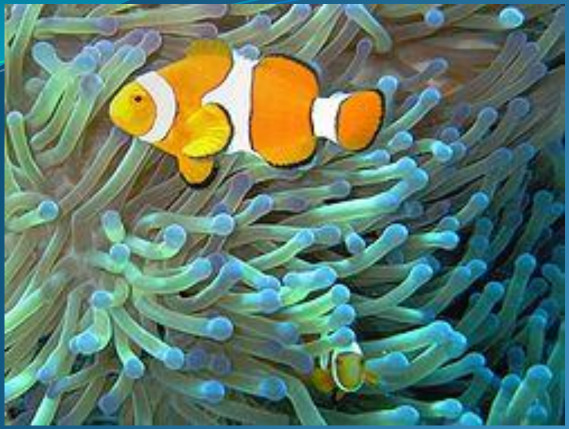


Figure 5-5 These prey species have developed specialized ways to avoid their predators: (a, b) *camouflage*, (c–e) *chemical warfare*, (d, e) *warning coloration*, (f) *mimicry*, (g) *deceptive looks*, and (h) *deceptive behavior*.

Parasitism

Great Lakes Fishery Commission

Figure 5-7 *Parasitism:* This blood-sucking parasitic sea lamprey has attached itself to an adult lake trout from the Great Lakes (USA).



In a symbiotic mutualistic relationship, theclownfish feeds on small invertebrates that otherwise have potential to harm the sea anemone, and the fecal matter from the clownfish provides nutrients to the sea anemone. The clownfish is additionally protected from predators by the anemone's stinging cells, to which the clownfish is immune. The clownfish also emits a high pitched sound that deters butterfly fish, which would otherwise eat the anemone.[1]

Mutualism

Mutualism is an interaction between two or more species, where species derive a mutual benefit

Similar interactions within a species are known as co-operation.

One or both species involved in the interaction may be obligate, meaning they cannot survive in the short or long term without the other species.

Though mutualism has historically received less attention than other interactions such as predation,[9] it is very important subject in ecology. Examples include cleaner fish, pollination and seed dispersal, and nitrogen fixation by fungi.

Commensalism

Climate and Biodiversity

Different Climates Support Different Life Forms

Climate and Biodiversity

What factors influence climate?

Weather:
is a set of physical conditions of the lower atmosphere such as temperature, precipitation, humidity, wind speed, cloud cover, and other factors in a given area over a period of hours or days.

Climate, which is an area's general pattern of atmospheric conditions over periods of at least three decades and up to thousands of years.
In other words, climate is weather, averaged over a long time.

Climate and Biodiversity

Three major factors determine
how air circulates in the lower atmosphere:

1. *Uneven heating of the earth's surface by the sun.* Air is heated much more at the equator, where the sun's rays strike directly, than at the poles, where sunlight strikes at an angle and spreads out over a much
greater area (Figure 7-3, right). These differences in the input of solar energy help explain why tropical regions near the equator are hot, why polar regions are cold, and why temperate regions in between generally have warm and cool temperatures (Figure 7-2). The intense input of solar radiation in tropical regions leads to greatly increased evaporation
of moisture from forests, grasslands, and bodies of water. As a result, tropical regions normally receive more precipitation than do other areas of the earth.

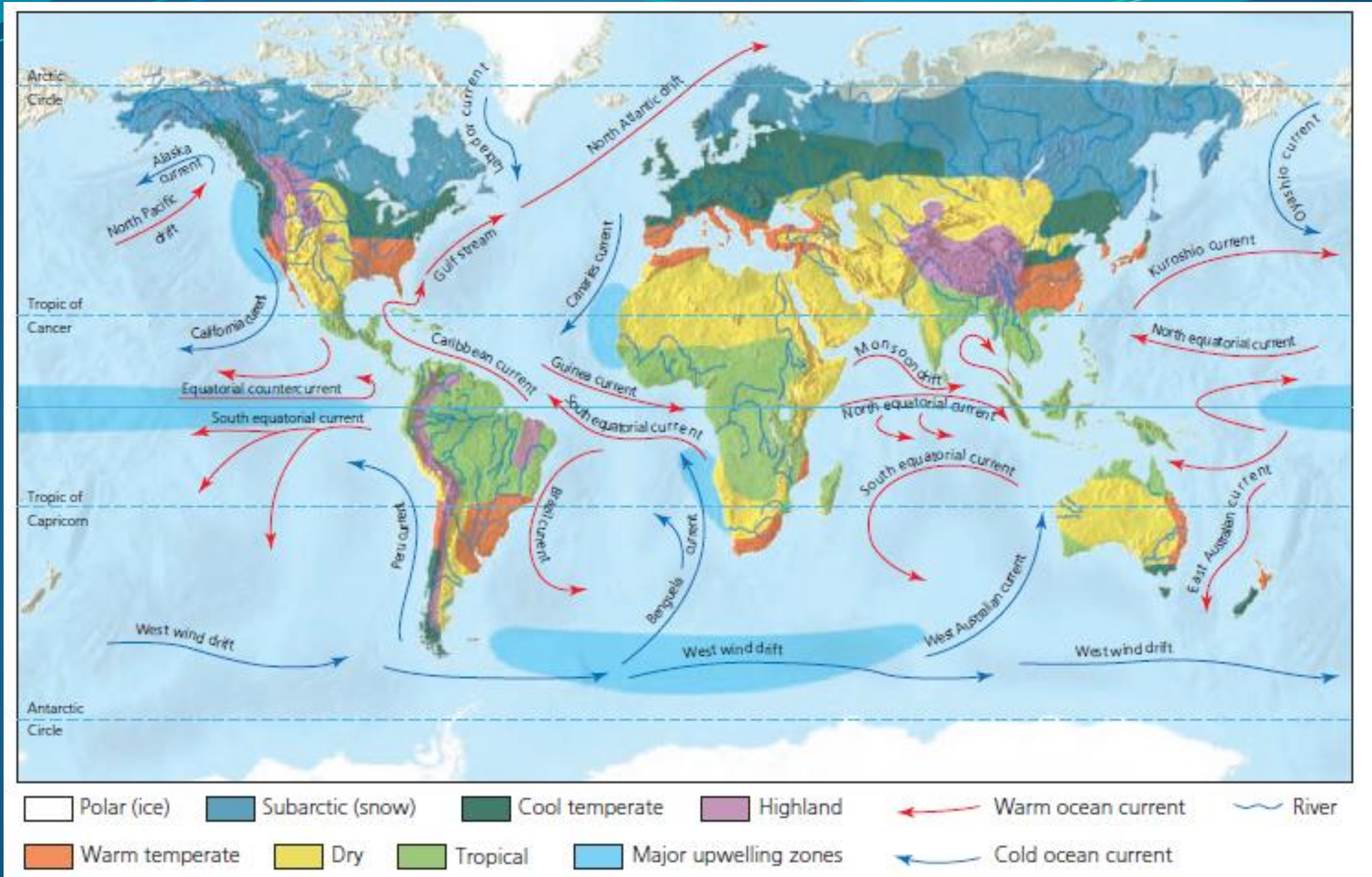
Climate and Biodiversity

2- *Rotation of the earth on its axis*. As the earth rotates around its axis, the equator spins faster than regions to its north and south. As a result, heated air masses, rising above the equator and moving north and south to cooler areas, are deflected to the west or east over different parts of the planet's surface (Figure 7-3, right). The atmosphere over these different areas is divided into huge regions called *cells*, distinguished by the direction of air movement. The differing directions of air movement are called *prevailing winds* (Figure 7-3, left)—major surface winds that blow almost continuously and help to distribute heat and moisture over the earth's surface and to drive ocean currents.

Climate and Biodiversity

3- Properties of air, water, and land. Heat from the sun evaporates ocean water and transfers heat from the oceans to the atmosphere, especially near the hot equator. This evaporation of water creates giant cyclical convection cells that circulate air, heat, and moisture both vertically and from place to place in the atmosphere, as shown in Figure 7-4.

Climate and Biodiversity



CENGAGENOW™ **Active Figure 7-2 Natural capital:** This generalized map of the earth's current climate zones shows the major ocean currents and upwelling areas (where currents bring nutrients from the ocean bottom to the surface). *See an animation based on this figure at* CengageNOW. **Question:** Based on this map, what is the general type of climate where you live?

Climate and Biodiversity

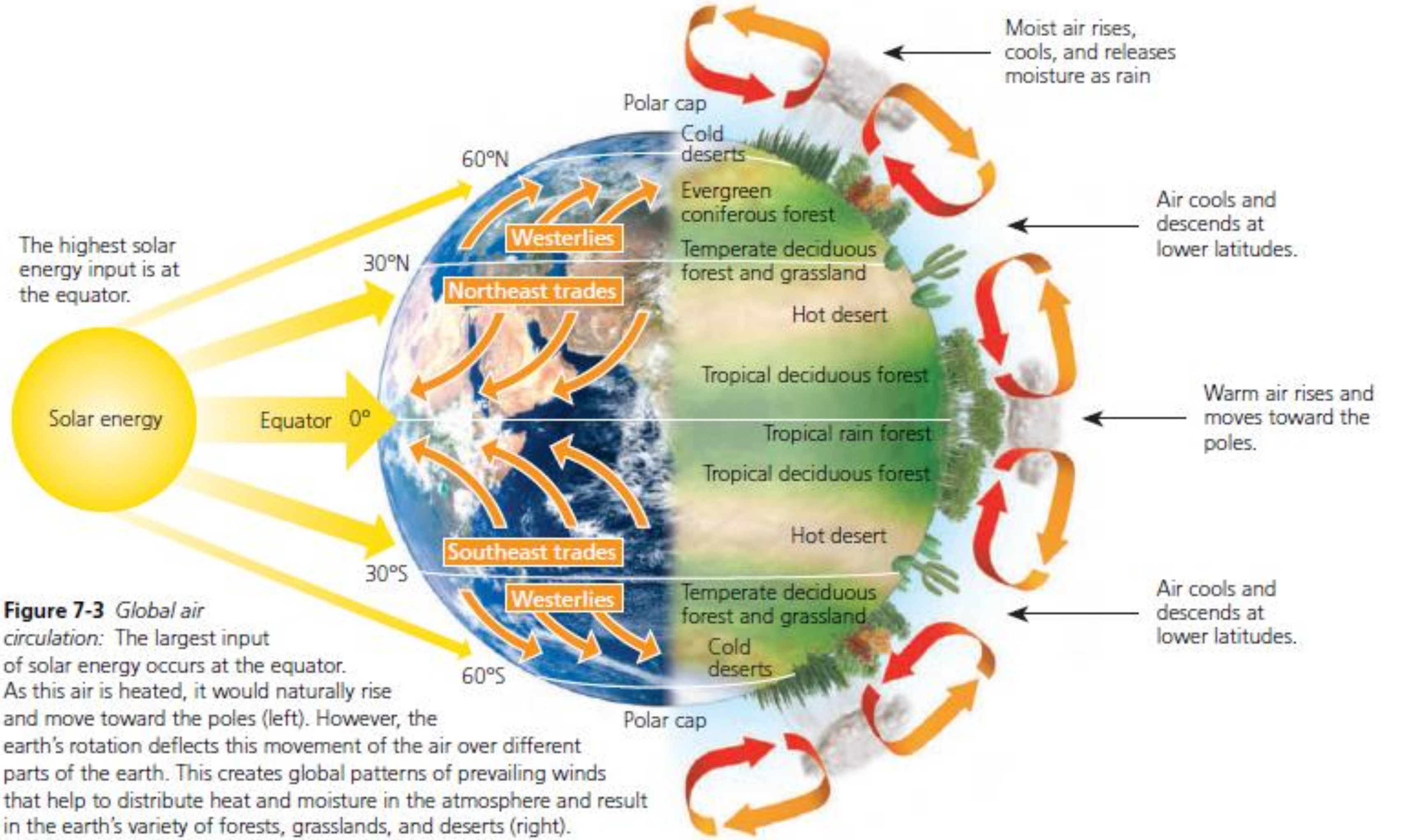


Figure 7-3 *Global air circulation:* The largest input of solar energy occurs at the equator. As this air is heated, it would naturally rise and move toward the poles (left). However, the earth's rotation deflects this movement of the air over different parts of the earth. This creates global patterns of prevailing winds that help to distribute heat and moisture in the atmosphere and result in the earth's variety of forests, grasslands, and deserts (right).

Climate and Biodiversity

Water also moves vertically in the oceans as denser water sinks while less dense water rises. This creates a connected loop of deep and shallow ocean currents (which are separate from those shown in Figure 7-2). This loop acts somewhat like a **giant conveyer belt** that moves heat to and from the deep sea and transfers warm and cold water between the tropics and the poles (Figure 7-5).

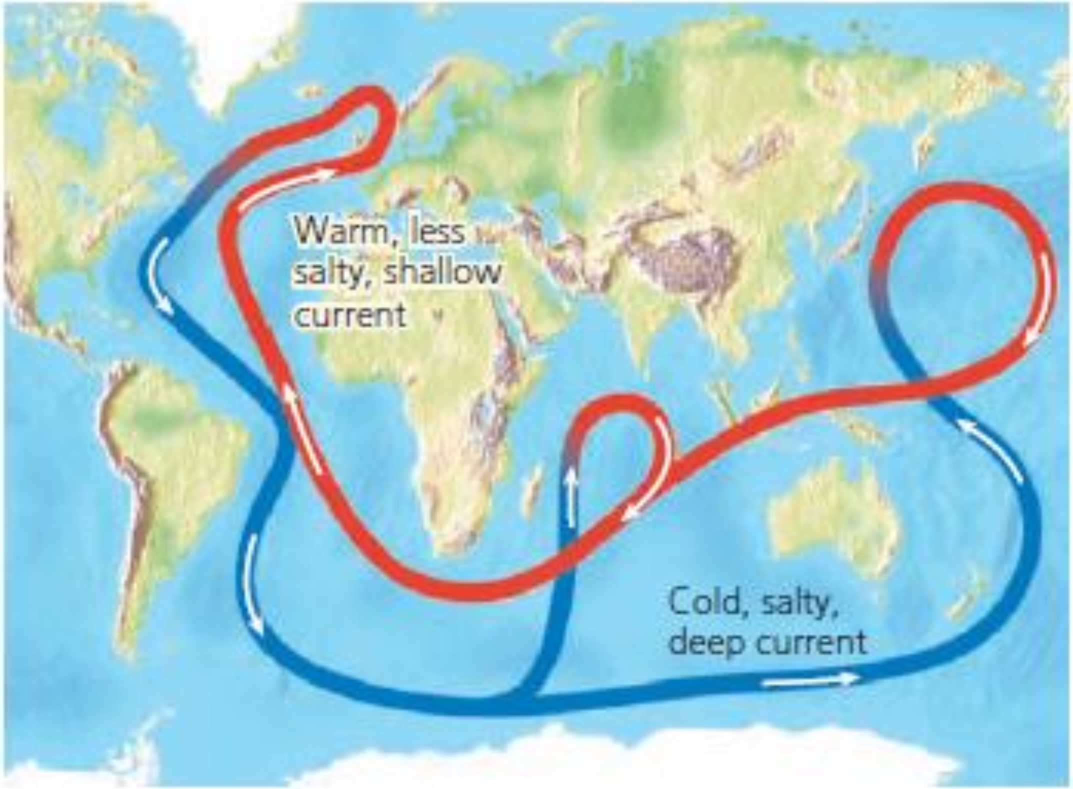


Figure 7-5 *Connected deep and shallow ocean currents:* A connected loop of shallow and deep ocean currents transports warm and cool water to various parts of the earth. This loop, which rises in some areas and falls in others, results when ocean water in the North Atlantic near Iceland is dense enough (because of its salt content and cold temperature) to sink to the ocean bottom, flow southward, and then move eastward to well up in the warmer Pacific. A shallower return current, aided by winds, then brings warmer, less salty, and thus less dense water to the Atlantic. This water then cools and sinks to begin this extremely slow cycle again. **Question:** How do you think this loop affects the climates of the coastal areas around it?

Climate and Biodiversity

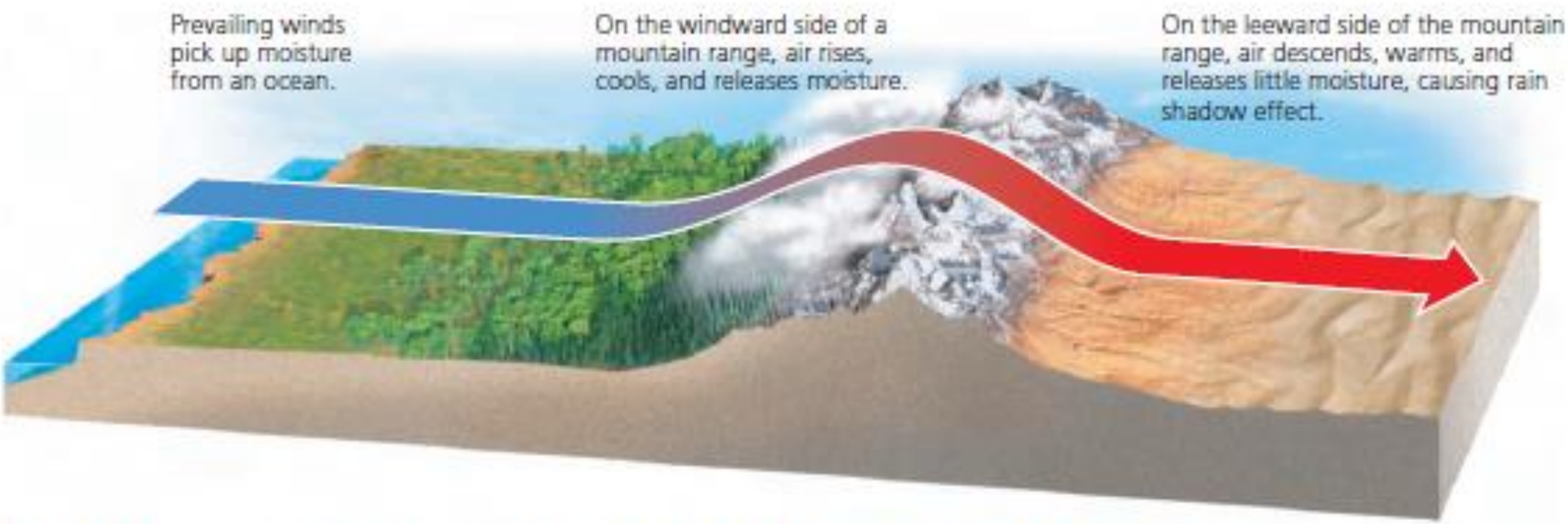


Figure 7-6 The *rain shadow effect* is a reduction of rainfall and loss of moisture from the landscape on the side of mountains facing away from prevailing surface winds. Warm, moist air in onshore winds loses most of its moisture as rain and snow that fall on the windward slopes of a mountain range. This leads to semiarid and arid conditions on the leeward side of the mountain range and the land beyond. The Mojave Desert in the U.S. state of California and Asia's Gobi Desert were both created by this effect.

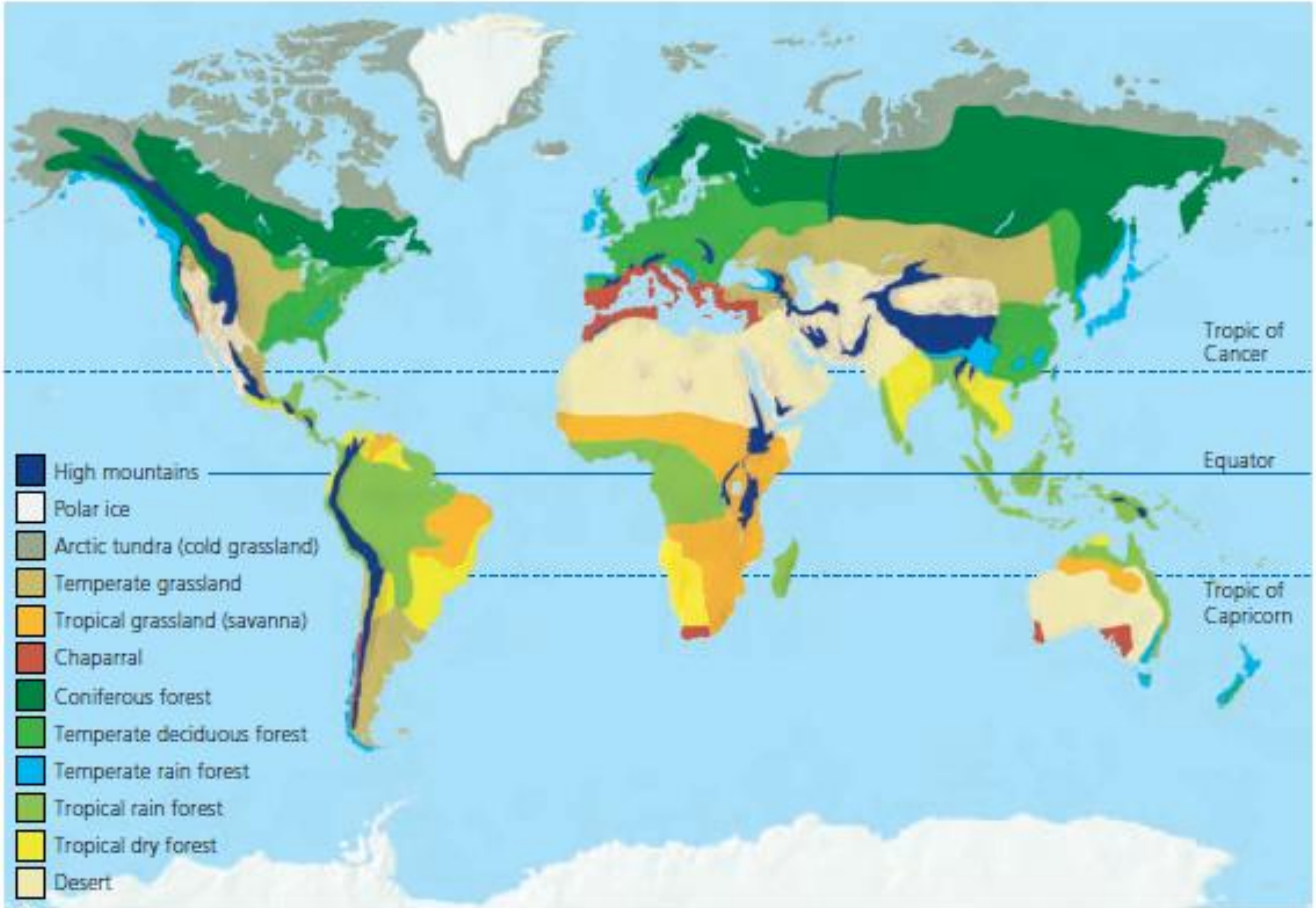
Climate and Biodiversity

How Does Climate Affect the Nature and Location of Biomes?

Differences in climate (Figure 7-2) explain why one area of the earth's land surface is a desert, another a grassland, and another a forest. They can also explain why global air circulation patterns (Figure 7-3) account for different types of deserts, grasslands, and forests.

Figure 7-7 shows how scientists have divided the world into several major **biomes**—large terrestrial regions, each characterized by certain types of climate and dominant plant life.

Climate and Biodiversity



CENGAGENOW™ **Active Figure 7-7** **Natural capital:** The earth's major *biomes*—each characterized by a certain combination of climate and dominant vegetation—result primarily from differences in climate (**Core Case Study**). Each biome contains many ecosystems whose communities have adapted to differences in climate, soil, and other environmental factors. People have removed or altered much of the natural vegetation in some areas for farming, livestock grazing, obtaining timber and fuelwood, mining, and construction of towns and cities. (Figure 3, p. S33, in Supplement 8 shows the major biomes of North America.) *See an animation based on this figure at* CengageNOW. **Question:** If you take away human influences such as farming and urban development, what kind of biome do you live in?

Climate and Biodiversity

Figure 7-8 This diagram shows the generalized effects of elevation (left) and latitude (right) on climate and biomes (Core Case Study). Parallel changes in vegetation type occur when we travel from the equator toward the north pole and from lowlands to mountaintops. **Question:** How might the components of the left diagram change as the earth warms during this century? Explain.

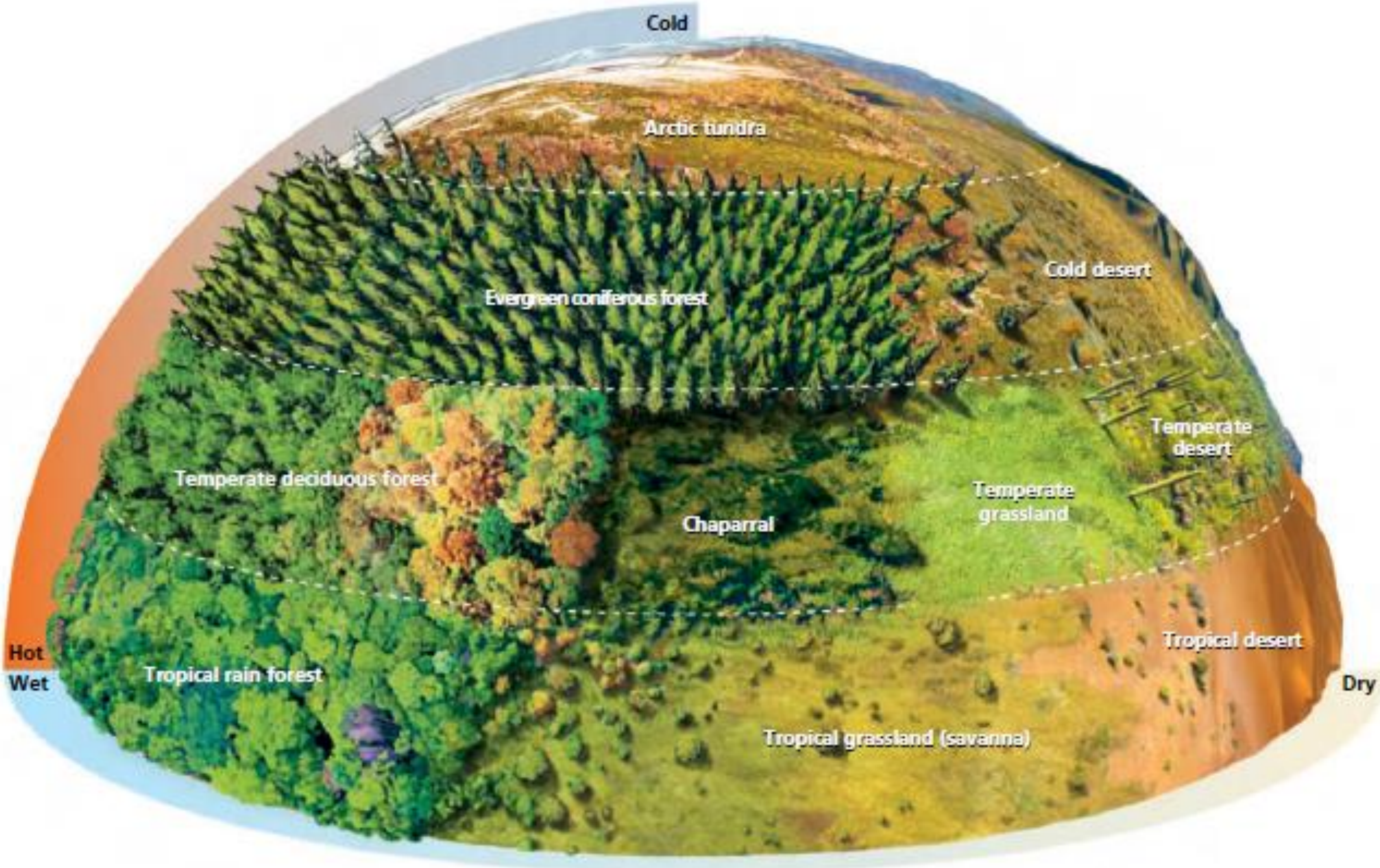


Figure 7-9 **Natural capital:** This diagram demonstrates that average precipitation and average temperature, acting together as limiting factors over a long time, help to determine the type of desert, grassland, or forest in a particular area, and thus the types of plants, animals, and decomposers found in that area (assuming it has not been disturbed by human activities).

There Are Three
Major Types of Deserts

In a *desert*, annual precipitation is low and often scattered unevenly throughout the year. During the day, the baking sun warms the ground and evaporates water from plant leaves and the soil. But at night, most of the heat stored in the ground radiates quickly into the atmosphere. Desert soils have little vegetation and moisture to help store the heat and the skies above deserts are usually clear. This explains why in a desert you may roast during the day but shiver at night.

The lack of vegetation, especially in tropical and polar deserts, makes them vulnerable to sandstorms driven by winds that can spread sand from one area to another. Desert surfaces are also vulnerable to disruption from vehicles such as SUVs (Figure 7-10, top photo).
A combination of low rainfall and varying average temperatures creates tropical, temperate, and cold deserts (Figures 7-9 and 7-10).

Tropical deserts (Figure 7-10) such as the Sahara and the Namib of Africa are hot and dry most of the year (Figure 7-10). They have few plants and a hard, windblown surface strewn with rocks and some sand. They are the deserts we often see in the movies.

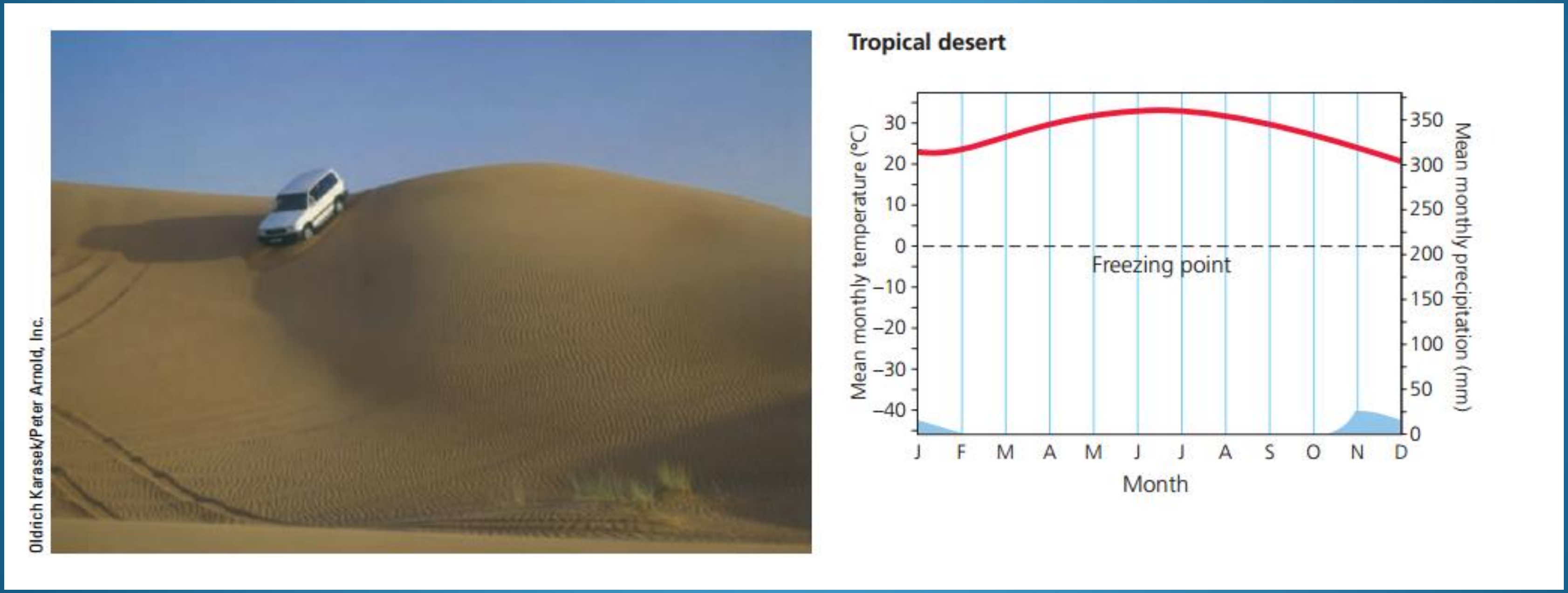
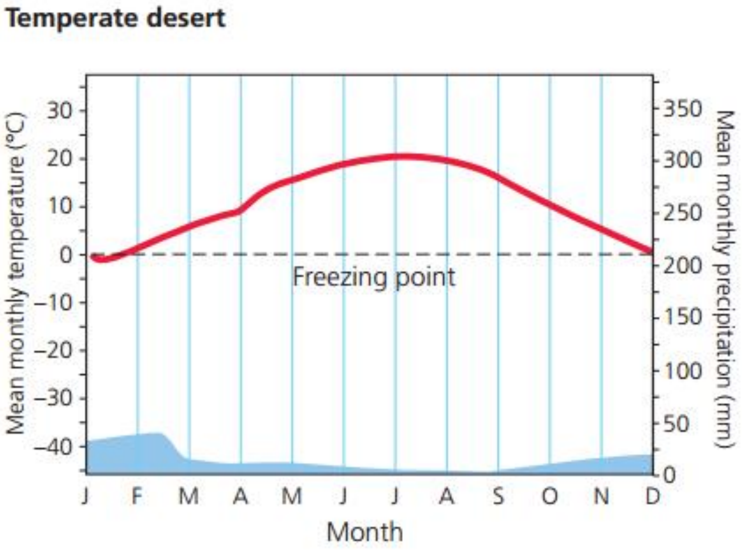


Figure 7-10 These climate graphs track the typical variations in annual temperature (red) and precipitation (blue) in tropical, temperate, and cold deserts. Top photo: a *tropical desert* in the United Arab Emirates, in which a sport utility vehicle (SUV) participates in a popular but environmentally destructive SUV rodeo. Center photo: a *temperate desert* in southeastern California, with saguaro cactus, a prominent species in this ecosystem. Bottom photo: a *cold desert*, Mongolia's Gobi Desert, where Bactrian camels live. **Question:** What month of the year has the highest temperature and the lowest rainfall for each of the three types of deserts?

In ***temperate deserts*** (Figure 7-10, center photo) such as the Sonoran Desert in southeastern California, southwestern Arizona, and northwestern Mexico, daytime temperatures are high in summer and low in winter and there is more precipitation than in tropical deserts (Figure 7-10, center graph). The sparse vegetation consists mostly of widely dispersed, drought-resistant shrubs and cacti or other succulents adapted to the lack of water and temperature variations.



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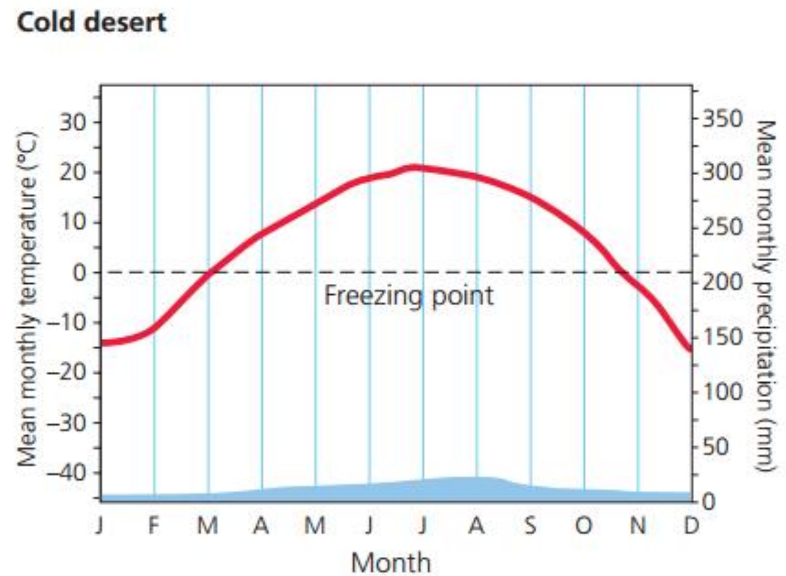
In ***cold deserts*** such as the Gobi Desert in Mongolia, vegetation is sparse (Figure 7-10). Winters are cold, summers are warm or hot, and precipitation is low (Figure 7-10). Desert plants and animals have adaptations that help them to stay cool and to get enough water to survive.



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Desert ecosystems are fragile. Their soils take from decades to hundreds of years to recover from disturbances such as off-road vehicle traffic (Figure 7-10, top photo). This is because deserts have slow plant growth, low species diversity, slow nutrient cycling (due to low bacterial activity in the soils), and very little water. Also, off-road vehicle traffic in deserts can destroy the habitats for a variety of animals that live underground in this biome.

There Are Three Major Types of Grasslands

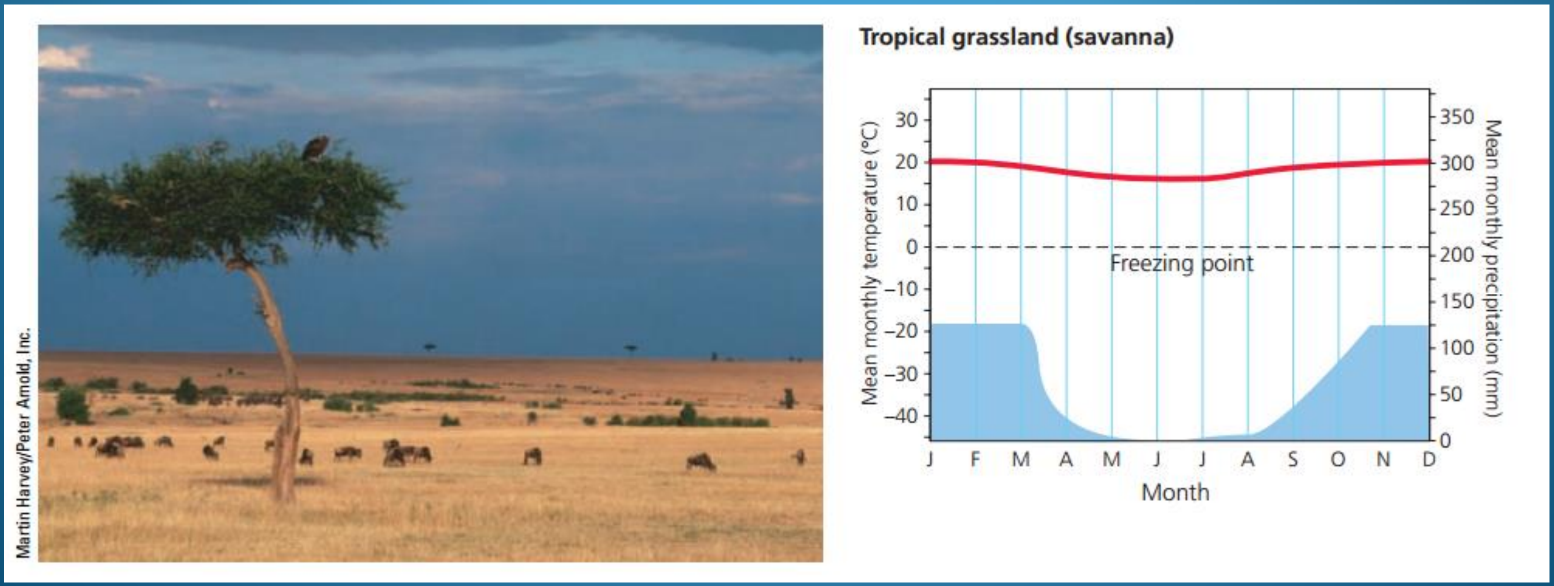
Grasslands occur mostly in the interiors of continents in areas that are too moist for deserts to form and too dry for forests to grow (Figure 7-7). Grasslands persist because of a combination of seasonal drought, grazing by large herbivores, and occasional fires—all of which keep shrubs and trees from growing in large numbers.

The three main types of grassland—**tropical, temperate, and cold (arctic tundra)**—result from combinations of low average precipitation and varying average temperatures (Figures 7-9 and 7-11).

Note the locations in Figure 7-7 of large areas of tropical grasslands in South America and Africa, temperate grasslands in North America and Asia, and cold grasslands (arctic tundra) in far northern areas.

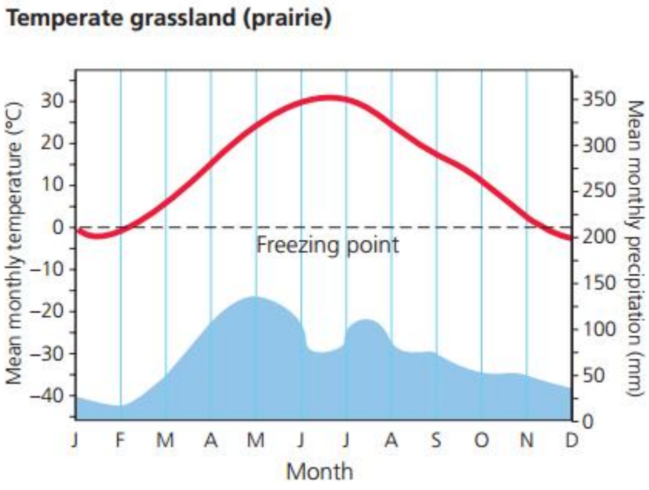
One type of tropical grassland, called a ***savanna***, contains widely scattered clumps of trees such as acacia (Figure 7-11, top photo), which are covered with thorns that keep some herbivores away. This biome usually has warm temperatures year-round and alternating dry and wet seasons (Figure 7-11, top graph).

Tropical savannas in East Africa are home to *grazing* (mostly grass-eating) and *browsing* (twig- and leafnibbling) hoofed animals, including wildebeests (Figure 7-11, top photo), gazelles, zebras, giraffes, and antelopes, as well as their predators such as lions, hyenas, and humans. Herds of these grazing and browsing animals migrate to find water and food in response to seasonal and year-to-year variations in rainfall (Figure 7-11, blue region in top graph) and food availability. Savanna plants, like hose in deserts, are adapted to survive drought and extreme heat; many have deep roots that can tap into groundwater.



In a ***temperate grassland***, winters can be bitterly cold, summers are hot and dry, and annual precipitation is fairly sparse and falls unevenly throughout the year (Figure 7-11, center graph). Because the aboveground parts of most of the grasses die and decompose each year, organic matter accumulates to produce a deep, fertile topsoil. This topsoil is held in place by a thick network of the drought-tolerant grasses' intertwined roots (unless the topsoil is plowed up, which exposes it to being blown away by high winds found in these biomes). The natural grasses are also adapted to fires that burn the plant parts above the ground but do not harm the roots, from which new grass can grow.

Two types of temperate grasslands are the *short-grass prairies* (Figure 7-11, center photo) and the *tall-grass prairies* of the mid-western and western areas of the United States and Canada (which get more rain).



In all prairies, winds blow almost continuously and evaporation is rapid, often leading to fires in the summer and fall. This combination of winds and fires helps maintain such grasslands by hindering tree growth and adding ash to the soil.

Many of the world's natural temperate grasslands have been converted to farmland, because their fertile soils are useful for growing crops (Figure 7-12) and grazing cattle.

Cold grasslands, or *arctic tundra* (Russian for "marshy plain"), lie south of the arctic polar ice cap (Figure 7-7).

During most of the year, these treeless plains are bitterly cold (Figure 7-11, bottom graph), swept by frigid winds, and covered with ice and snow. Winters are long with short days, and scant precipitation falls mostly as snow.

Under the snow, this biome is carpeted with a thick, spongy mat of low-growing plants, primarily grasses, mosses, lichens, and dwarf shrubs (Figure 7-11, bottom photo). Trees or tall plants cannot survive in the cold and windy tundra because they would lose too much of their heat. Most of the annual growth of the tundra's plants occurs during the 7- to 8-week summer, when the sun shines almost around the clock.

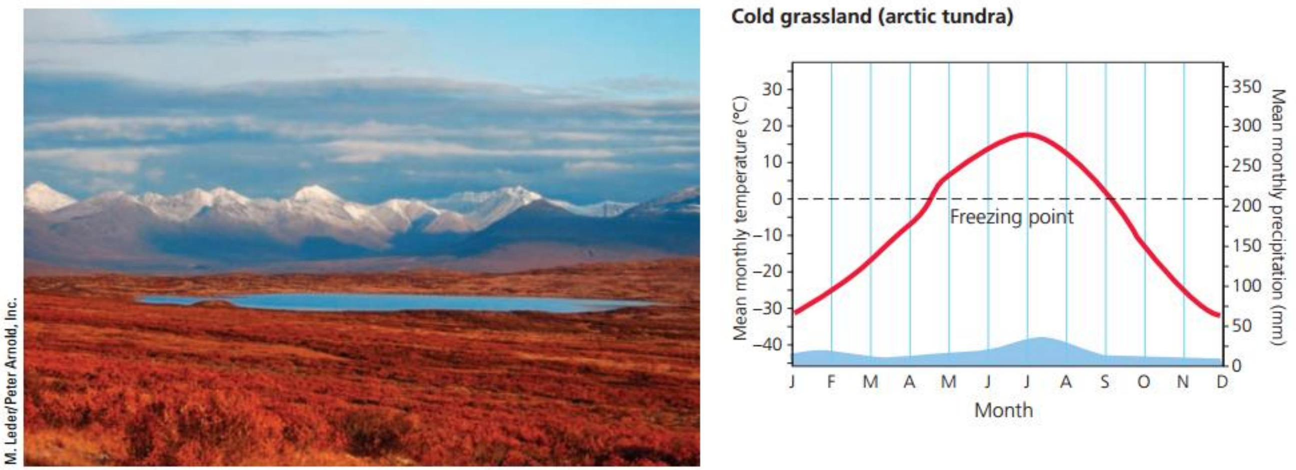


Figure 7-11 These climate graphs track the typical variations in annual temperature (red) and precipitation (blue) in tropical, temperate, and cold (arctic tundra) grasslands. Top photo: *savanna* (*tropical grassland*) in Maasai Mara National Park in Kenya, Africa, with wildebeests grazing. Center photo: *prairie* (*temperate grassland*) near East Glacier Park in the U.S. state of Montana, with wildflowers in bloom. Bottom photo: *arctic tundra* (*cold grassland*) in autumn in the U.S. state of Alaska (see also Figure 7-1, bottom). **Question:** What month of the year has the highest temperature and the lowest rainfall for each of the three types of grassland?

One outcome of the extreme cold is the formation of **permafrost**, underground soil in which captured water stays frozen for more than 2 consecutive years.

During the brief summer, the permafrost layer keeps melted snow and ice from draining into the ground. As a consequence, many shallow lakes, marshes, bogs, ponds, and other seasonal wetlands form when snow and frozen surface soil melt on the waterlogged tundra (Figure 7-1, bottom photo). Hordes of mosquitoes, black flies, and other insects thrive in these shallow surface pools. They serve as food for large colonies of migratory birds (especially waterfowl) that return from the south to nest and breed in the bogs and ponds. Animals in this biome survive the intense winter cold through adaptations such as thick coats of fur (arctic wolf, arctic fox, and musk oxen) and feathers (snowy owl) and living underground (arctic lemming). In the summer, caribou migrate to the tundra to graze on its vegetation.

Tundra is a fragile biome. Most tundra soils formed about 17,000 years ago when glaciers began retreating after the last Ice Age (see Figure 4-9, p. 89). These soils usually are nutrient poor and have little detritus. Because of the short growing season, tundra soil and vegetation recover very slowly from damage or disturbance. Human activities in the arctic tundra—mostly on and around oil drilling sites, pipelines, mines, and military bases—leave scars that persist for centuries.

Another type of tundra, called *alpine tundra*, occurs above the limit of tree growth but below the permanent snow line on high mountains (Figure 7-8, left).

The vegetation is similar to that found in arctic tundra, but it receives more sunlight than arctic vegetation gets. During the brief summer, alpine tundra can be covered with an array of beautiful wildflowers.

In some areas, especially in coastal regions that border on deserts, we find fairly small patches of a biome known as ***temperate shrubland* or *chaparral*** (Figure 7-7). It consists mostly of dense growths of low-growing evergreen shrubs and occasional small trees with leathery leaves that reduce evaporation. This biome is found along coastal areas of southern California in the United States, the Mediterranean Sea, central Chile, southern Australia, and southwestern Africa.

People like living in this biome because of its moderate, sunny climate with mild, wet winters and long, warm, and dry summers. As a result, many people live in such areas and have modified this biome significantly.

There Are Three Major Types of Forests

Forests are lands dominated by trees. The three main types of forest—*tropical, temperate,* and *cold* (northern coniferous, or boreal)—result from combinations of varying precipitation levels and varying average temperatures (Figures 7-9).

Tropical rain forests (Figure 7-13, top photo and Figure 7-1, top photo) are found near the equator (Figure 7-7), where hot, moisture-laden air rises and dumps its moisture (Figure 7-3). These lush forests have year round, uniformly warm temperatures, high humidity, and almost daily heavy rainfall (Figure 7-13, top graph).

This fairly constant warm and wet climate is ideal for a wide variety of plants and animals. These forests are often called *jungle*, but that word refers to the thickest and most dense parts of a tropical rain forest.

Figure 7-14 (p. 161) shows some of the components and food web interactions in these extremely diverse ecosystems. Tropical rain forests are dominated by *broadleaf evergreen plants*, which keep most of their leaves year-round. The tops of the trees form a dense canopy (Figure 7-13, top photo) that blocks most light from reaching the forest floor. For this reason, there is little vegetation on the forest floor. Many of the plants that do live at the ground level have enormous leaves to capture what little sunlight filters through to the dimly lit forest floor.

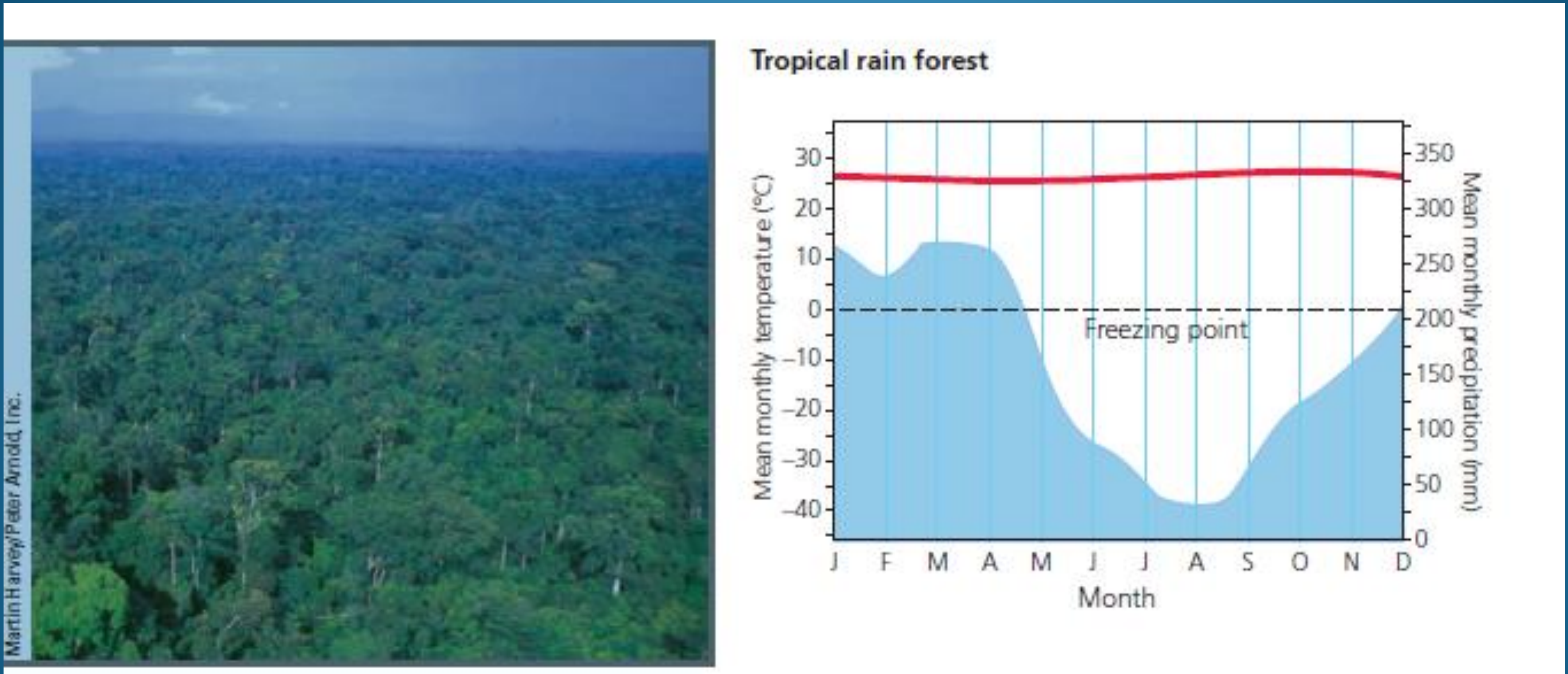


Figure 7-13-the closed canopy of a tropical rain forest in the western Congo Basin of Gabon, Africa.

Figure 7-14- This diagram shows some of the components and interactions in a tropical rain forest ecosystem. When these organisms die, decomposers break down their organic matter into minerals that plants use. Colored arrows indicate transfers of matter and energy between producers; primary consumers (herbivores); secondary, or higher level, consumers (carnivores); and decomposers. Organisms are not drawn to scale. See an animation based on this figure at CengageNOW.

Some trees are draped with vines (called lianas) that reach for the treetops to gain access to sunlight. Once up into the canopy, the vines grow from one tree to another, providing walkways for many species living there. When a large tree is cut down, its network of lianas can pull down other trees.

Tropical rain forests have a very high net primary productivity. They are teeming with life and possess incredible biological diversity. Although tropical rain forests cover only about 2% of the earth's land surface, ecologists estimate that they contain at least half of the earth's known terrestrial plant and animal species. For example, a single tree in these forests may support several thousand different insect species.

Plants from tropical rain forests are a source of chemicals used as blueprints for making most of the world's prescription drugs.

Figure 7-15- This diagram illustrates the stratification of specialized plant and animal niches in a *tropical rain forest*. Filling such specialized niches enables species to avoid or minimize competition for resources and results in the coexistence of a great variety of species.

Temperate deciduous forests such as the one shown in Figure 7-13, center photo, grow in areas with moderate average temperatures that change significantly with the seasons. These areas have long, warm summers, cold but not too severe winters, and abundant precipitation, often spread fairly evenly throughout the year (Figure 7-13, center graph).

This biome is dominated by a few species of *broadleaf deciduous trees* such as oak, hickory, maple, poplar, and beech. They survive cold winters by dropping their leaves in the fall and becoming dormant through the winter (see Photo 1 in the Detailed Contents). Each spring, they grow new leaves whose colors change in the fall into an array of reds and golds before the leaves drop, as shown in Figure 7-1, middle (**Core Case Study**).

Because they have cooler temperatures and fewer decomposers, these forests have a slower rate of decomposition than tropical forests have. As a result, they accumulate a thick layer of slowly decaying leaf litter, which becomes a storehouse of nutrients. On a global basis, this biome has been disturbed by human activity more than any other terrestrial biome. However, within 100–200 years, areas cleared of their trees can return to a deciduous forest through secondary ecological succession
(see Figure 5-20 p. 120).

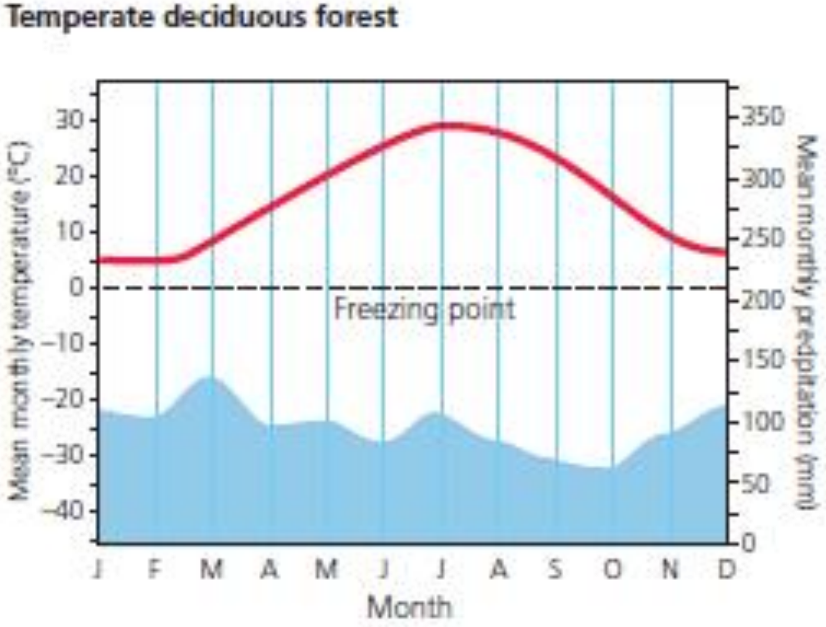


Figure 7-13: a *temperate deciduous forest* in the U.S. state of Rhode Island during the fall. (Photo 1 in the Detailed Contents shows this same area of forest during winter when its trees have lost their leaves.)

Evergreen coniferous forests (Figure 7-13, bottom photo) are also called *boreal forests* and *taigas* (“TIEguhs”). These cold forests are found just south of the arctic tundra in northern regions across North America, Asia, and Europe (Figure 7-7) and above certain altitudes in the Sierra Nevada and Rocky Mountain ranges of the United States. In this subarctic climate, winters are long, dry, and extremely cold; in the northernmost taigas, winter sunlight is available only 6–8 hours per day. Summers are short, with cool to warm temperatures (Figure 7-13, bottom graph), and the sun shines up to 19 hours a day. Most boreal forests are dominated by a few species of *coniferous* (cone-bearing) *evergreen trees* such as spruce, fir, cedar, hemlock, and pine that keep most of their leaves year-round.

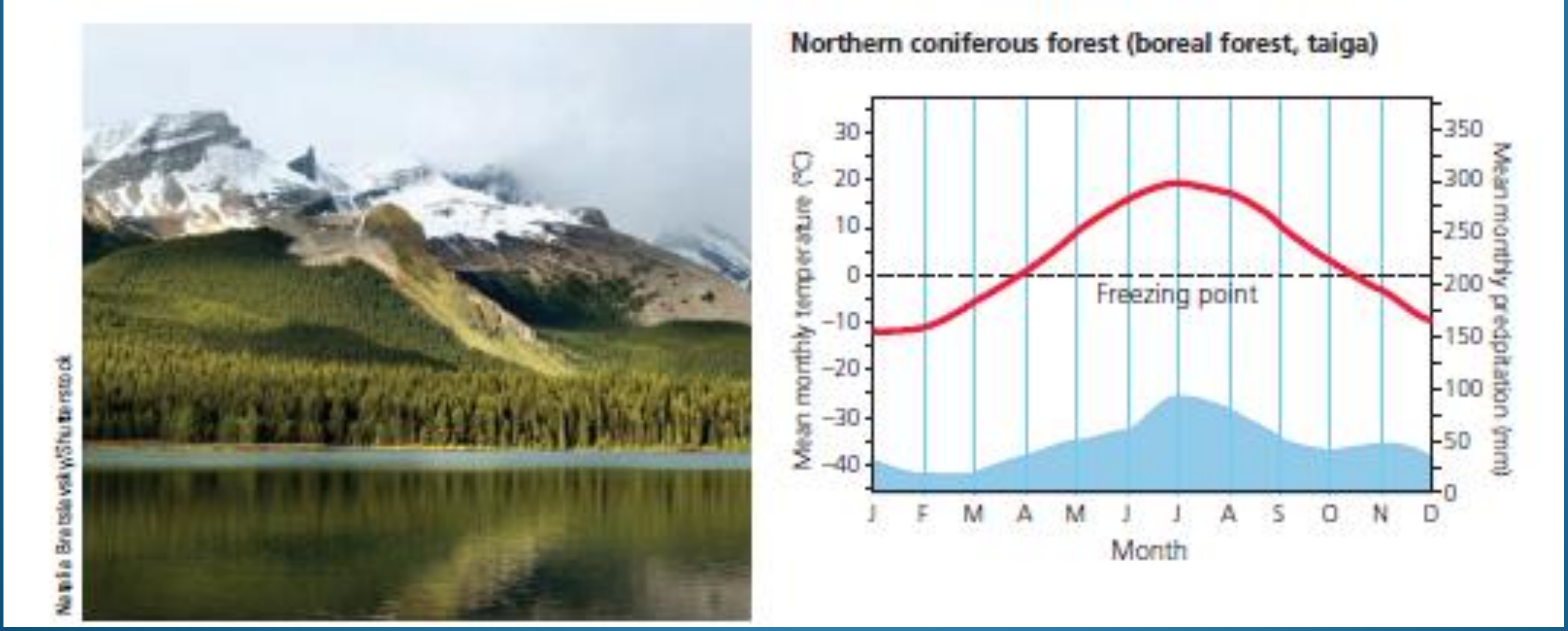


Figure 7-13: a *northern coniferous forest* in Canada’s Jasper National Park.

Most of these species have small, needle-shaped, wax-coated leaves that can withstand the intense cold and drought of winter, when snow blankets the ground. Such trees are ready to take advantage of the brief summers because they need not take time to grow new needles. Plant diversity is low because few species can survive the winters when soil moisture is frozen.

Beneath the stands of trees is a deep layer of partially decomposed conifer needles. Decomposition is slow because of low temperatures, the waxy coating on the needles, and high soil acidity. The decomposing conifer needles make the thin, nutrient-poor topsoil acidic and prevent most other plants (except certain shrubs) from growing on the forest floor.

Coastal coniferous forests or ***temperate rain forests*** (Figure 7-16) are found in scattered coastal temperate areas with ample rainfall or moisture from dense ocean fogs. Dense stands of these forests with large conifers such as Sitka spruce, Douglas fir, and redwoods once dominated undisturbed areas of these biomes along the coast of North America, from Canada to northern California in the United States.

Figure 7-16 Temperate rain forest in Olympic National Park in the U.S. state of Washington.

How Do Communities and Ecosystems Respond to Changing Environmental Conditions?

Communities and Ecosystems Change over Time: Ecological Succession

The types and numbers of species in biological communities and ecosystems change in response to changing environmental conditions such as a fires, volcanic eruptions, climate change, and the clearing of forests to plant crops. The normally gradual change in species composition in a given area is called **ecological succession**.

Ecologists recognize two main types of ecological succession, depending on the conditions present at the beginning of the process. **Primary ecological succession** involves the gradual stablishment of biotic communities in lifeless areas where there is no soil in a terrestrial ecosystem or no bottom sediment in an aquatic ecosystem. Examples include bare rock exposed by a retreating glacier (Figure 5-19), newly cooled lava, an abandoned highway or parking lot, and a newly created shallow pond or reservoir. Primary succession usually takes hundreds to thousands of years because of the need to build up fertile soil or aquatic sediments to provide the nutrients needed to establish a plant community.

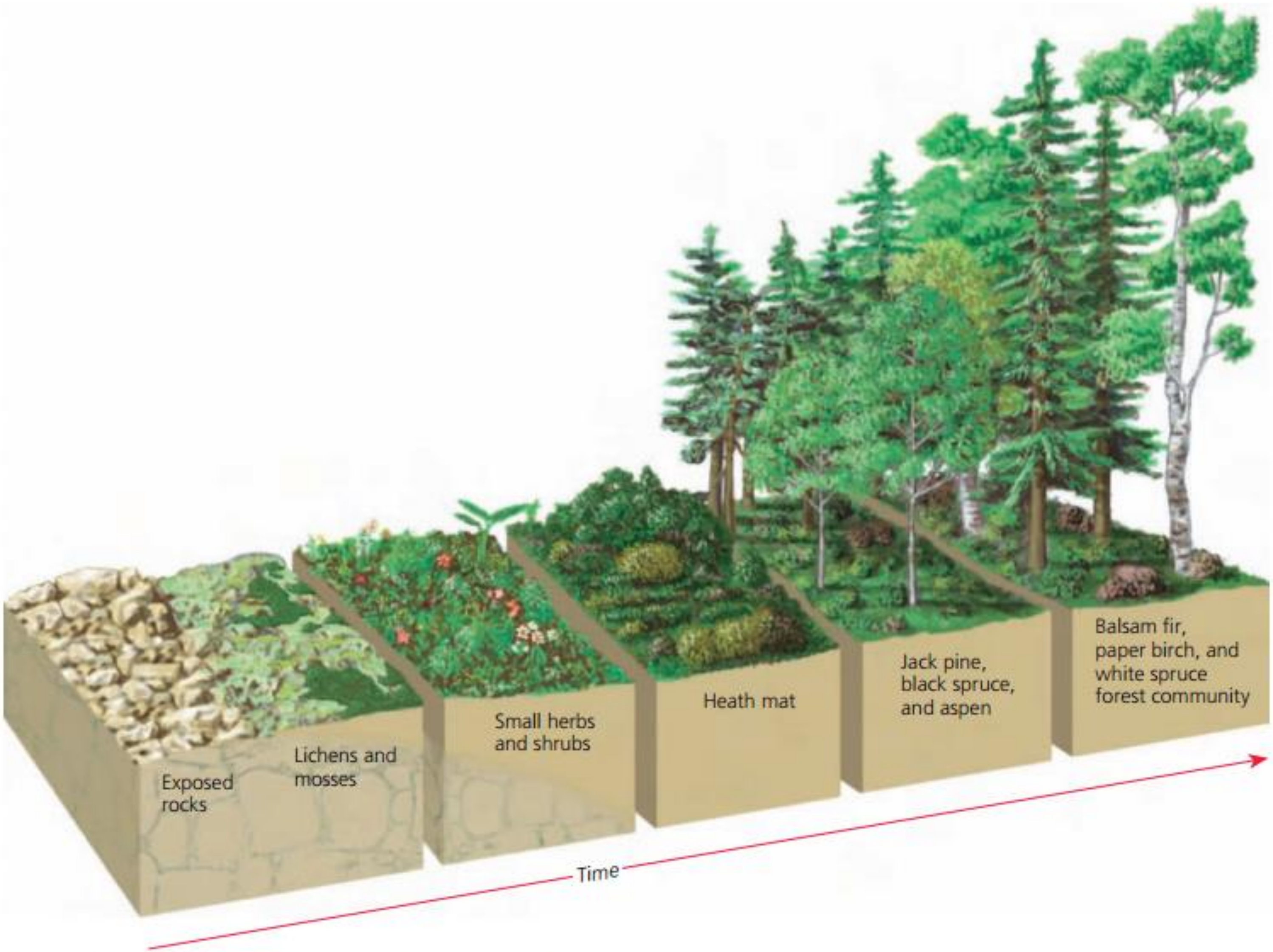


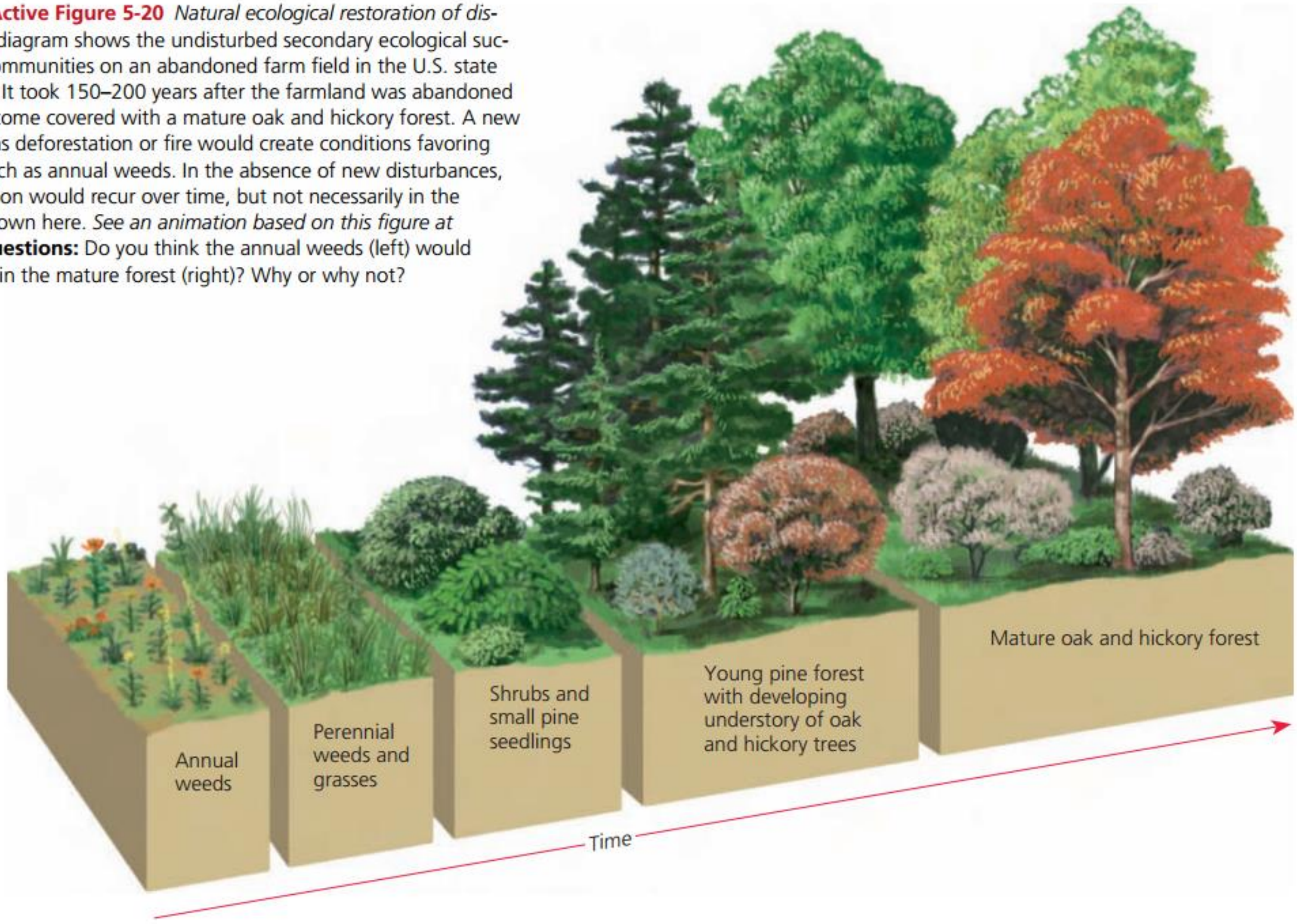
Figure 5-19 *Primary ecological succession:* Over almost a thousand years, these plant communities developed, starting on bare rock exposed by a retreating glacier on Isle Royal, Michigan (USA) in northern Lake Superior. The details of this process vary from one site to another. **Question:** What are two ways in which lichens, mosses, and plants might get started growing on bare rock?

How Do Communities and Ecosystems Respond to Changing Environmental Conditions?

The other, more common type of ecological succession is called **secondary ecological succession**, in which a series of communities or ecosystems with different species develop in places containing soil or bottom sediment. This type of succession begins in an area where an ecosystem has been disturbed, removed, or destroyed, but some soil or bottom sediment remains.

Candidates for secondary succession include abandoned farmland (Figure 5-20), turned or cut forests (Figure 5-21), heavily polluted streams, and land that has been flooded. Because some soil or sediment is present, new vegetation can begin to germinate, usually within a few weeks. It begins with seeds already in the soil and seeds imported by wind or in the droppings of birds and other animals.

CENGAGE**NOW**™ **Active Figure 5-20** *Natural ecological restoration of disturbed land:* This diagram shows the undisturbed secondary ecological succession of plant communities on an abandoned farm field in the U.S. state of North Carolina. It took 150–200 years after the farmland was abandoned for the area to become covered with a mature oak and hickory forest. A new disturbance such as deforestation or fire would create conditions favoring pioneer species such as annual weeds. In the absence of new disturbances, secondary succession would recur over time, but not necessarily in the same sequence shown here. *See an animation based on this figure at* CengageNOW. **Questions:** Do you think the annual weeds (left) would continue to thrive in the mature forest (right)? Why or why not?



Jim Peacoe/U.S. National Park Service

Figure 5-21 These young lodgepole pines growing around standing dead trees after a 1998 forest fire in Yellowstone National Park are an example of secondary ecological succession.