Chapter 55

Ecosystems and Restoration Ecology

An **ecosystem** consists of all the organisms living in a community, as well as the abiotic factors with which they interact

Ecosystems range from a microcosm, such as an aquarium, to a large area, such as a lake or forest

Regardless of an ecosystem’s size, its dynamics involve two main processes: energy flow and chemical cycling

Energy flows through ecosystems, whereas matter cycles within them

Physical laws govern energy flow and chemical cycling in ecosystems

Ecologists study the transformations of energy

and matter within ecosystems

Conservation of Energy

Laws of physics and chemistry apply to ecosystems, particularly energy flow

The first law of thermodynamics states that energy cannot be created or destroyed, only transformed

Energy enters an ecosystem as solar radiation, is conserved, and is lost from organisms as heat

The second law of thermodynamics states that every exchange of energy increases the entropy of the universe

In an ecosystem, energy conversions are not completely efficient, and some energy is always lost as heat

Conservation of Mass

The **law of conservation of mass** states that matter cannot be created or destroyed

Chemical elements are continually recycled within ecosystems

In a forest ecosystem, most nutrients enter as dust or solutes in rain and are carried away in water

Ecosystems are open systems, absorbing energy and mass and releasing heat and waste products

Energy, Mass, and Trophic Levels

Autotrophs build molecules themselves using photosynthesis or chemosynthesis as an energy source

Heterotrophs depend on the biosynthetic output of other organisms

Energy and nutrients pass from **primary producers** (autotrophs) to **primary consumers** (herbivores) to **secondary consumers** (carnivores) to **tertiary consumers** (carnivores that feed on other carnivores)

Detritivores, or **decomposers**, are consumers that derive their energy from **detritus**, nonliving organic matter

Prokaryotes and fungi are important detritivores

Decomposition connects all trophic levels

Energy and other limiting factors control primary production in ecosystems

In most ecosystems, **primary production** is the amount of light energy converted to chemical energy by autotrophs during a given time period

In a few ecosystems, chemoautotrophs are the primary producers

Ecosystem Energy Budgets

The extent of photosynthetic production sets the spending limit for an ecosystem’s energy budget

The Global Energy Budget

The amount of solar radiation reaching Earth's surface limits the photosynthetic output of ecosystems

Only a small fraction of solar energy actually strikes photosynthetic organisms, and even less is of a usable wavelength

Gross and Net Production

Total primary production is known as the ecosystem's **gross primary production (GPP)**

GPP is measured as the conversion of chemical energy from photosynthesis per unit time

Net primary production (NPP) is GPP minus energy used by primary producers for respiration

NPP is the amount of new biomass added in a given time period

Only NPP is available to consumers

Standing crop is the total biomass of photosynthetic autotrophs at a given time

Ecosystems vary greatly in NPP and contribution to the total NPP on Earth

Tropical rain forests, estuaries, and coral reefs are among the most productive ecosystems per unit area

Marine ecosystems are relatively unproductive per unit area but contribute much to global net primary production because of their volume

Net ecosystem production (NEP) is a measure of the total biomass accumulation during a given period

NEP is gross primary production minus the total respiration of all organisms (producers and consumers) in an ecosystem

NEP is estimated by comparing the net flux of CO_2 and O_2 in an ecosystem, two molecules connected by photosynthesis

The release of O_2 by a system is an indication that it is also storing CO_2

Energy transfer between trophic levels is typically only 10% efficient

Secondary production of an ecosystem is the amount of chemical energy in food converted to new biomass during a given period of time

Production Efficiency

When a caterpillar feeds on a leaf, only about one-sixth of the leaf's energy is used for secondary production

An organism's **production efficiency** is the fraction of energy stored in food that is not used for respiration

$$\text{Production efficiency} = \frac{\text{Net secondary production} \times 100\%}{\text{Assimilation of primary production}}$$

Birds and mammals have efficiencies in the range of 1–3% because of the high cost of endothermy

Fishes have production efficiencies of around 10%

Insects and microorganisms have efficiencies of 40% or more

Trophic Efficiency and Ecological Pyramids

Trophic efficiency is the percentage of production transferred from one trophic level to the next

It is usually about 10%, with a range of 5% to 20%

Trophic efficiency is multiplied over the length of a food chain

Approximately 0.1% of chemical energy fixed by photosynthesis reaches a tertiary consumer

A pyramid of net production represents the loss of energy with each transfer in a food chain

In a biomass pyramid, each tier represents the dry mass of all organisms in one trophic level

Most biomass pyramids show a sharp decrease at successively higher trophic levels

Certain aquatic ecosystems have inverted biomass pyramids: producers (phytoplankton) are consumed so quickly that they are outweighed by primary consumers

Turnover time is the ratio of the standing crop biomass to production

Dynamics of energy flow in ecosystems have important implications for the human population

Eating meat is a relatively inefficient way of tapping photosynthetic production

Worldwide agriculture could feed many more people if humans ate only plant material

Biological and geochemical processes cycle nutrients and water in ecosystems

- Life depends on recycling chemical elements
- Nutrient cycles in ecosystems involve biotic and abiotic components and are often called **biogeochemical cycles**

Biogeochemical Cycles

Gaseous carbon, oxygen, sulfur, and nitrogen occur in the atmosphere and cycle globally

Less mobile elements include phosphorus, potassium, and calcium

These elements cycle locally in terrestrial systems but more broadly when dissolved in aquatic systems

A model of nutrient cycling includes main reservoirs of elements and processes that transfer elements between reservoirs

All elements cycle between organic and inorganic reservoirs

In studying cycling of water, carbon, nitrogen, and phosphorus, ecologists focus on four factors

- Each chemical’s biological importance
- Forms in which each chemical is available or used by organisms
- Major reservoirs for each chemical
- Key processes driving movement of each chemical through its cycle

The Water Cycle

Water is essential to all organisms

Liquid water is the primary physical phase in which water is used

The oceans contain 97% of the biosphere’s water; 2% is in glaciers and polar ice caps, and 1% is in lakes, rivers, and groundwater

Water moves by the processes of evaporation, transpiration, condensation, precipitation, and movement through surface and groundwater

The Carbon Cycle

Carbon-based organic molecules are essential to all organisms

Photosynthetic organisms convert CO_2 to organic molecules that are used by heterotrophs

Carbon reservoirs include fossil fuels, soils and sediments, solutes in oceans, plant and animal biomass, the atmosphere, and sedimentary rocks

CO_2 is taken up and released through photosynthesis and respiration; additionally, volcanoes and the burning of fossil fuels contribute CO_2 to the atmosphere

The Nitrogen Cycle

Nitrogen is a component of amino acids, proteins, and nucleic acids

The main reservoir of nitrogen is the atmosphere (N_2), though this nitrogen must be converted to ammonium or nitrate for uptake by plants, via nitrogen fixation by bacteria

Organic nitrogen is decomposed to NH_4^+ by ammonification, and NH_4^+ is decomposed to NO_3^- by nitrification

Denitrification converts NO_3^- back to N_2

The Phosphorus Cycle

Phosphorus is a major constituent of nucleic acids, phospholipids, and ATP

Phosphate (PO_4^{3-}) is the most important inorganic form of phosphorus

The largest reservoirs are sedimentary rocks of marine origin, the oceans, and organisms

Phosphate binds with soil particles, and movement is often localized

Decomposition and Nutrient Cycling Rates

Decomposers (detritivores) play a key role in the general pattern of chemical cycling

Rates at which nutrients cycle in different ecosystems vary greatly, mostly as a result of differing rates of decomposition

The rate of decomposition is controlled by temperature, moisture, and nutrient availability

Rapid decomposition results in relatively low levels of nutrients in the soil

Cold and wet ecosystems store large amounts of undecomposed organic matter as decomposition rates are low

Decomposition is slow in anaerobic muds

Restoration ecologists help return degraded ecosystems to a more natural state

Given enough time, biological communities can recover from many types of disturbances

Restoration ecology seeks to initiate or speed up the recovery of degraded ecosystems

Two key strategies are bioremediation and augmentation of ecosystem processes

Bioremediation

- **Bioremediation** is the use of organisms to detoxify ecosystems
- The organisms most often used are prokaryotes, fungi, or plants
- These organisms can take up, and sometimes metabolize, toxic molecules
  - For example, the bacterium *Shewanella oneidensis* can metabolize uranium and other elements to insoluble forms that are less likely to leach into streams and groundwater

Biological Augmentation

Biological augmentation uses organisms to add essential materials to a degraded ecosystem

For example, nitrogen-fixing plants can increase the available nitrogen in soil

For example, adding mycorrhizal fungi can help plants to access nutrients from soil