Climates, Biomes, and Ecological Restoration

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1 Introduction

Ecology is the scientific study of the interactions between organisms and the environment. These interactions may be organized into a hierarchy:

- **Organismal ecology:** studies how an organism's structure, physiology, and behavior meet the challenges of its environment
- **Population ecology:** a *population* is a group of individuals of the same species living in an area; studies the factors that affect changes in population size
- **Community ecology:** a *community* is a group of populations in an area; studies how interspecific interactions affect community structure
- **Landscape ecology:** a *landscape* is a group of connected ecosystems; studies the factors controlling exchanges of energy, materials, and organisms across multiple ecosystems
- **Global ecology:** a *biosphere* is the sum of the planet's ecosystems and landscapes; studies how the regional exchange of materials influences the global distribution of organisms

2 Climate

Climate, the long-term prevailing weather conditions in a given area, is the most significant influence on the distribution of terrestrial organisms. Climate is composed primarily of four physical factors: temperature, precipitation, sunlight, and wind.

2.1 Global Climate Patterns

1. **Latitudinal variation in sunlight intensity:** The intensity of sunlight varies depending on Earth's latitude. Sunlight strikes the tropics, or lower latitudes, more directly, delivering more heat and light.

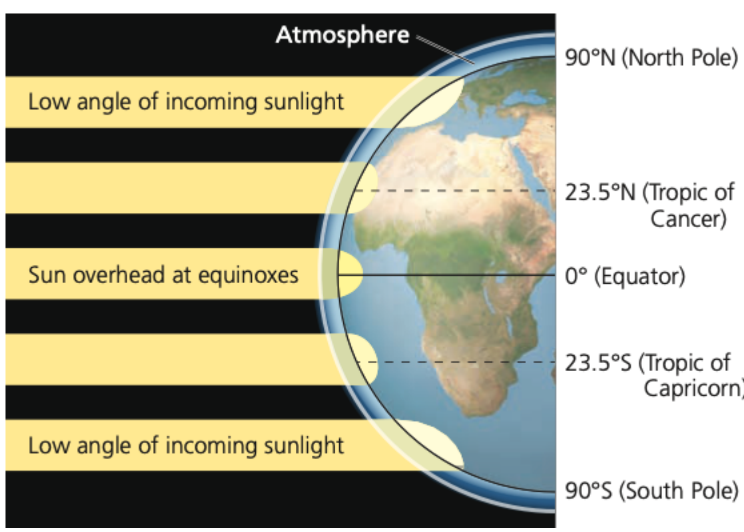

Figure 1: Sunlight strikes the tropics most directly and the higher latitudes at more oblique angles. (Source: *Campbell Biology)*

2. **Air circulation and precipitation patterns:** In the tropics, high temperatures cause warm, wet air masses to evaporate, *releasing* water as they expand and cool. The cool, dry air masses descend at higher latitudes, *absorbing* moisture and creating an arid climate. This process repeats as descending air flows further toward the poles.

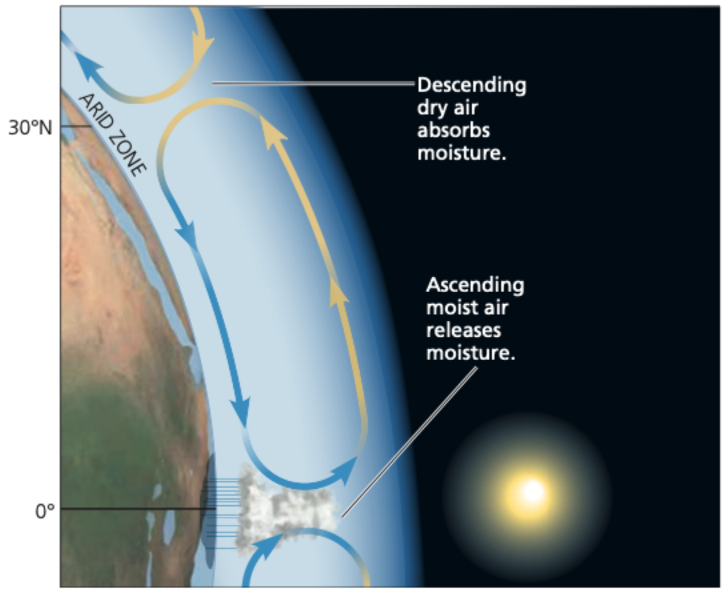

Figure 2: The circulation of air masses. (Source: *Campbell Biology)*

2.2 Regional and Local Climate Patterns

At the regional level, climate may vary based on seasonal changes and the presence of large bodies of water and mountain ranges. **Microclimates** are very fine, localized patterns in climatic conditions—for example, the area under a forest tree—which are affected by environmental features.

Seasonality: Seasonal cycles in day length, solar radiation, and temperature strengthen in middle to high latitudes. As the angle of the sun changes, belts of wet and dry air move slightly northward and southward, producing wet and dry seasons around 20° north and 20° south and causing the development of tropical deciduous forests. Seasonal changes in wind patterns alter ocean currents, sometimes causing *upwelling zones* of cold, nutrient-rich water from deep ocean layers.

Bodies of water: Due to water's high specific heat, large bodies of water moderate the climate of nearby land. Ocean currents flowing toward the equator carry cold water *from* the poles, while currents flowing away from the equator carry warm water *to* the poles.

Mountains: Mountains influence air flow over land. Warm, moist air on the *windward* side of a mountain rises and cools as it ascends, releasing moisture; cool, dry air on the *leeward* side absorbs moisture as it descends, producing a "rain shadow" where little precipitation occurs. Many deserts, such as the Mojave and Gobi Deserts, are located in such leeward rain shadows.

Mountains also influence sunlight patterns: south-facing slopes in the Northern Hemisphere are warmer and drier, allowing shrubby, drought-resistant plants to grow, while plants such as conifers grow on the cooler north-facing slopes.

Vegetation: Forests are darker in color than deserts and grasslands and therefore absorb more solar energy, increasing *transpiration*, the evaporative loss of water from a plant that cools the plant's surface. Because transpiration is much greater in forests than in other ecosystems, forests reduce Earth's surface temperature and increase precipitation rates.

2.3 Global Climate Change

Climate change is a long-term (lasting three or more decades) directional change to the global climate. The burning of fossil fuels and deforestation are increasing the concentrations of greenhouses gases in the atmosphere, warming Earth's temperatures, shifting wind and precipitation patterns, and increasing the frequency of extreme weather events (e.g., major storms and droughts).

Rapid warming forces species distributions to expand northward into more suitable habitats. While some species move northward rapidly, slower species experience a "lagging" effect in which their range expansion lags several thousand years behind the shift in suitable habitat. Decreased rain and snow at higher elevations has also caused plant species to move to lower elevations. Species forced to move into new geographic areas may harm other organisms living there.

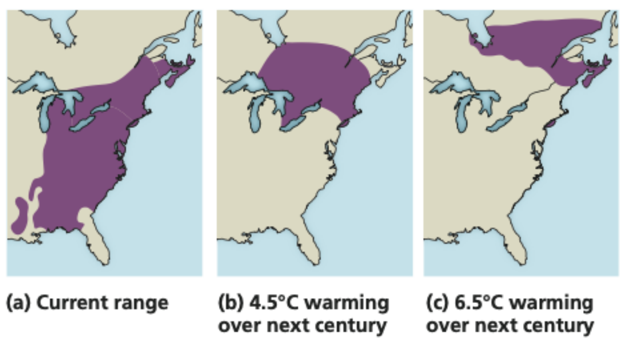

Figure 3: Current and predicted ranges for the American beech under two climate-change scenarios. (Source: *Campbell Biology)*

3 Biomes

3.1 Terrestrial Biomes

Life on earth is distributed across **biomes**, or major life zones. Terrestrial biomes are characterized by *vegetation type*, which is in turn influenced strongly by climate. Biomes can be plotted on a **climograph**, a graph of the annual mean temperature and precipitation in a particular region.

Most terrestrial biomes are named for their major climactic features and predominant vegetation (i.e., *temperate grasslands* are located in moderate climates and dominated by grass species). Rather than having distinct boundaries, terrestrial biomes usually grade into neighboring biomes; this area of intergradation is called an **ecotone**.

Vegetation in terrestrial biomes is *vertically layered*: many forests consist of, from top to bottom, the (1) upper canopy, (2) low-tree layer, (3) shrub understory, (4) ground layer of herbaceous plants, (5) forest floor (litter layer), and (6) root layer. This layering provides many different habitats for organisms, which sometimes exist in well-defined feeding groups.

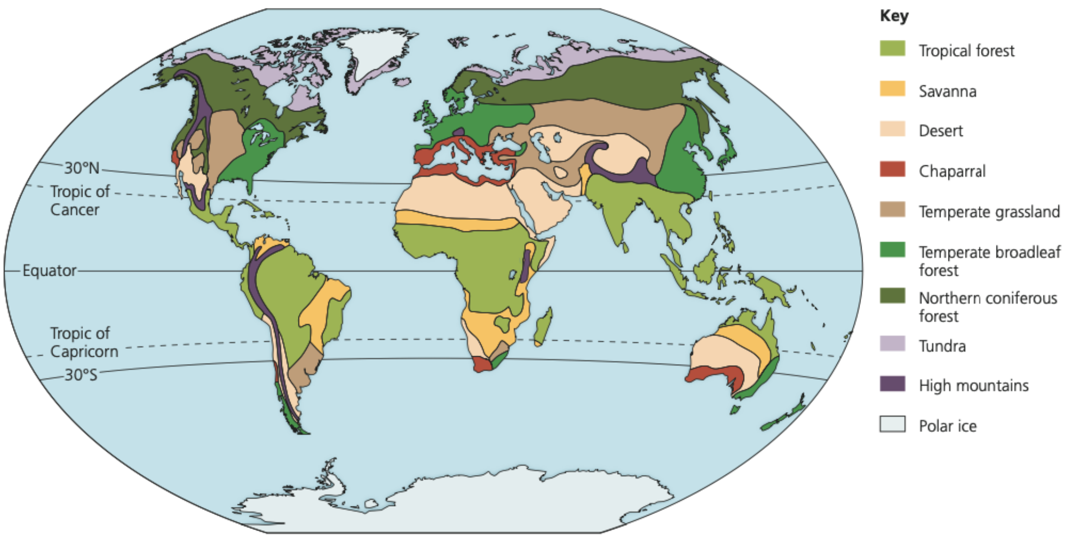

Figure 4: The distribution of major terrestrial biomes. (Source: *Campbell Biology)*

3.2 Aquatic Biomes

Aquatic biomes are characterized by their *physical* (light penetration; temperature; depth) and *chemical* (salinity; oxygen concentration; nutrient density) environment and show less latitudinal variation than terrestrial biomes. The oceans make up the largest marine biome, covering about 75% of Earth's surface.

3.2.1 Zonation

Many aquatic biomes are stratified both vertically and horizontally. Light is absorbed by water and photosynthetic organisms, so its intensity decreases rapidly with depth.

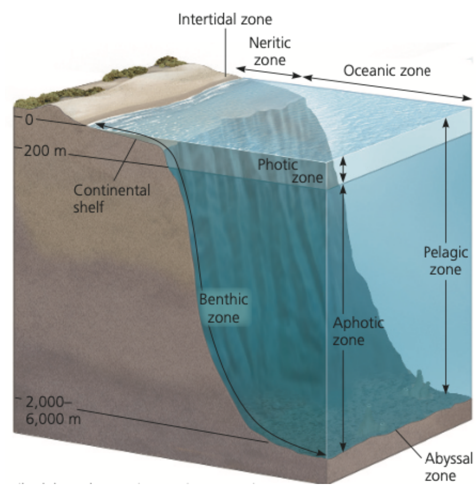

Figure 5: The marine environment is classified based on light penetration (photic and aphotic), distance from shore and water depth (itnertidal, neritic, and oceanic), and whether the environment is open water (pelagic) or on the bottom (benthic and abyssal).
(Source: *Campbell Biology)*

- **Pelagic zone:** contains the *photic zone*, where there is sufficient light for photosynthesis, and the *aphotic zone*, where where little light penetrates
- **Abyssal zone**
- **Benthic zone:** made up of sand and sediment; inhabited by communities of organisms collectively called the *benthos*, many of which feed on dead organic matter called *detritus* which drifts down from the photic zone

The ocean and most lakes contain a **thermocline**, a narrow layer of abrupt temperature change which separates the warm upper layer from cold deeper layers. Many temperate lakes undergo a **turnover**, or semiannual mixing of their waters, in autumn (as surface water cools and sinks) and spring (as surface water warms and mixes with the below layers). This turnover mixes oxygenated water from the surface and nutrient-rich water from the bottom.

- **Lakes:** Large standing bodies of water. Lakes range widely in salinity, oxygen concentration, and nutrient content.
  - *Oligotrophic* lakes are nutrient-poor and oxygen-rich, with low amonts of decomposable organic matter, while *eutrophic* lakes are nutrient-rich and oxygen-poor, with high rates of decomposition.
  - *T*he shallow, well-lit *littoral zone* contains aquatic plants, while the farther, deeper *limnetic zone* contains a variety of phytophankton.
  - Runoff from fertilized land leads to nutrient enrichment in lakes, which can produce large numbers of algae (called an *algal bloom*) and deplete oxygen. This is known as **cultural eutrophication**.
- **Wetlands:** Habitats inundated by water at least some of the time which support plants adapted to water-saturated soil. Wetlands are productive and low in dissolved oxygen, with high rates of organic production and decomposition, and have a high capacity for filtration of dissolved nutrients and chemicals.
- **Streams and rivers:** Bodies of continuously-flowing water, stratified into vertical zones. *Headwaters* are generally cold, clear, and rich in oxygen, while *downstream* waters are generally warmer and more turbid.
- **Estuaries:** Transition areas between rivers and seas. Salinity varies spatially and with the rise and fall of the tides. Nutrients from the river make estuaries highly productive, acting as crucial feeding areas for waterfowl and some marine mammals.
- **Intertidal zones:** Highly diverse zones which are periodically submerged and exposed by the tides (twice daily on most marine shores).
- **Ocean pelagic zone:** A vast zone of open water, constantly mixed by ocean currents. Covers approximately 70% of Earth's surface. Photosynthetic plankton in the ocean pelagic zone account for about half of Earth's photosynthetic activity.
- **Coral reefs:** Areas formed largely from the calcium carbonate skeletons of corals. Coral reefs typically begin as *fringing reefs* on young, high islands, then form an offshore *barrier reef* and eventually become a *coral atoll* as the island submerges.
- **Marine benthic zone:** The seafloor below the surface waters of the coastal (neritic) zone and the offshore pelagic zone. Contains no sunlight; temperature declines and pressure increases with depth. Most consumers depend entirely on organic matter from the photic zone. Unique organisms live near deep-sea *hydrothermal vents*.

Example 3.1 (USABO Semifinal Exam 2016) Seasonal turnover of lakes occurs during

(A) Summer only.
(B) Spring and autumn.
(C) Summer and winter.
(D) Spring, summer, and autumn.
(E) All four seasons.

Solution: Turnover, or the mixing of surface water and lower layers, occurs semiannually: once when the icy surface water warms and mixes with the below layers, and once when temperatures lower, causing surface water to cool and sink. The answer is therefore **(B) Spring and autumn.**

3.3 Factors Influencing Species Distribution

- **Dispersal** is the movement of individuals of gametes away from their area of origin or from centers of high population density, often resulting in *range expansion*. Successful *transplantation* of a species to a new area indicates that the potential range of the species is larger than its actual range.
- **Biotic factors**, or other species, limit a species' ability to survive and reproduce through predation or herbivory.
- **Abiotic factors** are physical conditions such as temperature, salinity, and sunlight. Unsuitable conditions limit a species' distribution.

4 Ecosystems

An **ecosystem** consists of all of the organisms in a community and the abiotic factors with which they interact. Ecosystems can be as large as the entire biosphere or as small as the area under a fallen log, and ecosystem dynamics are governed by two processes: *energy flow* and *chemical cycling*. These processes are determined by trophic relationships.

- **Primary producers:** Autotrophs; mostly photosynthetic plants, algae, or prokaryotes that use light energy to synthesize organic compounds.
- **Primary consumers:** Herbivores that eat primary producers.
- **Secondary consumers:** Carnivores that eat herbivores.
- **Tertiary consumers:** Carnivores that eat other carnivores.
- **Detritivores:** Get energy from *detritus*, nonliving organic material such as the remains of dead organisms, feces, and wood (i.e., prokaryotes and fungi).
  - Detritivores recycle chemical elements back to primary producers by converting organic materials to inorganic compounds usable by primary producers.

4.1 Energy Flow

Energy enters most ecosystems in the form of sunlight, which is converted to chemical energy by autotrophs, passed to heterotrophs in the organic compounds of food, and dissipated as heat.

According to the *first law of thermodynamics*, energy cannot be created or destroyed. In ecosystems, solar energy is converted to chemical energy by plants and photosynthetic organisms, so the total amount of energy stored in organic molecules plus the amounts reflected and dissipated as heat must equal the total solar energy intercepted by the plant.

According to the *second law of thermodynamics*, every exchange of energy increases the entropy of the universe. In an ecosystem, some energy is lost as heat in any conversion process.

The amount of light energy converted by chemical energy by an ecosystem's autotrophs in a given period is an ecosystem's **primary production**. The total primary production in an ecosystem is **gross primary production (GPP)**, the amount of light energy that is converted to chemical energy by photosynthesis per unit time. **Net primary production (NPP)** is equal to gross primary production minus the energy used by primary producers for respiration (R):

$$NPP = GPP - R$$

In many ecosystems, NPP is about half of GPP. NPP represents the stored chemical energy that is available to consumers in the ecosystem.

- Net primary production can be expressed as energy per unit area per unit time (J/m2·yr), or as biomass of vegetation added to the ecosystem per unit area per unit time (g/m2·yr).
- The **standing crop** is the total biomass of photosynthetic autotrophs present in a given time, while NPP is the amount of new biomass added in a given period of time.
- Forests have a large standing crop biomass, but their primary production may actually be less than that of some grasslands, which do not accumulate vegetation because animals consume the plants rapidly and because grasses and herbs decompose more quickly than trees do.
  - Tropical rainforests have high NPP per unit area and contribute a large portion of Earth's overall NPP.
  - Estuaries and coral reefs have very high NPP per unit area, but they cover only about one-tenth the area covered by tropical rain forests, so they contribute less to global NPP.
  - The open ocean has a relatively low NPP per unit area but contributes as much global net primary production as terrestrial systems because of its vast size.

In aquatic ecosystems, light and nutrients limit primary production, because solar radiation can penetrate to only a certain depth (the photic zone). A *limiting nutrient* is an element that must be added for production to increase in a particular area. In marine zones, the limiting nutrient is most often nitrogen or phosphorus, which are very low in the photic zone.

- Nutrient limitation is common in freshwater lakes. In *eutrophication*, sewage and fertilizer pollution add large amounts of nutrients to lakes, causing cyanobacteria and algae populations to grow rapidly, ultimately reducing oxygen concentrations and visibility in the water.

In terrestrial ecosystems, temperature and moisture are the key factors limiting primary production. Contrasts in climate can be represented by *actual evapotranspiration*, the annual amount of water transpired by plants and evaporated from a landscape.

4.2 Chemical Cycling

Chemical elements are cycled among abiotic and biotic components of an ecosystem.

- Photosynthetic organisms assimilate chemical elements in organic form from the air, soil, and water, and incorporate them into their biomass.
- Some of these chemical elements are consumed by animals.
- The elements are returned in organic form to the environment by the metabolism of plants and animals and by decomposers such as bacteria and fungi, which break down organic wastes and dead organisms.

Example 4.1 (USABO Semifinal Exam 2018) The main distinction between nutrient and energy dynamics in rangeland ecosystems is:

(A) Nutrients flow through ecosystem components while energy is cycled.
(B) Nutrients cycle through ecosystem components while energy flows.
(C) Nutrients are confined to living portions of the ecosystem while energy is not.
(D) The main source of all nutrients is the soil while the sun supplies energy.

Solution: As covered in this section, the answer is **(B) Nutrients cycle through ecosystem components while energy flows.**

5 Restoration Ecology

Conservation biology integrates ecology, evolutionary biology, physiology, molecular biology, genetics, and behavioral ecology to conserve biological diversity at all levels. **Restoration ecology** applies ecological principles in an effort to return degraded ecosystems to conditions as similar as possible to their natural, predegraded state.

5.1 Biodiversity

The accelerated rate of extinction caused by human activity threatens Earth's biodiversity. Biodiversity has three levels:

- **Genetic diversity** refers to the genetic variation within a species. It comprises the individual genetic variation within a population *and* the genetic variation between populations.
- **Species diversity** is the variety of species in an ecosystem or the biosphere, and is greatly affected by the biodiversity crisis.

  - *Endangered species* are in danger of extinction throughout a significant portion of their range, and *threatened species* are likely to become endangered in the foreseeable future. Species extinction may be local (lost in one area) or global (lost in all locales).

- **Ecosystem diversity** is the variety of the biosphere's ecosystems. Ecosystems such as wetlands in the U.S. and native riparian communities in California, Arizona, and New Mexico are being altered at a rapid pace.

The three major threats to biodiversity are habitat loss, introduced species, and overexploitation.

- **Habitat loss** is the single greatest threat to biodiversity, caused mainly by human activities such as urban development, deforestation, and mining. Habitat fragmentation, the breaking up of natural landscapes, leads to species loss in almost all cases.

- **Introduced species** are moved by humans from native locations to new geographic regions. Introduced species often disrupt their adopted community by outcompeting native species for resources—for example, zebra mussels native to Europe have extensively disrupted freshwater ecosystems and clogged water-intake systems in North America.

- **Overexploitation** is the human harvesting of wild plants and animals at rates that exceed the ability of those populations to rebound. Species with restricted habitats (i.e., small islands) and large organisms with low reproductive rates are particularly vulnerable to overexploitation.

Example 5.1 (USABO Semifinal Exam 2018) What are the three principal levels of biodiversity?

(A) genetic, species and ecosystem
(B) individual, population and community
(C) population, community and ecosystem
(D) community, ecosystem and landscape

Solution: As covered in this section, the main levels of biodiversity are **(A) genetic, species and ecosystem** diversity.

5.2 Biological Strategies

- **Bioremediation** is the use of living organisms, usually prokaryotes, fungi, or plants, to detoxify (*remove* toxins from) polluted ecosystems.

  - *Example:* Plants adapted to soils containing heavy metals can remove high concentrations of potentially toxic metals from polluted environments.

- **Biological augmentation** uses organisms to *add* essential materials to a degraded ecosystem.

  - *Example:* Nitrogen-fixing herbs can be planted in ecosystems disturbed by mining to increase nitrogen concentrations in soil.

6 Conclusion

This handout covered the basics of ecology at the global and landscape levels, focusing largely on the interactions between organisms and abiotic factors found across Earth's biomes. Information *not* covered in this handout includes details on the major terrestrial biomes and nutrient cycles, which you may want to review after reading. To learn about the interactions between organisms at the community and population levels, read on to the Population Ecology, Community Ecology, and Ethology handout.