Overview: The Scope of Ecology

- **Ecology** is the scientific study of the interactions between organisms and their environment.

**Concept 52.1 Ecology is the study of interactions between organisms and the environment**

- Ecologists ask questions about factors affecting the distribution and abundance of organisms.
- Ecologists might study how interactions between organisms and the environment affect the number of species living in an area, the cycling of nutrients, or the growth of populations.

*Ecology and evolutionary biology are closely related sciences.*

- Ecology has a long history as a descriptive science.
- Modern ecology is also a rigorous experimental science.
- Ecology and evolutionary biology are closely related sciences.
- Events that occur over ecological time (minutes to years) translate into effects over evolutionary time (decades to millennia).
  - For example, hawks feeding on field mice kill certain individuals (over ecological time), reducing population size (an ecological effect), altering the gene pool (an evolutionary effect), and selecting for mice with fur color that camouflages them in their environment (over evolutionary time).

*Ecological research ranges from the adaptations of individual organisms to the dynamics of the biosphere.*

- The environment of any organism includes the following components:
  - **Abiotic components**: nonliving chemical and physical factors such as temperature, light, water, and nutrients.
  - **Biotic components**: all living organisms in the individual’s environment.
- Ecology can be divided into a number of areas of study.
- **Organismal ecology** is concerned with the behavioral, physiological, and morphological ways individuals interact with the environment.
• A population is a group of individuals of the same species living in a particular geographic area. Population ecology examines factors that affect population size and composition.

• A community consists of all the organisms of all the species that inhabit a particular area. Community ecology examines the interactions between species and considers how factors such as predation, competition, disease, and disturbance affect community structure and organization.

• An ecosystem consists of all the abiotic factors in addition to the entire community of species that exist in a certain area. Ecosystem ecology studies energy flow and cycling of chemicals among the various abiotic and biotic components.

• A landscape or seascape consists of several different ecosystems linked by exchanges of energy, materials, and organisms. Landscape ecology deals with arrays of ecosystems and their arrangement in a geographic region.
  ° Each landscape or seascape consists of a mosaic of different types of patches, an environmental characteristic ecologists refer to as patchiness. Landscape ecological research focuses on the factors controlling exchanges of energy, materials, and organisms among ecosystem patches.

• The biosphere is the global ecosystem, the sum of all of the planet’s ecosystems. The biosphere includes the entire portion of Earth inhabited by life, ranging from the atmosphere to a height of several kilometers to the oceans and water bearing rocks to a depth of several kilometers.

Ecology provides a scientific context for evaluating environmental issues.

• It is important to clarify the difference between ecology, the scientific study of the distribution and abundance of organisms, and environmentalism, advocacy for the protection or preservation of the natural environment.

• To address environmental problems, we need to understand the interactions of organisms and the environment.
  ° The science of ecology provides that understanding.

• In 1962, Rachel Carson’s book Silent Spring warned that the use of pesticides such as DDT was causing population declines in many nontarget organisms.

• Today, acid precipitation, land misuse, toxic wastes, habitat destruction, and the growing list of endangered or extinct species are just a few of the problems that threaten the Earth.

• Many influential ecologists feel a responsibility to educate legislators and the general public about decisions that affect the environment.
  ° It is important to communicate the scientific complexity of environmental issues.
• Our ecological information is always incomplete. The precautionary principle (essentially “an ounce of prevention is worth a pound of cure”) can guide decision making on environmental issues.

**Concept 52.2 Interactions between organisms and the environment limit the distribution of species**

• Ecologists have long recognized distinct global and regional patterns in the distribution of organisms.

• Biogeography is the study of past and present distributions of individual species in the context of evolutionary theory.

• Ecologists ask a series of questions to determine what limits the geographical distribution of any species.

*Species dispersal contributes to the distribution of organisms.*

• The movement of individuals away from centers of high population density or from their area of origin is called dispersal.

• The dispersal of organisms is crucial to understanding geographic isolation in evolution and the broad patterns of geographic distribution of species.

• One way to determine if dispersal is a key factor limiting distribution is to observe the results when humans have accidentally or intentionally transplanted a species to areas where it was previously absent.
  ○ For the transplant to be considered successful, the organisms must not only survive in the new area, but also reproduce there.

• If the transplant is successful, then the potential range of the species is larger than its actual range.

• Species introduced to new geographic locations may disrupt the communities and ecosystems to which they are introduced.
  ○ Consequently, ecologists rarely conduct transplant experiments today.
  ○ Instead, they study the outcome when a species has been transplanted accidentally or for another purpose.

*Behavior and habitat selection contribute to the distribution of organisms.*

• Sometimes organisms do not occupy all of their potential range but select particular habitats.

• Does behavior play a role in limiting distribution in such cases?

• Habitat selection is one of the least-understood ecological processes, but it appears to play an important role in limiting the distribution of many species.
**Biotic factors affect the distribution of organisms.**

- Do biotic factors limit the distribution of species?
  - Negative interactions with other organisms in the form of predation, parasitism, disease, or competition may limit the ability of organisms to survive and reproduce.
    - Predator-removal experiments can provide information about how predators limit distribution of prey species.
  - Absence of other species may also limit distribution of a species.
    - For example, the absence of a specific pollinator or prey species may limit distribution of an organism.

**Abiotic factors affect the distribution of organisms.**

- The global distribution of organisms broadly reflects the influence of abiotic factors such as temperature, water, and sunlight.

- The environment is characterized by spatial and temporal heterogeneity.

- Environmental temperature is an important factor in the distribution of organisms because of its effect on biological processes.
  - Very few organisms can maintain an active metabolism at very high or very low temperatures.
  - Some organisms have extraordinary adaptations to allow them to live outside the temperature range habitable for most other living things.

- The variation in water availability among habitats is an important factor in species distribution.
  - Most aquatic organisms are restricted to either freshwater or marine environments.
  - Terrestrial organisms face a nearly constant threat of desiccation and have adaptations to allow them to obtain and conserve water.

- Sunlight provides the energy that drives nearly all ecosystems.
  - Intensity of light is not the most important factor limiting plant growth in most terrestrial environments, although shading by a forest canopy makes competition for light in the understory intense.
  - In aquatic environments, light intensity limits distribution of photosynthetic organisms.
    - Every meter of water depth selectively absorbs 45% of red light and 2% of blue light passing through it.
    - As a result, most photosynthesis in aquatic environments occurs near the surface.
  - Photoperiod, the relative length of daytime and nighttime, is a reliable indicator of seasonal events and is an important cue for the development or behavior of many organisms.
• Wind amplifies the effects of temperature by increasing heat loss due to evaporation and convection. It also increases water loss by increasing the rate of evaporative cooling in animals and transpiration in plants.

• The physical structure, pH, and mineral composition of soils and rocks limit distribution of plants and, thus, of the animals that feed upon them, contributing to the patchiness of terrestrial ecosystems.

• In streams and rivers, substrate composition can affect water chemistry, affecting distribution of organisms.

• In marine environments, the structure of substrates in the intertidal areas or seafloor limits the organisms that can attach to or burrow in those habitats.

Four abiotic factors are the major components of climate.

• Climate is the prevailing weather conditions in an area.
  ° Four abiotic factors—temperature, water, sunlight, and wind—are the major components of climate.
  ° Climatic factors, especially temperature and water, have a major influence on the distribution of organisms.

• Climate patterns can be described on two scales. Macroclimate patterns are on global, regional, or local levels, and microclimate patterns are very fine patterns such as the conditions experienced by a community of organisms under a fallen log.

• Climate determines the makeup of biomes, the major types of ecosystems.
  ° Annual means for temperature and rainfall are reasonably well correlated with the biomes found in different regions.

• Global climate patterns are determined by sunlight and Earth’s movement in space.
  ° The sun’s warming effect on the atmosphere, land, and water establishes the temperature variations, cycles of air movement, and evaporation of water that are responsible for latitudinal variations in climate.

• Bodies of water and topographic features such as mountain ranges create regional climatic variations, while smaller features of the landscape affect local climates.

• Ocean currents influence climate along the coast by heating or cooling overlying air masses, which may pass over land.
  ° Coastal regions are generally moister than inland areas at the same latitude.
  ° In general, oceans and large lakes moderate the climate of nearby terrestrial environments.
    • In certain regions, cool, dry ocean breezes are warmed when they move over land, absorbing moisture and creating a hot, rainless climate slightly inland.
- This Mediterranean climate pattern occurs inland from the Mediterranean Sea.
  - Ocean currents also influence climate in coastal areas.
- Mountains have a significant effect on the amount of sunlight reaching an area, as well as on local temperature and rainfall.
  - In the Northern Hemisphere, south-facing slopes receive more sunlight than north-facing slopes, and are therefore warmer and drier.
  - These environmental differences affect species distribution.
- At any given latitude, air temperature declines 6°C with every 1,000-m increase in elevation.
  - This temperature change is equivalent to that caused by an 880-km increase in latitude.
- As moist, warm air approaches a mountain, it rises and cools, releasing moisture on the windward side of the peak.
  - On the leeward side of the mountain, cool, dry air descends, absorbing moisture and producing a rain shadow.
  - Deserts commonly occur on the leeward side of mountain ranges.
- The changing angle of the sun over the course of a year affects local environments.
  - Belts of wet and dry air on either side of the equator shift with the changing angle of the sun, producing marked wet and dry seasons around 20° latitude.
  - Seasonal changes in wind patterns produce variations in ocean currents, occasionally causing the upwelling of nutrient-rich, cold water from deep ocean layers.
- Lakes are also sensitive to seasonal temperature changes.
  - During the summer and winter, many temperate lakes are thermally stratified or layered vertically according to temperature.
  - These lakes undergo a semiannual mixing, or turnover, of their waters in spring and fall. Turnover brings oxygenated water to the bottom and nutrient-rich water to the surface.
- Many features in the environment influence microclimates.
  - Forest trees moderate the microclimate beneath them.
    - Cleared areas experience greater temperature extremes than the forest interior.
  - A log or large stone shelters organisms, buffering them from temperature and moisture fluctuations.
  - Every environment on Earth is characterized by a mosaic of small-scale differences in abiotic factors that influence the local distribution of organisms.
- Long-term climate changes profoundly affect the biosphere.
• One way to predict possible effects of current climate changes is to consider the changes that have occurred in temperate regions since the end of the last Ice Age.

• Until about 16,000 years ago, continental glaciers covered much of North America and Eurasia.

• As the climate warmed and the glaciers melted, tree distribution expanded northward.
  - A detailed record of these migrations is captured in fossil pollen in lake and pond sediments.

• If researchers can determine the climatic limits of current geographic distributions for individual species, they can predict how that species distribution will change with global warming.
  - A major question for tree species is whether seed dispersal is rapid enough to sustain the migration of the species as climate changes.
  - Consider the American beech, *Fagus grandifolia*.
    - Climate models predict that the northern and southern limit of the beech’s range will move 700–900 km north over the next century.
      - The beech will have to migrate 7–9 km per year to maintain its distribution.
    - However, since the Ice Age, the beech has migrated into its present range at a rate of only 0.2 km per year.
    - Without human assistance, the beech will become extinct.

**Concept 52.3 Abiotic and biotic factors influence the structure and dynamics of aquatic biomes**

• Varying combinations of biotic and abiotic factors determine the nature of the Earth’s biomes, major types of ecological associations that occupy broad geographic regions of land or water.

**Aquatic biomes occupy the largest part of the biosphere.**

• Ecologists distinguish between freshwater and marine biomes on the basis of physical and chemical differences.
  - Marine biomes generally have salt concentrations that average 3%, while freshwater biomes have salt concentrations of less than 1%.

• Marine biomes cover approximately 75% of the earth’s surface and have an enormous effect on the biosphere.
  - The evaporation of water from the oceans provides most of the planet’s rainfall.
  - Ocean temperatures have a major effect on world climate and wind patterns.
- Photosynthesis by marine algae and photosynthetic bacteria produce a substantial proportion of the world's oxygen. Respiration by these organisms consumes huge amounts of atmospheric carbon dioxide.

- Freshwater biomes are closely linked to the soils and biotic components of the terrestrial biomes through which they pass.
  - The pattern and speed of water flow and the surrounding climate are also important.

- Most aquatic biomes are physically and chemically stratified.

- Light is absorbed by the water and by photosynthetic organisms, so light intensity decreases rapidly with depth.
  - There is sufficient light for photosynthesis in the upper photic zone.
  - Very little light penetrates to the lower aphotic zone.

- The substrate at the bottom of an aquatic biome is the benthic zone.
  - This zone is made up of sand and sediments and is occupied by communities of organisms called benthos.
  - A major food source for benthos is dead organic material or detritus, which rains down from the productive surface waters of the photic zone.

- Sunlight warms surface waters, while deeper waters remain cold.
  - As a result, water temperature in lakes is stratified, especially in summer and winter.
  - In the ocean and most lakes, a narrow stratum of rapid temperature change called a thermocline separates the more uniformly warm upper layer from more uniformly cold deeper waters.

- In aquatic biomes, community distribution is determined by depth of the water, distance from shore, and open water versus bottom.

- In marine communities, phytoplankton, zooplankton, and many fish species live in the relatively shallow photic zone.

- The aphotic zone contains little life, except for microorganisms and relatively sparse populations of luminescent fishes and invertebrates.

- The major aquatic biomes include lakes, wetlands, streams, rivers, estuaries, intertidal biomes, oceanic pelagic biomes, coral reefs, and marine benthic biomes.

- Freshwater lakes vary greatly in oxygen and nutrient content.
  - Oligotrophic lakes are deep, nutrient poor, oxygen rich, and contain little life.
  - Eutrophic lakes are shallow, nutrient rich, and oxygen poor.

- In lakes, the littoral zone is the shallow, well-lit water close to shore.
• **The limnetic zone** is the open surface water.

- **Wetlands** are areas covered with sufficient water to support aquatic plants.
  - They can be saturated or periodically flooded.
  - Wetlands include marshes, bogs, and swamps.
  - They are among the most productive biomes on Earth and are home to a diverse community of invertebrates and birds.
  - Because of the high organic production and decomposition in wetlands, their water and soil are low in dissolved oxygen.
  - Wetlands have a high capacity to filter dissolved nutrients and chemical pollutants.
  - Humans have destroyed many wetlands, but some are now protected.

- **Streams and rivers** are bodies of water moving continuously in one direction.
  - Headwaters are cold, clear, turbulent, and swift.
    - They carry little sediment and relatively few mineral nutrients.
  - As water travels downstream, it picks up $O_2$ and nutrients on the way.
  - Nutrient content is largely determined by the terrain and vegetation of the area.
    - Many streams and rivers have been polluted by humans, degrading water quality and killing aquatic organisms.
    - Damming and flood control impairs the natural functioning of streams and rivers and threatens migratory species such as salmon.

- **Estuaries** are areas of transition between river and sea.
  - The salinity of these areas can vary greatly.
  - Estuaries have complex flow patterns, with networks of tidal channels, islands, levees, and mudflats.
  - They support an abundance of fish and invertebrate species and are crucial feeding areas for many species of waterfowl.

- **An intertidal zone** is a marine biome that is periodically submerged and exposed by the tides.
  - The upper intertidal zone experiences longer exposure to air and greater variation in salinity and temperature than do the lower intertidal areas.
  - Many organisms live only at a particular stratum in the intertidal.

- **The oceanic pelagic biome** is the open blue water, mixed by wind-driven oceanic currents.
  - The surface waters of temperate oceans turn over during fall through spring.
  - The open ocean has high oxygen levels and low nutrient levels.
• This biome covers 70% of the Earth’s surface and has an average depth of 4,000 meters.

• **Coral reefs** are limited to the photic zone of stable tropic marine environments with high water clarity. They are found at temperatures between 18°C and 30°C.
  o They are formed by the calcium carbonate skeletons of coral animals.
  o Mutualistic dinoflagellate algae live within the tissues of the corals.
  o Coral reefs are home to a very diverse assortment of vertebrates and invertebrates.
  o Collecting of coral skeletons and overfishing for food and the aquarium trade have reduced populations of corals and reef fishes.
  o Global warming and pollution contribute to large-scale coral mortality.

• The **marine benthic zone** consists of the seafloor below the surface waters of the coastal or *neritic zone* and the offshore *pelagic zone*.
  o Most of the ocean’s benthic zone receives no sunlight.
  o Organisms in the very deep *abyssal zone* are adapted to continuous cold (about 3°C) and extremely high pressure.
  o Unique assemblages of organisms are associated with deep-sea hydrothermal vents of volcanic origin on mid-ocean ridges.
    ▪ The primary producers in these communities are chemoautotrophic prokaryotes that obtain energy by oxidizing H₂S formed by a reaction of volcanically heated water with dissolved sulfate (SO₄²⁻).

**Concept 50.4 Climate largely determines the distribution and structure of terrestrial biomes**

• **Because** there are latitudinal patterns of climate over the Earth’s surface, there are also latitudinal patterns of biome distribution.

• A **climograph** denotes the annual mean temperature and precipitation of a region.
  o Temperature and rainfall are well correlated with different terrestrial biomes, and each biome has a characteristic climograph.

• Most terrestrial biomes are named for major physical or climatic features or for their predominant vegetation.

• Vertical stratification is an important feature of terrestrial biomes.
° The canopy of the tropical rain forest is the top layer, covering the low-tree stratum, shrub understory, ground layer, litter layer, and root layer.
° Grasslands have a canopy formed by grass, a litter layer, and a root layer.
° Stratification of vegetation provides many different habitats for animals.

- Terrestrial biomes usually grade into each other without sharp boundaries. The area of intergradation, called the ecotone, may be narrow or wide.
- The species composition of any biome differs from location to location.
- Biomes are dynamic, and natural disturbance rather than stability tends to be the rule.
  ° Hurricanes create openings for new species in tropical and temperate forests.
  ° In northern coniferous forests, snowfall may break branches and small trees, producing gaps that allow deciduous species to grow.
  ° As a result, biomes exhibit patchiness, with several different communities represented in any particular area.
- In many biomes, the dominant plants depend on periodic disturbance.
  ° For example, natural wildfires are an integral component of grasslands, savannas, chaparral, and many coniferous forests.
- Human activity has radically altered the natural patterns of periodic physical disturbance.
  ° Fires are now controlled for the sake of agricultural land use.
- Humans have altered much of the Earth’s surface, replacing original biomes with urban or agricultural ones.
- The major terrestrial biomes include tropical forest, desert, savanna, chaparral, temperate grassland, coniferous forest, temperate broadleaf forest, and tundra.
- **Tropical forests** are found close to the equator.
  ° **Tropical rain forests** receive constant high amounts of rainfall (200 to 400 cm annually).
  ° In tropical dry forests, precipitation is highly seasonal.
  ° In both, air temperatures range between 25°C and 29°C year round.
  ° Tropical forests are stratified, and competition for light is intense.
  ° Animal diversity is higher in tropical forests than in any other terrestrial biome.
• **Deserts** occur in a band near 30° north and south latitudes and in the interior of continents.
  - Deserts have low and highly variable rainfall, generally less than 30 cm per year.
  - Temperature varies greatly seasonally and daily.
  - Desert vegetation is usually sparse and includes succulents such as cacti and deeply rooted shrubs.
  - Many desert animals are nocturnal, so they can avoid the heat.
  - Desert organisms display adaptations to allow them to resist or survive desiccation.

• **Savanna** is found in equatorial and subequatorial regions.
  - Rainfall is seasonal, averaging 30-50 cm per year.
  - The savanna is warm year-round, averaging 24–29°C with some seasonal variation.
  - Savanna vegetation is grassland with scattered trees.
  - Large herbivorous mammals are common inhabitants.
    - The dominant herbivores are insects, especially termites.
  - Fire is important in maintaining savanna biomes.

• **Chaparrals** have highly seasonal precipitation with mild, wet winters and dry, hot summers.
  - Annual precipitation ranges from 30 to 50 cm.
  - Chaparral is dominated by shrubs and small trees, with a high diversity of grasses and herbs.
  - Plant and animal diversity is high.
  - Adaptations to fire and drought are common.

• **Temperate grasslands** exhibit seasonal drought, occasional fires, and seasonal variation in temperature.
  - Large grazers and burrowing mammals are native to temperate grasslands.
  - Deep fertile soils make temperate grasslands ideal for agriculture, especially for growing grain.
  - Most grassland in North America and Eurasia has been converted to farmland.

• **Coniferous forest**, or *taiga*, is the largest terrestrial biome on Earth.
  - Coniferous forests have long, cold winters and short, wet summers.
  - The conifers that inhabit these forests are adapted for snow and periodic drought.
  - Coniferous forests are home to many birds and mammals.
  - These forests are being logged at a very high rate and old-growth stands of conifers may soon disappear.

• **Temperate broadleaf forests** have very cold winters, hot summers, and considerable precipitation.
A mature temperate broadleaf forest has distinct vertical layers, including a closed canopy, one or two strata of understory trees, a shrub layer, and an herbaceous layer.

The dominant deciduous trees in Northern Hemisphere broadleaf forests drop their leaves and become dormant in winter.

In the Northern Hemisphere, many mammals in this biome hibernate in the winter, while many bird species migrate to warmer climates.

Humans have logged many temperate broadleaf forests around the world.

- Tundra covers large areas of the Arctic, up to 20% of the Earth’s land surface.
  - Alpine tundra is found on high mountaintops at all latitudes, including the tropics.
    - The plant communities in alpine and Arctic tundra are very similar.
  - The Arctic tundra winter is long and cold, while the summer is short and mild. The growing season is very short.
  - Tundra vegetation is mostly herbaceous, consisting of a mixture of lichens, mosses, grasses, forbs, and dwarf shrubs and trees.
  - A permanently frozen layer of permafrost prevents water infiltration and restricts root growth.
  - Large grazing musk oxen are resident in Arctic tundra, while caribou and reindeer are migratory.
  - Migratory birds use Arctic tundra extensively during the summer as nesting grounds.
  - Arctic tundra is sparsely settled by humans but has recently become the focus of significant mineral and oil extraction.