Ecosystems

Chapter 6: FUNCTIONING ECOSYSTEM

Learning Objectives: Upon completion of this chapter, students should be able to:

- Describe the relationships of organisms in an ecosystem.
- Differentiate between autotrophs and heterotrophs.
- Explain trophic levels and their significance.
- Construct and interpret food chains and food webs.
- Illustrate energy flow within an ecosystem.
- Explain ecological pyramids (numbers, biomass, energy).
- Discuss energy losses in transformations within an ecosystem.
- Describe the laws of thermodynamics in relation to energy flow.
- Analyze nutrient cycling, including carbon, nitrogen, and water cycles.
- Explain the process of decomposition in nature.

6.1 Relationships of Organisms in an Ecosystem

Organisms in an ecosystem interact in various ways, forming complex relationships that influence their survival and the overall health of the ecosystem.

- **Autotrophs (Producers):** Organisms that produce their own food using light energy (photosynthesis) or chemical energy (chemosynthesis). They form the base of almost all food chains.
    - *Examples:* Green plants, algae, some bacteria.
- **Heterotrophs (Consumers):** Organisms that obtain energy by consuming other organisms.
    - **Herbivores (Primary Consumers):** Feed on producers (plants). *Examples:* Deer, rabbits, caterpillars.
    - **Carnivores (Secondary Consumers):** Feed on herbivores. *Examples:* Lions, wolves, snakes.
    - **Tertiary Consumers:** Feed on secondary consumers. *Examples:* Eagles, larger predators.
    - **Omnivores:** Feed on both plants and animals. *Examples:* Humans, bears, raccoons.
    - **Detritivores:** Feed on dead organic matter (detritus). *Examples:* Earthworms, millipedes.

- **Decomposers:** Organisms (primarily bacteria and fungi) that break down dead organic matter and waste products, returning nutrients to the soil and atmosphere. They are crucial for nutrient cycling.
    - *Examples:* Bacteria, fungi.
- **Types of Interspecific Relationships (Interactions between different species):**
    1. **Predation:** One organism (predator) hunts, kills, and consumes another organism (prey).
        - *Example:* Lion hunting a zebra.
        - *Effect:* Benefits predator, harms prey; helps control prey populations.
    2. **Competition:** Organisms compete for limited resources (food, water, space, mates).
        - *Intraspecific Competition:* Between individuals of the same species.
        - *Interspecific Competition:* Between individuals of different species.
        - *Effect:* Harms both species, as resources are limited; can lead to competitive exclusion or resource partitioning.
    3. **Symbiosis:** A close and long-term interaction between two different species.
        - **Mutualism (+/+):** Both species benefit from the interaction.
            - *Example:* Bees pollinating flowers (bees get nectar, flowers get pollinated).
            - *Example:* Lichens (fungus and alga) – fungus provides structure, alga provides food via photosynthesis.
        - **Commensalism (+/0):** One species benefits, while the other is neither helped nor harmed.
            - *Example:* Barnacles on a whale (barnacles get a place to live and filter feed, whale is unaffected).
        - **Parasitism (+/-):** One species (parasite) benefits at the expense of the other (host), usually without immediately killing the host.
            - *Example:* Tapeworm in a human intestine (tapeworm gets nutrients, humans are harmed).

6.2 Trophic Levels

- **Definition:** Trophic levels describe the position an organism occupies in a food chain. It indicates how an organism obtains its energy.
- **Levels:**
    1. **Producers (Autotrophs):** First trophic level. Convert light/chemical energy into organic matter. (e.g., plants, algae).
    2. **Primary Consumers (Herbivores):** Second trophic level. Feed directly on producers. (e.g., rabbits, grasshoppers).
    3. **Secondary Consumers (Carnivores/Omnivores):** Third trophic level. Feed on primary consumers. (e.g., snakes, small birds).
    4. **Tertiary Consumers (Carnivores/Omnivores):** Fourth trophic level. Feed on secondary consumers. (e.g., eagles, large predators).
    5. **Quaternary Consumers (Carnivores):** Fifth trophic level. Feed on tertiary consumers. (Less common, usually top predators).
    - **Decomposers:** Break down dead organic matter from all trophic levels, returning nutrients. They are not usually assigned a trophic level in the main chain but are essential for nutrient cycling.

6.3 Food Chains and Food Webs

- **Food Chain:** A linear sequence showing how energy is transferred from one organism to another through feeding relationships. It starts with a producer and moves up through consumers.
    - *Example:* Grass \rightarrow Grasshopper \rightarrow Frog \rightarrow Snake \rightarrow Eagle
    - *Arrows:* Always point in the direction of energy flow (from the organism being eaten to the organism that eats it).
- **Food Web:** A more realistic representation of feeding relationships in an ecosystem. It consists of multiple interconnected food chains, showing that most organisms feed on, and are fed upon by, more than one type of organism.
    - *Importance:* Shows the complexity and interdependence of species. If one species is removed, it can have cascading effects throughout the web.

6.4 Energy Flow in an Ecosystem

Energy flow in an ecosystem is unidirectional and follows the laws of thermodynamics.

- **Source of Energy:** The ultimate source of energy for most ecosystems is the sun.
- **Path of Energy Flow:**
    - Sunlight is captured by producers (photosynthesis).
    - Energy is transferred to primary consumers when they eat producers.
    - Energy is transferred to secondary consumers when they eat primary consumers, and so on.
- **Ecological Pyramids:** Graphical representations that show the quantitative relationships between different trophic levels.
    1. **Pyramid of Numbers:** Shows the number of individual organisms at each trophic level.
        - *Shape:* Usually upright (decreasing numbers at higher levels), but can be inverted (e.g., one large tree supporting many insects).
    2. **Pyramid of Biomass:** Shows the total dry mass (biomass) of organisms at each trophic level.
        - *Shape:* Usually upright (decreasing biomass at higher levels), but can be inverted in aquatic ecosystems (e.g., small biomass of phytoplankton supporting a larger biomass of zooplankton at a given time).
    3. **Pyramid of Energy:** Shows the total amount of energy (usually in Joules or calories) at each trophic level over a period of time.
        - *Shape:* **Always upright.** This is because energy is lost at each transfer.
        - *Most accurate representation of energy flow.*
- **Energy Losses in Transformations (10% Rule):**
    - Only about **10% of the energy** from one trophic level is transferred to the next trophic level. The remaining 90% is lost.
    - **How Energy is Lost:**
        - **Metabolic Processes:** Respiration (heat loss during cellular activities).
        - **Incomplete Consumption:** Not all parts of an organism are eaten.
        - **Undigested Food:** Some consumed energy is egested as waste.
        - **Heat Loss:** Energy is lost as heat to the environment at each transfer.

    - **Consequences:**
        - Limits the number of trophic levels in a food chain (typically 3-5).
        - Explains why there are fewer top predators than producers.
        - Highlights the inefficiency of energy transfer.
- **Laws of Thermodynamics in Energy Flow:**
    1. **First Law of Thermodynamics (Law of Conservation of Energy):** Energy cannot be created or destroyed, only transformed from one form to another.
        - *In Ecosystems:* Solar energy is converted to chemical energy (glucose) by producers; chemical energy is converted to mechanical energy, heat, etc., by consumers. The total amount of energy remains constant.
    2. **Second Law of Thermodynamics (Law of Entropy):** During every energy transfer or transformation, some energy is converted into a less usable form, usually heat, leading to an increase in the entropy (disorder) of the universe.
        - *In Ecosystems:* The 90% energy loss at each trophic level is primarily due to this law. Energy becomes less organized and usable as it moves up the food chain. This explains why food chains are relatively short and why energy flow is unidirectional.

6.5 Nutrient Cycling (Biogeochemical Cycles)

Unlike energy, matter (nutrients) is recycled within an ecosystem. Decomposers play a vital role in returning nutrients to the environment.

1. **Water Cycle (Hydrologic Cycle):**
    - **Processes:**
        - **Evaporation:** Water changes from liquid to vapor from bodies of water and land.
        - **Transpiration:** Water vapor released from plants through stomata.
        - **Condensation:** Water vapor cools and forms clouds.
        - **Precipitation:** Water falls back to Earth as rain, snow, hail.
        - **Runoff:** Water flows over land surfaces.
        - **Infiltration/Percolation:** Water seeps into the ground, becoming groundwater.
    - **Importance:** Essential for all life processes, regulates climate, transports nutrients.
2. **Carbon Cycle:**
    - **Main Reservoir:** Atmosphere (as CO_2), oceans, fossil fuels, biomass.
    - **Processes:**
        - **Photosynthesis:** Producers absorb CO_2 from the atmosphere to make organic compounds.
        - **Respiration:** All living organisms release CO_2 into the atmosphere through cellular respiration.
        - **Decomposition:** Decomposers break down dead organic matter, releasing CO_2.
        - **Combustion:** Burning of fossil fuels (coal, oil, gas) and biomass releases large amounts of CO_2.
        - **Oceanic Exchange:** CO_2 dissolves in and is released from oceans.
    - **Human Impact:** Burning fossil fuels, deforestation, industrial processes increase atmospheric CO_2, contributing to climate change.

3. **Nitrogen Cycle:**
    - **Main Reservoir:** Atmosphere (as N_2 gas, about 78%). Atmospheric nitrogen is unusable by most organisms.
    - **Processes:**
        - **Nitrogen Fixation:** Conversion of atmospheric N_2 into ammonia (NH_3) or ammonium (NH_4^+) by nitrogen-fixing bacteria (e.g., *Rhizobium* in legume root nodules, free-living bacteria in soil, lightning).
        - **Ammonification:** Decomposers break down organic nitrogen (from dead organisms and waste) into ammonia/ammonium.
        - **Nitrification:** Conversion of ammonium to nitrites (NO_2^-) by nitrifying bacteria (*Nitrosomonas*), and then to nitrates (NO_3^-) by nitrifying bacteria (*Nitrobacter*). Nitrates are readily absorbed by plants.
        - **Assimilation:** Plants absorb nitrates/ammonium and incorporate them into their proteins and nucleic acids. Animals obtain nitrogen by eating plants or other animals.
        - **Denitrification:** Conversion of nitrates back to atmospheric N_2 gas by denitrifying bacteria (*Pseudomonas*) under anaerobic conditions.
    - **Importance:** Nitrogen is a key component of proteins, nucleic acids (DNA, RNA), and ATP.
    - **Human Impact:** Use of synthetic nitrogen fertilizers can lead to water pollution (eutrophication) and increased nitrous oxide emissions (greenhouse gas).

6.6 Decomposition in Nature

- **Definition:** The process by which dead organic matter (dead plants, animals, and waste products) is broken down into simpler inorganic substances.
- **Key Players:**
    - **Decomposers:** Primarily bacteria and fungi. They secrete digestive enzymes externally onto the dead matter and absorb the digested nutrients.
    - **Detritivores:** Organisms that physically consume and break down detritus (e.g., earthworms, maggots, millipedes). They facilitate the work of decomposers by increasing surface area.
- **Importance of Decomposition:**
    - **Nutrient Cycling:** Releases essential nutrients (e.g., nitrogen, phosphorus, carbon) back into the soil, water, and atmosphere, making them available for producers. Without decomposition, nutrients would be locked up in dead organic matter, and ecosystems would cease to function.
    - **Waste Removal:** Prevents the accumulation of dead organic material.
    - **Soil Formation:** Contributes to the formation of humus, which improves soil structure and fertility.