Ecosystem

Definition and Overview

An ecosystem is a functional unit of nature where living organisms interact among themselves and with the surrounding physical environment. It is a self-regulating structural and functional unit of the biosphere.

Types of Ecosystems

Ecosystems are broadly classified into:

- **Terrestrial Ecosystems:** These include forests, grasslands, deserts, etc.
- **Aquatic Ecosystems:** These include ponds, lakes, wetlands, rivers, estuaries, and oceans.
- **Man-made Ecosystems:** Examples include crop fields and aquariums.

Structure and Function

An ecosystem consists of biotic (living organisms) and abiotic (non-living elements like water, temperature, and soil) components that function as a unit. Energy flows unidirectionally within these components. Vertical distribution of species occupying different levels is called stratification, such as emergents, canopy, under canopy, and shrub layers in forests.

Components of Ecosystem

The components include:

- **Biotic Components:** Producers (plants), consumers (herbivores, carnivores), and decomposers (bacteria and fungi).
- **Abiotic Components:** Non-living elements such as water, soil, temperature, and sunlight.

Example: In a pond ecosystem, abiotic components include water and soil; autotrophic components include phytoplankton and aquatic plants; consumers include tadpoles, snails, and fish; decomposers include fungi and bacteria.

Functions of Ecosystem

The main functions are:

- Productivity: Conversion of inorganic substances into organic material by autotrophs using solar energy.
- Decomposition: Breakdown of dead organic matter by decomposers.
- Energy Flow: Unidirectional movement of energy through trophic levels.
- Nutrient Cycling: Recycling of nutrients within the ecosystem.

Productivity

Productivity is the rate of biomass production in an ecosystem, expressed in grams per square meter per year ($gm^{-2}\ yr^{-1}$) or kilocalories per square meter per year ($kcal\ m^{-2}\ yr^{-1}$).

Primary Productivity: The amount of organic matter produced by plants through photosynthesis.

Gross Primary Productivity (GPP): Total rate of photosynthesis.

Net Primary Productivity (NPP): GPP minus the energy used in plant respiration (R). NPP is the biomass available for consumption by heterotrophs.

$$NPP = GPP - R$$

Primary productivity depends on plant species, environmental factors, nutrient availability, and photosynthetic capacity.

Secondary Productivity: Rate of formation of new organic matter by consumers (heterotrophs), reflecting biomass increase at higher trophic levels.

Decomposition

Decomposition is the breakdown of complex organic matter into simpler inorganic substances by decomposers, mainly bacteria and fungi. It is largely an oxygen-requiring process.

Detritus: Dead organic matter such as leaves, bark, and animal remains.

Detritivores: Animals that feed on detritus, e.g., earthworms, termites, snails.

Steps in Decomposition

- **Fragmentation:** Breakdown of detritus into smaller particles by detritivores, increasing surface area.
- **Leaching:** Water-soluble nutrients are washed down into soil horizons.
- **Catabolism:** Enzymatic degradation of detritus into simpler inorganic substances by microbes.
- **Humification:** Formation and accumulation of humus, a dark, resistant organic substance in soil.
- **Mineralisation:** Conversion of organic nutrients into inorganic forms usable by plants.

Factors Influencing Decomposition

Decomposition rate depends on:

- **Chemical Composition:** Slower if detritus is rich in lignin and chitin; faster if rich in nitrogen and water-soluble substances.
- **Climatic Factors:** Temperature and soil moisture affect microbial activity; warm and moist conditions favor decomposition, while low temperature and anaerobic conditions inhibit it.

Nutrient Immobilisation: Temporary binding of nutrients in microbial biomass, making them unavailable to other organisms.

Solved Examples

Example 1

Question: How are productivity, gross primary productivity, net primary productivity, and secondary productivity interrelated?

Solution:

Net Primary Productivity (NPP) is the difference between Gross Primary Productivity (GPP) and respiration losses (R) by plants:

$NPP = GPP - R$

Where:

- GPP is the total rate of organic matter production by photosynthesis.
- R is the energy used by plants for respiration.
- NPP is the biomass available for consumption by heterotrophs.

Secondary productivity is the rate of formation of new organic matter by consumers, reflecting biomass increase at higher trophic levels.

Example 2

Question: Write the outcomes of the following events:

(a) Elimination of all producers.

(b) Elimination of all herbivores.

(c) Elimination of all top carnivores.

Answer:

(a) Primary production would cease, leading to unavailability of biomass for higher trophic levels, causing ecosystem collapse.

(b) Primary productivity and biomass of producers would increase due to lack of herbivory; carnivores would decline due to lack of food.

(c) Herbivore populations would increase unchecked, leading to overgrazing and possible desertification.

Practice Set

- **Level 1 (Easy):** Define an ecosystem and list its main components.
- **Level 2 (Moderate):** Explain the difference between gross primary productivity and net primary productivity.
- **Level 3 (Challenging):** Describe the steps involved in the decomposition process and explain how climatic factors influence decomposition.

Answer Key

- **Level 1:** An ecosystem is a functional unit of nature where living organisms interact with each other and with their physical environment. Its main components are biotic (producers, consumers, decomposers) and abiotic (water, soil, temperature, sunlight) components.
- **Level 2:** Gross primary productivity (GPP) is the total amount of organic matter produced by photosynthesis. Net primary productivity (NPP) is GPP minus the energy used by plants for respiration; it represents the biomass available for consumers.
- **Level 3:** Decomposition involves fragmentation (breaking detritus into smaller pieces), leaching (washing soluble nutrients into soil), catabolism (microbial breakdown of organic matter), humification (formation of humus), and mineralisation (conversion to inorganic nutrients). Warm and moist climates favor microbial activity and faster decomposition, while cold or dry conditions slow it down.

Energy Flow

Source and Capture of Energy

The sun is the primary source of energy for all ecosystems. Less than 50% of solar radiation is photosynthetically active radiation (PAR). Producers such as green plants and photosynthetic bacteria capture this energy and convert it into chemical energy through photosynthesis.

Producers

Producers are autotrophs that synthesize food using solar energy. In terrestrial ecosystems, producers include herbaceous and woody plants. In aquatic ecosystems, phytoplankton, algae, and higher plants serve as primary producers.

Consumers

Consumers are heterotrophs that depend on producers for food. They are classified as:

- **Primary Consumers:** Herbivores feeding on plants (e.g., insects, birds, mammals).
- **Secondary Consumers:** Primary carnivores feeding on herbivores (e.g., frogs, foxes).
- **Tertiary Consumers:** Secondary carnivores feeding on primary carnivores.

Food Chains and Food Webs

Grazing Food Chain (GFC): Starts with producers and moves through herbivores to carnivores.

Detritus Food Chain (DFC): Begins with dead organic matter and involves decomposers.

Food chains interconnect to form food webs, showing complex feeding relationships.

Trophic Levels and Standing Crop

Organisms occupy specific trophic levels based on their feeding position. The standing crop is the mass of living material at a trophic level, measured as biomass or number of individuals.

Lindemann's 10% Law

Only about 10% of energy is transferred from one trophic level to the next; the rest is lost as heat or used in metabolic processes.

Solved Examples

Example 1

Question: Explain Lindemann's 10% law of energy transfer in an ecosystem.

Solution: Lindemann's 10% law states that when energy passes from one trophic level to the next, only about 10% of the energy is transferred. The remaining 90% is lost as heat or used for metabolic activities. For example, if producers capture 1000 J of energy, primary consumers receive 100 J, secondary consumers 10 J, and tertiary consumers 1 J.

Practice Set

- **Level 1 (Easy):** What is the primary source of energy for ecosystems?
- **Level 2 (Moderate):** Differentiate between grazing food chain and detritus food chain.
- **Level 3 (Challenging):** Explain the significance of Lindemann's 10% law in limiting the number of trophic levels in an ecosystem.

Answer Key

- **Level 1:** The sun is the primary source of energy for ecosystems.
- **Level 2:** Grazing food chain starts with producers and moves through herbivores to carnivores, while detritus food chain begins with dead organic matter and involves decomposers.
- **Level 3:** Lindemann's 10% law limits the number of trophic levels because only 10% of energy is transferred to the next level, so energy becomes insufficient to support many levels.

Ecological Pyramids

Definition and Types

Ecological pyramids graphically represent the relationship between producers and consumers at various trophic levels. The base represents producers, and the apex represents top consumers.

There are three types of ecological pyramids:

- **Pyramid of Number:** Shows the number of individuals at each trophic level.
- **Pyramid of Biomass:** Represents the dry mass of organisms at each trophic level.
- **Pyramid of Energy:** Depicts the flow of energy through trophic levels.

Characteristics

Most pyramids are upright, showing a decrease in number, biomass, and energy from producers to top consumers. Exceptions include inverted pyramids, such as the pyramid of biomass in aquatic ecosystems where consumers may have greater biomass than producers.

Limitations

- Does not account for species occupying multiple trophic levels.

- Assumes simple food chains, not complex food webs.
- Excludes saprophytes despite their ecological importance.

Solved Examples

Example 1

Question: Why is the pyramid of energy always upright?

Solution: The pyramid of energy is always upright because energy decreases at each trophic level due to metabolic losses and heat dissipation. Energy flow is unidirectional and cannot be recycled, so less energy is available to higher trophic levels.

Practice Set

- **Level 1 (Easy):** Name the three types of ecological pyramids.
- **Level 2 (Moderate):** Explain why the pyramid of biomass in aquatic ecosystems can be inverted.
- **Level 3 (Challenging):** Discuss the limitations of ecological pyramids.

Answer Key

- **Level 1:** Pyramid of number, pyramid of biomass, and pyramid of energy.
- **Level 2:** In aquatic ecosystems, phytoplankton have low biomass but reproduce rapidly, supporting a larger biomass of zooplankton, causing an inverted pyramid of biomass.
- **Level 3:** Limitations include ignoring species at multiple trophic levels, assuming simple food chains, and excluding saprophytes.

Quick Reference Table

Ecosystem: Functional unit of nature with biotic and abiotic components.

Types: Terrestrial, aquatic, man-made.

Components: Producers, consumers, decomposers, abiotic factors.

Productivity: GPP (total photosynthesis), NPP (GPP - respiration), secondary productivity (consumer biomass formation).

Decomposition Steps: Fragmentation, leaching, catabolism, humification, mineralisation.

Energy Flow: Sun → Producers → Consumers → Decomposers; 10% energy transfer rule.

Ecological Pyramids: Number, biomass, energy; mostly upright except some aquatic biomass pyramids.

Common Mistakes and Misconceptions

- Confusing freshwater and marine ecosystems; they have distinct biotic and abiotic components.
- Mixing roles of producers, consumers, and decomposers.
- Confusing primary productivity (producers) with secondary productivity (consumers).
- Assuming energy flow is cyclical like nutrient cycling; energy flow is unidirectional.
- Confusing decomposition with mineralisation; mineralisation is a specific step releasing inorganic nutrients.
- Assuming all ecological pyramids are upright; some aquatic pyramids can be inverted.

Glossary

- **Autotrophs:** Organisms that produce their own food using sunlight or chemical energy.
- **Biomass:** Total mass of living organisms in a given area.
- **Decomposers:** Organisms that break down dead organic matter into simpler substances.
- **Detritus:** Dead organic matter serving as food for decomposers.
- **Gross Primary Productivity (GPP):** Total organic matter produced by photosynthesis.
- **Net Primary Productivity (NPP):** Organic matter remaining after plant respiration.
- **Primary Consumers:** Herbivores that feed on producers.
- **Secondary Consumers:** Carnivores that feed on herbivores.
- **Trophic Level:** Position of an organism in a food chain based on feeding relationships.