3

BIODIVERSITY AND CONSERVATION

KEY CONCEPTS

- Factors such as the earth's rotation, atmospheric and ocean movements, and topographic features influence climate and global distribution of biomes.
- Abiotic factors such as dissolved oxygen, sunlight, salinity, and nutrients needed for photosynthesis, as well as temperature, regulate biodiversity in aquatic ecosystems.
- Terrestrial ecosystems provide vital ecological services such as providing oxygen, storing atmospheric carbon dioxide, filtering water, reducing soil erosion, influencing climate, absorbing and releasing water, and providing habitat space for numerous organisms.
- Coastal zones provide vital ecosystem services including nutrient cycling, moderate climate, absorbing carbon dioxide, providing habitats and nursery areas for many organisms, and reducing the impacts of storm surges.
- Both terrestrial and aquatic ecosystems provide humans with vital economic resources such as food resources, energy resources, medicines, building materials, and areas for recreation.
- The increasing human population is stressing our global ecosystems and depleting biodiversity by creating habitat loss, habitat fragmentation, introducing invasive species, pollution, and causing climate change.
- Current practices that sustain human activities need to be modified so that biodiversity in both terrestrial and aquatic ecosystems can be preserved.

Biodiversity and conservation are discussed in depth in *Living in the Environment*, Chapters 7–11, in both the 16th and 17th editions.

Key Vocabulary

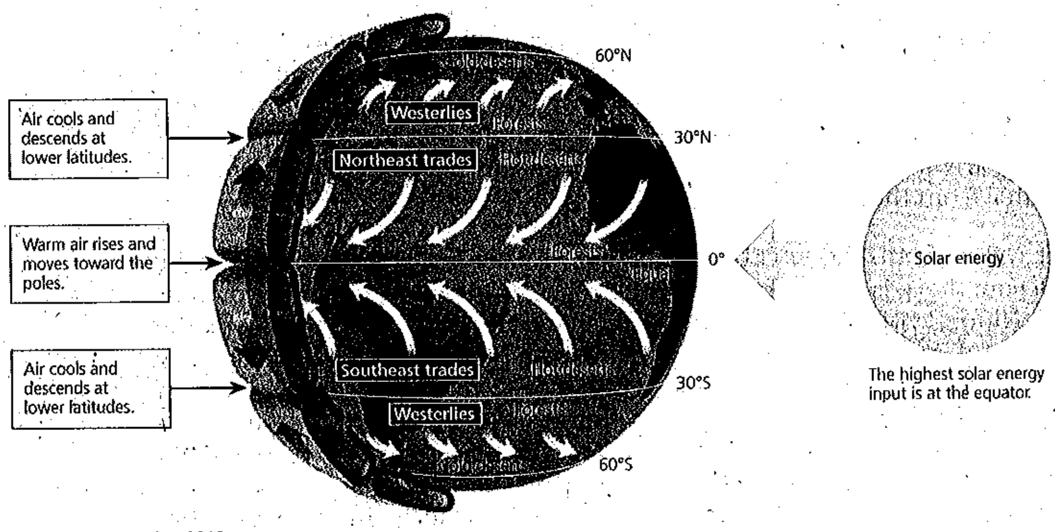
- abyssal
- background extinction
- bathyl
- benthos
- clear-cutting
- climate
- Coriolis effect
- cultural eutrophication
- currents
- dissolved oxygen
- El Niño
- endangered species
- estuaries
- euphotic
- eutrophic
- greenhouse effect
- habitat fragmentation
- inland wetlands
- intertidal zone
- La Niña
- limnetic
- littoral
- marine vs. freshwater biomes
- mass extinction
- nekton
- old-growth forests
- oligotrophic
- pastures
- permafrost
- plankton
- prevailing winds
- rain shadow effect
- rangelands
- riparian zones
- runoff
- second growth forests
- selective cutting
- source zone
- strip cutting
- thermocline
- threatened species
- transition zone
- turbidity
- upwelling
- watershed
- weather

Weather and Climate: An Introduction

Understanding the factors that influence climate is an integral piece in gaining insight into what dictates terrestrial biodiversity. It is not random or haphazard placement that has led to the global distribution of biomes. Rather it is differences in climatic patterns such as temperature and precipitation that led to the formation of these terrestrial ecosystems such as deserts, grasslands, and forests.

FACTORS THAT INFLUENCE CLIMATE

What is the difference between weather and climate? The **climate** of an ecosystem is that area's general pattern of atmospheric or weather conditions over long periods of time (decades to thousands of years). In contrast, **weather** is the local area's short-term temperature, precipitation, humidity, and other physical conditions of the troposphere measured over hours or days. Terrestrial climates vary across the earth due to patterns in global air circulation and ocean currents that unevenly distribute heat and precipitation. Three main factors affect how heat and moisture from the equator (tropics) are distributed by air circulation patterns to other parts of the earth's surface.



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1. **Properties of air, water, and land**: Solar energy creates continuous evaporation from ocean water, especially at the equator, thereby transferring heat from the oceans to the atmosphere. This creates cyclical convection cells that circulate air, heat, and moisture across the surface of the earth.
2. **Uneven heating of the earth's surface**: Since the shape of the earth is a sphere, solar radiation is not equally distributed across its surface. Sunlight is much more concentrated at the equator where the radiation is more direct, unlike the poles where the radiation enters at an angle and spreads out over a greater surface area. This helps explain why tropical regions along the equator are hot and arctic regions at the poles are cold. The differences in heating from the equator to the poles help create our global wind patterns.
3. **Rotation of the earth on its axis**: As the earth rotates on its axis, heated air masses begin rising above the equator and are deflected to the west or east over different parts of the planet's surface. As you can see in the diagram below, large regions of convection **cells** are created as warm, moist air rises and cools, and the resulting cooler, drier air begins to sink. This helps create our global

prevailing wind patterns that distribute heat and moisture in the atmosphere. Due to the **Coriolis effect,** the earth's rotation causes winds to be deflected to the right (clockwise) in the northern hemisphere and to the left (counterclockwise) in the southern hemisphere.

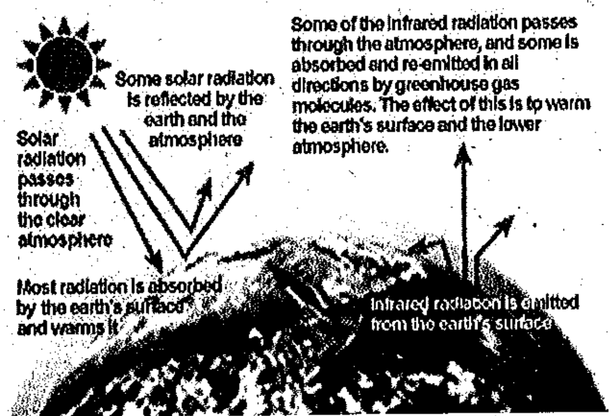
ATMOSPHERE AND OCEAN: INTERACTIONS THAT INFLUENCE CLIMATE

The atmosphere and the ocean are strongly linked as they impact one another. The heat from the ocean impacts atmospheric circulation just as atmospheric winds affect ocean currents. Prevailing winds and the rotation of the earth produce the earth's major oceanic **currents.** Warm-water and cold-water currents are created as the ocean absorbs heat from the atmosphere, primarily occurring in tropical waters. These differences in water temperature **(thermocline)** also create water density differentials that can fuel ocean **upwelling** events. Upwelling occurs when winds blowing along the coast push warmer surface water away from land and draw up deep cold, nutrient-rich water from the bottom to the top.

EL NIÑO – SOUTHERN OSCILLATION (ENSO) Every few years in the Pacific Ocean, there is a disruption of the ocean-atmosphere system known as El Niño. Typically, trade winds push warmer water away from the coast of South America. In El Niño years, trade winds weaken or reverse direction, which pushes warmer water toward the coast of South America and suppresses the thermocline. The result is a decrease in upwelling that causes a reduction in primary productivity by the phytoplankton and therefore a dramatic decline in many fish populations. The changing wind patterns also shift precipitation, causing flooding in some areas, such as Peru, and bringing drought to other areas, such as Brazil and parts of Indonesia. La Niña, which typically follows an El Niño, cools coastal surface water and restores upwelling events. La Niña, in general, has the opposite effects on the ocean-atmosphere system than El Niño. However, it can mean more Atlantic coast hurricanes as well as colder winters in the northeastern United States but warmer, drier winters in the southeastern United States.

RAIN SHADOW EFFECT Large bodies of water can create land and sea breezes because water absorbs and releases heat more slowly than land. Large topographic features also have major impacts on climate as well. As prevailing winds pick up moisture from the ocean and move across land, the moving air mass is forced upward over mountains. As this air mass rises it will cool and release much of its moisture as rain and snow on the windward side of the mountain. On the leeward side the descending air is therefore drier. As this air descends, it warms and picks up moisture from the landscape below, thereby leading to arid and semi-arid conditions on this side of the mountain. This is known as the **rain shadow effect.**

The Greenhouse Effect



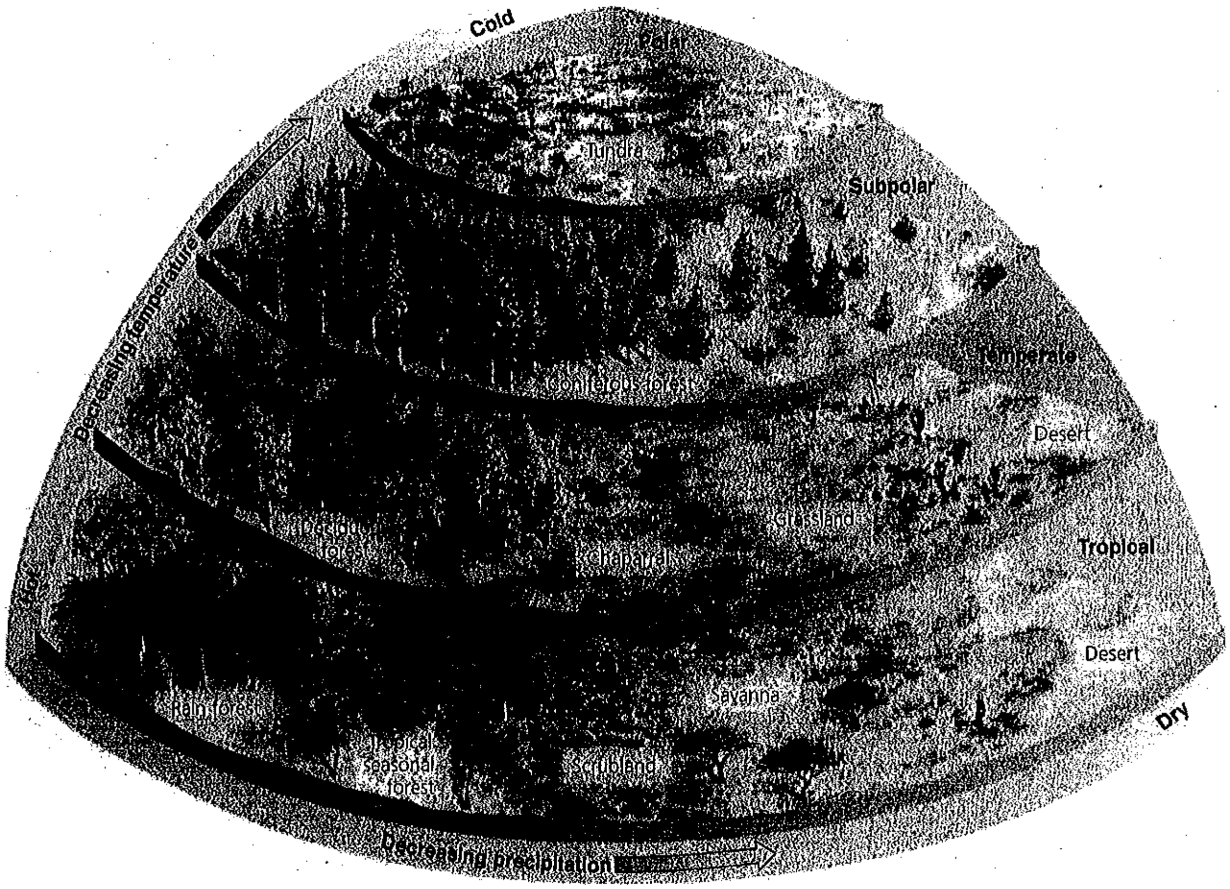
http://www.epa.gov/climatechange/images/greenhouse.jpg

THE GREENHOUSE EFFECT The earth's climate has greatly fluctuated over the last 5 billion years from ice age events to long periods of warming. However, our climate has been relatively stable over the last 2,000 years. According to the EPA, our current global average temperature is approximately 15°C (59°F), but without an atmosphere the average temperature would be only –18°C (0°F). The difference between the natural atmospheric temperature and the temperature we actually experience is accounted for by the warming properties of the earth's atmosphere known as the **greenhouse effect**. Primarily only four naturally produced gases—water vapor, methane, carbon dioxide, and nitrous oxide—help influence the earth's average temperature by significantly contributing to the greenhouse effect. These gases allow incoming, shorter-wavelength UV radiation through the atmosphere but trap outgoing longer-wavelength infrared radiation (heat) being emitted from the earth's surface. They emit even longer infrared radiation (heat) back into the troposphere thereby warming the lower atmosphere. Without these greenhouse gases our planet would be too cold for most living organisms to survive.

EARTH'S BIOMES: TERRESTRIAL DIVERSITY

Biomes are large terrestrial regions characterized by similar climate, soil, plants, and animals regardless of their global locations. Differences in average annual rainfall (precipitation) and temperature help us predict what type of desert, grassland, or forest biome we would see in a given geographical region.

Types of Forest Biomes: Our three main types of forest biomes, tropical, temperate, and taiga, are all dominated by trees. Forests, when compared to other biomes, are areas of high productivity and biodiversity.



Major Types of Grasslands: Grasslands exists in areas where there is too much moisture for desert biomes and too little moisture for forest biomes. Grassland ecosystems are regulated by seasonal drought, occasional fires, and the grazing of herbivores. Typically grasslands are found in the interior of continents. Low average precipitation and various average temperatures produce tropical, temperate, and cold grasslands.

Major Types of Deserts: Desert ecosystems occur in continental interiors where little precipitation is often distributed unevenly throughout the year. This also occurs on the leeward side of large mountain ranges (rain shadow effect). These biomes experience intense heat and evaporation during the day and cooler nights due to rapid heat loss from the little vegetation available to help radiate the heat more slowly.

The Chaparral (Temperate Shrubland): The chaparral biome, also known as a temperate shrubland, is found along the coastal areas of southern California, parts of the Mediterranean, and central Chile. This area is characterized by low-growing evergreen shrubs and occasional small trees. Like grassland ecosystems, plants here are adapted to occasional fires, which encourage seed production in many plant species. Fires can also increase nutrient availability in the soils depending on intensity and duration of the burn.

Type of Forest	Locations	Characteristics
Tropical Rain Forests	Typically found along the equator but also found from the equator to 30°N and 30°S Brazil, Central America, Indonesia, Central Africa	■ year-round consistently warm temperatures, high humidity, and heavy rainfall ■ dominated by broadleaf evergreen plants ■ high primary productivity and biodiversity ■ distinct strata (zones) such as canopy, emergent, sapling, and ground, provide habitat space for the abundance of life ■ poor soil quality due to low concentrations of stored nutrients
Temperate Deciduous Forests	Found between 30° and 60° north and south latitudes Eastern United States, most of Europe	■ moderate temperatures that fluctuate with seasons ■ dominated by a few species of broadleaf deciduous trees such as maple, beech, oak, and hickory ■ trees go dormant in winter by dropping their leaves in the fall ■ slow rate of decomposition of leaves provides abundant leaf litter and nutrients stored in the soil
Taigas (Boreal Forests)	Found just south of the arctic tundra in northern regions of North America (Canada), Asia, and Europe	■ winters are long, dry, and extremely cold ■ dominated by a few species of conifers such as pine, hemlock, cedar, and spruce ■ trees have small, waxy, needleshaped leaves to survive the cold winters ■ plant diversity is low ■ slow decomposition of needles; nutrient poor, acidic soils

Ecological Roles of Mountains: Although mountain ranges are not classified as one of our major biomes, they have dramatic impacts on our ecosystems by

- often providing habitat for many endemic species that are found no where else in the world
- helping to regulate earth's climate due to snow and ice reflecting solar radiation back into space
- melting mountain-top snowpack each spring and summer, providing surface water in streams for use by animals

Type of Grassland	Locations	Characteristics
Tropical Grassland (Savannas)	Largely found in Eastern Africa and also parts of South America and Australia	• warm temperatures and alternating warm and dry seasons (will experience several months of little/no rainfall) • large grazing herbivores such as gazelles, zebras, wildebeests • plants have deep roots to utilize groundwater supplies
Temperate Grasslands (tall-grass and short-grass prairies)	Found in Midwestern and western United States and Canada; also found in parts of South America and Russia	• rainfall determines whether it is a tall-grass or a short-grass prairie (tall-grass prairies receive almost three times as much rain as short-grass) • winters are cold, summers are hot and dry • as grasses die and decompose annually, large amounts of organic matter accumulates in the soil, making this area highly productive for crops • high winds and rapid evaporation promote fires in the summer and fall that eliminate other competing species
Cold Grasslands (arctic tundra)	Found just south of the arctic tundra in northern regions of North America (Canada), Asia, and Europe	• frigid, treeless plains that are covered with snow and ice much of the year • extreme cold forms **permafrost**—underground soil in which captured water stays frozen for more than two consecutive years • vegetation is limited to low-growing grasses, moss, and lichen • animals, such as arctic foxes and wolves, have adaptations such as thick coats of fur to survive the harsh climate

Type of Desert	Locations	Characteristics
Tropical Deserts	Cover much of northern Africa (the Sahara), and parts of the middle east (Saudi Arabia)	■ surface areas have little vegetation and are dominated by rocks and sand that are often blown about by frequent windstorms ■ extremely high daytime temperatures
Temperate Deserts	Found in the southwestern United States (Mojave and Sonoran deserts)	■ receive more precipitation than tropical deserts ■ characterized by patchy drought-resistant shrubs, cacti, and other succulents ■ have high daytime and low nighttime temperatures
Cold Deserts	Areas of the United States known as the Great Basin (Idaho, Utah); Gobi desert in northern China and southern Mongolia	■ vegetation is very sparse ■ winters are extremely cold

AQUATIC LIFE ZONES

Approximately 71% of the earth's surface is covered with saltwater. We divide the saltwater realm into four areas known as the Atlantic, Pacific, Indian, and Arctic oceans. Some basic abiotic factors help influence the presence of life in aquatic systems. These factors include sunlight, dissolved oxygen, and how clear the water is. **Turbidity** is the measure of how cloudy the water is due to suspended sediments or solids and greatly reduces sunlight from reaching photosynthetic organisms. **Salinity**, the concentration of dissolved salts in a given volume of water, also regulates aquatic life. Aquatic ecosystems are therefore divided into two life zones—freshwater and marine.

OCEANS AS NATURAL CAPITAL

The ocean provides us with many vital ecological benefits. We also harvest and utilize the vast resources present in the ocean, providing humans with numerous economic benefits.

ECOLOGICAL BENEFITS

- provides habitats and nursery areas
- moderates climate
- absorbs CO_2
- reduces storm impact (estuaries, mangroves)

ECONOMIC BENEFITS

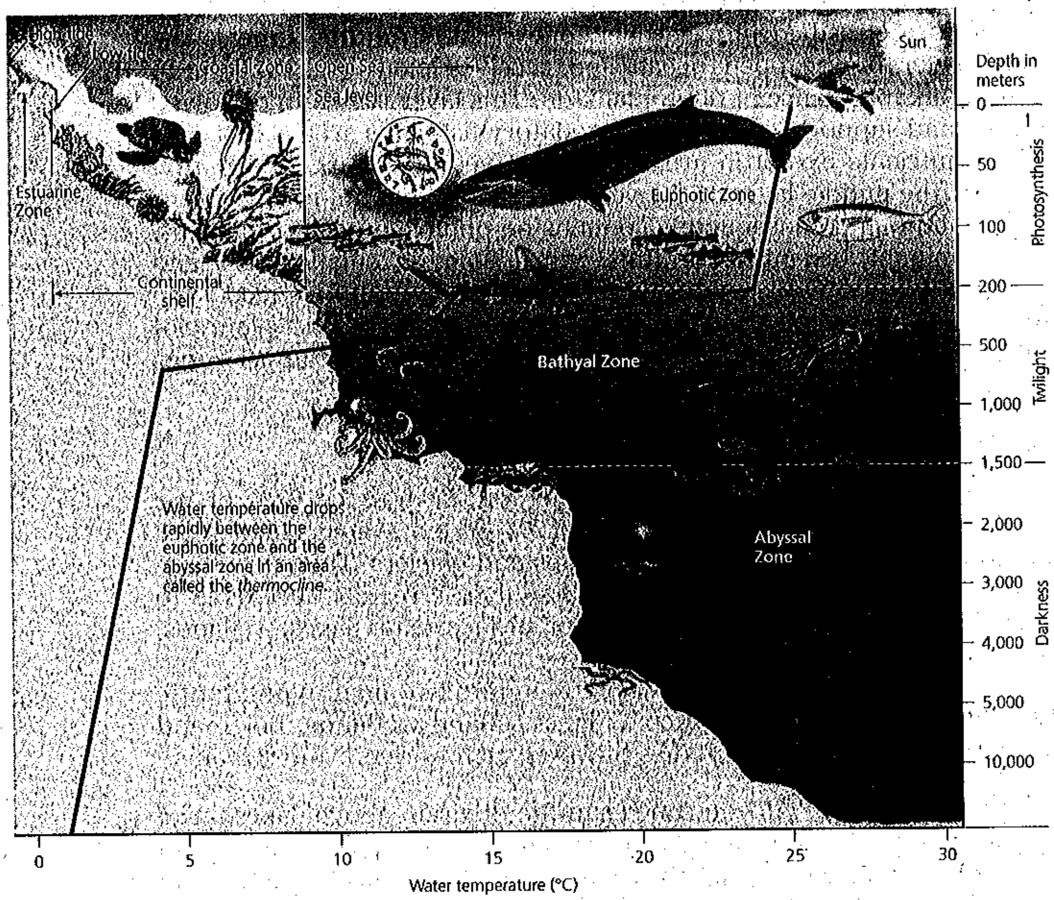
- food resources
- oil, natural gas, and mineral resources
- transportation routes
- provides areas for recreation

MARINE (SALTWATER) LIFE ZONES

Marine (saltwater) life zones include not only open oceanic waters but also shorelines, estuaries, coral reefs, and mangroves. The term **plankton**, a Greek word meaning "drifter," is used to describe the bottom trophic levels in the ocean. The dominant primary producers in the marine ecosystem are **phytoplankton**. Phytoplankton are free-floating single-celled algae such as diatoms. Phytoplankton populations are limited by available sunlight and are therefore found in the **euphotic zone**, or upper layer of the ocean. **Zooplankton** are drifting herbivores that make up the primary consumers in our marine ecosystems. The zooplankton group includes a variety of organisms from single-celled protozoa to a diversity of crustaceans, such as krill and copepods. Stronger-swimming organisms like fish are referred to as **nekton**. Bottom-welling organisms are known as **benthos** and live on or in the marine sediments found on the oceanic floor. For instance, oysters attach themselves to the bottom whereas clams and worms actually burrow into the sand. Other benthos organisms, such as crabs and lobsters, simply live on the ocean floor. These organisms are good scavengers, feeding on the detritus material that settles down to the bottom. These different types of consumers in aquatic systems are limited by **dissolved oxygen** concentrations, temperature, and food resources. Bacteria in marine zones, just as in terrestrial ecosystems, are decomposers that break down organic waste into the nutrients required by aquatic primary producers. Life in the oceans exists in three major zones: coastal, open sea, and ocean bottom. The greatest biodiversity in the marine ecosystem occurs in coral reefs, estuaries, and the deep-ocean floor. These ecosystems provide the necessary habitat space and nutrients to support an abundance of life.

COASTAL ZONES This area of the ocean is from the high tide mark to the edge of the continental shelf. The water in this area is warm and rich in nutrients. Since these ecosystems receive ample amounts of sunlight they are also areas of high net primary productivity. The coastal zone contains approximately 90% of all marine species.

ESTUARIES These coastal zones form where freshwater rivers meet the salty waters of the ocean. In temperate zones these areas include bays, inlets, sounds, and salt marshes; in tropical zones they include mangrove forests. Estuaries are highly productive due to large inputs of nutrients from the river and ample sunlight that supports only a few dominant primary producers. Typically, only a few plant species do well with the variations in temperature and salinity that occur daily and seasonally with changing tides and river inputs. Estuaries provide many vital ecological services. The large amount of vegetation in this ecosystem acts as a natural filter to prevent toxins, excess nutrients, and sediments from entering the waterways. They also provide large habitat space for many species and serve as breeding grounds for not only aquatic organisms but waterfowl as well. Since estuaries lie right



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on the coastline, they also provide a natural buffer from storm surges created by hurricanes or tsunamis.

Intertidal The diversity of life that exists in this zone is influenced by the stress of the rising and falling tides that occur about every six hours due to the gravitational pull of the moon and sun. Some intertidal zones have gently sloping, sandy shores while others have rocky shorelines where tidal pools form in deep rock crevices from the crashing and retreating waves. Most organisms in the intertidal zone have some adaptation to withstand wave activity, whether it is by burrowing in sediments, attaching to rocks, or retreating into their shells.

Coral Reefs These slow-growing, highly diverse ecosystems occur primarily along the equator in warm tropical waters. They are sensitive to any type of salinity or temperature change. They also require clear water so sunlight can reach the mutualistic, photosynthetic algae (zooxanthellae) that provide nutrients to coral polyps. Although coral reefs cover less than 1% of the earth's surface, they provide millions of people with food and jobs.

Open Ocean and Sea Floor The open sea is a great expanse of the ocean that extends off the continental shelf. This region is defined by sunlight penetration and temperature changes as depth increases and is therefore classified into vertical zones. The **euphotic zone** is the upper layer of the open ocean and receives plenty of sunlight to support an abundance of phytoplankton. This layer is rich in dissolved oxygen and supports many larger predatory fish. This area is naturally low in nutrients except in areas where upwelling occurs. The **bathyl zone**, or the middle layer of the vertical oceanic column, receives very little sunlight and consequently contains no photosynthetic organisms. The dominant organisms in this zone, such as smaller fish and zooplankton, migrate to the euphotic zone at night to feed. The **abyssal zone** receives no sunlight. However, there are plenty of nutrients to support life here as most organic waste from upper zones settles to the bottom—this is known as **marine snow**.

FRESHWATER LIFE ZONES

There are limited supplies of freshwater on earth since 97% of the earth's water is saline (oceans). Almost 2% of our water supplies are locked up as frozen freshwater in icecaps and glaciers. Therefore there is less than 1% of remaining freshwater that is readily accessible to humans or organisms as groundwater or surface water (lakes, wetlands, and rivers).

Freshwater life zones can be separated into two main types: **lentic** (standing) bodies of water such as lakes, inland wetlands, bogs, and ponds, and **lotic** (moving) bodies of water such as rivers and streams.

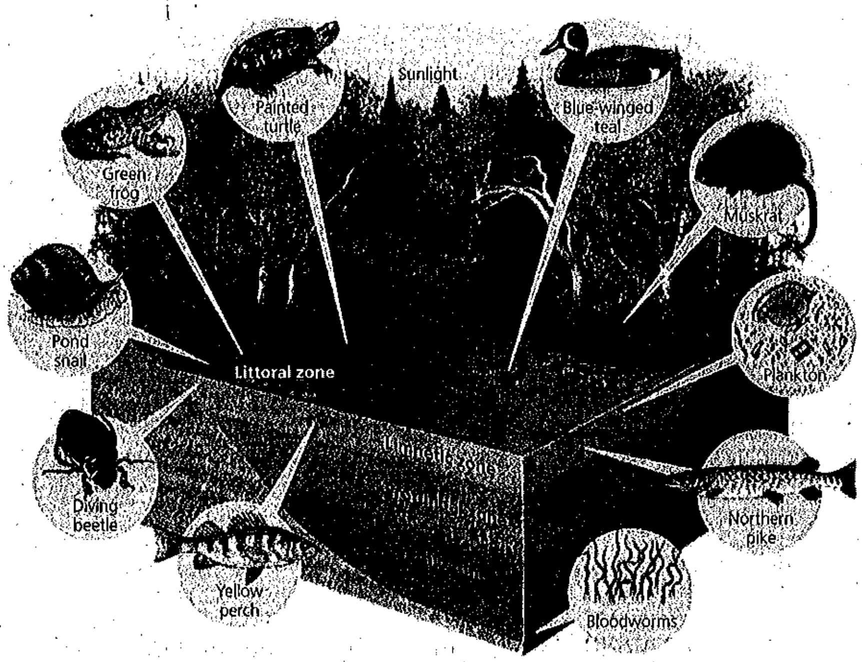
LAKES (LENTIC ZONES) As you can see in the diagram above, lakes make up the large majority of our fresh surface water on earth. Lakes form as surface water runoff, groundwater, and rainfall fill depressions in the earth's surface that have been created through tectonic, glacial, volcanic, and human activity (reservoirs for dams). Lakes vary greatly in surface area, depth, and nutrient concentrations. Deep lakes have distinct zones that are defined by their depth and distance from shore.

Littoral zone: This shallow zone is closest to shore and receives plenty of sunlight and nutrients and therefore supports a wide variety of life. There are many species of **submergent** (underwater) and **emergent** (rooted in water yet penetrates air/water boundary) plants in this zone.

Limnetic zone: This upper layer of the lake, away from shore, receives a large amount of sunlight that supports abundant growth of phytoplankton. These primary producers make up the base of the food chain in the lake and supply the majority of the dissolved oxygen for aerobic consumers.

Profundal zone: This mid-level lake zone receives little sunlight and is low in nutrients and dissolved oxygen. Organisms living in this zone must be adapted to colder water and pressure.

Benthic zone: This bottom lake zone contains mostly decomposers who feed on the organic waste that trickles down from the upper zones.



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NUTRIENT ENRICHMENT IN LAKE SYSTEM Lakes are classified by concentration of nutrients and primary productivity rates. Clear, deep lakes that have low nutrient levels and therefore limited primary productivity are referred to by ecologists as **oligotrophic**. These lakes are typically colder and support a wide variety of fish species due to the high levels of dissolved oxygen. Over time, lakes will naturally start to increase in nutrient concentration and decrease in depth. This is due to the runoff of sediment and organic material, increasing the level of organic nutrients in the lake. These added nutrients will also promote the growth of primary producers over time. Once lakes have accumulated a high concentration of nutrients that support high levels of net primary productivity by producers they are known as **eutrophic**. These lakes are often more shallow and murky than oligotrophic systems. This same process can occur as large amounts of nutrients are added to lake systems due to human activities, such as runoff of fertilizers; this is known as **cultural eutrophication**.

INLAND WETLANDS (LENTIC ZONES) This freshwater life zone includes swamps (dominated with trees), marshes (dominated by grasses), flood plains, and bogs. These ecosystems are away from coastlines and are covered with freshwater either all or part of the time. Similar to marine estuaries, these areas have an abundance of biodiversity, high levels of net primary productivity, and provide numerous ecosystem services. These services include:

- natural recharge to groundwater system
- habitat space to many organisms (for example, beavers, fish, migratory waterfowl, otters)
- acting as a nursery for many aquatic species and spawning ground for many fish
- filtering toxins and excess nutrients from waterways
- reducing flooding and erosion

Rivers (Lotic Zones)

Rivers are classified as moving water systems that receive most of their input and recharge from **runoff** of precipitation or snow melt. This moving surface water also carries with it sediments and dissolved substances it picks up along the way. The land area that delivers this runoff to the river or its tributaries (small streams that feed into rivers) is known as the drainage basin or **watershed**. The downward movement of water as the river flows to the ocean creates three basic zones. The **source zone** contains rivers and streams that are directly fed by mountain snowmelt. They are fast moving, shallow, and cold, and low in nutrients. The **transition zone** typically has streams and rivers with more turbid water due to the increase in sediments flowing into them. They are typically deeper, wider, slower moving, and contain less dissolved oxygen than the rivers and streams in the source zone.

Human Activities: The Impact on Biodiversity

Why should the protection of biodiversity be important to the human population? Not only do organisms provide vital ecological services such as providing oxygen, recycling nutrients, and keeping natural populations in check, they also serve numerous economic roles as well. Some of these economic services provided by organisms include food products (crops and livestock), lumber, paper, fuelwood, and medicines. However, human population has experienced a rapid rate of increase over the last two hundred years. This growth has elicited a continuous increase in the destruction of natural habitat space of wild species in order to make room for societal expansion (cities, farms, houses). Increasing population growth also fuels the demands for harvesting earth's natural resources that also depletes wild species not only through habitat destruction but also through pollution, overfishing, and climate change. The major cause of biodiversity depletion is habitat loss, habitat fragmentation, and introduction of invasive species.

Habitat Loss: Scientists have discovered that the largest impact on species diversity is habitat loss. Large areas of forested areas (deforestation), wetlands, and grasslands have been destroyed to create room for urbanization or agricultural fields. Many tropical rainforests are currently being subjected to slash-and-burn agricultural practices. This is devastating to biodiversity as the tropics have the largest concentration of different species. Coastal ecosystems such as coral reefs, mangroves, and estuaries are also being destroyed by fishing practices and removal for purposes of urban development.

Habitat Fragmentation: Fragmentation of a habitat occurs when large adjacent ecosystems are divided into smaller, more isolated areas by the addition of housing developments, urban areas (cities), roadways, removal of trees (logging practices), or creating agricultural fields. Since habitat space is being reduced, this can increase population density and therefore increase competition for resources. Organisms will therefore be more susceptible to disease, predators, and natural disasters such as fires.

Invasive Species: Many nonnative species have been introduced into new ecosystems either intentionally or accidently. We have deliberately introduced some species into new ecosystems for new food crops, medicines, or soil erosion control. However, many species are accidently introduced to new ecosystems as they "hitchhike" their way across the globe through transportation practices. For example, many insects have entered new areas through shipping crates made from wood in their native habitat. If these new species out-compete native species for resources and do not have any known predators in their new environment, they can become invasive species. Most invasive species have a high reproductive rate (r-selected) and are generalists. Invasive species typically experience uncontrolled population growth in their new environment and deplete the native species population. Examples of intentionally introduced species include Japanese beetles, Nile Perch, African honeybees, Kudzu, and the European wild boar. Examples of accidently introduced invasive species include the Zebra mussel, Gypsy moth larvae, Formosan termites, and Argentina fire ant.

EXTINCTION

As you learned in Chapter 2, for most of the long history that life has existed on earth there have been very slow, continuous, low levels of **background extinction.** In general, biodiversity on earth has continued to increase over time except for five **mass extinctions** that eliminated 50–95% of species on the planet. **Biological extinctions** occur when a species is no longer found in any ecosystem on earth. Although this type of extinction can occur naturally, some species are becoming prematurely extinct at a rapid rate due to human activities. Examples include, but are not limited to, the Golden Toad, Dodo bird, and Passenger Pigeon. Some species are at risk for biological extinction. Scientists have two categories to describe organisms at risk. **Endangered species** are organisms whose population size has decreased to such a low level that they are at extreme risk of becoming extinct over most or all of their natural habitats. Organisms whose populations are declining due to human activity and could potentially become endangered in the near future are referred to as **threatened species.** Some species have characteristics that make them particularly vulnerable to possible extinction. These characteristics include low reproductive rates (K-selected), need for large territories, feeding at top of food chain (tertiary consumers), specialized niche, and narrow distribution. Also, organisms that are of value commercially, such as elephants for their tusks, are at a higher risk than others.

LEGISLATION AND TREATIES TO PROTECT ENDANGERED SPECIES

U.S. Endangered Species Act of 1973: This law is intended to identify and provide protection for organisms that are at risk for extinction (endangered). This act prohibits any federal agencies (except the Defense Department) from following through with projects that would change or destroy the habitat of any identified endangered species. This law also allows for fines to be imposed on private lands that have modified or disrupted the habitat of an endangered species.

Convention on International Trade in Endangered Species (CITES): This 1975 treaty to place bans on the selling, hunting, or capturing of threatened or endangered species has now been signed by 172 countries. However, the strength of this treaty varies on how well it is actually enforced in the different countries.

SUSTAINING TERRESTRIAL DIVERSITY

FOREST ECOSYSTEMS

Ecologists classify forests as either old-growth forests or secondary-growth forests. An **old-growth forest** has not been modified by human activities or natural disasters in 200 years or more. **Secondary-growth forests** form from secondary succession once land has been cleared due to human activity (deforestation) or some type of natural disaster (fires, volcanoes, hurricanes). Scientists estimate that forested areas provide habitat for two-thirds of the earth's terrestrial species, and tropical rain forests are home to more than 50% of the world's species. Not only are forests areas of high biodiversity but they provide crucial ecosystem services such as releasing oxygen, storing carbon dioxide, reducing soil erosion, promoting nutrient cycling, and influencing local and regional climate. Forests afford many economic benefits to humans as well by providing recreational areas, medicines, fuelwood, and jobs in lumber and paper industries.

THREATS TO FOREST ECOSYSTEMS Although forests provide numerous economic and ecological services, they are currently under a rapid rate of removal due to deforestation practices. **Deforestation** either temporarily or permanently removes large tracts of forested land for fuelwood, agriculture, or urban development. In areas like South America, Africa, and Indonesia, large tracts of tropical forests are being removed to provide space for cash cropping, raising livestock, or harvesting timber resources. According to the United Nations, Indonesia has already removed approximately 78% of its original intact forested land. This type of habitat loss and fragmentation greatly depletes the wealth of biodiversity found in tropical forests.

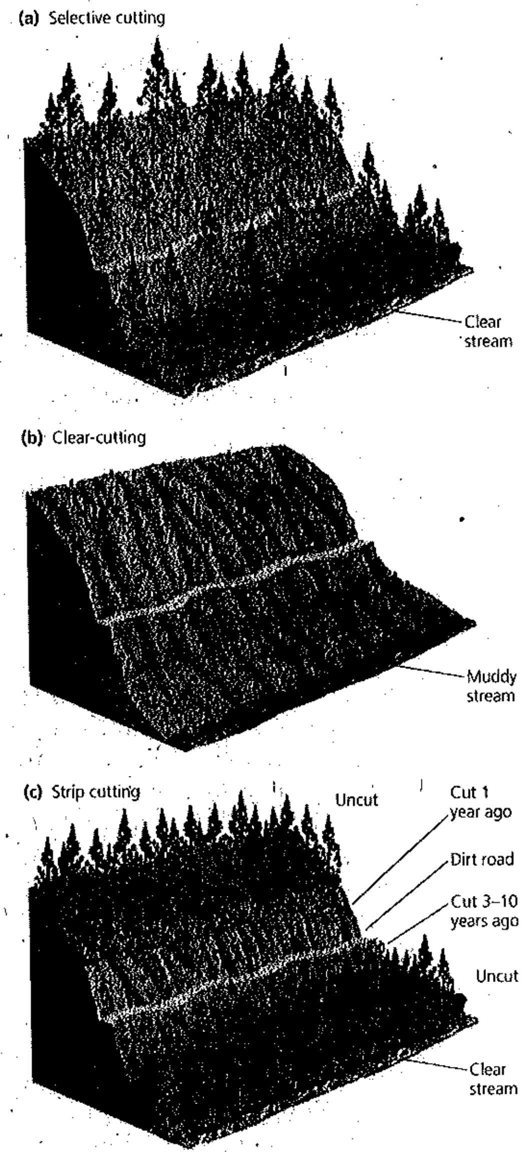
LOGGING PRACTICES In order to begin harvesting a forested area, logging roads are established first. These roads fragment the habitat and increase soil erosion into local rivers and streams. There are three main types of logging practices: clear-cutting, selective cutting, and strip cutting.

Clear-cutting: Clear cutting removes all of the trees in one area at one time. Although this is the most efficient method for loggers, it causes the most damage to the forest ecosystem. Clear-cutting of forests ecosystems results in the heavy loss of soil nutrients, increased sediment loading into rivers and streams, and biodiversity loss. **Tree plantations** (tree farms) are areas that are commercially maintained for timber resources. They typically have one to two genetically uniform tree species that will be clear-cut and replanted at regular intervals. Theses areas are not biologically diverse and, over time, this practice depletes the nutrients in the soil.

More sustainable methods of logging would include:

Selective cutting: In selective cutting, either mature or intermediate-age trees are selectively removed from forested areas that have an uneven-age tree community.

Strip cutting: Strip cutting involves removing an entire strip of trees along the contour of the land in a narrow corridor that allows for quick regeneration of the trees. Once the strip begins to grow back the loggers will clear-cut another strip of trees next to the first.



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FOREST FIRES Surface fires, fires that only burn leaf litter on the forest floor, can be beneficial to forests by stimulating germination in some trees and freeing up vital mineral nutrients. Since surface fires remove large amounts of flammable ground material they also help prevent more serious fires. If surface fires do not occur for several decades, then the forest ecosystem is a risk for a crown fire. Crown fires burn tops of trees and spread easily from one treetop to the next. These large forests fires are difficult to control and kill not only the trees but local wildlife. These fires also increase soil erosion into local waterways and can cause destruction to human urban developments and housing. In many tropical regions large tracts of forested land are being cleared through burning practices. These fires will greatly reduce wildlife populations, increase local air pollution, and increases atmospheric carbon dioxide. A strategy for reducing harm caused by forest fires is to set small prescribed fires in high-risk areas to remove large areas of overgrown underbrush. In 2003, the Healthy Forests Restoration Act was passed allowing timber companies to remove medium-size commercially valuable trees in an attempt to thin forests at risk for fires. However, many critics of this act say that removing these trees actually promotes the growth of smaller, more flammable trees, putting forests at even greater risk for forest fires.

INSECTS AND CLIMATE CHANGE Forest ecosystems have also fallen victim to invasive insect species and disease introduced into the United States. Diseases such as Dutch elm and chestnut blight have almost eliminated the American elm and chestnut trees from the United States. Rising temperatures due to climate change make it even easier for invasive insect species and diseases to do well in our forest ecosystems.

Solutions for Sustaining Forest Ecosystems

- practice strip cutting and selective cutting rather than clear-cutting logging methods
- protect remaining old-growth forests
- certify timber grown by sustainable methods
- governments in tropical regions provide subsidies to sustainable forestry practices
- re-plant and rehabilitate clear-cut forests
- funding and visitor regulations in national parks and wildlife reserves
- build habitat corridors between fragmented forests to encourage animal migration

AP Tip

It is a good idea as you go through your course of study in AP Environmental Science to make note of the important people who have contributed to this field. You may be asked to recall their importance on the AP Exam. For example, Wangari Maathai is a Kenyan woman who won the 2004 Nobel Peace Prize for starting the Green Belt Movement. This movement began as a humble tree nursery in her backyard and has now grown to over 50,000 members in over 6,000 different villages in Africa. Today, this project has planted over two billion trees in 55 different countries. While reducing soil erosion, these trees also provide sustainable supplies of fuelwood, building materials, and food. Such projects also reduce poverty for women as they are employed in maintaining the nurseries and have a new source of income by selling the products from the trees that are harvested. For a full list of important people to know for the AP Environmental Science Exam, see the list in the Supplement section in Part 3.

Grassland Ecosystems

Much like forests, grasslands provide many ecological services such as promoting nutrient cycling, encouraging soil formation, controlling erosion, and storing carbon dioxide. Historically, these ecosystems have been valuable to humans as cropland due to their fertile soils and the abundant grasses that provide food for grazing livestock. Grasslands are utilized for livestock grazing in two ways: rangelands and pastures. **Rangelands** are wide-open, non-restricted areas for grazing by grass-eating and shrub-eating livestock (cattle, sheep, goats). **Pastures** are fenced areas that are maintained by ranchers through planting of domesticated grasses or shrubs.

Overgrazing: Overgrazing occurs when the number of livestock animals exceed the carrying capacity for that particular rangeland, thereby depleting the grass cover. This exposes valuable topsoil to erosion by wind and water, and it also compacts soil, decreasing its water retention properties.

SUSTAINING GRASSLAND ECOSYSTEMS Grassland ecosystems are naturally maintained by periodic fires. Fires can eliminate other plants competing with grasses' space and resources and it may promote the availability of valuable soil nutrients. Recently, ecologists have been conducting controlled burns in these ecosystems to try and promote native grasses to damaged regions.

Grasses grow from the base of the blade, not the tip, so if grazing livestock is done in a sustainable manner then grasslands serve as a renewable resource. An alternative method for grazing livestock is known as rotational grazing. In **rotational grazing** cattle or livestock are contained in fenced-off spaces where they are rotated from one field to another over the course of the year. This way, ranchers can control the amount of grazing that occurs to their fields and can prevent overgrazing of any one area.

SUSTAINING AQUATIC ECOSYSTEMS

THREATS TO MARINE ECOSYSTEMS

Much like forests, the major threat to marine ecosystems is habitat destruction. Much of our coral reefs, mangroves, and estuary systems have suffered major damage at the hands of human activities. Many coastal estuaries have been drained and mangroves removed to provide urban development space. Other human activities that put these areas at risks are unsustainable fishing practices, climate change, and pollution.

Overharvesting: Current fishing practices are not only depleting biodiversity by causing damage to ocean habitats, they are also causing a rapid decline in our commercially important fish populations. Although most commercial fishing vessels target only a small group of valuable fish species, many non-target species are also killed in the miles and miles of netting and baited hooks used by the fishing industry. These species are referred to as **bycatch**. Bycatch from fishing practices depletes numerous non-commercial fish species, turtles, marine mammals (seals, dolphins), and sharks.

Pollution: It is predicted that by 2020 almost 80% of the world's population will live on or near the coast in urban areas. Most of the pollution that makes its way to the ocean comes from land-based activities along the coast. This coastal pollution includes runoff of sediments from building and agricultural activities, fertilizers, pesticides, industrial solvents and waste, plastics, and excess nutrients from animal feed lots or municipal sewage that leads to eutrophication.

Climate Change: The rising global temperature is causing severe impacts to oceanic systems. The average sea level has risen by 10–20 cm over the last 100 years. Rising sea levels can cause habitat destruction to many coral reef and mangrove ecosystems. The Arctic region is currently warming twice as fast as the rest of the world, which means a reduction in floating sea ice. This ice is extremely important to polar bears as they utilize this surface area for hunting seals. The United States listed the polar bear as a threatened species under the Endangered Species Act in 2008.

Invasive Species: Species from all over the world are being transported to new ecosystems through ballast water in cargo ships. Almost two-thirds of the introduced nonnative marine species have occurred by ship, ballast water being most common (EPA statistics). These invasive species are depleting biodiversity in marine ecosystems by outcompeting and thereby eliminating local native species.

Solutions for Sustaining Marine Biodiversity

- practice sustainable commercial fishing that reduces bycatch
- set catch limits for commercial fish species below sustainable maximum yield
- filter organisms from ship ballast water to reduce invasive species
- establish no-fishing zones and marine sanctuaries
- reduce carbon dioxide emissions to reduce impacts of climate change
- use integrated coastal management techniques

Marine Mammal Protection Act of 1972: This act prohibits, with certain exceptions, any United States citizen from harassing, hunting, or killing any marine mammals. This act was amended in 1994 to include:

- a program to monitor incidental taking of marine mammals during commercial fishing practice (bycatch regulations)
- preparation of stock assessments for all marine mammals in waters under United States jurisdiction

Threats to Freshwater Ecosystems

Many freshwater systems have been damaged by human activities. Rivers and lakes have suffered a 50% loss in fish species due to human interaction. River species have been depleted due to the building of dams along our major rivers limiting the flow of water and nutrient-rich silt downstream. Lakes are being impacted by the overharvesting of water resources for agricultural irrigation practices and municipal use in homes and industries.

Pollution: Our freshwater systems have a constant influx of toxins from human activities. These toxins include, but are not limited to, pesticides, industrial solvents, oils, sediments, and excess nutrients from fertilizers and animal wastes. These excess nutrients deplete biodiversity by causing **cultural eutrophication** in many of our lakes and inland wetlands.

Destruction of riparian zones: Riparian zones are strips of vegetation that surround streams and rivers. Vegetation in these zones acts as a natural buffer by controlling floods and by filtering and removing many of the toxins and excess nutrients before they reach our waterways. Construction in these zones, or their actual removal through stream channelization, can destroy a natural stream ecosystem.

Invasive Species: An increasing problem in our lake ecosystems is invasive species. The Zebra mussel has had devastating impacts on our Great Lakes while the sea lamprey is killing native fish species throughout the United States and Canada. The Nile Perch was introduced to Lake Victoria (Africa) in the 1950s as a food source. Since that time it has caused the extinction or near depletion of many of the native fish species, particularly cichlids. Scientists estimate the annual cost of aquatic invasive species in the United States to be approximately $9 billion a year (www.nbii.gov—a division of the USGS).

Sustaining Freshwater Biodiversity: In 1968, the United States passed the National Wild and Scenic Rivers Act. Under this legislation, rivers were classified as wild rivers accessible only by trail, or scenic; and those free from dams and accessible by only a few roadways. These rivers are protected from damming, widening, dredging, or filling. Other methods for protecting freshwater ecosystems include:

- reuse treated wastewater for irrigation to reduce reservoir use
- protect and increase riparian buffer zones
- reduce fertilizer use in agricultural fields and urban homes and golf courses
- reduce use of pesticides on agricultural fields

Multiple-Choice Questions

1. Which of the following biomes is maintained through occasional fires?
   (A) Tundra
   (B) Tropical forest
   (C) Grassland
   (D) Mountain ranges
   (E) Taiga

2. Characteristics that would lead to a nonnative organism's becoming invasive in a new environment would include which of the following characteristics?
   I. High reproductive rate
   II. Short-lived
   III. Generalists

   (A) I only
   (B) II only
   (C) III only
   (D) I and III only
   (E) I, II, and III

3. Which of the following non-point pollution types is most likely to cause cultural eutrophication in lake ecosystems?
   (A) Oil from parking lots
   (B) Fertilizer from agricultural fields
   (C) Heavy metals from mining practices
   (D) Sediments from erosion of agricultural fields
   (E) Pesticides from agricultural fields

4. Photosynthetic organisms such as phytoplankton would be most abundant in which oceanic zone?
   (A) Bathyl
   (B) Benthos
   (C) Littoral
   (D) Limnetic
   (E) Euphotic

5. All of the following are associated with an El Niño event EXCEPT
   (A) decreased upwelling events
   (B) suppressed thermocline in the Pacific Ocean
   (C) increased Atlantic coast hurricanes
   (D) torrential rain and flooding in Peru
   (E) drought in Indonesia

6. Which country would have the largest percentage of boreal forests?
   (A) Russia
   (B) United States
   (C) Australia
   (D) Brazil
   (E) Nepal

7. The land area that delivers recharge to smaller tributary streams that flow into larger rivers is known as
   (A) watershed
   (B) source zone
   (C) flood plain
   (D) delta
   (E) estuary

8. Oceanic currents act as a conveyor belt system creating a connected loop of deep and shallow ocean currents that transfers warm and cold water between the tropics and the poles. The strongest influence on this system of ocean currents is due to
   (A) upwelling events that bring cold nutrient-rich water from the bottom to the top
   (B) the rotation of the earth on its axis
   (C) differences in water density due to temperature and salinity concentrations
   (D) atmospheric convection causing large inputs of freshwater into the ocean by precipitation
   (E) location of continents that help determine direction and flow of ocean currents

9. The most biologically diverse areas of the ocean include coral reefs and estuaries. All of the following characteristics are reasons why these ecosystems can support such a high level of diversity EXCEPT:
   (A) They are areas of high primary productivity.
   (B) Both ecosystems have abundant nutrient flow that supports phytoplankton populations.
   (C) Coral reefs and estuaries receive an abundant amount of sunlight.
   (D) Both ecosystems provide plenty of habitat space for organisms.
   (E) These ecosystems do not have commercially important species; therefore human impact on biodiversity is limited.

10. Deep lakes that are characterized by steep banks and have a relatively small supply of plant nutrients are known as
   (A) autotrophic
   (B) euphotic
   (C) mesotrophic
   (D) oligotrophic
   (E) eutrophic

11. Marine biologists have found that increasing atmospheric carbon dioxide levels are lowering ocean pH, a condition known as ocean acidification. This also causes a decrease in the concentration of calcium carbonate ions. If this rise were to continue it would have a devastating impact on coral ecosystems because
   (A) it would cause a decline in the endosymbiotic algae the coral depend on
   (B) it would decrease the ability of the corals to form their exoskeleton
   (C) it would increase the amount of dissolved oxygen beyond the tolerance of the coral
   (D) it would increase the turbidity of the water beyond the corals' range of tolerance
   (E) it would decrease the number of crustaceans that act as keystone species in the coral reef ecosystem

12. The direction of the rotation of large cyclones—winds around the center of a cyclone rotate clockwise in the northern hemisphere and counterclockwise in the southern hemisphere—is due to the
   (A) earth's rotation
   (B) temperature differences in oceanic currents
   (C) Coriolis effect
   (D) tropical vortex effect
   (E) uneven heating of the earth by the sun

13. This ecosystem is characterized by long, hot summers and moderate, moist winters. It supports many small mammals, and most vegetation germinates after a period exposed to fire. It is mostly found along coastal areas such as the Pacific coast of North America, southern Texas and Mexico, and the coastal hills of Chile and the Mediterranean.
    (A) tundra
    (B) desert
    (C) grassland
    (D) chaparral
    (E) taiga forest

14. The Amazon Basin, in South America, is the world's largest tropical rainforest. Forest cover in the "Arc of Deforestation" in the southern region of the basin is rapidly decreasing due to logging and conversion of forests to agricultural lands. Scientists estimate that if this trend continues it will reduce the forest coverage to only 20% of its original size by the year 2016. The loss of forested land would most likely
    (A) increase the concentration of water vapor in the air due to increased transpiration rates
    (B) decrease the local regional flooding that occurs
    (C) increase available supplies for plant-derived medicines
    (D) decrease the amount of total atmospheric nitrogen
    (E) increase the amount of total atmospheric carbon dioxide

15. All of the following are threats to biodiversity in river systems EXCEPT
    (A) increasing of riparian zones along stream banks
    (B) pesticides entering local rivers from agricultural runoff
    (C) habitat fragmentation by dams
    (D) runoff of animal wastes from feedlots
    (E) dredging river bottoms to increase ability for transportation

FREE-RESPONSE QUESTION

The Chesapeake Bay is the largest estuary in the United States. It has had a long history of water pollution problems due to human activities in the states surrounding the bay that makes up the watershed. The Chesapeake has nine major tributary rivers that feed into the estuary. Scientists are monitoring the concentrations of nitrates and phosphates that are entering the estuary each year. Load is the mass of nutrient transported by streamflow over time, and is estimated as the product of nutrient concentration and streamflow (reported here in pounds per year, or lbs/yr). The three rivers that have the highest flow—the Susquehanna, the Potomac, and the James Rivers—contribute the largest nutrient loads to the tidal part of the Chesapeake Bay Basin. Yield is the load per unit area of each basin (reported in pounds per year per square mile, or lbs/yr/mi^2), and is computed by dividing load by basin area. Although the larger rivers typically have more nutrient yield, scientists are also concerned with the nutrient contributions from some of the smaller rivers. Scientists are currently examining nutrient concentrations from the Mattaponi River in Virginia that has 600mi^2 of upstream surface area land.

(a) The Mattaponi River contributes a load of 60 million pounds of nitrates every four months into the Chesapeake Bay estuary. Calculate the yearly load of nitrates into the Chesapeake from this tributary river.

(b) Calculate the nutrient yield that this tributary river contributes each year into the Chesapeake Bay.

(c) Identify and describe TWO ecological services provided by estuary systems.

(d) Discuss how the increase in nutrient levels in this estuary can impact the aquatic diversity.

ANSWERS

MULTIPLE-CHOICE QUESTIONS

1. ANSWER: C. Grassland ecosystems are maintained by occasional fires that eliminate competing plant species as well as increase availability of nutrients in the soil (*Living in the Environment*, 16th ed., page 232 / 17th ed., pages 156–158).

2. ANSWER: D. Characteristics that make a nonnative species a successful invasive species include the ability to reproduce quickly, their long life, ability to feed on many different things, and a wide range of tolerance (generalists) (*Living in the Environment*, 16th ed., page 201 / 17th ed., page 198).

3. ANSWER: B. Cultural eutrophication occurs from high levels of limiting nutrients, such as nitrates and phosphates, entering waterways. These nutrients often come from runoff of agricultural areas in the form of fertilizers or animal waste. They can also come from runoff of urban lawns and golf courses that have been treated with fertilizers (*Living in the Environment*, 16th ed., pages 174–176 / 17th ed., pages 182–183).

4. ANSWER: E. Since phytoplankton, such as diatoms and dinoflagelletes, are primary producers and require sunlight for photosynthesis, they will be most abundant in the euphotic zone, as it is the top layer of the ocean and receives the most sunlight (*Living in the Environment*, 16th ed., pages 164–166 / 17th ed., pages 172–173).

5. ANSWER: C. During an El Niño the increased wind shear over the Atlantic Ocean is responsible for less hurricane activity. Wind shear is defined as the amount of change in the wind's direction or speed as altitude increases. This means the tropical storms that develop have latent heat spread over a greater surface area, decreasing the chance of organizing into

a hurricane (*Living in the Environment,* 16th ed., pages 143, S48–S49 / 17th ed., pages S26–S27).

6. **ANSWER: A.** The taiga biome (also known as the boreal forest or coniferous forest) is largely found in Russia and also Canada (*Living in the Environment,* 16th ed., page 146 / 17th ed., page 153).

7. **ANSWER: A.** The watershed, also known as a drainage basin, is the land area that delivers runoff, sediment, and dissolved substances to a stream (*Living in the Environment,* 16th ed., page 176 / 17th ed., page 183).

8. **ANSWER: C.** Oceanic currents develop from differences in density of water due to temperature and salinity. Less dense, warmer water with a lower salinity will rise as dense, cold, salty water will sink. This process, aided by prevailing wind patterns, creates shallow- and deep-water currents that form a conveyor belt system around the earth (*Living in the Environment,* 16th ed., pages 142–143 / 17th ed., pages 150–151).

9. **ANSWER: E.** Both coral reef ecosystems and estuaries are in the coastal zone and can be easily accessed by humans. They do support an abundance of biodiversity and many species in these ecosystems are commercially important to humans (*Living in the Environment,* 16th ed., pages 166–170, 254 / 17th ed., pages 168, 177–179).

10. **ANSWER: D.** Lakes are typically classified by nutrient content levels. Oligotrophic lakes have very low nutrient levels and are typically very deep with steep banks and clear water (*Living in the Environment,* 16th ed., pages 174–175 / 17th ed., pages 181–182).

11. **ANSWER: B.** This would impact the coral's ability to create its exoskeleton since it is largely composed of calcium carbonate (*Living in the Environment,* 16th ed., pages 166–170, 254 / 17th ed., pages 168, 177–179).

12. **ANSWER: C.** The Coriolis effect is caused by the rotation of the earth. Large-scale wind patterns are deflected to the right (clockwise) in the northern hemisphere and to the left (counterclockwise) in the southern hemisphere (*Living in the Environment,* 16th ed., page 143 / 17th ed., pages 148–150).

13. **ANSWER: D.** The chaparral ecosystem is found in limited distribution on the earth. It is also known as the temperate scrubland and borders many desert ecosystems (*Living in the Environment,* 16th ed., page 152 / 17th ed., page 159).

14. **ANSWER: E.** Trees are primary producers and during the process of photosynthesis they take in carbon dioxide and store it in their tissue as biomass and release oxygen. Removing large amounts of forested land from the earth

would increase total atmospheric levels of carbon dioxide through a reduction in the terrestrial stores of carbon (*Living in the Environment*, 16th ed., pages 222–226 / 17th ed., pages 224–227).

15. ANSWER: A. Riparian zones are vegetation areas that border stream banks. They aid the stream by filtering out toxins and excess nutrients before they reach the streams. They also keep soil intact and prevent erosion and sedimentation into the waterway. Therefore, increasing riparian buffers would help protect river biodiversity—not deplete it (*Living in the Environment*, 16th ed., page 232 / 17th ed., page 235).

FREE-RESPONSE SCORING GUIDELINES

(a) The Mattaponi River contributes a load of 60 million pounds of nitrates every four months into the Chesapeake Bay estuary. Calculate the yearly load of nitrates into the Chesapeake from this tributary river.

2 points can be earned—1 point for correct setup and 1 point for correct answer with units

60×10^6 lbs. nitrates	12 months
4 months	1 yr

= 180 million lbs/yr of nitrates

(you may also simply multiply 60 million lbs. by 3 as your setup)

(b) Calculate the nutrient yield that this tributary river contributes each year into the Chesapeake Bay.

2 points can be earned—1 point for correct setup and 1 point for correct answer with units

180 × 106 lbs/yr	
600 mi²	= 300,000 lbs/yr/mi²

(c) Identify and describe TWO ecological services provided by estuary systems.

4 points can be earned—2 points for each correctly identified ecological service with correct description

- storm buffers—estuaries are buffer zones against storm surge and protect inland areas from erosion
- water filtration—estuaries naturally remove toxins from the water
- habitat—estuary systems are highly diverse and provide space for many organisms

- breeding ground—many aquatic organisms come here to breed as well as many waterfowl
- productivity—estuaries are areas of high primary productivity which supports large amounts of diversity

(d) Discuss how the increase in nutrient levels in this estuary can impact the aquatic diversity.

2 points can be earned—1 point for describing how nutrient loading increases algal growth and 1 point for a negative impact to biodiversity due to algal growth

Negative impacts due to algal growth
- decreased penetration of sunlight reduces submergent vegetation and photosynthesis
- bacteria from rapidly decomposing algal blooms consume available oxygen and lower dissolved oxygen in ecosystem thereby causing fish, oysters, and crustaceans to die off
- nutrient loading can provide conditions for invasive nonnative species to succeed and outcompete native populations