15

ECOLOGY

SLO 15.1 to 15.6 — Ecology

Students will be able to:

15.1 Define species population, community, and ecosystem.
15.2 Distinguish between various modes of nutrition different species possess.
15.3 Identify plants as producers for converting light energy to chemical energy.
15.4 Define trophic levels.
15.5 Discuss the loss of energy between trophic levels.
15.6 Interpret the pyramids of number, biomass, and energy.

ECOSYSTEMS

Definition of an Ecosystem

- The study of the relationships of living organisms with each other and their physical surroundings is called **ecology**.
- An **ecosystem** is a principal unit in ecology. It consists of the atmosphere, hydrosphere, soil, and biological communities.
- It is a self-sustaining geographic area where living organisms interact with their nonliving environment.
- They form cohesive units where plant and animal communities are inseparable from their environment.

Biodiversity and its Role

- **Biodiversity** is a key characteristic of ecosystems. The variety of plants, animals, and microorganisms within an ecosystem is called biodiversity.
- Each species in an ecosystem contributes to the ecosystem's balance and function. Therefore, biodiversity is crucial for the stability and resilience of the ecosystem.
- **Species** are groups of related organisms that can freely interbreed in nature and produce fertile offspring. They form populations within a given geographic area at a specific time.
- Members of species living in a geographical area at a given time form a population.

Interactions within Ecosystems

- Populations of different species interact in various ways, such as **competition for resources**, **predation**, and **symbiotic relationships**. All of these interactions collectively form a community.
- These interactions are vital for the survival and well-being of all organisms within the ecosystem.

The Biosphere and Environmental Conditions

- Ecosystems vary greatly in size, from small ponds to vast rainforests. They collectively form the **biosphere.**
- The biosphere is the thin layer of life enveloping the Earth.
- The existence of life on Earth depends on several conditions being met, including a steady supply of energy from the sun, the availability of water as a medium for life, suitable temperature ranges, appropriate mineral proportions, and the protection from ultraviolet radiation provided by the ozone layer.

Components of an Ecosystem

An ecosystem comprises two basic parts: abiotic components and biotic components.

Abiotic Components

The non-living factors present in an ecosystem are called the abiotic components.

- These include light, air, water, soil, and essential elements and compounds that contribute to environment's physical and chemical conditions.

Biotic Components

- The living parts of the ecosystem are called the biotic components.
- Biotic components are further classified as producers, **consumers** and **decomposers.**
- The producers are the autotrophs present in an ecosystem.
- Producers are organisms that can synthesize complex organic compounds (food) from inorganic materials. Producers form the basis of any ecosystem.
- Producers include plants, algae, and photosynthetic bacteria.
  - In terrestrial ecosystems, plants are the main producers.
  - In aquatic ecosystems, the main producers are the floating photosynthetic organisms (mainly a called phytoplankton and shallow water-rooted plants.

Test Your Skills

1. How do different species interact within an ecosystem?
2. Compare the roles of producers in terrestrial and aquatic ecosystems.
3. What environmental conditions are critical for supporting life within the biosphere?
4. How do biotic and abiotic components interact to sustain life within an ecosystem?

Plants as Major Autotrophs in Ecosystems

Photosynthesis: The Basis of Autotrophy

- Plants are the major autotrophs in terrestrial ecosystems. They convert light energy into chemical ene through photosynthesis.

Mechanism

- **CO_2 Absorption**: Carbon dioxide is absorbed from the atmosphere through the stomata and taken i mesophyll cells.
- **Water Uptake**: Water is absorbed by the roots and transported up to the leaves through the xyle driven by transpiration pull.
- **Glucose Synthesis**: In the mesophyll cells, CO_2 and water combine to synthesize glucose, using ener from sunlight.
- **Energy Capture**: Chlorophyll and other photosynthetic pigments capture various wavelengths of ligh They provide the necessary energy for the synthesis processes.

Consumers in Ecosystems

- Consumers are **heterotrophs** that cannot synthesize their own food and depend on producers.
- This group includes all animals, fungi, protozoans, and many bacteria.

Classification of Consumers

Herbivores (Primary Consumers):

- They feed directly on producers and are also known as **herbivores.**
- In terrestrial ecosystems, primary consumers include insects, reptiles, birds, and mammals such a cattle, deer, and rabbits.
- In aquatic ecosystems, primary consumers are crustaceans, mollusks, and herbivorous fishes.

Carnivores (Secondary and Tertiary Consumers):

Secondary Consumers:

- These organisms feed on primary consumers and are carnivorous by nature.
- Examples include many fishes, frogs, snakes, predatory birds, and mammals like lions and tigers.

Tertiary Consumers:

- They feed on secondary consumers and include **apex predators like wolves, owls, and hawks.**

Role of Decomposers in Ecosystems

- Decomposers play an important role in utilizing the energy stored in the dead bodies of organisms and waste matter.
- They ensure that materials are not wasted but are recycled within the ecosystem.

Major Decomposers

- The primary decomposers in most ecosystems are bacteria and fungi.

Process:

- **Digestive Breakdown**: These organisms secrete digestive enzymes onto dead organic matter to decompose it into simpler molecules.
- **Nutrient Absorption and Release**: Decomposers absorb some of these materials for their own use and release others back into the environment.

Importance in the Ecosystem

- **Nutrient Availability**: The substances released by decomposers are made available again to producers, such as plants.
- **Ecosystem Balance**: This cycle of decomposition and nutrient release is necessary for maintaining the ecological balance. It ensures that nutrients continue to circulate within the ecosystem.

Food Chains and Food Webs

Food Chains

- The food chain is a **sequence of organisms** through which food and nutrients move in an ecosystem.
- Energy-rich organic molecules produced by autotrophs (producers) serve as food for heterotrophs (consumers).
- This sequence continues as animals that feed on plants are themselves eaten by other animals, transferring energy and nutrients from one organism to another in a defined sequence.

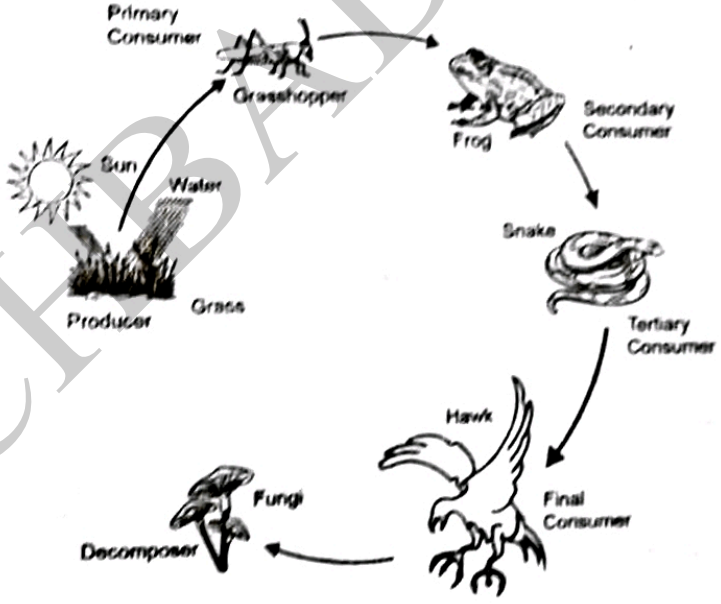

Figure: Food Chain

Food Webs

- Unlike the simplified linear arrangement of food chains, food webs consist of interconnecting food chains, forming a complex network of feeding relationships.

Example in a Grassland Ecosystem

- The grass is consumed by both grasshoppers and mice.
- Mice may be preyed upon by snakes or hawks, while grasshoppers are eaten by frogs.
- Frogs can be eaten by snakes, which are in turn preyed upon by hawks.

- Hawks feed on both snakes and frogs
- This shows multiple feeding relationships at each trophic level.

Importance of Food Webs

- Food webs provide multiple food sources at each trophic level and are crucial for maintaining balance within the ecosystem.
- By providing alternative food sources, food webs enhance the resilience and stability of the ecosystem.

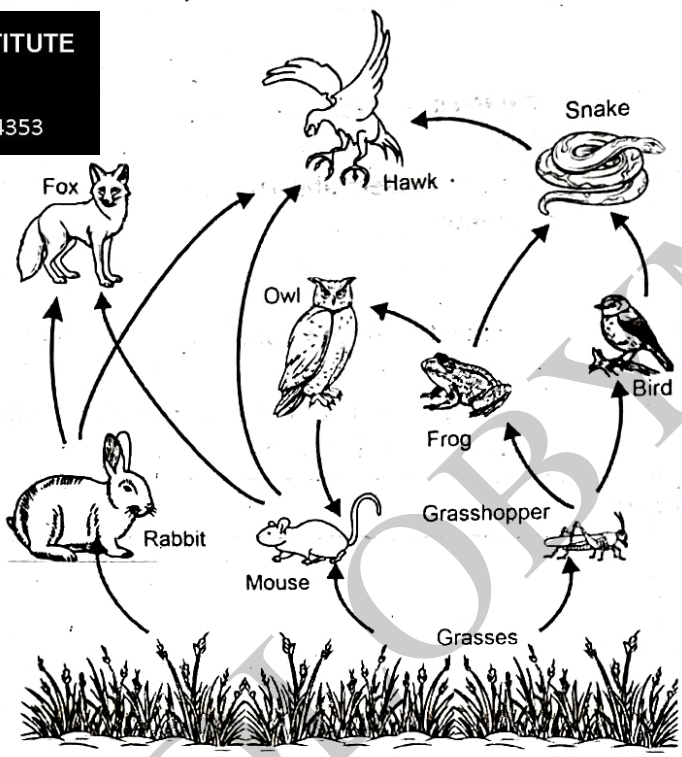

Figure: Food Web

Test Your Skills

1. How do decomposers contribute to nutrient cycling in ecosystems, and why is this process essential for maintaining ecological balance?
2. How do disruptions in one part of a food web affect other organisms within the same ecosystem?
3. Why are there typically fewer individuals and biomass at higher trophic levels compared to lower levels? What factors contribute to this pattern?

Trophic Levels in a Natural Community

Definition of Trophic Levels

- In an ecosystem, **each stage** of the food chain is referred to as a **trophic level.**
- These levels indicate the hierarchical positions within the food chain. They are the path through which energy and nutrients flow from one organism to another.

Structure of Trophic Levels

- **First Trophic Level (T1):** It consists of producers such as plants, algae, and some bacteria. These organisms synthesize their own food from sunlight and inorganic materials.
- **Second Trophic Level (T2):** It comprises primary consumers, which are mainly herbivores that feed directly on autotrophs.
- **Third Trophic Level (T3):** It includes secondary consumers, which are carnivores that prey on herbivorous animals.
- **Fourth Trophic Level (T4):** It consists of tertiary consumers, carnivores that feed on other carnivores.
- **Higher Trophic Levels:** In some ecosystems, there are additional levels, such as quaternary consumers (T5), who feed on tertiary consumers.

Energy Flow and Trophic Levels

- **Energy Decrease with Higher Levels:** As energy is transferred from one trophic level to the next, it becomes less available. This results in fewer organisms being able to sustain themselves at higher trophic levels due to energy loss at each step.

Primary Productivity in Ecosystems

Energy Source

- **Sunlight as Energy:** The sun's radiation is the ultimate source of energy for life on Earth.
- **Role of Producers:** Producers in an ecosystem capture this solar energy to synthesize food molecules during photosynthesis.

Understanding Productivity

- **Definition:** The rate at which organic matter is produced by producers in an ecosystem through photosynthesis is known as the productivity of the ecosystem.
- Measurement: It is typically measured as the biomass produced per unit area over a specific time period.

Types of Primary Productivity

- **Gross Primary Productivity (GPP):** It represents the total amount of solar energy that producers fix through photosynthesis. GPP is influenced by the availability of light, water, inorganic nutrients, and suitable temperatures.
- **Net Primary Productivity (NPP):** It is defined as the energy that remains after producers have met their own respiratory needs. This remaining energy contributes to the organic matter or biomass of producers.

Importance of NPP

- **Ecological Significance:** NPP is a crucial ecological parameter because it indicates the amount of energy available to support the food web, including herbivores, carnivores, and decomposers in the ecosystem.

Energy Flow in Ecosystems

Energy Conversion Efficiency

- **Photosynthetic Conversion:** Under optimal conditions, only about 1% of solar radiation is converted by producers into gross primary productivity (GPP) through photosynthesis.
- **Source of Energy for Heterotrophs:** The organic food produced by autotrophs serves as the energy source for heterotrophic organisms, including animals and decomposers.

Energy Loss between Trophic Levels

- **Mechanisms of Energy Loss:** Energy is lost at each trophic level due to respiration, growth, reproduction, non-predatory death, heat emission, and as excretory products or feces.
- **Decreasing Energy Levels:** As energy transfers from one trophic level to the next, it diminishes, leading to progressively lower energy availability down the food chain.

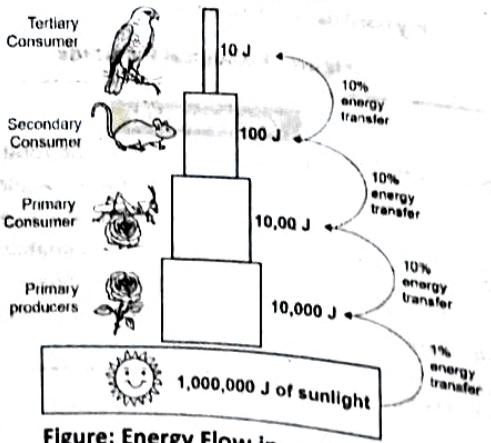

Figure: Energy Flow in an Ecosystem

Ecological Pyramids

- Ecological pyramids visually represent the relationships of energy, biomass, or numbers of organisms at each trophic level in an ecosystem.

Types of Ecological Pyramids

1. **Pyramids of Energy**
   - **Description**: The energy pyramid shows the amount of energy available at each trophic level, starting with the highest at the producer level and decreasing at each subsequent level.
   - **Significance**: This pyramid is particularly useful as it accurately illustrates the energy used for life processes and the energy lost as waste or heat at each level.
2. **Pyramids of Biomass**
   - **Description:** The biomass pyramid shows the total dry weight of all living organisms at each trophic level.
   - **Trend:** The largest biomass is found at the producer level, with a progressive decrease at higher trophic levels.
3. **Pyramids of Number**
   - **Description:** The number pyramid shows the count of organisms at each trophic level.
   - **Variability:** This pyramid does not always show a regular pattern. Typically, producers are most numerous with fewer consumers at higher levels.

Pyramid of Energy
In a pyramid of energy, each level represents the amount of energy that is available to that trophic level. With each step up, there is an energy loss of 90 percent.

Pyramid of Biomass
In a pyramid of biomass each level represents the amount of biomass consumed by the level above it.

Pyramid of Numbers
In a pyramid of numbers each level represents the number of individual organisms consumed by the level above it.

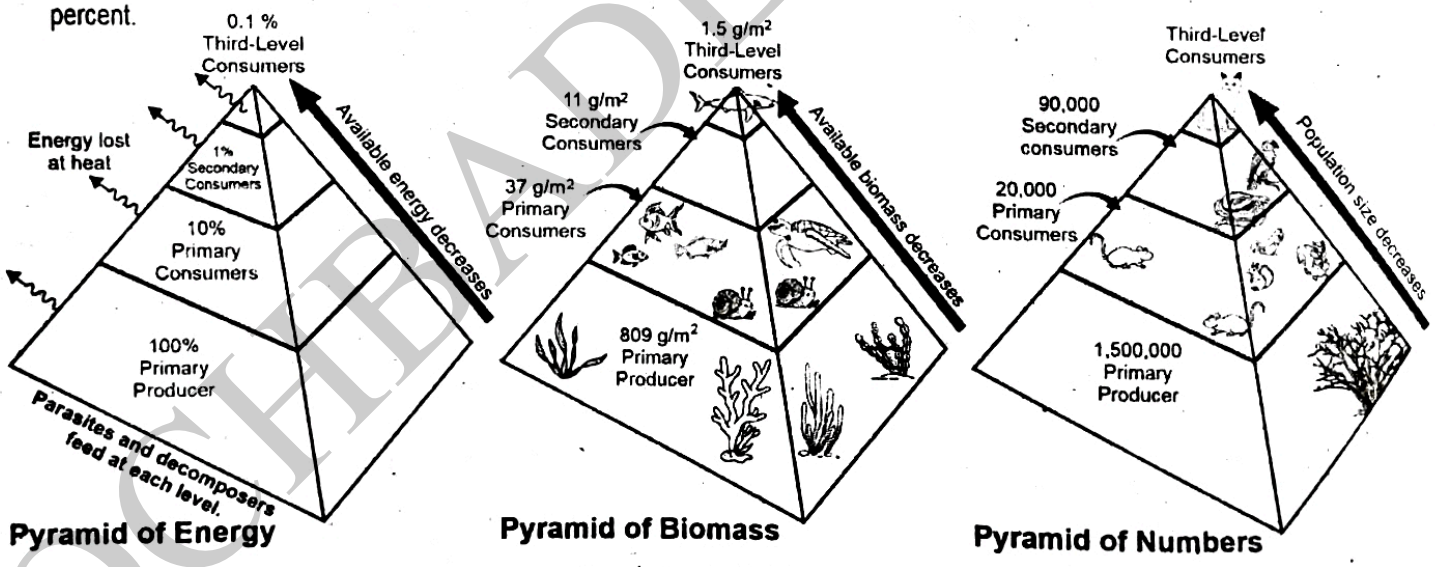

Figure: Ecological Pyramids

Test Your Skills

1. How resource availability influences trophic interactions and food web stability.
2. What are the limitations of each type of pyramid in different ecological contexts?
3. Discuss the inefficiencies in energy transfer between trophic levels. How does this phenomenon influence the carrying capacity of ecosystems and the sustainability of human food systems?
4. Debate whether ecosystems with more trophic levels are inherently more stable than those with fewer levels. Consider factors such as energy efficiency, species diversity, and resilience to environmental changes.

SLO 15.7 to 15.10 — Biogeochemical Cycles

Students will be able to:

15.7 Define biogeochemical cycles and locate the primary reservoirs of the chemicals in these cycles.
15.8 Describe water cycle in detail.
15.9 Define the terms aquifers and water table.
15.10 Discuss nitrogen cycle in detail.

BIOGEOCHEMICAL CYCLES

Nutrient Cycling

- **Need for Nutrients**: Every organism requires nutrients for survival. Organisms obtain nutrients from the environment.
- **Definition of Biogeochemical Cycle**: The nutrients move in a cyclic manner from the environment to organisms and back to the environment. This is known as the **biogeochemical cycle of nutrients**.

Primary Reservoirs of Nutrients

- The general model of nutrient cycling consists of the main reservoir of elements and the processes that transfer elements between reservoirs.
- Each reservoir is defined by two characteristics: whether it contains **organic or inorganic materials** and whether or not the **materials are directly available** for use by organisms.

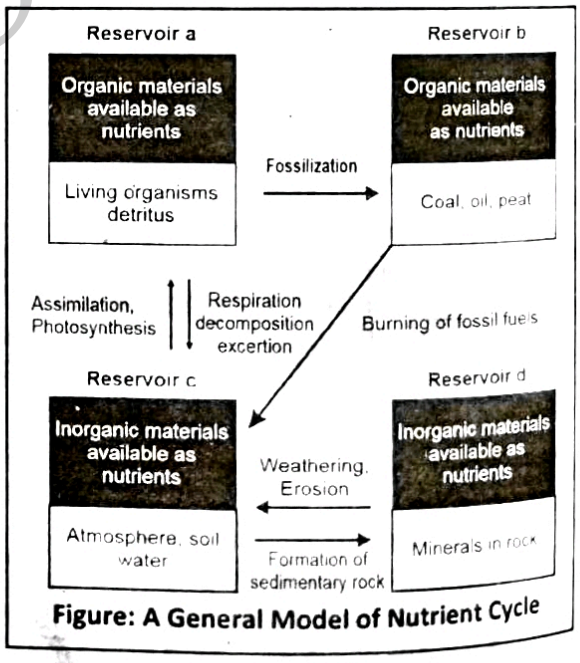

Figure: A General Model of Nutrient Cycle

Specific Reservoirs and Their Roles

1. **Living Organic and Detritus (Reservoir A)**
   - **Description**: This reservoir contains nutrients within living organisms and detritus.
   - **Availability:** The nutrients in this reservoir are accessible to other organisms through consumption, and when **detritivores** consume non-living organic matter.
2. **Fossilized Organic Reservoir (Reservoir B)**
   - **Formation**: This reservoir was formed long ago when dead organisms were buried under sediment. They became coal, oil, or peat.
   - **Availability**: Nutrients in these deposits are not directly accessible for use by organisms.
3. **Dissolved Inorganic Materials (Reservoir C)**
   - **Location**: This reservoir includes elements and compounds dissolved in water in soil or air.
   - **Direct Use**: The nutrients in this reservoir are directly usable by organisms. Organisms assimilate and return chemicals to this reservoir through respiration, excretion, and decomposition.

4. **Inorganic Elements in Rocks (Reservoir D)**
   - **Accessibility**: This reservoir includes elements that are not directly accessible but may become available through slow processes like weathering and erosion.
   - **Transition to Availability**: The unavailable organic materials move into available inorganic nutrients when fossil fuels are burned, and nutrients are released into the atmosphere.

Water Cycle

- The continuous movement of water within the Earth and its atmosphere is known as the **water cycle**. It is driven by solar energy and gravity.

The Major Reservoir: The Ocean

- Over 97% of Earth's water is found in the oceans. These vast bodies of water serve as the main source for the water cycle.

Solar Energy and Precipitation

- **Solar Energy**: Solar energy heats the water in oceans. It causes water to evaporate into the air.
- **Gravity**: Gravity pulls water back to Earth in various forms of precipitation, such as **rain, snow, dew,** and **sleet** (which is rain mixed with snow or hail).

Paths of Water on Land

- After water falls as precipitation, it can take several paths:

Evaporation

- Some water evaporates directly from the soil, lakes, and streams back into the atmosphere.

Runoff

- Some water flows over the land and returns to rivers, which ultimately reach the oceans.

Infiltration and the Water Table

- When rain falls, some water percolates or seeps into the ground. It saturates the soil up to a level. This level is known as the **water table**.
- Some water collects in natural basins or channels and forms lakes, ponds (in basins), and streams or rivers (in channels).

Groundwater and Aquifers

- Some groundwater travels through underground pathways. These are known as aquifers. Aquifers are, in fact, underground rivers.

Water in Living Organisms

- Living organisms also play a significant role in the water cycle:

Absorption and Transpiration in Plants

- Plants absorb water through their roots. A significant amount of this water is then released back into the atmosphere from their leaves. This process is called **transpiration**.

Photosynthesis and Respiration

- Plants use some of the absorbed water, along with carbon dioxide, to create high-energy molecules during photosynthesis.
- These molecules are later broken down in cellular respiration. This process releases water back into the environment.

Water Intake in Heterotrophs

- Heterotrophs obtain water either from the food they eat or by drinking directly.

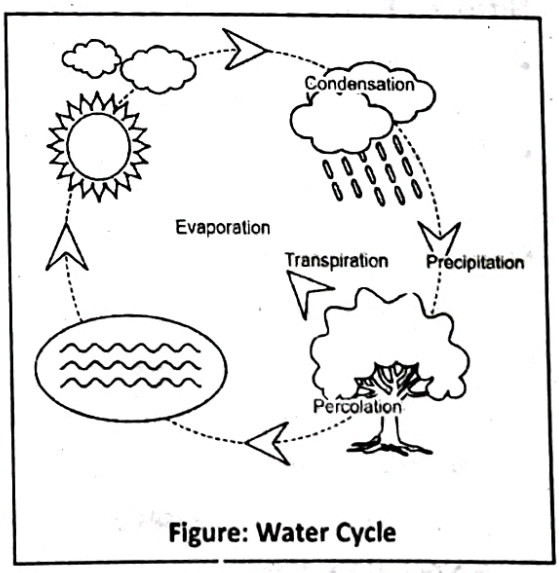

Figure: Water Cycle

Test Your Skills

1. Compare the roles of plants and animals in the water cycle
2. How does plant transpiration influence regional climate patterns, and how do animals contribute to nutrient cycling through water intake and excretion?
3. Analyze the consequences of depleting reservoirs of dissolved inorganic materials (Reservoir C) through pollution or overuse. What strategies could be implemented to sustain these essential nutrient sources?
4. How do deforestation or agriculture impact nutrient availability and cycling in ecosystems?

Nitrogen Cycle

- Nitrogen is essential for all living organisms. It is required to create proteins, nucleic acids, and other organic molecules.
- The natural processes that transform nitrogen gas in the air into organic substances in the soil and then back to the environment are called the **nitrogen cycle**.
- It is a continuous cycle maintained by the decomposers and the bacteria.
- This cycle consists of several steps: **ammonification, nitrification, nitrogen fixation, assimilation,** and **denitrification.**

Ammonification

- When animals and plants die, their nitrogenous waste is broken down by **saprophytic soil bacteria** and **fungi**.
- These microorganisms decompose the organic matter to form simpler substances, such as amino acids, which are further broken down into ammonia or ammonium ions. This process is called ammonification.
- Ammonification occurs in the soil within an aerobic (**oxygen-rich**) environment.

Nitrification

- The conversion of ammonia and ammonium ions to nitrates is called **nitrification.**
- Ammonia and ammonium ions in the soil are converted into nitrate compounds by two groups of aerobic nitrifying bacteria.
- The first group, such as **Nitrosomonas**, converts ammonia to **nitrites**, and the second group, such as **Nitrobacter**, transforms nitrites into **nitrates**.
- This process occurs in **well-aerated soils**.

Nitrogen Fixation

- Nitrogen fixation is a chemical process that converts atmospheric nitrogen into ammonia, which is absorbed by organisms.
- Nitrogen gas in the atmosphere consists of two nitrogen atoms held together by a strong triple bond. It requires significant energy to break.

Methods of Fixation:

Atmospheric Fixation

- Lightning breaks nitrogen bonds. The nitrogen combines with oxygen to form **oxides of nitrogen**, which are then absorbed by the soil. Only a small amount (5–8%) of nitrogen is fixed in this way.

Industrial Fixation

- Human-made processes produce nitrogen-containing fertilizers.

Biological Fixation

- Certain bacteria, like **Azotobacter** (aerobic) and **Clostridium** (anaerobic), convert atmospheric nitrogen into ammonia. They provide a vital source of nitrogen for plants.

- Nitrogen is also fixed by the symbiotic association of some nitrogen-fixing bacteria with plants, e.g. Rhizobium.
- Nitrogen-fixing bacteria fix 60% of nitrogen gas in the atmosphere.
- Bacteria convert atmospheric nitrogen to ammonia:

$$N_2 + 3H_2 \rightarrow 2NH_3$$

Assimilation

- It is the process of utilization of nitrogenous compounds in living bodies.
- Many microorganisms are able to utilize free nitrogen directly from the atmosphere.
- Plants obtain nitrogen in the form of inorganic nitrogenous compounds like ammonia and nitrates from the soil.
- Animals take their nitrogen from the eating of plants or other animals.

Denitrification

- Denitrification is the process in which nitrate and nitrite compounds are converted into gaseous forms of nitrogen.
- In oxygen-poor environments, some bacteria like Pseudomonas break down nitrates and release nitrogen gas back into the atmosphere. They use the oxygen for their own respiration.
- This process maintains the balance of nitrogen in the air and soil.

$$\underset{\text{(Nitrate)}}{NO_3} \rightarrow \underset{\text{(Nitrite)}}{NO_2} \rightarrow \underset{\text{(Nitrogen Oxides)}}{NO+NO_2} \rightarrow \underset{\text{(Nitrogen Gas)}}{N_2}$$

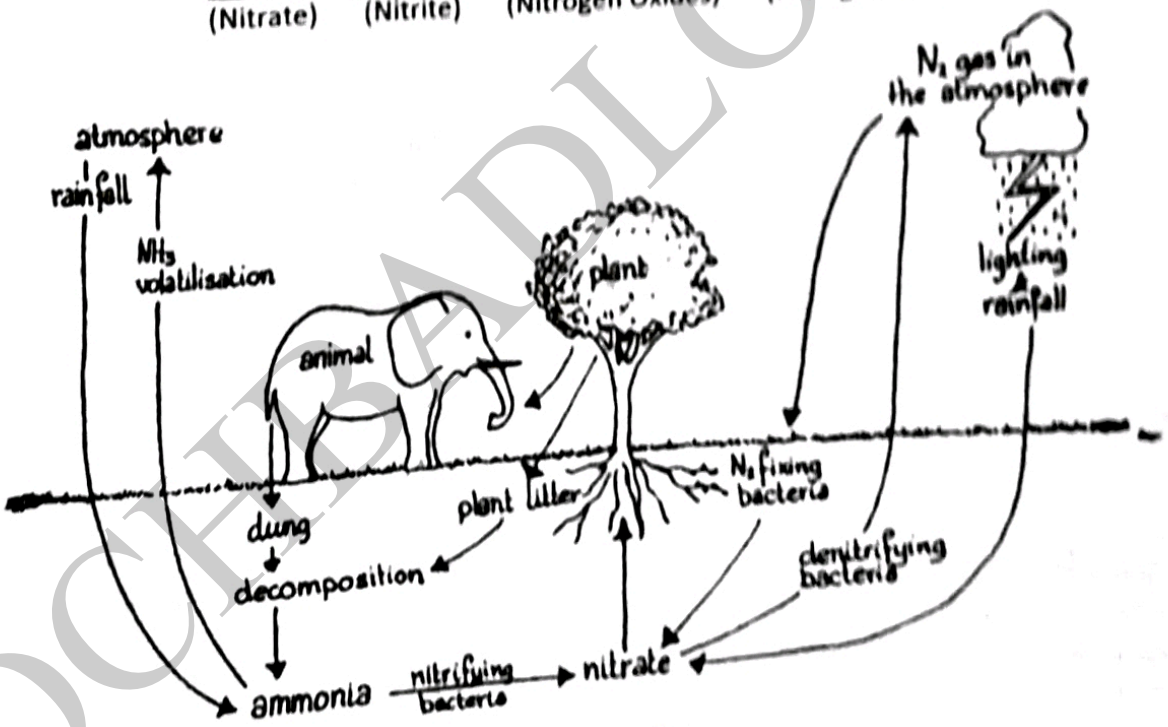

Figure: Nitrogen Cycle

Test Your Skills

1. How does eutrophication resulting from excess nitrogen inputs affect biodiversity and ecosystem services?
2. How do nutrient limitations in ecosystems affect the growth and productivity of species at various trophic levels?
3. How changes in soil pH or temperature affect the rates of ammonification and nitrification processes. What agricultural practices can optimize these processes to enhance soil fertility sustainably?

SLO 15.11 to 15.14 — Ecological Succession

Students will be able to:

15.11 Define ecological succession as the process through which ecosystems change from simple to complex.

15.12 Describe primary and secondary succession.

15.13 Differentiate between xerarch and hydrarch succession.

15.14 Explain the xerarch succession on a bare rock starting from the small pockets of lichens to the vegetations of flowering plants.

ECOLOGICAL SUCCESSION

- Ecological succession is the natural process where a community of species in a habitat changes over time.
- This occurs when new habitats are created or existing ones are disturbed by natural events like volcanic eruptions, glaciers retreating, fires, or hurricanes.
- During succession, early-arriving species are gradually replaced by other species, which may themselves be replaced later on.
- This happens because the new species are better adapted to the prevailing environmental conditions.
- Individual successions are known as **seres** and the development phases are called **seral stages**.

Types of Ecological Succession

- Ecological succession can be categorized into two main types based on the condition of the habitat at the start of the succession:

Primary Succession

- This type of succession occurs in habitats that were previously uninhabited by organisms, such as newly exposed rock surfaces from volcanic lava or glaciers.
- The area starts without any soil and the initial life forms are usually lichens and mosses that can grow on rocks.

Secondary Succession

- This occurs in areas where a pre-existing community of organisms was substantially altered or removed but where soil remains.

Examples:

  - Abandoned farm fields that revert back to natural forest.
  - Forest areas recovering from disturbances like fires or floods.

Special Cases of Succession

- Succession can also be categorized based on the environment in which it occurs:

Hydrarch Succession

- This type of succession begins in aquatic environments like ponds, lakes, and marshes.
- Its developmental stages are known as **hydroseres**.

Xerarch Succession

- Succession that starts in dry, water-deficient areas like bare rocks, sand dunes, or rocky slopes is called xerarch succession.
- Its development stages are known collectively as **xerosere**.

<=============== Time ===============>
3 Years 5 Years 40+ years

Figure: Secondary Succession

Stages of Ecological Succession

Ecological succession occurs through a series of progressive stages. Each stage is characterized by different communities and environmental changes.

1. **Migration and Colonization**
   - **Pioneers:** The first step in succession involves the arrival of organisms from surrounding areas. These initial colonizers are known as **pioneers**. They are typically hardy species that can thrive in harsh, barren conditions. They play a crucial role in establishing a foothold in the area.
   - **Characteristics of Pioneers:** Pioneers are usually plants like lichens and mosses or certain hardy grasses and weeds that can survive with minimal nutrients and water.
2. **Establishment and Aggregation**
   - **Soil Formation:** As pioneers take hold, they begin to change the environment. Their growth, death, and decay gradually increase the organic matter, moisture, and nitrogen content of the soil.
   - **Role of Pioneers:** By modifying the soil, pioneers create conditions that are more hospitable for subsequent species.
3. **Seral Community Development**
   - **Seral Stages:** Following the pioneers, the next groups of plants and animals to invade are known as seral communities. Each group that establishes and thrives represents a seral stage in the succession process.
   - **Environmental Modification:** These seral communities further modify the environment, often making it unsuitable for themselves but favorable for a new set of species.
4. **Replacement and Transition**
   - **Change Over Time:** As the environment continues to change due to the activities of each seral community, it becomes less suitable for the current inhabitants but more suitable for different species. This leads to a transition from one seral stage to another, each with its own dominant community.
5. **Climax Community Formation**
   - **Stable Community:** The final stage of ecological succession is the development of a climax community. This is a relatively stable and mature community that forms after several seral stages. The climax community remains relatively unchanged as long as the environment remains stable.
   - **Characteristics of a Climax Community:** The species composition of a climax community is well-suited to the local climate and soil conditions. It typically has greater species diversity and a complex structure compared to earlier stages.

Xerarch Succession

Xerarch succession describes the ecological succession that occurs in dry, arid environments like sand dunes, rocky slopes, and bare rocks. It leads to the development of a climax community through several distinct stages:

1. **Crustose-Lichen Stage (Pioneer Stage)**
   - **Initial Colonizers:** Crustose lichens, such as Licanora and Rhinodina, begin the colonization process on bare rocks. These lichens are slow-growing and can withstand extreme dryness.

- **Impact on the Environment:** During rainfall, these lichens absorb water and help decompose the rock surface by secreting acids, gradually contributing to soil formation.

2. **Foliose-Lichen Stage**
   - **Further Soil Development:** As a thin layer of soil accumulates from the breakdown of rocks, foliose lichens (leaf-like lichens) such as Permelia and Dermatocarpon appear, adding more organic matter to the developing soil.
   - **Introduction of Mosses:** Alongside lichens, xerophytic mosses begin to grow, enhancing soil depth and moisture retention through their decay, forming a mat that holds water.
3. **Herb Stage**
   - **Emergence of Herbaceous Plants:** Herbaceous weeds, mostly annuals, start to invade. Their deep-rooting systems release acids that further the rock weathering process.
   - **Soil Enrichment:** The death and decay of these herbs add humus to the soil, reduce soil evaporation, and slightly increase the temperature, making the environment less harsh and more suitable for biennial and perennial herbs and xeric grasses.
4. **Shrub Stage**
   - **Shrub Colonization:** Xeric shrubs begin to grow in the now richer soil, either from seeds or by invading from adjacent areas through rhizomes.
   - **Transition Dynamics:** Shrubs overshadow the herbaceous plants, making conditions unsuitable for the herbs due to reduced light and competition, leading to their replacement by shrubs.

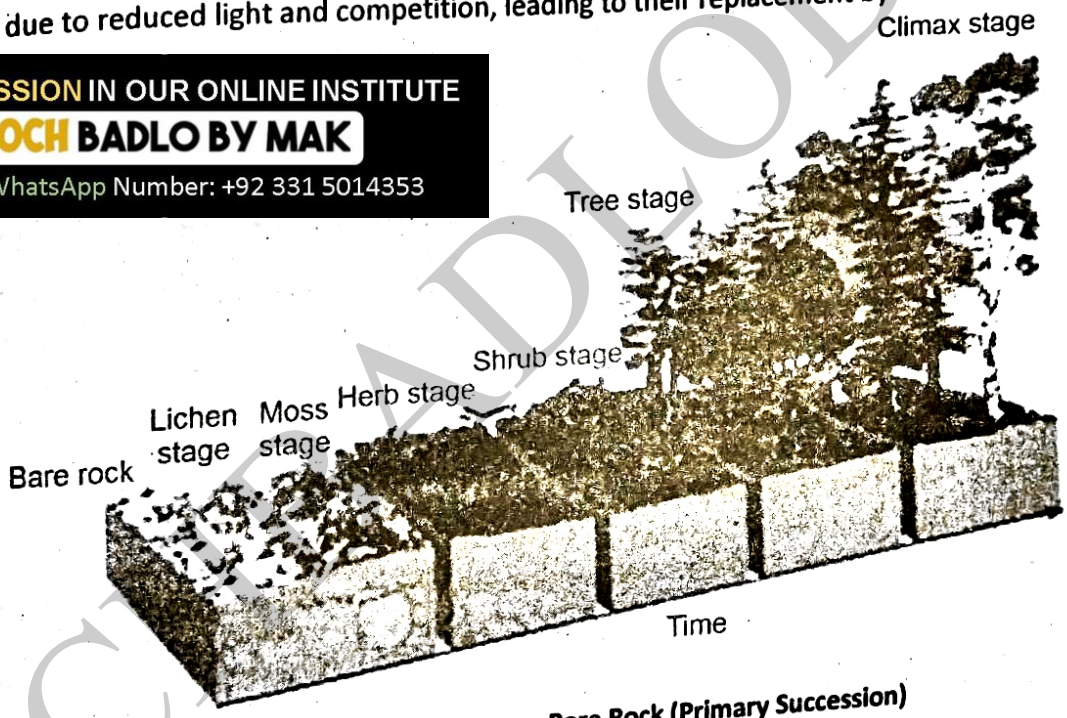

Figure: Xerarch Succession on Bare Rock (Primary Succession)

5. **Tree Stage**
   - **Tree Colonization:** As the environment becomes less xeric, tree saplings start to establish among the shrubs. These trees form a canopy, which shades the area and supports the growth of shade-loving secondary vegetation.
   - **Soil Improvement:** The accumulation of leaf litter and the decay of roots further enrich the soil, enhancing its capacity to support more diverse tree species.
6. **Climax Stage**
   - **Mature Forest Development:** Initially, more drought-resistant xeric trees dominate, but as the soil deepens and improves, these are gradually replaced by mesophytic tree species, leading to the development of a mature forest.
   - **Stable Ecosystem:** This climax forest represents a stable ecosystem adapted to the local climate and soil conditions, concluding the xerarch succession process.

SLO 15.15 to 15.21 — Population Dynamics

Students will be able to:

15.15 Describe characteristics of a population, such as growth, density, distribution, carrying capacity, minimum/viable size.

15.16 Explain the effect of growth of the human population on the ecosystem

15.17 Describe productivity in terms of gross primary productivity and net primary productivity.

15.18 Explain the greenhouse effect with examples of gases that exhibit this behavior.

15.19 Describe the harmful effects of greenhouse gases on the environment.

15.20 Explain with regards to ocean acidification, that coral reefs are used as a barometer for the health of an aquatic ecosystem.

15.21 Describe the four important ecosystems of Pakistan.

POPULATION DYNAMICS

- The variations in the number and structure of an animal population over time are called **population dynamics**.
- It focuses on understanding both the **short-term** and **long-term** changes in population size, as well as the factors that influence these changes.

Key Components of Population Dynamics

- Population dynamics is regulated by two main types of factors — those that increase the population (inflow factors) and those that decrease it (outflow factors):
  - **Inflow Factors:** These are elements that contribute to the growth of the population.
    - **Births:** The number of new individuals born into the population.
    - **Immigration:** The arrival of new individuals from other areas into the population.
  - **Outflow Factors:** These are elements that reduce the population.
    - **Culling:** The process of selectively removing individuals from the population, often for management or health reasons (e.g., culling of seal or deer populations).
    - **Predation:** When animals are hunted and killed by predators.
    - **Natural Deaths:** Deaths that occur due to old age or diseases.
    - **Accidents:** Unforeseen events that lead to death.
    - **Emigration:** The movement of individuals out of the population to other areas.

Characteristics of Population

- The individuals from the same species who live in the same area are called the population.
- These individuals depend on the same resources, experience similar environmental conditions, and are likely to interact and breed with each other..

Key Characteristics of a Population

Growth

- Population growth refers to an increase in the number of individuals in a population.
  When a few individuals colonize a new area with sufficient resources and minimal threats from predators or disease, their numbers will initially increase slowly.
  After settling in, the population may experience exponential growth, where its size doubles at regular intervals. This rapid increase is also known as geometric growth.

Density

- The number of individuals per unit area or volume is known as the density of the population.
  For example, it could be the number of mulberry trees per square kilometer in Islamabad or the number of *E.Coli* bacteria per milliliter in a test tube.

Distribution

- It is also known as dispersion. It refers to how individuals within a population are spaced out across a given area. The three main types of distribution are:
  - **Clumped:** Individuals form groups or clusters in certain parts of the area.
  - **Uniform:** Individuals are evenly spaced throughout the area.
  - **Random:** The spacing between individuals does not have any predictable pattern.

Carrying Capacity

- This is the maximum number of individuals that the environment can sustain indefinitely. Carrying capacity can change depending on resource availability and environmental conditions.

The Role of the Population Welfare Department

- The Department of Population Welfare plays a crucial role in promoting family planning and the reproductive health of the human population. It offers various services through:
  - **Family Welfare Centres**
  - **Mobile Service Units**
  - **Reproductive Health Services (RHS) Centres**
    RHS are often operated by NGOs with support from the department.

Human Impact on Ecosystems

- Human activities have significantly altered ecosystems across the globe.
- They generally causing negative effects such as environmental degradation, loss of biodiversity, and disruption of natural processes.

Types of Human Impact

Habitat Destruction and Fragmentation

- **Deforestation:** Clearing forests for agriculture, urban development, and industry removes habitat for many species.
- **Urbanization:** Expanding urban areas reduce and split habitats, isolating animal populations and decreasing their genetic diversity.
- **Infrastructure Development:** Building roads, dams, and other structures divides natural habitats and interrupts wildlife migration.

Pollution

- **Air Pollution:** Industrial, vehicular, and agricultural emissions cause acid rain and smog, affecting the health of both wildlife and humans.
- **Water Pollution:** Contaminants released into water bodies harm aquatic life and disrupt ecosystem balance.
- **Soil Pollution:** Chemicals from various industries pollute the soil, impacting plants and animals living in and on it.

Climate Change

- **Greenhouse Gas Emissions:** The combustion of fossil fuels releases carbon dioxide and other greenhouse gases, warming the planet.
- **Temperature Changes:** Shifts in climate patterns affect where species can live, their migration patterns, and their survival strategies.
- **Sea Level Rise:** As ice caps melt, rising sea levels threaten coastal habitats and communities.

Overexploitation

- **Overfishing:** Excessive fishing depletes fish stocks, alters marine food webs, and affects dependent ecosystems.
- **Hunting and Poaching:** Illegal hunting threatens species with extinction and disrupts natural predator-prey dynamics.
- **Defaunation:** The decline of large animals disrupts their roles in seed dispersal and ecosystem balance.

Invasive Species

- **Introduction of Non-Native Species:** These species compete with native ones for resources, often leading to declines or extinctions.
- **Altered Ecosystem Dynamics:** Invasive species can change soil composition, nutrient cycles, and fire patterns, which can transform ecosystems.

Land Use Changes

- **Agricultural Expansion:** Extensive agriculture destroys habitats, degrades soil, and increases reliance on harmful chemicals.
- **Monoculture Farming:** Cultivating single crop types over large areas reduces biodiversity and increases vulnerability to pests and diseases.

Loss of Biodiversity

- **Extinction:** Certain human activities have driven numerous species to extinction, which disrupts ecological balance.
- **Genetic Erosion:** Smaller populations lead to inbreeding and reduce genetic diversity, making species more susceptible to challenges.

Resource Depletion

- **Water Depletion:** Intensive water use for various purposes drains aquifers and dries up wetlands, affecting aquatic life.
- **Soil Depletion:** Overuse and unsustainable farming practices lead to soil erosion, reduced fertility, and the spread of desert-like conditions.

Test Your Skills

1. Compare and contrast the impacts of births, deaths, immigration, and emigration on population dynamics.
2. Predict how changes in environmental conditions (e.g., climate change, habitat fragmentation) might alter population dynamics.
3. Discuss the interconnectedness of air, water, and soil pollution in terrestrial and aquatic ecosystems

GREENHOUSE EFFECT

The Natural Greenhouse Effect

- The greenhouse effect is a **natural process** that warms the Earth, making it habitable.
- This process begins when solar radiation, in the form of heat, reaches the Earth.
- Some of this heat is absorbed by the Earth's surface and warms it. The rest is reflected back towards space.
- The heat is absorbed or trapped by the greenhouse gases in the Earth's atmosphere. These gases prevent it from escaping into space.
- This trapped heat helps keep the Earth's surface warmer than it would be if the heat were just radiated back into space.

Human Impact on the Greenhouse Effect

- Human activities, especially the burning of fossil fuels like coal, oil, and natural gas, along with deforestation, have significantly increased the levels of greenhouse gases in the atmosphere.
- This increase **enhances the natural greenhouse effect**, which leads to a rise in the Earth's surface temperature.
- The **enhanced greenhouse effect** due to human activities leads to global warming. It is a significant challenge for the Earth's climate and ecosystems.
- The main greenhouse gases contributing to this effect are:
  - **Carbon Dioxide (CO_2)**: This is the most common greenhouse gas resulting from human activities. It is primarily emitted when fossil fuels are burned for energy. The removal of forests also lowers the number of trees that can absorb CO_2, increasing its concentration in the atmosphere.

- **Methane (CH_4)**: Methane is a potent greenhouse gas with a greater ability to trap heat compared to CO_2. However, it is less abundant. It is released during the extraction and transportation of fossil fuels and from certain agricultural practices, such as livestock farming.
- **Nitrous Oxide (N_2O)**: This gas is emitted from agricultural activities, industrial actions, combustion of fossil fuels, and burning of solid waste.
- **Fluorinated Gases**: These are synthetic gases used in various industrial applications. Common types include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). These gases have a strong greenhouse effect and are emitted during their production and use in industry.

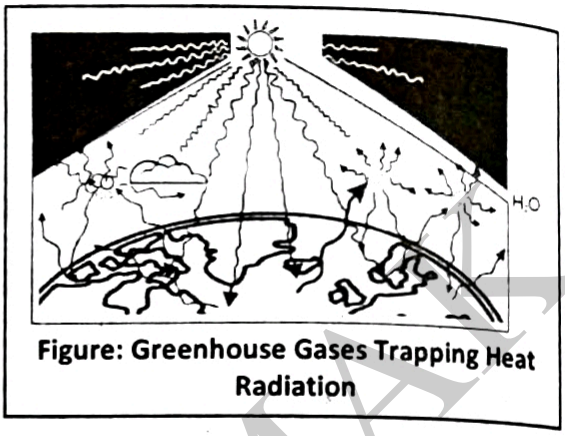

Figure: Greenhouse Gases Trapping Heat Radiation

Effects of Greenhouse Gases

Global Warming

- **Definition**: Global warming is the long-term rise in Earth's average surface temperature due to increased concentrations of greenhouse gases (GHGs) in the atmosphere.
- **Impact**: This increase in temperature leads to changes in weather patterns, such as more frequent and severe heat waves, affecting natural and human systems.

Climate Change

- **Role of Greenhouse Gases**: GHGs are primary drivers of climate change, influencing various aspects of climate.

  Consequences:
  - Altered precipitation patterns and seasonal temperatures
  - More intense storms and extreme weather events like droughts and floods
  - These changes disrupt ecosystems and human activities, posing challenges to both.

Melting Polar Ice and Glaciers

- **Effects**: Increased global temperatures cause polar ice caps and glaciers to melt faster than usual.
- Outcomes:
  - Rising sea levels, threatening coastal communities and ecosystems
  - Disruption of habitats for species such as polar bears and penguins

Ocean Acidification

- **Process**: Excess CO_2 from the atmosphere is absorbed by the oceans, reducing the pH level of seawater.
- **Impact on Marine Life**: Acidic waters harm marine organisms, particularly those with calcium carbonate structures like corals and shellfish, affecting marine biodiversity and ecosystems.

Biodiversity Loss

- **Causes**: Disruptions in ecosystems and habitats due to climate change can alter species distributions.
- **Effects**: Increased risk of extinction for species that cannot quickly adapt or migrate to new conditions, leading to a reduction in biodiversity.

Impact on Agriculture

- **Climate Effects on Farming**: Changes in temperature and rainfall affect crop growth and agricultural productivity.

  Results:
  - Some regions may see decreased crop yields due to droughts or excessive heat.
  - Increase in pest and disease activity, impacting food supply and prices.

Health Impacts

Health Risks from Climate Change:

- Heat-related illnesses and respiratory problems are exacerbated by poor air quality.
- Greater spread of diseases transmitted by insects like mosquitoes.

Economic Consequences

- **Financial Impacts**: The environmental and societal effects of greenhouse gases lead to significant economic costs.

Examples:

- Expenses related to disaster response and infrastructure repair.
- Healthcare costs and losses in agricultural output.

Test Your Skills

1. How does the balance between natural greenhouse gases and human-induced greenhouse gases affect the Earth's climate over the long term?
2. How might the current rate of global warming impact ecosystems differently in polar regions compared to the tropical regions?
3. To what extent can technological innovations, such as carbon capture and storage, mitigate the effects of greenhouse gases on climate change?
4. How can communities and industries collaborate to reduce their carbon footprints while maintaining economic stability and growth?

CORAL REEFS: THE RAINFORESTS OF THE SEA

- Coral reefs are complex marine ecosystems located in shallow, tropical, and subtropical waters.
- They are formed by **coral polyps**.
- Coral polyps are small animals that create calcium carbonate skeletons which build up the reef structure. They are known for their extraordinary biodiversity.
- Coral reefs are often compared to rainforests because of the wide variety of life they support.

Composition and Biodiversity

- **Coral Polyps**: These are the main builders of the reef, forming the hard structures by secreting calcium carbonate.
- **Symbiotic Relationships**: Coral polyps live in a mutual relationship with photosynthetic algae, which provide nutrients and contribute to the corals' vibrant colors.
- **Marine Life**: Coral reefs provide habitat to thousands of species, including reef fish, predators, and herbivores, as well as vital sea-grasses and algae.

Protective Role of Reefs

Coral reefs act as natural barriers that protect coastlines from the effects of erosion, storms, and waves, helping to preserve shorelines and reduce the impact of natural disasters.

Threats from Climate Change and Ocean Acidification

- **Carbon Dioxide Impact**: Oceans absorb significant amounts of CO_2, which increases with the burning of fossil fuels and deforestation. This absorption affects the ocean's chemistry, leading to ocean acidification.
- **Acidification Effects**: When CO_2 combines with seawater, it forms carbonic acid, lowering the pH of the ocean. This process is exacerbated by rising sea temperatures. About 25% of CO_2 is produced by oceans; it is about 22 million tons of CO_2 per day.

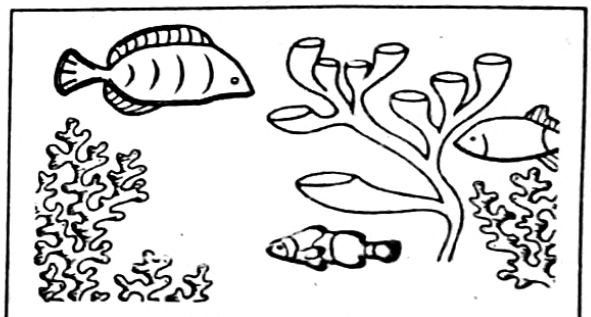

Figure: Coal Reefs

- **Impact on Marine Life**: Acidification particularly threatens organisms with calcium carbonate structures, like corals and mollusks. These species struggle to maintain their structures in acidic conditions, leading to weaker defenses against predators and diseases.
- **Future Projections**: It is predicted that by 2080, ocean conditions will be so acidic that coral erosion will occur faster than coral growth, posing a significant threat to these ecosystems.
- Pakistan is a country with diverse ecosystems due to its varied topography and climate.
- Some important ecosystems of Pakistan are:
  - **Grassland Ecosystem**
  - **Desert Ecosystems**
  - **Coniferous Alpine and Boreal Forests**
  - **Temperate Deciduous Forests**

Grassland Ecosystems in Pakistan

- Grasslands in Pakistan vary significantly and can be divided into two main types: **tropical** and **temperate** grasslands, each with unique environmental characteristics.

Climate Conditions

Tropical Grasslands

- **Rainfall**: These areas experience a monsoon climate, with annual rainfall varying from 200 mm to 600 mm depending on the region.
- **Temperature**: Daytime temperatures during summer often exceed 40°C (104°F), cooling significantly at night. Winters are mild and dry, with average temperatures between 10°C and 20°C (50°F to 68°F).

Temperate Grasslands

- **Rainfall**: These grasslands receive less rainfall than tropical grasslands, with annual precipitation ranging from 150 mm to 500 mm, making them more susceptible to droughts.
- **Temperature**: There are distinct seasonal changes, with warm summers averaging 25°C to 35°C (77°F to 95°F) and cold winters that can drop below the freezing point.

Flora and Fauna

- **Flora**: Typical grass species include buffelgrass (*Cenchrus ciliaris*), Indian red oats (*Themeda anathera*), weedy rice grass (*Apluda mutica*), velvet grass (*Panicum antidotale*), and species from the *Dicanthium*, *Stipagrostis*, and *Heteropogon* genera.
- **Fauna**: These ecosystems support a diverse range of wildlife, including:
  - **Herbivores**: Deer, antelopes, gazelles, and wild goats.
  - **Rodents and Birds**: Various species that are integral to the ecosystem.
  - **Predators**: Foxes, wolves, jackals, big cats, and birds of prey.

Productivity and Adaptation

- **Tropical Grasslands**: Also known as savannas, these areas have moderate to high productivity. The vegetation is well-adapted to handle periodic droughts and fires.
- **Temperate Grasslands**: Typically found in Balochistan and parts of Punjab, these areas have lower productivity due to limited water and nutrients.

Threats and Conservation

- **Threats**: Overgrazing by livestock is a significant threat, leading to soil erosion and loss of biodiversity. Other human activities, such as agriculture, urbanization, and infrastructure development, also contribute to habitat loss and fragmentation. Additionally, changing climate patterns affect rainfall and temperatures, impacting these ecosystems.
- **Conservation Efforts**: Pakistan is focusing on sustainable land management, wildlife protection, and raising awareness about the importance of grasslands for biodiversity and local communities.

Figure: Grassland Ecosystem

Test Your Skills

1. How can traditional knowledge and practices of indigenous communities in Pakistan contribute to sustainable management and conservation of grassland ecosystems in the face of modern environmental challenges?
2. How can scientific research and technological advancements support conservation efforts in Pakistan's diverse ecosystems, from monitoring biodiversity to implementing innovative solutions for sustainable development?
3. Considering coral reefs as "rainforests of the sea," what are the ethical considerations in balancing economic development and conservation efforts to protect these fragile ecosystems?
4. How do the symbiotic relationships between coral polyps and algae compare to other mutualistic relationships in ecosystems, and what implications do these relationships have for biodiversity conservation?

Desert Ecosystems of Pakistan

- Deserts are the driest terrestrial ecosystems.
- Pakistan is home to several deserts including the Thar, Cholistan, Thal, Kharan, and the cold desert of Skardu.
- These regions feature unique flora and fauna adapted to the arid conditions.

Climate and Environmental Conditions

- **Rainfall**: Desert areas in Pakistan receive low and unpredictable rainfall, ranging from about 100 to 250 millimeters annually, primarily during the monsoon season from July to September.
- **Temperature Range**: These regions experience extreme temperatures. Summers can see temperatures soaring above 40°C (104°F), occasionally reaching up to 50°C. Winters, on the other hand, can be quite cold, with temperatures often dropping below 10°C (50°F).

Flora: Adaptations to Aridity

- **Xerophytic Plants**: Plants such as cacti, thorny bushes (e.g., Acacia and Prosopis species), and succulents are prevalent in these deserts. These plants have adapted features like modified leaves or stems to minimize water loss through transpiration.

Fauna: Diverse Desert Dwellers

- **Mammals**: Includes rodents like jerboas and desert gerbils, along with carnivores such as desert foxes and wildcats.
- **Reptiles**: Common desert reptiles include various snakes and lizards.
- **Birds**: Species like sandgrouse, larks, and raptors are adapted to desert conditions, possessing specific behaviors and physiological traits to cope with the harsh environment.
- **Insects**: Desert insects such as ants, beetles, and some butterflies have mechanisms to endure the arid conditions.

Ecosystem Productivity and Food Chains

- **Primary Productivity**: This is relatively low due to limited water availability and sparse vegetation. Drought-resistant grasses and shrubs primarily support the desert food chain.
- **Food Chains**: Herbivores feed on desert vegetation, while predators consume these herbivores. Scavengers are vital for nutrient recycling, feeding on deceased organisms.

Figure: Desert Ecosystem

Adaptations for Survival

- **Water Conservation**: Desert species have developed remarkable adaptations for water conservation. Plants often have deep root systems to access underground water, while animals might exhibit adaptations like concentrated urine and efficient cooling methods.

- **Nocturnal Behavior**: Many desert animals are active at night to avoid the extreme daytime heat.
- **Burrowing**: Numerous desert creatures, including rodents and reptiles, are adept at burrowing, using burrows to escape extreme temperatures and conserve water.

Coniferous Alpine and Boreal Forests of Pakistan

- Coniferous alpine and boreal forests are primarily located in the northern, mountainous regions of Pakistan, such as the Western Himalayas and the Karakoram Range.
- They are adapted to cold climates.
- These forests experience a range of environmental conditions that shape their unique ecosystems.

Climate Conditions

- **Temperature**: These forests are known for their cold temperatures, particularly during the winter months, with average temperatures frequently dropping below freezing.
- **Rainfall**: They receive moderate to high levels of precipitation, mainly as snow in winter and rain in summer. This moisture is crucial for the survival and growth of the vegetation in these areas.

Flora: Plant Life

- **Tree Species**: The dominant vegetation includes various types of conifers like pine, spruce, fir, and cedar. These trees have needle-like leaves which help conserve water and are well-suited to the cold conditions.
- **Other Plants**: Besides conifers, you can find alpine plants such as rhododendrons and junipers, along with various grass species. These plants are capable of surviving the harsh conditions of high altitudes and cold temperatures.

Fauna: Animal Life

- **Mammals**: The region supports diverse mammals including snow leopards, brown bears, Himalayan tahrs, red foxes, and various deer species.
- **Birds**: Bird species such as golden eagles, griffon vultures, chukar partridges, and various finches and warblers thrive here.
- **Insects and Amphibians**: Common insects include butterflies and moths. Some areas also host unique amphibian species adapted to the cold, mountainous environment.

Ecosystem Productivity

- **Growth Conditions**: Productivity in these forests is relatively low due to the severe environment. The growing season is short, and soil nutrients are limited, leading to slower growth rates of plants.
- **Biodiversity Significance**: Despite the slow growth, these forests are considered biodiversity hotspots. They support a range of plant and animal species that are uniquely adapted to the challenging conditions of cold, high altitudes.

Environmental Variability

- The specific characteristics of the flora, fauna, and overall productivity in these forests can vary greatly depending on altitude, local microclimates, and other environmental factors within the alpine and boreal regions.

Figure: Coniferous Alpine and Boreal Forest System

Temperate Deciduous Forests of Pakistan

Geographic Distribution

- Temperate deciduous forests in Pakistan are predominantly located in the northern regions, especially in the foothills of the Himalayas and the Karakoram Range, including areas like Azad Kashmir.

Climate Conditions

- **Rainfall**: These forests receive a moderate amount of rainfall spread throughout the year.
- **Temperature**: There is a seasonal variation in temperature, with warm summers and cool winters. The specific climate can vary with altitude and geographical location within the region.

Flora: Plant Life

- **Trees**: The forests are characterized by broadleaf trees that lose their leaves annually in autumn. Common species include oak, maple, pine, ash, walnut, and deodar cedar.
- **Undergrowth**: The forest floor may host ferns, mosses, and a variety of wildflowers, contributing to the biodiversity of the area.

Figure: Temperate Deciduous

Fauna: Wildlife

- **Birds**: Species such as pheasants, partridges, and eagles are prevalent.
- **Mammals**: The forests are home to the Himalayan brown bear, snow leopard, various deer species, and monkeys.
- **Other Wildlife**: A diverse array of insects, amphibians, and reptiles also inhabit these forests.

Ecosystem Productivity

- **Factors Influencing Productivity**: Soil quality, climate, and plant diversity play critical roles in the productivity of these forests.
- **Biodiversity and Ecosystem Services**: These forests are rich in biodiversity and essential for providing habitat, regulating water flow, and supporting nutrient cycling.

Human Impacts and Conservation

- **Deforestation and Logging**: Unsustainable logging practices and deforestation have significantly reduced these forests, causing environmental concerns and biodiversity loss.
- **Agricultural and Developmental Impacts**: Agricultural expansion and infrastructure development have further led to habitat loss and fragmentation, threatening various plant and animal species.
- **Conservation Needs**: Protecting the remaining temperate deciduous forests is crucial for maintaining biodiversity and ecological balance in these regions.

Test Your Skills

1. What are the socio-economic benefits of preserving coniferous alpine and boreal forests in Pakistan?
2. How do the environmental conditions and biodiversity of coniferous alpine and boreal forests in Pakistan compare to similar forests found in other mountainous regions around the world?
3. Considering the unique flora and fauna of Pakistan's deserts, what are the ethical considerations in balancing economic development, such as mining and infrastructure projects, with conservation efforts to protect these fragile ecosystems?
4. How do the adaptations of desert plants and animals to extreme aridity compare to those found in other ecosystems with severe environmental conditions, such as polar regions or high-altitude mountains?