



La-Net

BIO 202



INTRODUCTORY ECOLOGY

Understanding the relationships
between organisms and their
environment.



ORGANISMS



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Course code: BIO 202

Course title: Introductory Ecology

Course credit load: 2 Units

Series 1: Concepts and Terminologies of Ecosystem

- **Part 1.1: Ecology and the Ecosystem Concept**

- Sub Part 1.1.1: Definition and scope of ecology
- Sub Part 1.1.2: Definition and components of an ecosystem
- Sub Part 1.1.3: Types of ecosystems

- **Part 1.2: Abiotic Components of the Ecosystem**

- Sub Part 1.2.1: Climatic factors
- Sub Part 1.2.2: Edaphic (soil) factors
- Sub Part 1.2.3: Topographic factors

- **Part 1.3: Biotic Components of the Ecosystem**

- Sub Part 1.3.1: Producers (autotrophs)
- Sub Part 1.3.2: Consumers (heterotrophs)
- Sub Part 1.3.3: Decomposers and detritivores

- **Part 1.4: Key Ecological Concepts and Terminologies**

- Sub Part 1.4.1: Habitat, niche, and ecotone
- Sub Part 1.4.2: Biome, biosphere, and ecological levels of organisation
- Sub Part 1.4.3: Energy flow and productivity



Introduction

Ecology is the scientific study of the relationships between living organisms and their environment. It provides the framework for understanding how organisms interact with each other and with the physical world around them. The ecosystem is the fundamental operational unit of ecology, integrating all living organisms in an area with their non-living surroundings.

This opening Series introduces the language and conceptual framework of ecology. A firm grasp of ecological definitions and terminology is essential for understanding everything that follows in this course: habitat classification, community ecology, natural cycles, population dynamics, and environmental change. All subsequent Series build directly on the concepts introduced here.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 1.1** define ecology and explain its scope and relationship to other sciences (Linked to Part 1.1),
- **SLO 1.2** define an ecosystem, identify its components, and classify the major types of ecosystems (Linked to Part 1.1),
- **SLO 1.3** describe the major abiotic factors (climatic, edaphic, and topographic) that influence ecosystems (Linked to Part 1.2),
- **SLO 1.4** describe the biotic components of an ecosystem (producers, consumers, decomposers) and explain their roles (Linked to Part 1.3),
- **SLO 1.5** define and distinguish between habitat, niche, ecotone, biome, and biosphere (Linked to Part 1.4), and
- **SLO 1.6** explain the concepts of energy flow and productivity in an ecosystem (Linked to Part 1.4).



1.1 Ecology and the Ecosystem Concept

1.1.1 Definition and scope of ecology

Ecology is the scientific study of the interactions between organisms and their environment, including both the living (biotic) and non-living (abiotic) components. The term was coined by Ernst Haeckel in 1866, derived from the Greek oikos (house) and logos (study). Ecology seeks to understand the distribution and abundance of organisms and the processes that determine them.

Ecology operates at several levels of organisation: individual ecology (autecology: the response of a single organism or species to its environment); population ecology (the study of groups of the same species in an area); community ecology (synecology: the study of multiple species and their interactions); and ecosystem ecology (the study of the community together with its abiotic environment). Ecology overlaps with physiology, genetics, evolutionary biology, and environmental science.

Fill in the blank: Ecology was coined by Ernst _____ in 1866 from the Greek words oikos (house) and logos (study); it is the scientific study of the interactions between organisms and their environment.

1.1.2 Definition and components of an ecosystem

An ecosystem is a functional unit consisting of all the living organisms (biotic community) in a defined area, together with all the non-living (abiotic) factors of their environment, interacting as a system. The term was introduced by A.G. Tansley in 1935. An ecosystem has no fixed size: it may be as small as a puddle or a decaying log, or as large as a tropical rainforest or an ocean.

An ecosystem has two major components: abiotic (non-living) components, which include climate, soil, water, light, temperature, wind, and mineral nutrients; and biotic (living) components, which include all the organisms: producers (plants and other autotrophs), consumers (animals and other heterotrophs), and decomposers (bacteria and fungi). Energy flows through the ecosystem (from producers to consumers) and matter cycles between biotic and abiotic components.



Fill in the blank: The term "ecosystem" was introduced by A.G. _____ in 1935; it includes all the living organisms (biotic community) and all the non-living (abiotic) factors in a defined area, interacting as a system.

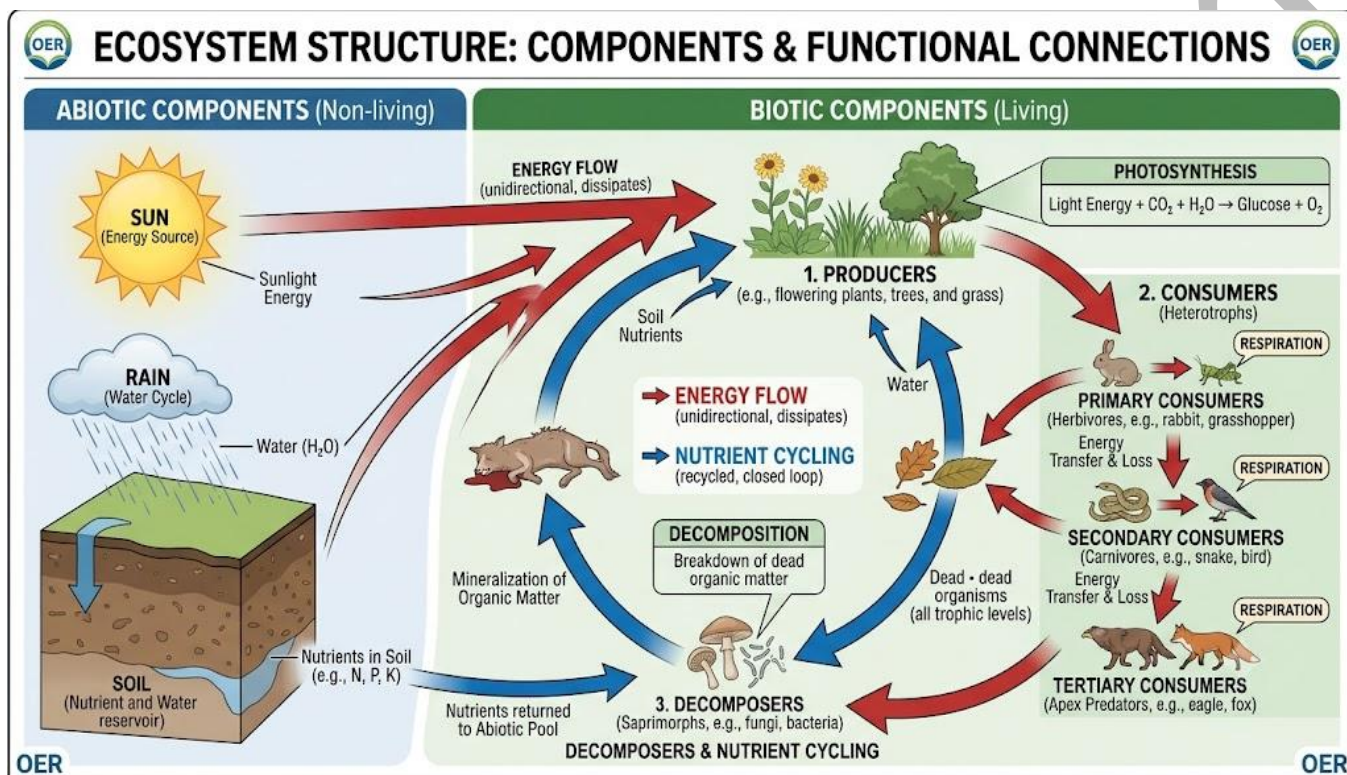


Figure 1.1: Diagram of the structure of an ecosystem showing biotic and abiotic components and their interactions

1.1.3 Types of ecosystems

Ecosystems are broadly classified as natural or artificial. Natural ecosystems develop without significant human modification; they include terrestrial ecosystems (forests, grasslands, deserts, tundra) and aquatic ecosystems (freshwater: rivers, lakes, ponds, swamps; marine: oceans, coral reefs, estuaries, mangroves). Artificial (man-made) ecosystems are created and maintained by humans; they include agricultural ecosystems (farms, plantations), aquaculture ponds, and urban ecosystems.

Ecosystems can also be classified by the level of human input required to maintain them. Self-sustaining ecosystems need only solar energy and basic abiotic inputs; most natural ecosystems



are self-sustaining. Subsidised natural ecosystems receive additional energy or nutrient inputs from outside (e.g. estuaries receive nutrients from rivers). Dependent artificial ecosystems require continuous human energy and material inputs to persist (e.g. cropland, which requires ploughing, irrigation, and fertiliser). Nigeria's ecosystems range from mangrove forests in the Niger Delta to Sahel savanna in the far north.

Fill in the blank: Ecosystems are broadly classified as _____ (developing without human modification: forests, grasslands, aquatic) or artificial (created by humans: farms, fish ponds, urban areas).

Pilot questions 1.1

1. Define ecology and state its four levels of organisation.
2. Define an ecosystem and name its two major components.
3. Classify ecosystems into major types with one Nigerian example of each.
4. Explain what is meant by a self-sustaining ecosystem.
5. State who coined the term "ecology" and who introduced the term "ecosystem".

1.2 Abiotic Components of the Ecosystem

1.2.1 Climatic factors

Climatic factors are non-living physical and chemical properties of the atmosphere and climate that influence organisms. Light (solar radiation): the primary energy source for all ecosystems; controls photosynthesis; photoperiod (day length) controls flowering and reproduction in many organisms; light intensity and quality vary with latitude, season, and canopy cover. Temperature: affects metabolic rate, enzyme activity, and distribution of species; determines whether an area supports tropical or temperate life forms.

Rainfall (precipitation): the amount, timing, and reliability of rainfall is the most critical determinant of terrestrial ecosystem type in Nigeria; ranges from over 4,000 mm per year in parts of the Niger Delta to under 500 mm in the Sahel. Humidity: the water vapour content of the air;



affects transpiration, evaporation, and fungal growth. Wind: disperses seeds, pollen, and spores; increases evaporation and transpiration; affects fire behaviour. Atmospheric gases: CO₂ concentration directly affects photosynthesis; O₂ levels affect aerobic respiration; N₂ is fixed by specialised bacteria.

Fill in the blank: _____ (precipitation) is the most critical climatic determinant of terrestrial ecosystem type in Nigeria; it ranges from over 4,000 mm per year in the Niger Delta to under 500 mm in the Sahel.

1.2.2 Edaphic (soil) factors

Edaphic factors are properties of the soil that influence the organisms living in and on it. Soil texture: the relative proportions of sand, silt, and clay particles; affects drainage, aeration, and nutrient-holding capacity. Sandy soils drain rapidly and hold few nutrients; clay soils retain water and nutrients but may become waterlogged and anaerobic; loam soils (intermediate texture) are most fertile. Soil structure: the aggregation of particles into clumps (peds); good structure improves aeration and root penetration.

Soil pH: the acidity or alkalinity of the soil; most plants grow best at pH 6 to 7; strongly acidic soils (pH below 5) limit nutrient availability and favour acidophilic plants; alkaline soils (pH above 8) limit iron and manganese availability. Soil organic matter (humus): decomposed organic material; improves soil structure, water retention, and nutrient availability; high in forest soils. Soil mineral content: provides essential macronutrients (N, P, K, Ca, Mg) and micronutrients (Fe, Mn, Zn) for plant growth. Soil biota: bacteria, fungi, earthworms, and other organisms cycle nutrients and improve soil structure.

Fill in the blank: _____ soils have an intermediate texture of sand, silt, and clay; they have the best combination of drainage, aeration, nutrient retention, and root penetration and are the most agriculturally fertile soils.



SOIL SCIENCE REFERENCE GUIDE

OER (Open Educational Resource)

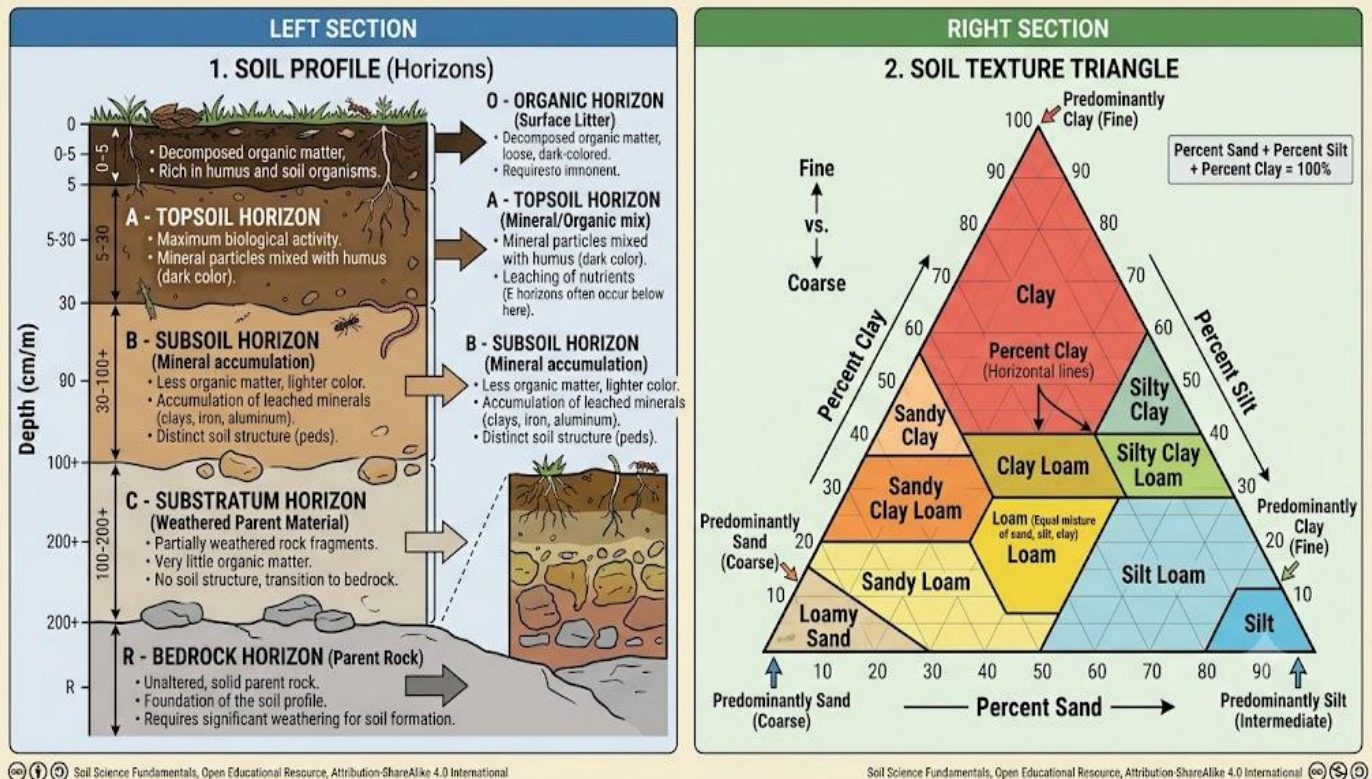


Figure 1.2: Diagram of soil profile showing horizons and properties

1.2.3 Topographic factors

Topographic (physiographic) factors relate to the physical features of the landscape: slope, altitude, aspect, and drainage. Altitude: temperature decreases approximately 6.5 degrees Celsius per 1,000 metres elevation; higher altitudes have reduced atmospheric pressure, higher UV radiation, and stronger winds; this produces zonation of vegetation with altitude (altitudinal zonation) similar to latitudinal zonation of biomes. In Nigeria, Jos Plateau (approximately 1,200 m) supports a cooler, different vegetation from the surrounding lowlands.

Slope and aspect: steep slopes have faster water runoff, less deep soil, and greater erosion; gentle slopes retain more moisture and deeper soil. In the Northern Hemisphere, south-facing slopes receive more direct sunlight and are warmer and drier than north-facing slopes (the reverse in the Southern Hemisphere). In Nigeria, the aspect of a slope affects local microclimate and vegetation. Drainage: poorly drained low-lying areas (e.g. flood plains of the Niger and Benue



rivers) support wetland and swamp vegetation; well-drained elevated areas support upland forest or savanna.

Fill in the blank: _____ decreases approximately 6.5 degrees Celsius per 1,000 metres elevation, producing altitudinal zonation of vegetation; the Jos Plateau in Nigeria at approximately 1,200 m supports cooler vegetation than the surrounding lowlands.

Pilot questions 1.2

1. State five climatic factors and explain how each affects organisms.
2. Explain why loam soil is the most suitable for agriculture.
3. Explain how soil pH affects plant growth.
4. Explain how altitude affects vegetation distribution.
5. State three edaphic factors and the role of each in determining ecosystem type.

1.3 Biotic Components of the Ecosystem

1.3.1 Producers (autotrophs)

Producers (autotrophs) are organisms that synthesise organic compounds from inorganic raw materials using an external energy source. Photoautotrophs use light energy (photosynthesis): green plants, algae, and cyanobacteria. Chemoautotrophs use chemical energy (chemosynthesis): certain bacteria (e.g. nitrifying bacteria, sulphur bacteria, iron bacteria). Producers form the foundation of all food chains and food webs because they are the entry point of energy into the ecosystem.

In terrestrial ecosystems, green plants are the dominant producers; in tropical Nigeria, forest trees and grasses account for most primary production. In aquatic ecosystems, phytoplankton (microscopic algae and cyanobacteria) are the dominant producers; they are responsible for approximately 50% of global photosynthesis. Macroalgae (seaweeds) dominate rocky marine shores. Net primary productivity (NPP) is the total organic matter produced by photosynthesis minus that consumed by plant respiration; it is highest in tropical rainforests and estuaries.



Fill in the blank: Producers (_____) are organisms that synthesise organic compounds from inorganic raw materials using light (photoautotrophs) or chemical energy (chemoautotrophs); they form the base of all food chains.

1.3.2 Consumers (heterotrophs)

Consumers (heterotrophs) obtain energy by consuming other organisms. They are classified by feeding level (trophic level). Primary consumers (herbivores): eat producers directly; examples in Nigeria: cattle, goats, rabbits, caterpillars, grasshoppers, snails, zooplankton. Secondary consumers (primary carnivores): eat primary consumers; examples: lizards eating insects, small birds eating caterpillars, toads eating worms. Tertiary consumers (secondary carnivores): eat secondary consumers; examples: snakes eating lizards, hawks eating small birds.

Omnivores consume both plants and animals; they occupy more than one trophic level simultaneously; examples: humans, rats, pigs, chimpanzees. Scavengers feed on dead organisms; examples: vultures, hyenas, dung beetles. The distinction between trophic levels is important for understanding energy flow: only approximately 10% of energy is transferred from one trophic level to the next; the remaining 90% is lost as heat. This means ecosystems can support fewer top carnivores than herbivores.

Fill in the blank: Only approximately _____ per cent of energy is transferred from one trophic level to the next; the remaining 90 per cent is lost as heat, which is why food chains rarely exceed four or five links.

1.3.3 Decomposers and detritivores

Decomposers (saprotrophs) are organisms that break down dead organic matter (detritus) into simple inorganic molecules by secreting enzymes externally and absorbing the soluble products. They include bacteria and fungi. Decomposers are essential for releasing nutrients locked in dead organisms back into the soil and water, making them available for uptake by producers again. Without decomposers, nutrients would accumulate in dead biomass and become unavailable, and ecosystems would cease to function.



Detritivores are animals that feed on dead organic matter (detritus) but digest it internally; they differ from decomposers which digest externally. Examples: earthworms, millipedes, woodlice, dung beetles, and some marine invertebrates. Detritivores physically fragment detritus, greatly increasing its surface area for microbial decomposition. In Nigerian forest soils, earthworms and termites are among the most important detritivores. The decomposition rate depends on temperature (high in tropical Nigeria), moisture, oxygen availability, and the chemical composition of the detritus.

Fill in the blank: _____ are organisms that feed on dead organic matter internally (e.g. earthworms, millipedes), physically fragmenting it and increasing its surface area for subsequent microbial decomposition by decomposers (bacteria and fungi).

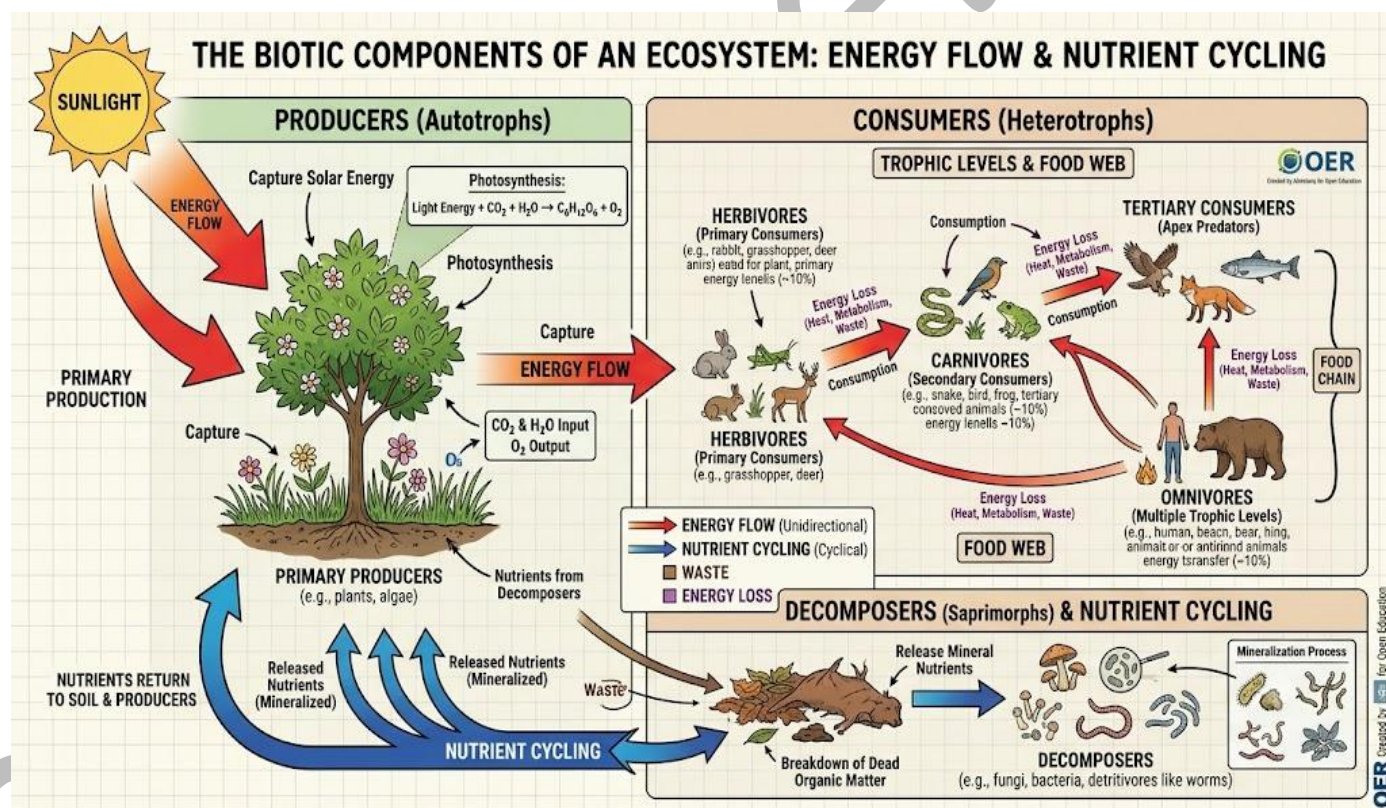


Figure 1.3: Diagram of the biotic components of an ecosystem and their relationships

Pilot questions 1.3

1. Define producers and distinguish between photoautotrophs and chemoautotrophs.
2. Classify consumers by trophic level with one Nigerian example at each level.



3. Explain why food chains rarely exceed four or five links.
4. Distinguish between decomposers and detritivores.
5. Explain the ecological importance of decomposers.

1.4 Key Ecological Concepts and Terminologies

1.4.1 Habitat, niche, and ecotone

A habitat is the physical place or environment where an organism lives; it provides the resources (food, water, shelter, breeding sites) the organism needs. For example, the habitat of a mangrove crab is the tidal mangrove swamp; the habitat of a savanna elephant is the West African savanna woodland. Each habitat has characteristic abiotic conditions (soil type, temperature, rainfall, light) that determine which species can live there. The term habitat describes where an organism lives; the niche describes how.

The ecological niche is the functional role of an organism within its community: what it eats, when it is active, what it eats and what eats it, how it uses space, and how it affects the abiotic environment. The niche includes the fundamental niche (the full range of conditions the organism can potentially exploit) and the realised niche (the narrower set of conditions it actually occupies due to competition). An ecotone is a transition zone between two adjacent ecosystems or biomes; examples: the zone between forest and savanna; mangrove-forest edge; river bank. Ecotones often support higher species diversity (edge effect) because species from both adjacent communities are present.

Fill in the blank: An _____ is a transition zone between two adjacent ecosystems; it often supports higher species diversity than either adjacent community because species from both communities can be present (edge effect).



1.4.2 Biome, biosphere, and ecological levels of organisation

A biome is a large-scale terrestrial or aquatic ecosystem characterised by a particular climate and dominated by a characteristic type of vegetation and associated animal communities. Major terrestrial biomes: tropical rainforest (high rainfall, high temperature year-round; e.g. southern Nigeria); savanna/tropical grassland (seasonal rainfall; e.g. middle and northern Nigeria); desert (very low rainfall; e.g. Sahel fringe of northernmost Nigeria); tropical dry forest; temperate grassland; temperate deciduous forest; boreal forest/taiga; tundra.

The biosphere is the global ecological system integrating all living organisms and their relationships with the lithosphere (land), hydrosphere (water), and atmosphere; it is the zone of Earth where life exists. Ecological levels of organisation, from smallest to largest: organism → population (same species, same area) → community (all populations in an area) → ecosystem (community plus abiotic environment) → biome (a group of ecosystems sharing climate and vegetation type) → biosphere (all ecosystems on Earth). Each level has emergent properties not seen at lower levels.

Fill in the blank: The _____ is the global ecological system integrating all living organisms and their relationships with the land, water, and atmosphere; it is the zone of Earth where life exists, extending from ocean depths to the lower atmosphere.



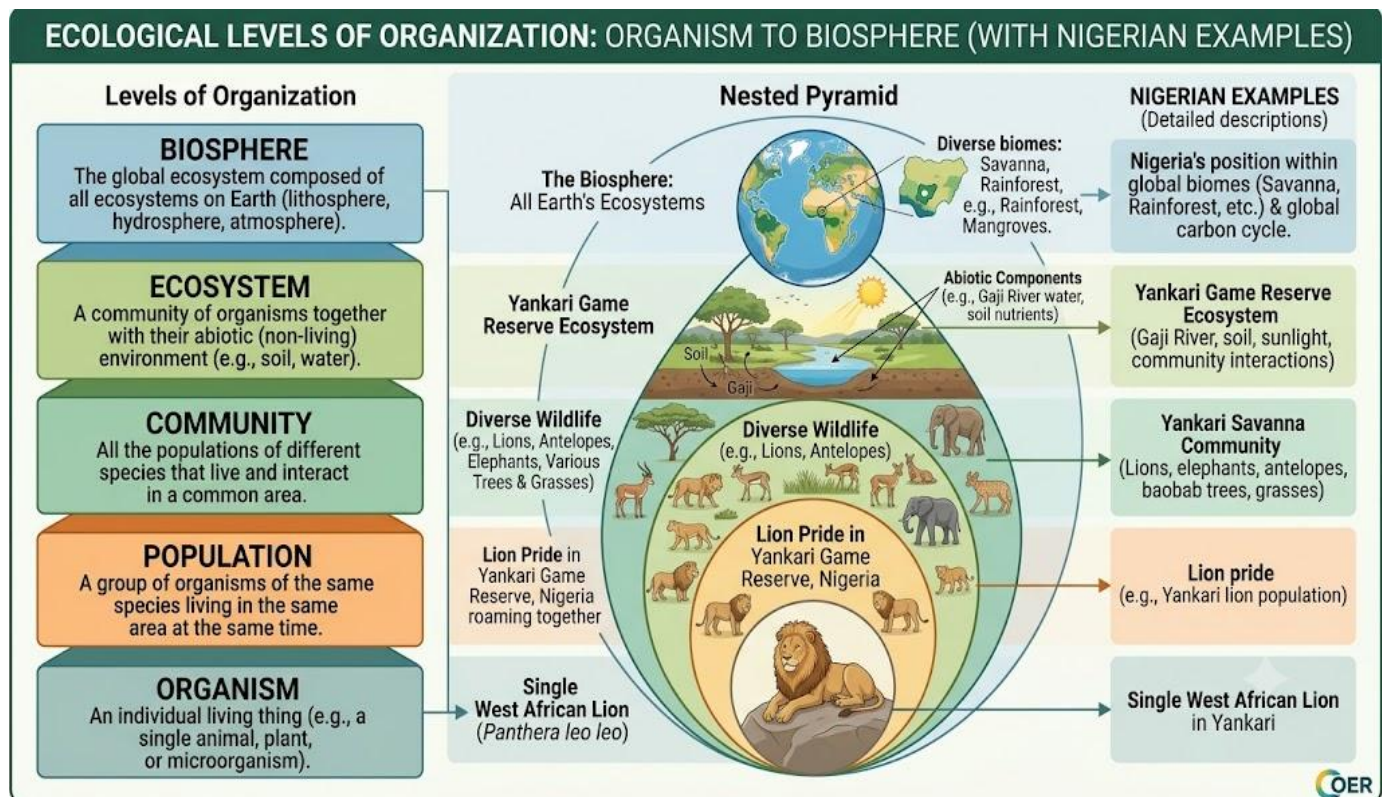


Figure 1.4: Diagram of ecological levels of organisation from organism to biosphere

1.4.3 Energy flow and productivity

Energy enters ecosystems as solar radiation captured by producers through photosynthesis. Gross Primary Productivity (GPP): the total energy fixed by all producers per unit area per unit time. Net Primary Productivity (NPP): GPP minus energy used by producers for their own respiration ($NPP = GPP - \text{plant respiration}$). NPP represents the organic matter available to consumers. In Nigerian tropical rainforest, NPP is approximately 1,000 to 2,000 g dry matter per m² per year, among the highest of any terrestrial ecosystem.

Secondary productivity: the rate of energy storage at consumer trophic levels; always less than NPP because of the approximately 10% efficiency of energy transfer. The 10% rule: on average, only 10% of the energy at one trophic level is available at the next; the remaining 90% is lost as metabolic heat, respiration, egestion, and excretion. This inefficiency limits food chain length and explains why the biomass at each trophic level decreases: a pyramid of biomass typically shows the largest mass at the producer level and decreasing masses at each consumer level.



Fill in the blank: Net Primary Productivity (NPP) equals Gross Primary Productivity (GPP) minus plant _____; it represents the organic matter actually available to primary consumers and higher trophic levels.

<u>Term</u>	<u>Definition</u>
<u>Ecology</u>	The study of interactions between organisms and their environment.
<u>Ecosystem</u>	A community of organisms interacting with each other and with their physical environment.
<u>Habitat</u>	The natural environment where an organism lives.
<u>Niche</u>	The role or function of an organism within its ecosystem, including its interactions and resource use.
<u>Ecotone</u>	A transitional zone between two ecosystems or communities.
<u>Biome</u>	A large ecological region characterized by distinct climate, vegetation, and animal life.
<u>Biosphere</u>	The global sum of all ecosystems; the part of Earth where life exists.
<u>GPP</u>	Gross Primary Productivity – the total amount of energy captured by producers through photosynthesis.
<u>NPP</u>	Net Primary Productivity – the energy remaining after producers use some for respiration; available to consumers.

Box 1.1: Summary of key ecological terms and their definitions

Pilot questions 1.4

1. Distinguish between habitat and ecological niche with one example of each.
2. Define ecotone and explain the edge effect.
3. Name the major biomes in Nigeria and describe the climate of each.
4. Define GPP and NPP and state the relationship between them.
5. Explain why only 10 per cent of energy is transferred between trophic levels.



Series Summary

This Series introduced the foundational concepts and terminology of ecology and ecosystems. Ecology was defined as the study of interactions between organisms and their environment, operating across four levels of organisation from the individual through population and community to the ecosystem. The ecosystem concept, formalised by Tansley in 1935, was examined as an integrated system of biotic and abiotic components: the biotic side encompasses producers (photoautotrophic green plants and algae, and chemoautotrophic bacteria), consumers arranged across primary, secondary, and tertiary trophic levels including herbivores, carnivores, omnivores, and scavengers, and decomposers and detritivores that process dead organic matter through external and internal digestion respectively. Abiotic factors were surveyed across climatic, edaphic, and topographic categories, with rainfall identified as the key determinant of ecosystem type in the Nigerian context.

Essential ecological terminology was then established: habitat as the physical location of an organism, niche as its functional role within the community, ecotone as the transition zone between adjacent ecosystems with its associated edge effect, biome as a large-scale ecosystem defined by shared climate and vegetation type, and biosphere as the totality of life on Earth. Energy flow through ecosystems was introduced through the relationship between gross primary productivity, plant respiration, and net primary productivity, and the approximately ten percent ecological efficiency governing the transfer of energy between successive trophic levels, establishing the quantitative framework for food web analysis covered later in the course.

Glossary of Terms

- **Abiotic:** the non-living physical and chemical components of the environment; includes light, temperature, rainfall, soil, and wind.
- **Autecology:** the study of the ecology of a single organism or species and its relationship with its environment.



- **Autotroph:** an organism that produces its own organic food from inorganic raw materials using light (photoautotroph) or chemical energy (chemoautotroph).
- **Biome:** a large-scale terrestrial or aquatic ecosystem characterised by a particular climate and dominated by characteristic vegetation and associated animals.
- **Biosphere:** the global ecological system including all living organisms and their relationships with the land, water, and atmosphere of Earth.
- **Biotic:** the living components of the environment; includes all organisms: producers, consumers, and decomposers.
- **Chemoautotroph:** an autotroph that uses chemical energy (from inorganic chemical reactions) to synthesise organic compounds; e.g. nitrifying bacteria.
- **Community:** all the populations of different species living together in the same area at the same time.
- **Consumer:** a heterotrophic organism that obtains energy by consuming other organisms; classified as primary (herbivore), secondary, or tertiary consumer.
- **Decomposer:** an organism (bacterium or fungus) that secretes enzymes to digest dead organic matter externally and absorbs the soluble products; essential for nutrient cycling.
- **Detritivore:** an animal that consumes detritus (dead organic matter) internally; examples include earthworms, millipedes, and woodlice; physically fragments detritus for microbial decomposition.
- **Ecology:** the scientific study of the interactions between living organisms and their environment (biotic and abiotic components); coined by Ernst Haeckel in 1866.
- **Ecotone:** a transition or boundary zone between two adjacent ecosystems or biomes; often supports higher species diversity due to the edge effect.
- **Edaphic factors:** soil-related properties that influence organisms; includes soil texture, pH, mineral content, organic matter, structure, and moisture content.
- **Edge effect:** the tendency for species diversity to be higher at the boundary (ecotone) between two communities than in either community alone.



- **Ecosystem:** all the living organisms (biotic community) in a defined area together with all the non-living (abiotic) factors of their environment, interacting as a functional system; introduced by A.G. Tansley in 1935.
- **Gross Primary Productivity (GPP):** the total rate of energy fixation by producers through photosynthesis per unit area per unit time.
- **Habitat:** the physical place or environment where an organism lives and which provides the resources it needs (food, water, shelter, breeding sites).
- **Heterotroph:** an organism that obtains energy by consuming organic material produced by other organisms.
- **Niche:** the functional role of an organism in its community; includes what it eats, what eats it, when it is active, and how it modifies the abiotic environment.
- **Net Primary Productivity (NPP):** the rate of organic matter accumulation by producers after subtracting their own respiration costs from GPP ($NPP = GPP - \text{plant respiration}$).
- **Photoautotroph:** an autotroph that uses light energy through photosynthesis to produce organic compounds; includes green plants, algae, and cyanobacteria.
- **Population:** a group of individuals of the same species living in the same area at the same time.
- **Producer:** an autotrophic organism that synthesises organic compounds from inorganic materials; forms the base of all food chains.
- **Realised niche:** the actual, narrower range of conditions an organism occupies in the presence of competitors and predators; a subset of the fundamental niche.
- **Synecology:** the ecology of communities; the study of the structure, distribution, and interactions of communities of organisms.
- **10% rule:** the ecological principle that approximately 10% of the energy at one trophic level is transferred to the next; the remaining 90% is lost as metabolic heat and waste.
- **Topographic factors:** landscape features (altitude, slope, aspect, drainage) that influence local climate and thereby affect the distribution and nature of ecosystems.



Concept Check Questions [Series 1]

Objective Questions

1. Ecology was coined by Ernst _____ in 1866 from the Greek words oikos (house) and logos (study). (Linked to SLO 1.1)
2. The term "ecosystem" was introduced by A.G. _____ in 1935 to describe all living organisms plus their abiotic environment in a defined area. (Linked to SLO 1.2)
3. _____ soil has an intermediate texture of sand, silt, and clay and is the most agriculturally fertile soil type. (Linked to SLO 1.3)
4. An _____ is a transition zone between two adjacent ecosystems; it often supports higher species diversity due to the edge effect. (Linked to SLO 1.5)
5. Net Primary Productivity (NPP) equals Gross Primary Productivity (GPP) minus plant _____; it represents the organic matter available to consumers. (Linked to SLO 1.6)

Short-Answer Questions

6. Define ecology and state its four levels of organisation. (Linked to SLO 1.1)
7. State five climatic factors and explain how each affects organisms. (Linked to SLO 1.3)
8. Distinguish between decomposers and detritivores with one example of each. (Linked to SLO 1.4)
9. Distinguish between habitat and ecological niche. (Linked to SLO 1.5)
10. Explain the 10% rule of energy transfer and its ecological significance. (Linked to SLO 1.6)

Long-Answer Questions

11. Define ecology, describe the concept and components of an ecosystem, and classify the major types of ecosystems with Nigerian examples. (Linked to SLOs 1.1, 1.2)
12. Describe the abiotic components of an ecosystem (climatic, edaphic, and topographic factors) and explain how each influences organism distribution. (Linked to SLO 1.3)



13. Describe the biotic components of an ecosystem; define and distinguish between habitat, niche, ecotone, biome, and biosphere; and explain energy flow and productivity in an ecosystem. (Linked to SLOs 1.4, 1.5, 1.6)

Answers to Concept Check Questions [Series 1]

Objective Questions

1. Haeckel.
2. Tansley.
3. Loam.
4. Ecotone.
5. Respiration.

Short-Answer Questions

6. Ecology: scientific study of interactions between organisms and their environment. Four levels: (1) individual/autecology (single organism); (2) population (same species, same area); (3) community/synecology (multiple species); (4) ecosystem (community plus abiotic environment).
7. Light (drives photosynthesis; controls photoperiod and reproduction); temperature (affects metabolic rate and enzyme activity; determines species distribution); rainfall (most critical for Nigerian ecosystem type; 500-4,000 mm range); humidity (affects transpiration and fungal growth); wind (disperses propagules; increases evaporation).
8. Decomposers (bacteria and fungi): digest dead organic matter externally by secreting enzymes; absorb soluble products; e.g. Rhizopus fungus on decaying fruit. Detritivores: consume dead organic matter internally; physically fragment it; e.g. earthworm feeding on leaf litter.
9. Habitat: the physical place where an organism lives and finds resources (food, water, shelter); e.g. mangrove swamp for a mangrove crab. Niche: the functional role of the



organism in its community (what it eats, what eats it, when it is active, how it modifies the environment); two species cannot occupy identical niches in the same community.

10. The 10% rule: approximately 10% of energy at one trophic level is transferred to the next; the remaining 90% is lost as heat, respiration, egestion, and excretion. Ecological significance: limits food chain length to 4-5 links; explains why ecosystems support far fewer top carnivores than producers; pyramid of biomass narrows at higher trophic levels.

Long-Answer Questions

11. Ecology (Haeckel, 1866): scientific study of organism-environment interactions; operates at individual, population, community, and ecosystem levels; overlaps with physiology, genetics, and environmental science. Ecosystem (Tansley, 1935): a functional unit of all living organisms (biotic community) plus all non-living (abiotic) factors in a defined area, interacting as a system; no fixed size (puddle to ocean). Components: abiotic (light, temperature, rainfall, soil, wind, minerals) and biotic (producers, consumers, decomposers). Classification: natural (terrestrial: forests, grasslands, deserts; aquatic: freshwater rivers, lakes, ponds; marine: oceans, coral reefs, mangroves) vs artificial (farms, fish ponds, urban areas). Nigerian examples: Niger Delta mangrove (natural aquatic); guinea savanna (natural terrestrial); rice paddy farm (artificial). Self-sustaining: needs only solar energy and basic abiotic inputs; subsidised: receives additional inputs (estuary); dependent artificial: requires continuous human inputs (cropland).
12. Climatic factors: light (drives photosynthesis; photoperiod controls flowering; varies with latitude and season); temperature (affects metabolic rate and enzyme activity; determines tropical vs temperate distributions); rainfall (most critical in Nigeria; 500 mm Sahel to over 4,000 mm Niger Delta; determines ecosystem type); humidity (affects transpiration, evaporation, fungal activity); wind (disperses seeds and spores; increases evaporation; affects fire). Edaphic factors: soil texture (sand/silt/clay ratio; sandy soils drain fast and hold few nutrients; clay retains water but may be anaerobic; loam is optimal); soil pH (pH 6-7 optimal for most plants; acidic soils reduce nutrient availability; alkaline limits iron and manganese); organic matter/humus (improves structure, water retention, and nutrients; high in forests); mineral content (N, P, K, Ca, Mg essential; micronutrients Fe, Mn, Zn); soil



biota (bacteria, fungi, earthworms cycle nutrients). Topographic factors: altitude (temperature falls 6.5 degrees Celsius per 1,000 m; altitudinal vegetation zonation; Jos Plateau at 1,200 m differs from surrounding lowlands); slope (steep = fast runoff, thin soil, erosion; gentle = moisture retention); aspect (south-facing warmer and drier in Northern Hemisphere); drainage (poorly drained lowlands = wetland vegetation; well-drained uplands = forest or savanna).

13. Biotic components: producers (autotrophs; photoautotrophs: green plants, algae, cyanobacteria; chemoautotrophs: nitrifying and sulphur bacteria; form base of all food chains; phytoplankton dominate aquatic; NPP highest in tropical rainforest); consumers (heterotrophs; primary/herbivores e.g. cattle, grasshoppers; secondary/primary carnivores e.g. lizards, toads; tertiary/top carnivores e.g. eagles, pythons; omnivores: humans, rats; scavengers: vultures, hyenas); decomposers (bacteria and fungi; external digestion; essential for nutrient recycling); detritivores (earthworms, millipedes, woodlice; internal digestion; fragment detritus for microbial attack). Habitat vs niche: habitat = where (physical place; resources); niche = how (functional role; fundamental niche = potential range; realised niche = actual range under competition). Ecotone: transition zone between adjacent ecosystems; edge effect = higher diversity because species of both adjacent communities co-occur; example: forest-savanna boundary. Biome: large ecosystem sharing climate and dominant vegetation; Nigerian biomes: tropical rainforest (south; high rainfall year-round), guinea savanna (middle; seasonal rainfall), sudan/sahel savanna (north; low seasonal rainfall). Biosphere: all life on Earth and its interactions with lithosphere, hydrosphere, atmosphere. Ecological levels: organism, population, community, ecosystem, biome, biosphere. Energy flow: solar energy enters via producers; GPP = total energy fixed; NPP = GPP minus plant respiration; approximately 10% transferred between trophic levels; 90% lost as heat; limits food chain to 4-5 links; pyramid of biomass narrows at higher levels; tropical rainforest NPP approximately 1,000-2,000 g dry matter/m²/year.

Answers to Pilot Questions [Series 1]

Part 1.1



1. Ecology: the scientific study of the interactions between living organisms and their environment, including both biotic (living) and abiotic (non-living) components; coined by Ernst Haeckel in 1866. Four levels: (1) individual/autecology (the ecology of a single organism or species); (2) population ecology (groups of the same species in an area); (3) community/synecology (multiple species and their interactions); (4) ecosystem ecology (community plus abiotic environment).
2. An ecosystem consists of all the living organisms (biotic community) in a defined area, together with all the non-living (abiotic) factors of their environment, interacting as a functional system; introduced by A.G. Tansley in 1935. Two major components: (1) abiotic (light, temperature, rainfall, wind, soil, minerals, water); (2) biotic (producers/autotrophs; consumers/heterotrophs; decomposers).
3. Natural ecosystems: terrestrial (tropical rainforest: southern Nigeria; guinea savanna: Middle Belt; semi-arid: northern Nigeria; mangrove: Niger Delta coast); freshwater aquatic (River Niger, River Benue, Lake Chad, freshwater ponds and swamps); marine/coastal (Atlantic ocean shelf; coral reef). Artificial ecosystems: agricultural (cassava and maize farms; rice paddies; cocoa plantations); aquaculture (fish ponds: catfish, tilapia); urban (Lagos, Abuja; dominated by built structures, roads, planted trees, urban mammals and birds).
4. A self-sustaining ecosystem is one that requires no external inputs other than solar energy and basic abiotic materials to maintain its structure and function indefinitely. Energy drives all biological processes; matter is cycled internally by decomposers and taken up by producers. Most undisturbed natural ecosystems are self-sustaining: the Nigerian rainforest maintains its productivity without human inputs because decomposers recycle nutrients, rainfall supplies water, and solar energy drives photosynthesis. In contrast, a farm is not self-sustaining because it requires constant human inputs of seed, labour, fertiliser, and water to persist.
5. The term "ecology" was coined by the German biologist Ernst Haeckel in 1866. The term "ecosystem" was introduced by the British botanist and ecologist Arthur George Tansley in 1935 in a paper in the journal Ecology; Tansley proposed the term to describe a system comprising both the community of organisms and its abiotic environment as an integrated unit.



Part 1.2

1. Five climatic factors: (1) Light (solar radiation): the primary energy source for all ecosystems; drives photosynthesis; photoperiod (day length) controls flowering, migration, and reproduction in many organisms; insufficient light in the understorey of dense forest limits plant species present. (2) Temperature: affects the rate of all biochemical reactions and enzyme activity; determines the thermal limits of species distribution (tropical species cannot survive temperate winters); influences evaporation and precipitation patterns. (3) Rainfall (precipitation): the amount, seasonality, and reliability of rainfall is the most important single factor determining terrestrial ecosystem type in Nigeria; the rainfall gradient from the Niger Delta (over 4,000 mm/year) to the Sahel (under 500 mm/year) produces a corresponding gradient from rainforest to semi-desert. (4) Humidity: the concentration of water vapour in the air; high humidity reduces transpiration from plant leaves and evaporation from soil surfaces; low humidity increases water stress; humidity affects the distribution and activity of fungi and the incidence of plant diseases. (5) Wind: physically disperses seeds, pollen, and spores, extending the range of plants and fungi; increases the rate of evaporation and transpiration, increasing water stress; strong wind causes mechanical damage to plants and increases fire spread in savanna during the dry season.
2. Loam soil is most suitable for agriculture because it has an intermediate texture of roughly equal proportions of sand, silt, and clay, which gives it the optimal combination of five properties: (1) drainage (adequate pores between sand particles allow excess water to drain and prevent waterlogging; roots need air as well as water); (2) water retention (the clay and silt component retains sufficient moisture between rain events for plant roots to access; pure sandy soils dry out too rapidly); (3) aeration (the open pore structure allows adequate oxygen to reach roots for aerobic respiration); (4) nutrient retention (the clay fraction carries a negative surface charge that attracts and holds positively charged mineral ions, preventing them from leaching away in rain water; sandy soils are very low in nutrients); (5) root penetration (the balanced texture allows roots to grow through without excessive resistance from compacted clay).
3. Soil pH affects plant growth through three main mechanisms: (1) Nutrient availability: most mineral nutrients reach maximum solubility and plant uptake in the pH range 6 to 7; below



pH 5 (strongly acidic), most macronutrients (N, P, K, Ca, Mg) become less soluble; above pH 8 (alkaline), iron and manganese become insoluble and plants show deficiency symptoms; (2) Aluminium and manganese toxicity: at pH below 5, aluminium and manganese become increasingly soluble and reach concentrations that are toxic to most plants, inhibiting root growth and mineral uptake; only acid-tolerant species (acidophiles) can grow at these pH values; (3) Soil microbial activity: most soil bacteria and decomposer fungi are most active at neutral pH (6-7); strongly acid soils have low bacterial activity and slower decomposition, leading to accumulation of raw organic matter (peat) and reduced nutrient recycling for plants.

4. Altitude affects vegetation distribution through its influence on temperature: atmospheric temperature decreases approximately 6.5 degrees Celsius for every 1,000 metres increase in altitude (the environmental lapse rate). This temperature decline with altitude produces altitudinal zonation of vegetation, similar in principle to the latitudinal zonation of biomes from equator to poles. In Nigeria, the Jos Plateau at approximately 1,200 to 1,800 m elevation supports deciduous woodland and grassland vegetation different from the guinea savanna of the surrounding lowlands; the cooler temperature reduces evapotranspiration and favours different species. Higher altitudes also have higher UV radiation intensity (thinner atmosphere), lower atmospheric pressure (reduced CO₂ partial pressure), stronger winds, and often different rainfall patterns, all of which contribute to the altitudinal plant communities.
5. Three edaphic factors: (1) Soil texture (relative proportions of sand, silt, and clay): determines drainage and water retention; sandy soils support drought-tolerant vegetation; clay-rich soils support wetland communities; loam supports the most diverse and productive communities; the soil texture map of Nigeria broadly reflects the rainfall gradient. (2) Soil pH: strongly acid soils (below pH 5) support only acid-tolerant species; neutral soils (pH 6-7) support the greatest diversity of plants and soil organisms; alkaline soils support calcicole species; rainforest soils in southern Nigeria tend to be more acidic than the neutral to slightly alkaline soils of the northern savanna. (3) Soil mineral content (nutrient availability): soils rich in nitrogen, phosphorus, and potassium support high-productivity vegetation; nutrient-poor soils (e.g. leached tropical forest soils) support vegetation adapted to low-nutrient conditions; the highly leached laterite soils of parts of southern Nigeria are naturally infertile despite receiving high rainfall.



Part 1.3

1. Producers are autotrophic organisms that synthesise organic compounds from inorganic raw materials using an external energy source; they form the base of all food chains.
Photoautotrophs use light energy (photosynthesis): green plants, algae, cyanobacteria; example: forest trees in Nigerian rainforest fixing CO₂ into glucose using solar energy.
Chemoautotrophs use chemical energy from inorganic redox reactions (chemosynthesis): nitrifying bacteria (*Nitrosomonas*, *Nitrobacter*) oxidise ammonia to nitrate; sulphur bacteria (*Thiobacillus*) oxidise hydrogen sulphide; iron bacteria oxidise ferrous iron; these are important in soil nutrient cycling and deep-sea hydrothermal vent ecosystems where no light is available.
2. Consumer trophic levels in Nigeria: Primary consumers (first trophic level above producers; herbivores: feed directly on plants): cattle (*Bos indicus*; grazing savanna grasses), grasshoppers (*Schistocerca gregaria*; feeding on crop leaves), caterpillars (various *Lepidoptera* larvae feeding on tree leaves), giant African snail (*Achatina achatina*; feeding on decaying plant matter and crops). Secondary consumers (second trophic level; primary carnivores: feed on primary consumers): agama lizard (*Agama agama*; eating insects); common toad (*Bufo maculatus*; eating worms and insects); small passerine birds (eating caterpillars). Tertiary consumers (third trophic level; secondary carnivores): African rock python (*Python sebae*; eating small mammals and birds); African fish eagle (*Haliaeetus vocifer*; eating fish at river surfaces); cobra (*Naja melanoleuca*; eating frogs, lizards, rodents). Quaternary/top consumers: lion (*Panthera leo*; eating large herbivores), African wild dog (*Lycaon pictus*; eating medium mammals).
3. Food chains rarely exceed four or five links because of the approximately 10% efficiency of energy transfer between trophic levels. Only approximately 10% of the energy stored in the biomass of one trophic level is converted into new biomass at the next level; the remaining approximately 90% is dissipated as heat during metabolic processes (respiration), lost in waste products (egestion and excretion), and used for maintenance rather than growth. If we start with 10,000 kJ of energy stored in producers, only 1,000 kJ is available to primary consumers, 100 kJ to secondary consumers, 10 kJ to tertiary consumers, and only 1 kJ to quaternary consumers; a fifth link would have only 0.1 kJ, which is insufficient to sustain a



viable population of animals. Therefore, the progressive dilution of energy up the food chain makes very long chains thermodynamically impractical.

4. Decomposers (saprotrophs: bacteria and fungi): break down dead organic matter by secreting hydrolytic enzymes onto it externally; the enzymes digest complex polymers (cellulose, lignin, protein) into small soluble monomers (sugars, amino acids); the decomposer then absorbs these soluble products into its cells; examples: *Aspergillus* (a saprophytic fungus on decaying fruit), *Bacillus subtilis* (a soil bacterium decomposing dead leaves). Detritivores (animals): consume detritus (fragmented dead organic matter) by ingesting it internally; they use their digestive systems to break down the organic matter; examples: earthworm (*Lumbricus*; ingests soil and leaf litter), millipede (feeding on dead leaves on the forest floor), woodlouse (*Porcellio*; under moist bark on fallen logs). Key distinction: decomposers = external digestion and absorption; detritivores = internal ingestion and digestion; detritivores also increase the surface area of detritus for subsequent decomposer attack.
5. Ecological importance of decomposers: (1) Nutrient recycling: decomposers are the only organisms capable of completely mineralising dead organic matter; they break down complex organic molecules in dead plants and animals back into inorganic ions (nitrate, phosphate, sulphate, CO₂, water) that can be taken up again by plant roots; without decomposers, nutrients would become locked in dead biomass and ecosystems would cease to function due to nutrient depletion. (2) Soil formation and fertility: the products of decomposition (humus) improve soil structure, water-holding capacity, and cation exchange capacity; bacteria in the soil cycle nitrogen (nitrifying bacteria convert ammonia to nitrate; denitrifying bacteria convert nitrate to N₂ gas); phosphate-solubilising bacteria release phosphorus from insoluble mineral forms. (3) Closing biogeochemical cycles: decomposers are essential components of the carbon, nitrogen, phosphorus, sulphur, and water cycles; they ensure that the finite supply of essential elements on Earth is continuously recycled. (4) Waste management: decomposers break down animal waste, dead wood, fallen leaves, and other organic waste; they are the natural waste management system of ecosystems.



1. **Habitat:** the physical environment in which an organism lives and finds all the resources it needs (food, water, shelter, mates, and breeding sites); describes where an organism is found; example: the habitat of the Nile monitor lizard (*Varanus niloticus*) is the banks of major rivers and lakes in Nigeria, where it finds water, basking rocks, and burrow sites.
Niche: the functional role of an organism in its community; describes what the organism does rather than where it lives; encompasses what the organism eats, what eats it, when it is active, how it uses space and resources, and how it influences the abiotic environment; example: the niche of the Nile monitor includes being a generalist carnivore eating fish, eggs, rodents, and carrion; being active during the day; and being preyed upon by large pythons and crocodiles; its niche therefore differs from that of the crocodile (*Crocodylus*) which shares the same riverside habitat.
2. **Ecotone:** a transition zone or boundary between two adjacent biotic communities or ecosystems, where the environmental conditions and species composition change from one community to the other; ecotones may be sharply defined (e.g. the edge of a mangrove forest and a sandy beach) or gradual (e.g. the transition from guinea savanna to sudan savanna as rainfall decreases northward in Nigeria). **Edge effect:** the phenomenon whereby the ecotone supports higher species diversity than either adjacent community alone; this occurs because the ecotone contains species characteristic of both neighbouring communities simultaneously, plus specialist edge species adapted to the intermediate conditions; examples: the forest-savanna boundary in Nigeria supports both forest species (forest duiker, African grey parrot) and savanna species (oribi antelope, marabou stork) as well as edge specialists; the mangrove-terrestrial boundary supports terrestrial mammals, shore birds, and mangrove specialists. The edge effect is exploited in agroforestry and conservation planning.
3. **Major biomes in Nigeria from south to north:** (1) Mangrove forest (coastal, Niger Delta): tidal saltwater; very high rainfall (over 2,500 mm); high humidity; dominated by red mangrove (*Rhizophora*), white mangrove (*Avicennia*), and associated fauna (mangrove crab, mudskipper, shore birds). (2) Tropical rainforest (south-western and south-eastern Nigeria, below approximately 7 degrees N): year-round high rainfall (1,500-4,000 mm); no dry season; high temperature (26-28 degrees Celsius); dominated by tall evergreen trees with closed canopy; extremely high biodiversity; characteristic trees: Iroko (*Milicia excelsa*), Obeche (*Triplochiton scleroxylon*). (3) Guinea savanna (Middle Belt, approximately 7-10



degrees N): seasonal rainfall (900-1,300 mm); distinct dry season; mixed woodland and tall grasses; characteristic species: dawadawa (*Parkia biglobosa*), shea butter tree (*Vitellaria paradoxa*). (4) Sudan savanna (northern Nigeria, approximately 10-12 degrees N): lower seasonal rainfall (500-900 mm); longer dry season; open woodland and short grasses; trees shorter and more scattered. (5) Sahel (northernmost Nigeria, above 12 degrees N): very low, unpredictable rainfall (below 500 mm); sparse scrub and annual grasses; risk of desertification; characteristic species: *Acacia senegal*, *Calotropis procera*.

4. Gross Primary Productivity (GPP): the total rate of energy fixation (glucose synthesis) by all producers in an ecosystem through photosynthesis per unit area per unit time; measured in g dry matter per m² per year or kJ per m² per year; GPP includes both the organic matter used by plants for their own metabolism and the surplus stored as new biomass. Net Primary Productivity (NPP): the rate of organic matter accumulation in an ecosystem after subtracting the energy used by producers for their own cellular respiration; $NPP = GPP - \text{plant respiration}$; NPP represents the organic matter that is actually available to primary consumers and all other heterotrophs in the ecosystem. Relationship: NPP is always less than GPP because plants must respire to maintain their own cellular processes; typically, plant respiration accounts for 20 to 50% of GPP, so NPP is 50 to 80% of GPP in productive ecosystems.
5. Only approximately 10% of the energy at one trophic level is transferred to the next because of multiple unavoidable losses at each level: (1) Metabolic heat: the largest fraction of energy (approximately 60-80% of assimilated energy) is released as heat during cellular respiration; this heat is irreversibly lost to the environment and cannot be used again by living organisms; the second law of thermodynamics (entropy increase) means that every energy transformation produces heat. (2) Respiration for maintenance: a large portion of assimilated energy is used for the maintenance metabolism of existing tissues (basal metabolic rate, movement, thermoregulation in endotherms) rather than for growth; only growth (new tissue) is available to predators. (3) Egestion: not all food consumed is digested and absorbed; indigestible material (cellulose, bones, keratin, chitin) passes through the gut and is lost in faeces as chemical energy that is not available to the next trophic level. (4) Excretion: some assimilated energy is excreted as urea, ammonia, or other nitrogenous waste products; this energy is not available to the next trophic level though it may be used by decomposers.



References and Attributions [Series 1]

Textual References (Books and External Sources)

- Odum, E. P., & Barrett, G. W. (2005). Fundamentals of ecology (5th ed.). Thomson Brooks/Cole.
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- FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable agriculture. FAO.

Figures, Plates, Tables, and Boxes

- Figure 1.1: Ecosystem structure diagram showing biotic and abiotic components Attribution: AI generated. Suggested OER search string: "ecosystem structure diagram biotic abiotic components producers consumers decomposers energy flow nutrient cycling OER".
- Figure 1.2: Soil profile diagram with horizons and soil texture triangle Attribution: AI generated. Suggested OER search string: "soil profile diagram horizons topsoil subsoil organic matter bedrock soil texture triangle OER".
- Figure 1.3: Biotic components of an ecosystem diagram Attribution: AI generated. Suggested OER search string: "biotic components ecosystem producers consumers trophic levels decomposers detritivores energy flow diagram OER".
- Figure 1.4: Ecological levels of organisation diagram Attribution: AI generated. Suggested OER search string: "ecological levels of organisation organism population community ecosystem biome biosphere diagram OER".
- Box 1.1: Key ecological terms and definitions glossary table Attribution: AI generated. Suggested OER search string: "ecological terminology glossary table ecology ecosystem habitat niche ecotone biome biosphere GPP NPP OER box".



Course code: BIO 202

Course title: Introductory Ecology

Course credit load: 2 Units

Series 2: Features of Habitat Types

- **Part 2.1: Terrestrial Habitat Types**

- Sub Part 2.1.1: Tropical rainforest habitat
- Sub Part 2.1.2: Savanna and grassland habitats
- Sub Part 2.1.3: Desert and semi-arid habitats

- **Part 2.2: Wetland and Mangrove Habitats**

- Sub Part 2.2.1: Features of freshwater wetlands
- Sub Part 2.2.2: Features of mangrove habitats
- Sub Part 2.2.3: Ecological importance of wetlands and mangroves

- **Part 2.3: Freshwater Aquatic Habitats**

- Sub Part 2.3.1: Lentic (still water) habitats: lakes and ponds
- Sub Part 2.3.2: Lotic (flowing water) habitats: rivers and streams
- Sub Part 2.3.3: Zonation in freshwater habitats

- **Part 2.4: Marine and Estuarine Habitats**

- Sub Part 2.4.1: Features of the marine habitat
- Sub Part 2.4.2: Estuarine habitats
- Sub Part 2.4.3: Coral reef habitats



Introduction

Each habitat type has a distinctive set of abiotic conditions (climate, soil, water, salinity) that determine which organisms can survive there. Understanding the features of different habitats is central to ecology: it explains species distributions, the composition of communities, and the adaptations organisms have evolved to survive in their particular environment.

This Series covers the defining physical and biological features of the major habitat types found in and around Nigeria: tropical rainforest, savanna and grassland, desert, freshwater wetlands, mangroves, lakes, rivers, marine environments, estuaries, and coral reefs. The Series builds on the abiotic factors introduced in Series 1 and applies them to real habitat contexts with Nigerian examples.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 2.1** describe the abiotic and biotic features of tropical rainforest, savanna, and desert habitats (Linked to Part 2.1),
- **SLO 2.2** describe the features and ecological importance of freshwater wetland and mangrove habitats (Linked to Part 2.2),
- **SLO 2.3** describe the features of lentic and lotic freshwater habitats and explain zonation within them (Linked to Part 2.3),
- **SLO 2.4** describe the features of marine and estuarine habitats and explain the ecology of coral reefs (Linked to Part 2.4), and
- **SLO 2.5** compare the major habitat types in terms of their key abiotic conditions, productivity, and characteristic biota (Linked to Parts 2.1 to 2.4).



2.1 Terrestrial Habitat Types

2.1.1 Tropical rainforest habitat

The tropical rainforest is the most species-rich terrestrial habitat on Earth. Abiotic features: high, year-round rainfall (1,500 to over 4,000 mm per year); high and relatively constant temperature (24 to 28 degrees Celsius); high humidity (80 to 100% relative humidity); low seasonal variation; deep, heavily leached, nutrient-poor soils (ferralsols and oxisols); most nutrients held in biomass rather than soil; high light interception by the canopy. In Nigeria, rainforest is found in Cross River State, Edo, Delta, and Ondo States.

Biotic features: stratified vertical structure (emergent layer above 30 m; main canopy 15 to 30 m; understorey 5 to 15 m; shrub layer and forest floor below 5 m); enormous tree diversity (over 400 species per hectare in parts of Cross River); epiphytes (orchids, ferns, bromeliads) growing on trees; lianas (woody climbers); buttress roots on large trees for support in shallow soils; dense invertebrate fauna; high diversity of reptiles, birds, and mammals; most animals are arboreal (tree-dwelling). Key Nigerian forest trees: Iroko (*Milicia excelsa*), Obeche (*Triplochiton scleroxylon*), African mahogany (*Khaya* spp.).

Fill in the blank: Tropical rainforest soils are typically _____ and nutrient-poor despite high rainfall, because intense leaching removes minerals; most nutrients are held in living biomass rather than the soil.



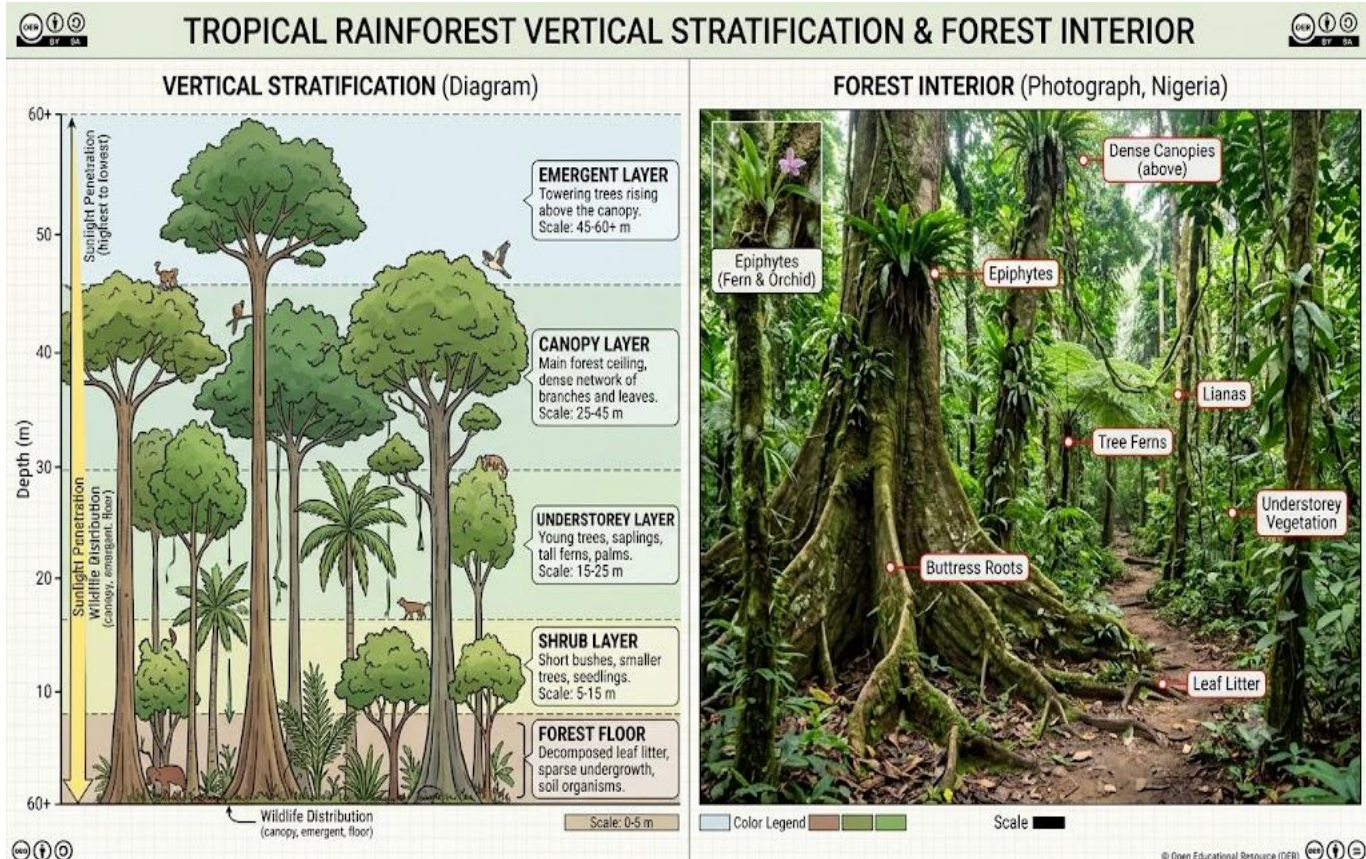


Figure 2.1: Diagram and photograph of tropical rainforest vertical stratification

2.1.2 Savanna and grassland habitats

Savanna is a tropical habitat characterised by a continuous grass layer with scattered trees and shrubs. Abiotic features: seasonal rainfall (700 to 1,500 mm per year in guinea savanna; 500 to 900 mm in sudan savanna); a pronounced dry season of 3 to 7 months when fires are common; high temperatures year-round (25 to 35 degrees Celsius); well-drained, relatively fertile soils (cambisols and luvisols in guinea savanna; shallower sandy soils in Sudan savanna). Fire is a defining ecological feature: annual dry-season fires maintain the grass-tree balance.

Biotic features of Nigerian savanna: characteristic grass species include Guinea grass (*Megathyrsus maximus*), Elephant grass (*Pennisetum purpureum*), and tall annual grasses. Trees include dawadawa (*Parkia biglobosa*), shea butter (*Vitellaria paradoxa*), locust bean, and baobab (*Adansonia digitata*) in drier areas. Large mammal herbivores include West African savanna buffalo, roan antelope, and kob. Significant numbers of cattle (*Bos indicus*) are kept by Fulani



pastoralists. Raptors, ground-nesting birds, and reptiles such as monitor lizards and pythons are characteristic. Termite mounds are prominent features of savanna soil.

Fill in the blank: _____ is a defining ecological feature of savanna habitats; it occurs annually during the dry season and maintains the balance between grass and trees by preventing forest development.

2.1.3 Desert and semi-arid habitats

Desert and semi-arid (Sahel) habitats occupy the northernmost part of Nigeria (above approximately 12 degrees N). Abiotic features: very low, unpredictable rainfall (below 500 mm per year; less than 250 mm in true desert); extreme diurnal temperature fluctuation (daytime temperatures above 40 degrees Celsius, cold nights); low humidity; high rates of evapotranspiration greatly exceeding precipitation; sandy or rocky substrates with minimal organic matter; alkaline, saline, or sodic soils in some areas; strong, desiccating winds (harmattan from October to March).

Biotic features: sparse vegetation dominated by drought-tolerant and drought-avoiding species; characteristic plants include *Acacia senegal* (gum arabic; important commercial species), *Calotropis procera* (sodom apple; toxic shrub), *Leptadenia hastata*, *Cenchrus biflorus* (cram-cram; a sharp grass), and annual ephemerals that complete their life cycle during the brief wet season. Animals show extensive physiological and behavioural adaptations to heat and water scarcity: nocturnal activity; deep burrowing; concentrated urine and dry faeces; metabolic water production. Desert rodents, reptiles, camels, and the endangered addax antelope are characteristic fauna.

Fill in the blank: The _____ wind (from October to March) is a hot, dry, desiccating wind from the Sahara that reduces humidity, increases evaporation, and carries dust across northern Nigeria's semi-arid habitat.

Pilot questions 2.1

1. Describe the abiotic features of a tropical rainforest habitat.



2. Explain the vertical stratification of the tropical rainforest.
3. State three ways in which fire shapes the savanna habitat.
4. Describe the abiotic conditions of a desert habitat.
5. Compare rainforest and savanna habitats in terms of rainfall, soil type, and biodiversity.

2.2 Wetland and Mangrove Habitats

2.2.1 Features of freshwater wetlands

Freshwater wetlands are areas where the water table is at or near the soil surface for at least part of the year; they include swamps (dominated by trees), marshes (dominated by herbaceous plants), bogs (acidic; dominated by Sphagnum moss; low nutrients; found in high-rainfall cooler areas), and fens (alkaline; richer in nutrients). The major freshwater wetlands in Nigeria include the inland Niger Delta (Lokoja area), the Hadejia-Nguru Wetlands in Jigawa and Yobe States, and swamp forests in the Delta region.

Abiotic features: permanently or seasonally flooded; low dissolved oxygen (anaerobic or hypoxic conditions in waterlogged soils); accumulation of organic matter (peat in some systems); high nutrient concentrations from floodwater inputs; fluctuating water levels with seasonal flooding. Biotic features: hydrophytes (water plants with aerenchyma for oxygen transport to roots); amphibians (frogs, toads); waterbirds (herons, egrets, jacanas, kingfishers); fish during flood season; insects (mosquitoes, dragonflies, water beetles); crocodiles and monitor lizards as top predators.

Fill in the blank: Freshwater wetlands have waterlogged, anaerobic soils because oxygen is consumed by decomposers faster than it can diffuse into _____ soil; wetland plants have aerenchyma (air spaces in their tissues) to transport oxygen to submerged roots.



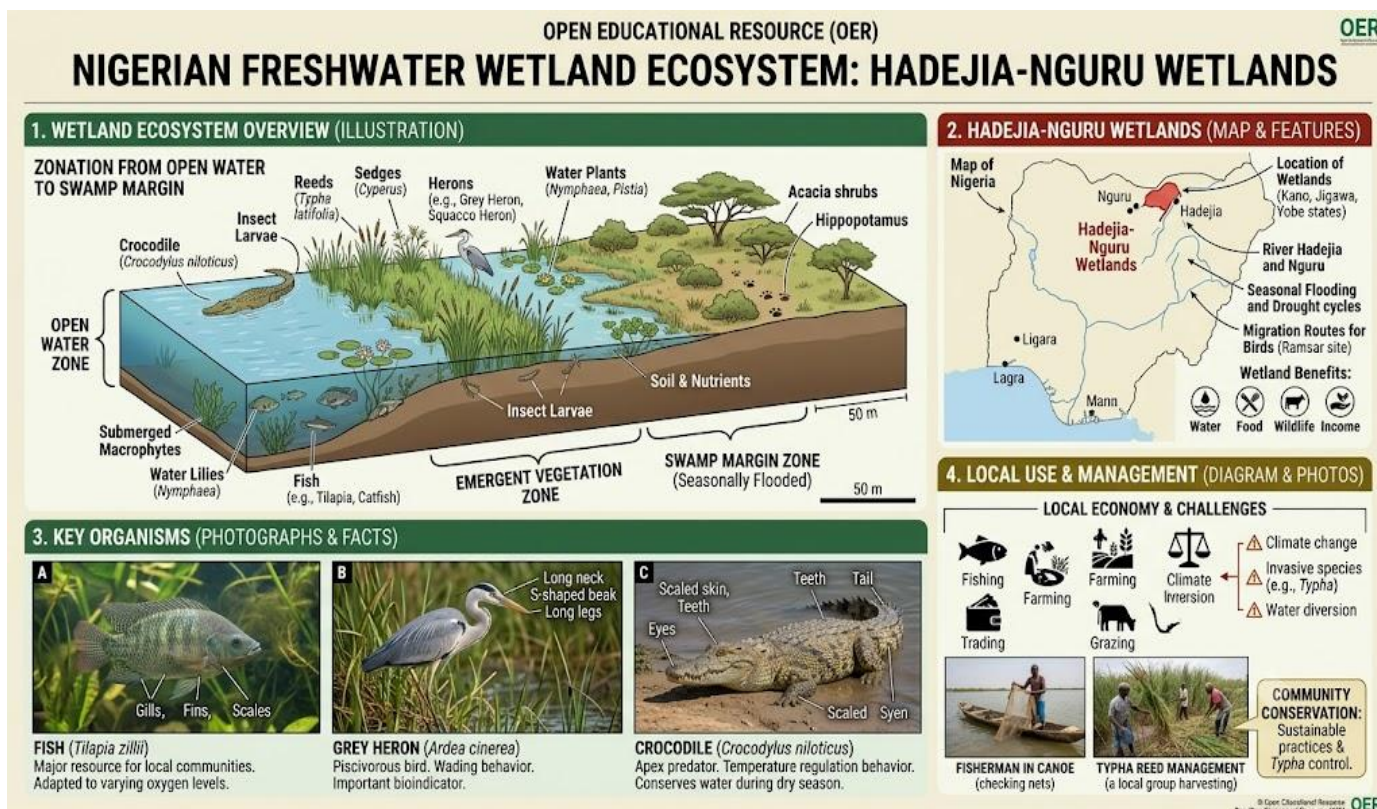


Figure 2.2: Photograph and diagram of the Hadejia-Nguru freshwater wetland ecosystem in northern Nigeria

2.2.2 Features of mangrove habitats

Mangroves are coastal wetland forests dominated by salt-tolerant trees (mangrove trees) growing in tidal zones along sheltered tropical coastlines, estuaries, and river deltas. Nigeria's mangrove forests in the Niger Delta are the largest in Africa and the third largest in the world. Abiotic features: daily tidal flooding with saline or brackish water; waterlogged, anaerobic, fine-grained muddy sediment; high salinity (10 to 35 parts per thousand); warm temperature (25 to 30 degrees Celsius); high sedimentation rates.

Biotic features and tree adaptations: the dominant species in Nigerian mangroves are *Rhizophora racemosa* (red mangrove; prop/stilt roots for anchorage in unstable mud); *Avicennia africana* (white/grey mangrove; pneumatophores, finger-like aerial roots that project above the mud for gas exchange); *Laguncularia racemosa*; and *Nypa fruticans* (nipa palm). Fauna: rich invertebrate communities (fiddler crabs *Uca*, periwinkles, oysters *Crassostrea* attached to roots); mudskippers



(Periophthalmus; amphibious fish); waterbirds; mangrove kingfisher; sea turtles nesting on adjacent beaches; manatees (West African manatee *Trichechus senegalensis*) in deeper channels.

Fill in the blank: Rhizophora (red mangrove) has prop or stilt _____ that provide anchorage in unstable muddy sediments, while Avicennia (white mangrove) has pneumatophores that project above the mud for gas exchange in anaerobic soil.

2.2.3 Ecological importance of wetlands and mangroves

Wetlands and mangroves provide critical ecosystem services. Biodiversity: mangroves and wetlands support exceptionally high biodiversity relative to their area; Nigeria's mangroves support over 150 bird species, dozens of fish species, and numerous invertebrates. Fisheries nursery: mangrove prop roots and shallow wetland waters serve as nursery habitats for the juveniles of many commercially important fish and shellfish species; approximately 75% of tropical coastal fish spend their juvenile stages in mangroves.

Coastal protection: mangrove forests absorb wave energy and reduce coastal erosion; they protect inland communities from storm surges and sea flooding. Carbon sequestration (blue carbon): mangroves and wetland soils store very large amounts of organic carbon in their anaerobic sediments; they are among the most carbon-dense ecosystems on Earth; their destruction releases large quantities of CO₂ and methane. Water filtration: wetlands filter sediments, excess nutrients, and pollutants from surface water before it reaches the sea. These services make wetland and mangrove conservation a critical priority in Nigeria.

Fill in the blank: Mangrove prop roots and shallow wetland waters serve as _____ habitats for the juveniles of many commercially important fish and shellfish species; approximately 75 per cent of tropical coastal fish spend part of their life cycle in mangroves.

Pilot questions 2.2

1. Define a wetland and name four types with one Nigerian example.
2. State three abiotic features of a mangrove habitat.
3. Describe the root adaptations of mangrove trees to their habitat.



4. Explain three ecosystem services provided by mangroves.
5. Explain why wetland soils are anaerobic.

2.3 Freshwater Aquatic Habitats

2.3.1 Lentic (still water) habitats: lakes and ponds

Lentic habitats are standing (still) freshwater bodies: lakes, ponds, reservoirs, and oxbow lakes. The key physical features of lentic habitats: temperature stratification (thermal stratification); light penetration decreasing with depth; dissolved oxygen decreasing with depth; nutrient concentration varying with depth and season. Large Nigerian lentic habitats include Lake Chad (the largest in West Africa, though greatly reduced in area; it is shared with Niger, Chad, and Cameroon), Kainji Lake (a man-made reservoir on the River Niger), and Jebba Lake.

Thermal stratification in deep lakes: in warm seasons, the surface layer (epilimnion) warms and becomes less dense, floating above the cold bottom layer (hypolimnion); they are separated by a zone of rapid temperature change called the thermocline; this stratification prevents mixing and causes oxygen depletion in the hypolimnion as decomposers consume oxygen without replenishment. Seasonal turnover (overturn) in temperate lakes brings nutrients from the bottom to the surface; in tropical lakes, turnover may be less regular. Lake Chad has no permanent thermal stratification due to its very shallow depth.

Fill in the blank: In a thermally stratified lake, the warm upper layer is called the _____; the cold bottom layer is the hypolimnion; and the zone of rapid temperature change between them is the thermocline.

2.3.2 Lotic (flowing water) habitats: rivers and streams

Lotic habitats are flowing freshwater bodies: rivers, streams, and springs. Key physical features: unidirectional water flow (current); high dissolved oxygen (turbulence aerates the water); water temperature lower and more constant than still water; substrate varies from boulders in fast-



flowing upland streams to fine silt and sand in slow lower reaches; nutrients carried from the catchment by runoff. Nigeria's major rivers include the Niger, Benue, Kaduna, Cross River, Anambra, and Ogun.

Zonation in a river from source to mouth: headwater zone (source to upper reaches): fast-flowing, cold, clear, turbulent, well-oxygenated; coarse substrate (boulders, gravel); few nutrients; algae and invertebrates clinging to rocks (rheophytes, mayfly larvae, stonefly larvae, caddisfly larvae). Middle reaches: slower flow; finer substrate; more nutrients from tributaries; greater diversity of fish. Lower reaches (lowland zone): slow flow; turbid; fine silt substrate; warm; less dissolved oxygen; high nutrient load; catfish, mudfish, and tilapia dominate; connecting to floodplain during wet season.

Fill in the blank: Lotic habitats have _____ dissolved oxygen than lentic habitats because turbulence at the water surface continuously mixes atmospheric oxygen into the flowing water; this is why fast-flowing streams are well-oxygenated.

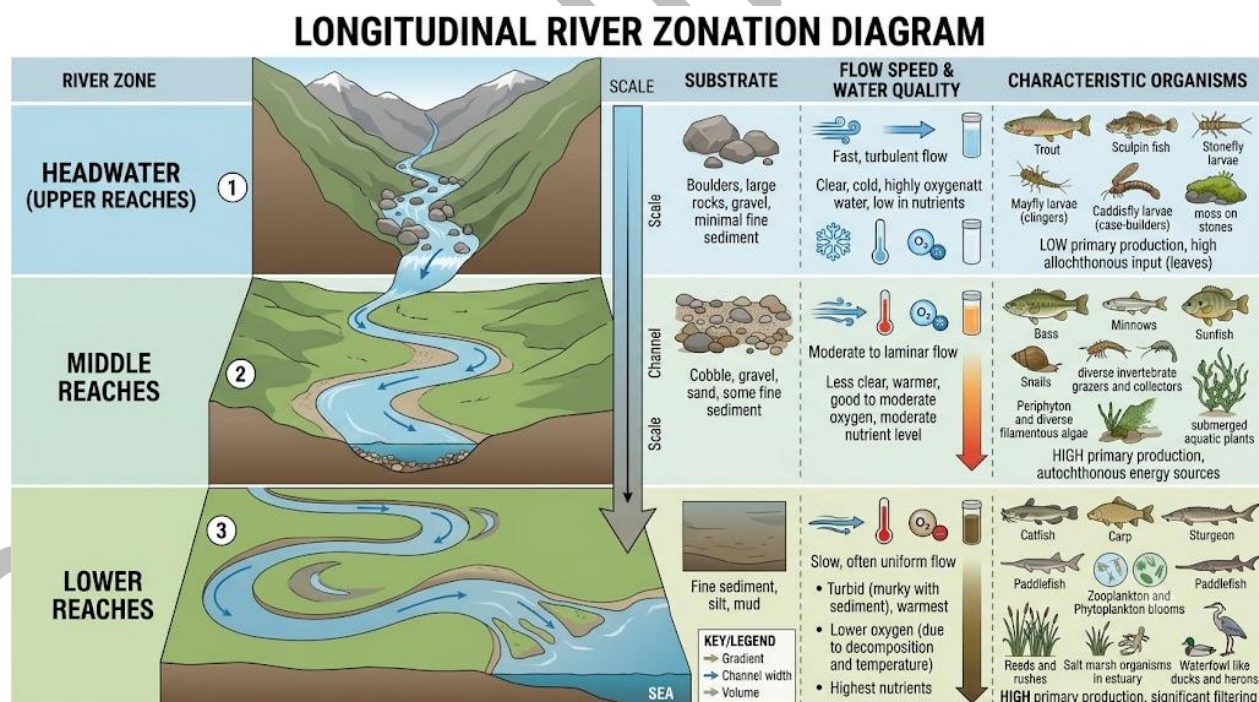


Figure 2.3: Diagram of river zonation from headwater to lower reaches



2.3.3 Zonation in freshwater habitats

Lentic habitats show horizontal zonation from the shore to open water and vertical zonation from surface to bottom. Horizontal zones: littoral zone (shallow water near shore; rooted aquatic plants; most productive; most diverse; sunlight reaches the bottom; water lily *Nymphaea*, bulrush *Typha*, submerged weeds); limnetic zone (open water away from shore above the photic zone limit; dominated by phytoplankton and zooplankton; pelagic fish); profundal zone (deep water below light penetration in large lakes; no photosynthesis; anaerobic; benthic invertebrates feeding on settled organic matter).

Vertical zonation in lentic habitats: photic zone (upper layer where sufficient light penetrates for photosynthesis; approximately the top 5 to 10 m in turbid tropical lakes; phytoplankton photosynthesis here supports all other aquatic life); aphotic zone (below light penetration; no photosynthesis; organisms depend on organic matter sinking from above). In rivers, the equivalent zonation is from midstream (riffle and run zones) to the river bank (marginal vegetation) and river bed (benthos). In Nigerian lakes, the littoral zone often has dense water hyacinth (*Eichhornia crassipes*) which has become an invasive species blocking navigation and fishing.

Fill in the blank: The _____ zone of a lake is the shallow nearshore area where sunlight reaches the bottom; it supports rooted aquatic plants and is the most productive and species-diverse zone of the lake.

Pilot questions 2.3

1. Define lentic and lotic habitats and give one Nigerian example of each.
2. Explain thermal stratification in a deep lake.
3. Describe the zonation of a river from source to mouth.
4. Name and describe the three horizontal zones of a lake.
5. Explain why the profundal zone of a deep lake is anaerobic.



2.4 Marine and Estuarine Habitats

2.4.1 Features of the marine habitat

The marine (ocean) habitat covers approximately 71% of Earth's surface and contains about 97% of all water. Key abiotic features: high and relatively constant salinity (approximately 35 parts per thousand; 3.5% NaCl equivalent); temperature ranging from minus 2 degrees Celsius in polar waters to over 30 degrees Celsius in tropical shallow seas; pressure increasing with depth (one atmosphere per 10 m); light penetrating only the upper 200 m (photic zone); vast nutrient reserves in deep waters. Nigeria's marine habitat is the Gulf of Guinea (Atlantic Ocean).

Zonation in the marine environment: intertidal zone (between high and low tide marks; exposed to air at low tide; subjected to wave action, temperature extremes, and desiccation; limpets, barnacles, mussels, and rockweed are characteristic); subtidal zone (permanently submerged; rich community); continental shelf (0 to 200 m; most productive; most fishing occurs here; Nigerian shelf is 150 to 200 km wide); continental slope (200 to 2,000 m); abyssal zone (2,000 to 6,000 m; cold, dark, high pressure; chemolithotrophs support deep-sea communities around hydrothermal vents). Pelagic (open water) vs benthic (sea floor) communities.

Fill in the blank: The _____ zone of the ocean is between the high and low tide marks; organisms here must tolerate alternating submersion and exposure to air, temperature extremes, wave action, and desiccation.



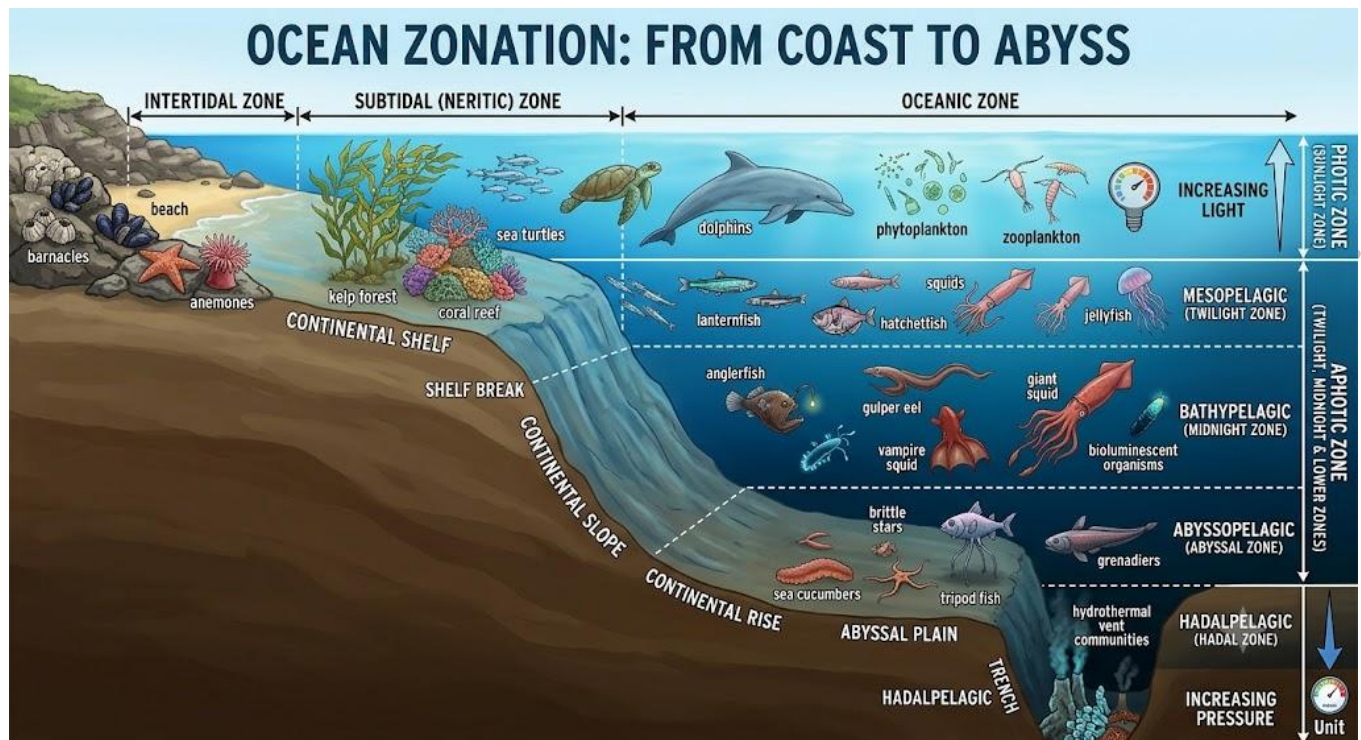


Figure 2.4: Diagram of ocean zonation from intertidal zone to the abyssal zone

2.4.2 Estuarine habitats

An estuary is a semi-enclosed coastal body of water with a free connection to the open sea, where freshwater from rivers mixes with salt water from the sea. Estuaries are among the most productive ecosystems on Earth because they receive nutrient inputs from both river runoff and tidal seawater. Key abiotic features: variable and fluctuating salinity (0 to 35 ppt depending on position and season); tidal fluctuation; fine silt and mud sediments; warm shallow water; high turbidity (suspended sediment from rivers). Nigerian estuaries include the Niger Delta estuary system and the Cross River estuary.

Estuarine biota must tolerate wide fluctuations in salinity (euryhaline species); organisms found in Nigerian estuaries: mangroves (dominant trees of estuarine shores); fiddler crabs (*Uca*); mudskippers (*Periophthalmus*); grey mullet (*Mugil*); snapper (*Lutjanus*); shrimps (*Penaeus*; important Nigerian export fishery); oysters (*Crassostrea gasar*); and numerous migratory bird species. Estuaries are critical nursery habitats for many marine species; their destruction through



oil pollution (especially in the Niger Delta), dredging, and mangrove clearance has severe consequences for both biodiversity and local fishing communities.

Fill in the blank: Estuaries are among the most _____ ecosystems on Earth because they receive nutrient inputs from both river runoff (freshwater) and tidal seawater, creating conditions that support very high primary and secondary productivity.

2.4.3 Coral reef habitats

Coral reefs are marine ecosystems built by reef-building (hermatypic) corals: colonial cnidarians (Anthozoa: Scleractinia) whose polyps secrete calcium carbonate skeletons; the living coral forms a thin veneer over vast accumulated skeletal deposits. Reef-building corals require: clear, warm, well-lit shallow water (18 to 28 degrees Celsius); high salinity (28 to 40 ppt); low nutrient concentrations (they rely on symbiotic zooxanthellae algae within their tissues for photosynthesis, which requires clear water for light penetration).

Coral reefs cover less than 0.1% of the ocean floor but support approximately 25% of all marine species; they are the most biodiverse marine habitat. They are found in tropical shallow seas; in Nigeria, small patch reefs occur in shallow coastal waters around Brass and in the Gulf of Guinea. Reef structure: fringing reef (attached to shore); barrier reef (separated from shore by a lagoon; Great Barrier Reef, Australia); atoll (ring-shaped reef around a central lagoon; typically over a submerged volcanic island). Coral bleaching occurs when water temperatures rise: corals expel their zooxanthellae, turn white, and may die; bleaching is driven by climate change-related ocean warming.

Fill in the blank: Coral bleaching occurs when water temperature rises and corals expel their symbiotic _____ algae (zooxanthellae); without these photosynthetic symbionts the coral turns white and may die; bleaching is driven by ocean warming from climate change.

<u>Habitat Type</u>	<u>Rainfall/Salinity</u>	<u>Temperature</u>	<u>Vegetation</u>	<u>Animals</u>
<u>Tropical Rainforest</u>	Very high rainfall (2000–3000 mm annually)	Warm, humid (25–28°C)	Dense canopy, hardwood trees	Primates (chimpanzees,



			(iroko, mahogany), shrubs	drills), forest elephants, parrots
<u>Guinea Savanna</u>	Moderate rainfall (1000–1500 mm)	Warm (20–30°C)	Tall grasses, scattered trees (sheanut, locust bean)	Antelopes, grasscutters, guinea fowl, cattle
<u>Sudan Savanna</u>	Lower rainfall (600–1200 mm)	Hot, semi-arid (25–35°C)	Short grasses, thorny shrubs, baobab trees	Goats, sheep, camels, ground squirrels
<u>Wetlands</u>	Waterlogged, seasonal flooding; salinity varies	Warm, humid	Swamps, marshes, mangroves, grasses	Fish, amphibians, crocodiles, herons
<u>Mangroves</u>	Saline/brackish water	Warm coastal climate	Mangrove trees (Rhizophora), salt-tolerant plants	Crabs, shrimps, mudskippers, manatees
<u>Montane (Highlands)</u>	Moderate rainfall (1500–2000 mm)	Cool (15–20°C at altitude)	Montane forests, grasses, shrubs	Endemic amphibians, monkeys, rare birds
<u>Semi-Arid/Desert Fringe</u>	Very low rainfall (<600 mm)	Extreme heat (30–40°C)	Sparse shrubs, acacia, grasses	Camels, desert foxes, reptiles

Box 2.1: Comparison of the major habitat types found in Nigeria

Pilot questions 2.4

1. State three abiotic features of the marine habitat.
2. Describe the zonation of the marine environment from the intertidal zone to the abyssal zone.
3. Define an estuary and explain why estuaries are so productive.
4. Explain what coral reefs are and state the conditions required for their formation.
5. Explain coral bleaching and state its main cause.



Series Summary

This Series examined the defining characteristics and biological communities of Nigeria's major terrestrial and aquatic habitat types. The tropical rainforest, found in Cross River and Edo States, was described as a stratified, species-rich ecosystem sustained by high year-round rainfall but underlain by nutrient-poor leached soils. Savanna was contrasted by its seasonal rainfall, annual dry-season fires, and characteristic tree species such as *Parkia* and *Vitellaria* supporting large mammal herbivore communities, while the semi-arid Sahel was distinguished by very low rainfall, extreme temperatures, harmattan winds, and fauna adapted to heat and drought through nocturnal behaviour and burrowing. Wetland ecosystems, including the Hadejia-Nguru system, were characterised by anaerobic flooded soils and aerenchymatous hydrophytes, and mangrove forests were examined through the structural adaptations of *Rhizophora* prop roots and *Avicennia* pneumatophores, and their ecological roles in fisheries, coastal protection, and carbon sequestration.

Freshwater and marine habitats were then surveyed. Lakes were described through their thermal stratification into epilimnion, thermocline, and hypolimnion layers and their spatial zonation into littoral, limnetic, and profundal regions, while rivers were characterised by the downstream gradient from high-oxygen turbulent headwaters to slower lowland reaches. Marine habitats were organised by depth from the photic zone through intertidal to abyssal zones. Estuaries, combining high productivity with variable salinity as critical nursery habitats, were discussed with reference to the Niger Delta and its oil pollution threat, and coral reefs were examined through their zooxanthellae symbiosis, exceptional biodiversity, and vulnerability to bleaching driven by ocean warming.

Glossary of Terms

- **Abyssal zone:** the deepest zone of the ocean (4,000 to 6,000 m); characterised by extreme pressure, near-zero temperature, complete darkness, and no photosynthesis.
- **Aerenchyma:** a plant tissue containing large air spaces that facilitate the movement of oxygen from aerial parts to submerged roots; found in wetland plants (hydrophytes).
- **Aphotic zone:** the zone of a lake or ocean below the depth of effective light penetration; no photosynthesis occurs; organisms depend on organic matter sinking from above.



- **Atoll:** a ring-shaped coral reef enclosing a central lagoon; typically forms over a subsided volcanic island.
- **Benthos:** organisms living on or in the bottom sediment of a lake, river, or ocean.
- **Coral bleaching:** the whitening and potential death of corals caused by expulsion of zooxanthellae following abnormally high water temperatures; strongly associated with ocean warming from climate change.
- **Continental shelf:** the shallow (0 to 200 m) submerged margin of a continent; the most productive zone of the ocean; most commercial fishing occurs here.
- **Epilimnion:** the warm, well-oxygenated, less dense upper layer of a thermally stratified lake; separated from the hypolimnion by the thermocline.
- **Estuary:** a semi-enclosed coastal body of water where freshwater from rivers mixes with salt water from the sea; among the most productive ecosystems on Earth.
- **Euryhaline:** an organism capable of tolerating wide fluctuations in salinity; characteristic of estuarine species.
- **Harmattan:** a dry, dusty, north-easterly trade wind blowing from the Sahara Desert across West Africa from October to March; responsible for low humidity and desiccation in northern Nigeria.
- **Hypolimnion:** the cold, dense, oxygen-depleted bottom layer of a thermally stratified lake; often anaerobic in productive lakes.
- **Intertidal zone:** the coastal zone between the high and low tide marks; exposed to air at low tide and submerged at high tide; organisms must tolerate wave action, temperature extremes, and desiccation.
- **Lentic:** referring to standing or still freshwater habitats; includes lakes, ponds, and reservoirs.
- **Limnetic zone:** the open water zone of a lake away from the shore, above the photic zone limit; dominated by phytoplankton and zooplankton.
- **Littoral zone:** the shallow nearshore zone of a lake where sunlight reaches the bottom; supports rooted aquatic plants and is the most productive and species-diverse zone.
- **Lotic:** referring to flowing freshwater habitats; includes rivers, streams, and springs.



- **Pelagic:** relating to the open water column of a lake or ocean, away from the bottom and the shore.
- **Photic zone:** the upper zone of a lake or ocean where sufficient light penetrates for photosynthesis; extends to approximately 200 m in clear ocean water.
- **Pneumatophore:** a specialised aerial root that projects vertically above waterlogged anaerobic sediment in mangroves (*Avicennia*); allows gas exchange for root respiration.
- **Profundal zone:** the deep, dark, often anaerobic zone of a large lake below light penetration; benthic invertebrates feed on organic matter settling from above.
- **Prop root (stilt root):** an aerial root that arches from the trunk or branches of a mangrove tree (*Rhizophora*) down into the mud, providing structural support in unstable sediment.
- **Savanna:** a tropical habitat characterised by a continuous grass layer with scattered trees; defined by seasonal rainfall, a dry season, and annual fire.
- **Thermocline:** a zone of rapid temperature change with depth in a thermally stratified lake or ocean, separating the warm epilimnion from the cold hypolimnion.
- **Wetland:** an area where the water table is at or near the soil surface for at least part of the year; includes swamps, marshes, bogs, fens, and floodplains.
- **Zooxanthellae:** symbiotic photosynthetic dinoflagellate algae living within the tissues of reef-building corals; they provide the coral host with photosynthetic organic products and give corals their colour.



Concept Check Questions [Series 2]

Objective Questions

1. Tropical rainforest soils are typically _____ and nutrient-poor despite high rainfall because intense leaching removes minerals to lower soil horizons. (Linked to SLO 2.1)
2. _____ is a defining ecological feature of savanna that occurs annually during the dry season and prevents forest encroachment by maintaining the grass-tree balance. (Linked to SLO 2.1)
3. Rhizophora (red mangrove) has prop/stilt roots while Avicennia (white mangrove) has _____ that project above the anaerobic mud for gas exchange. (Linked to SLO 2.2)
4. In a thermally stratified lake, the warm upper layer is the epilimnion, the cold bottom layer is the hypolimnion, and the zone of rapid temperature change between them is the _____. (Linked to SLO 2.3)
5. Coral bleaching occurs when water temperature rises and corals expel their symbiotic _____ algae (zooxanthellae), causing the coral to turn white and potentially die. (Linked to SLO 2.4)

Short-Answer Questions

1. Describe the vertical stratification of a tropical rainforest. (Linked to SLO 2.1)
2. State three abiotic features of a mangrove habitat. (Linked to SLO 2.2)
3. Explain three ecosystem services provided by mangroves and wetlands. (Linked to SLO 2.2)
4. Name and describe the three horizontal zones of a lake. (Linked to SLO 2.3)
5. Define an estuary and explain why estuaries are among the most productive ecosystems. (Linked to SLO 2.4)

Long-Answer Questions

1. Describe the abiotic and biotic features of tropical rainforest, savanna, and desert habitats in Nigeria. (Linked to SLO 2.1)
2. Describe the features and ecological importance of freshwater wetland and mangrove habitats in Nigeria. (Linked to SLO 2.2)



3. Describe the features of freshwater lakes and rivers; explain zonation in both; and describe the features of marine, estuarine, and coral reef habitats. (Linked to SLOs 2.3, 2.4)

Answers to Concept Check Questions [Series 2]

Objective Questions

1. Leached (ferralsols/oxisols).
2. Fire.
3. Pneumatophores.
4. Thermocline.
5. Zooxanthellae.

Short-Answer Questions

1. Emergent layer (above 30 m; isolated tall trees in full sun); main canopy (15-30 m; continuous; most photosynthesis); understorey (5-15 m; shade-tolerant trees and shrubs); shrub and herb layer (0-5 m; seedlings and low plants); forest floor (leaf litter; very low light; decomposers and invertebrates).
2. Daily tidal flooding with saline or brackish water (10-35 ppt); waterlogged, anaerobic, fine-grained muddy sediments; warm temperatures (25-30 degrees Celsius); high sedimentation rates; fluctuating water levels with tidal cycle.
3. Fisheries nursery (prop roots and shallow water serve as nursery for juvenile fish; approximately 75% of tropical coastal fish use mangroves); coastal protection (absorb wave energy; reduce coastal erosion and storm surge flooding); carbon sequestration/blue carbon (anaerobic sediments store very large amounts of organic carbon; mangrove destruction releases CO₂ and methane).
4. Littoral zone (shallow nearshore; sunlight reaches bottom; rooted plants; most productive and diverse). Limnetic zone (open water away from shore; phytoplankton and zooplankton; pelagic fish). Profundal zone (deep water below light penetration in large lakes; no photosynthesis; anaerobic; benthic invertebrates).



5. An estuary is a semi-enclosed coastal body of water where freshwater from rivers mixes with salt water from the sea. Productivity: estuaries receive nutrient inputs from both river runoff and tidal seawater; they have a large surface area in shallow water with good light penetration; continuous nutrient import sustains very high phytoplankton and plant growth, supporting dense consumer populations.

Long-Answer Questions

1. Tropical rainforest (southern Nigeria; Cross River, Edo, Delta States): abiotic (year-round high rainfall 1,500-4,000 mm; high constant temperature 24-28 degrees Celsius; high humidity 80-100%; low seasonal variation; deep, leached, nutrient-poor ferralsols; most nutrients in biomass); biotic (five vertical layers: emergent, canopy, understorey, shrub, floor; enormous tree diversity; epiphytes, lianas, buttress roots; high diversity of invertebrates, reptiles, birds, primates; arboreal mammals). Guinea savanna (Middle Belt): abiotic (seasonal rainfall 900-1,300 mm; distinct dry season 3-7 months; fire annually; warm year-round; well-drained fertile soils); biotic (Guinea grass, Elephant grass, *Parkia biglobosa*, *Vitellaria paradoxa*, baobab; buffalo, antelope, kob, raptors; termite mounds; Fulani cattle). Semi-arid/Sahel (above 12 degrees N): abiotic (below 500 mm rainfall; unpredictable; extreme diurnal temperature 40+ degrees Celsius day/cold night; low humidity; harmattan winds October-March; sandy, alkaline, low organic matter soils; evapotranspiration far exceeds precipitation); biotic (*Acacia senegal*, *Calotropis procera*, *Cenchrus biflorus*; drought-adapted annuals; nocturnal and burrowing animals; rodents, reptiles, camels; few large mammals).
2. Freshwater wetlands (Hadejia-Nguru, inland Niger floodplain): definition (area where water table is at or near surface for at least part of the year; includes swamps, marshes, fens); abiotic features (permanently or seasonally flooded; waterlogged, anaerobic soils; low dissolved oxygen; organic matter accumulation; high nutrients from floodwaters; fluctuating water levels); biotic features (hydrophytes with aerenchyma e.g. *Typha*, *Nymphaea*; amphibians; waterbirds: herons, egrets, jacanas, kingfishers; fish; crocodiles; insects: mosquitoes, dragonflies); anaerobic soil explanation (oxygen consumed by decomposers faster than it can diffuse into waterlogged soil; slow diffusion through water-filled pores). Mangroves (Niger Delta; largest in Africa; third largest in world): abiotic (tidal saline/brackish water 10-35 ppt; waterlogged anaerobic mud; high sedimentation; warm



temperature 25-30 degrees Celsius; tidal flooding daily); biotic (*Rhizophora racemosa* with prop/stilt roots; *Avicennia africana* with pneumatophores; *Laguncularia*, *Nypa fruticans*; fiddler crabs, periwinkles, oysters, mudskippers, waterbirds, manatees); ecological importance (biodiversity: 150+ bird species; fisheries nursery: 75% tropical coastal fish; coastal protection: wave energy absorption, storm surge buffer; blue carbon: large organic carbon stored in anaerobic sediments; water filtration: sediments and nutrients removed before reaching sea).

3. Lakes (lentic; still water; examples: Lake Chad, Kainji, Jebba): thermal stratification (warm, less dense epilimnion floats above cold, dense hypolimnion; separated by thermocline; stratification prevents mixing; hypolimnion becomes anaerobic; seasonal overturn in temperate lakes brings nutrients to surface); horizontal zones (littoral: shallow nearshore, sunlight to bottom, rooted plants, most productive; limnetic: open water, phytoplankton and zooplankton; profundal: deep, dark, anaerobic, benthic invertebrates on settled organic matter); Lake Chad is very shallow so has no permanent stratification. Rivers (lotic; flowing water; examples: Niger, Benue, Cross River): current (unidirectional flow); high O₂ from turbulence; substrate varies (boulders in headwaters to silt at lower reaches); longitudinal zonation (headwater: fast, cold, clear, turbulent, well-oxygenated, coarse substrate, algae and invertebrates; middle reaches: moderate flow, finer substrate, diverse fish; lower lowland reach: slow, turbid, warm, lower O₂, fine silt, catfish, tilapia, floodplain connection). Marine habitat: high constant salinity (35 ppt); temperature varies with latitude and depth; light penetrates top 200 m only; zones (intertidal: exposed at low tide, wave action, barnacles, limpets; subtidal; continental shelf 0-200 m most productive; continental slope; abyssal 4,000+ m: cold, dark, extreme pressure). Estuaries (Niger Delta): freshwater meets seawater; variable salinity 0-35 ppt; most productive ecosystems; euryhaline species (mangroves, fiddler crabs, grey mullet, shrimps *Penaeus*, oysters); critical nursery habitat; threatened by oil pollution, dredging, mangrove clearance. Coral reefs: built by hermatypic corals with symbiotic zooxanthellae; require clear, warm, shallow water 18-28 degrees Celsius; highest marine biodiversity (0.1% ocean floor, 25% marine species); reef types: fringing, barrier, atoll; bleaching from ocean warming expels zooxanthellae; climate change main threat.



Answers to Pilot Questions [Series 2]

Part 2.1

1. Tropical rainforest abiotic features: (1) very high, year-round rainfall (1,500 to over 4,000 mm per year with no true dry season; constant input of water throughout the year from regular convective rainfall); (2) high and relatively constant temperature throughout the year (24 to 28 degrees Celsius; minimal seasonal variation; driven by proximity to the equator and year-round solar input); (3) very high relative humidity (80 to 100%; the closed canopy traps evapotranspired water vapour near the forest floor); (4) intense but patchily distributed light (the canopy intercepts approximately 98% of incoming solar radiation; the forest floor may receive less than 2% of full sunlight; gaps in the canopy create high-intensity light patches called sunflecks); (5) deep but nutrient-poor, heavily leached soils (ferralsols and oxisols); despite high biomass, most nutrients are in the living vegetation and are rapidly recycled after death; the soils are red-orange due to high iron and aluminium oxide content; extremely low in nitrogen, phosphorus, and potassium.
2. The tropical rainforest is structured as five distinct vertical layers (strata), each with characteristic light levels, temperature, and humidity: (1) Emergent layer (above 30 m): isolated giant trees that project above the main canopy; exposed to full sunlight, strong winds, and large temperature fluctuations; characteristic animals include large raptors (crowned eagle *Stephanoaetus coronatus*) and soaring birds using wind thermals. (2) Main canopy (15 to 30 m): a continuous, interlocking layer of tree crowns; captures approximately 70-90% of all incident sunlight; most photosynthesis and most species (insects, birds, primates) concentrated here. (3) Understorey (5 to 15 m): shade-tolerant trees and large shrubs; much lower light intensity (2-10% of full sunlight); many plants have very large leaves to maximise light capture; characteristic birds include forest hornbills. (4) Shrub and herb layer (0 to 5 m): low shrubs, seedlings of tall trees waiting for a canopy gap, and shade-tolerant herbs; very low light; many plants have red-pigmented undersides to absorb reflected light from above. (5) Forest floor: leaf litter and decaying wood; extremely low light; rapid decomposition by fungi and bacteria; earthworms, millipedes, and termites dominate the soil fauna.



3. Three ways fire shapes the savanna habitat: (1) Preventing forest expansion: in the absence of fire, savanna trees and shrubs gradually grow taller and their canopy closes, shading out the grasses and beginning the transition to woodland or forest; annual dry-season fires kill the above-ground parts of trees and shrubs, suppressing their growth and maintaining the open tree-grass balance that defines savanna; without fire, many Nigerian guinea savanna areas would transition to woodland within decades. (2) Nutrient cycling and grass productivity: fire rapidly releases the nutrients stored in the dead dry-season grass biomass as smoke and ash; the ash provides a pulse of immediately available mineral nutrients (potassium, calcium) to the soil; when the first rains arrive after the burn, these nutrients flush into the soil and support a rapid flush of new grass growth; this fire-nutrient cycle maintains grass productivity. (3) Controlling savanna woody plant composition: different tree and shrub species have different fire tolerances; fire-tolerant species (with thick bark, root-sprouting ability, underground lignotubers for energy storage) survive and come to dominate; fire-sensitive species (thin-barked; cannot resprout from roots) are eliminated; fire therefore acts as a selective filter that shapes the plant species composition of the savanna community.
4. Desert/semi-arid abiotic conditions: (1) Very low and unpredictable rainfall: less than 250 mm per year in true desert; 250 to 500 mm in semi-arid Sahel; rainfall is highly seasonal (confined to a very brief wet season) and highly variable between years; entire years may pass without significant rainfall. (2) Extreme diurnal temperature fluctuation: daytime temperatures regularly exceed 40 degrees Celsius; at night, the lack of cloud cover and vegetation means heat radiates rapidly and temperatures may fall to near freezing; this extreme temperature range (often 20 to 30 degrees Celsius within 24 hours) is a major physiological challenge for organisms. (3) Very low humidity: relative humidity often below 10% during the harmattan season; this drives very high evapotranspiration; the Penman evapotranspiration rate greatly exceeds rainfall, creating a permanent water deficit. (4) Strong, desiccating winds: the harmattan (October to March) is a hot, dry, dust-laden north-easterly wind from the Sahara; it reduces visibility, increases evaporation, damages crops and vegetation, and deposits dust across the landscape. (5) Substrate and soils: sandy or rocky soils with minimal organic matter; very low water-holding capacity; some areas have alkaline or saline



soils (sodic or calcareous); soil crust formation (biological soil crusts of cyanobacteria and lichens) is important for stabilising sand surfaces.

5. Comparing rainforest and savanna: Rainfall: tropical rainforest receives 1,500 to over 4,000 mm per year with no dry season; guinea savanna receives 900 to 1,300 mm per year with a distinct dry season of 3 to 5 months; rainfall seasonality and reliability differ fundamentally. Soil type: rainforest has deep, heavily leached, nutrient-poor ferralsols (oxisols) that are red-orange due to iron and aluminium oxides; savanna has relatively fertile cambisols and luvisols in the guinea zone with higher organic matter than rainforest soils because slower decomposition during the dry season allows some organic accumulation; savanna soils are often richer in nutrients than rainforest soils. Biodiversity: the tropical rainforest is the most species-rich terrestrial habitat on Earth with hundreds of tree species per hectare, thousands of insect species, and high diversity of birds, reptiles, and mammals; the savanna has lower overall species richness but higher populations of large mammals (ungulates such as buffalo, kob, and antelope) and supports different specialists; the rainforest has higher plant diversity while the savanna has more accessible large herbivore biomass.

Part 2.2

1. A wetland is any area where the water table is at or near the soil surface for at least part of the year, resulting in waterlogged or flooded conditions that determine the soil development and the characteristic vegetation. Four types with Nigerian examples: (1) Swamp (dominated by trees in permanently waterlogged soil; e.g. freshwater swamp forest in the Niger Delta and Cross River State; also the Okomu swamp forest in Edo State). (2) Marsh (dominated by herbaceous plants: grasses, sedges, rushes in shallow standing or slow-moving water; e.g. the seasonal marshes on the Hadejia floodplain in Jigawa State). (3) Bog (acidic; low nutrients; dominated by Sphagnum moss; characteristically cooler climate; not well developed in tropical Nigeria but found in high-altitude areas). (4) Floodplain wetland (seasonally inundated by river overflow; extraordinarily productive when flooded; e.g. Hadejia-Nguru Wetlands in Jigawa and



Yobe States; these wetlands support approximately one million people through fishing, farming, and pastoralism).

2. Three abiotic features of mangrove habitat: (1) Daily tidal flooding with saline or brackish water: mangroves occupy the intertidal zone of sheltered tropical coasts; they are flooded by tidal seawater twice daily; salinity in Nigerian mangroves varies from nearly fresh (close to river mouths) to nearly full seawater salinity (35 ppt) near the open coast; the daily flooding and draining cycle is the defining physical feature of the mangrove environment. (2) Waterlogged, anaerobic, fine-grained muddy sediment: the combination of tidal flooding and settling of fine river and coastal sediments creates permanently waterlogged mud that contains almost no free oxygen; the anaerobic conditions mean that roots cannot obtain oxygen by normal diffusion from the soil as terrestrial roots do; all mangrove trees have evolved specialised root adaptations to supply oxygen to their roots above the anaerobic mud. (3) High sedimentation and turbidity: rivers entering the Niger Delta carry enormous quantities of fine silt and clay in suspension; as the flow slows on entering the mangrove and tidal zone, the sediment settles continuously; this creates the unstable muddy substrate that makes the environment difficult to colonise for non-adapted plants.
3. Root adaptations of mangrove trees: (1) Prop roots/stilt roots (*Rhizophora* species): these are adventitious roots that arch outward and downward from the trunk and lower branches of the tree, entering the mud at multiple points well away from the trunk; this creates a broad stable base (like the legs of a tripod multiplied many times) that anchors the tree securely in the soft, unstable, waterlogged mud; the prop roots also have lenticels (pores for gas exchange) on their above-water portions that allow oxygen to diffuse into the root interior. (2) Pneumatophores (*Avicennia* species): these are specialised horizontal cable roots from which vertical finger-like projections grow upward out of the mud surface; they project typically 20 to 30 cm above the mud level and carry lenticels on their surface; at low tide when the mud surface is exposed to the air, oxygen diffuses through the lenticels and then along gas-filled channels (aerenchyma) throughout the root system, supplying the oxygen needed for aerobic root respiration; at high tide when they are submerged, lenticels close. (3) Vivipary (in *Rhizophora*): the seeds germinate while still attached to the parent tree, producing a long, torpedo-shaped seedling (propagule) that drops from the tree and embeds itself in



the mud below; this adaptation bypasses the vulnerable seedling stage during which most terrestrial plants die from dessication or anaerobic soil.

4. Three ecosystem services from mangroves: (1) Fisheries nursery: the complex three-dimensional structure of mangrove prop roots provides shelter from predators for the juvenile stages of many commercially important fish and shellfish; the sheltered, nutrient-rich, warm, shallow waters are ideal for rapid juvenile growth; it is estimated that approximately 75% of tropical coastal fish species spend at least part of their juvenile stage in mangrove or estuarine habitats; Nigeria's artisanal fisheries (shrimps, snapper, mullet, barracuda) are highly dependent on mangrove nursery habitat; mangrove clearance directly reduces fish catches. (2) Coastal protection: the dense prop root systems and above-ground biomass of mangrove forests act as a physical barrier that absorbs wave energy before it reaches the shore; this significantly reduces coastal erosion, shoreline retreat, and damage from storm surges; coastal communities in the Niger Delta that have lost their mangrove buffer are significantly more vulnerable to flooding and erosion; mangroves are cheaper and more effective than artificial sea walls for coastline protection. (3) Blue carbon sequestration: the anaerobic, waterlogged sediments of mangroves and other coastal wetlands (saltmarshes, seagrasses) prevent the decomposition of organic matter that would normally release CO₂; instead, organic carbon from dead mangrove leaves, wood, and roots accumulates in the sediments for centuries to millennia; mangrove soils store 3 to 5 times more carbon per unit area than tropical rainforest soils; when mangroves are cleared, this carbon store is oxidised and released as CO₂, contributing to climate change.
5. Wetland soils are anaerobic because: (1) Oxygen consumption rate exceeds replenishment rate: in waterlogged soils, all air pores between soil particles are filled with water; oxygen dissolved in water diffuses approximately 10,000 times more slowly than oxygen in air; this means that the rate at which microbial decomposers (bacteria and fungi) and root respiration consume oxygen in the soil far exceeds the rate at which new oxygen can diffuse in from the atmosphere through the water-filled pores. (2) Rapid initial oxygen depletion: when soil first becomes waterlogged, any residual oxygen in the remaining air pockets is quickly consumed by the abundant aerobic microbial community; once this initial oxygen is exhausted, the soil becomes anoxic (completely



without free oxygen) within hours to days depending on temperature and microbial activity. (3) Anaerobic bacteria take over: once oxygen is depleted, aerobic bacteria die or become dormant and anaerobic bacteria (which can use nitrate, iron, sulphate, and CO₂ as alternative electron acceptors in place of oxygen) proliferate; the products of anaerobic decomposition include methane (CH₄), hydrogen sulphide (H₂S), which gives wetland soils their characteristic rotten-egg smell, and ethanol; these are the conditions that wetland plants with aerenchyma must overcome.

Part 2.3

1. Lentic habitats: standing (still) freshwater bodies; Nigerian example: Lake Chad (largest lake in West Africa, shared with Niger, Chad, and Cameroon; greatly reduced in area due to irrigation withdrawal and reduced rainfall). Lotic habitats: flowing (running) freshwater bodies; Nigerian example: River Niger (the third longest river in Africa at approximately 4,200 km; flows through Nigeria from the northwest to the Niger Delta in the south; the dominant river of West Africa).
2. Thermal stratification in deep lakes: (1) During warm seasons, solar radiation heats the surface water of the lake, making it less dense (warm water is less dense than cold water); this warm, less dense water sits on top of the cold, denser bottom water; the two layers cannot easily mix because of their density difference. (2) The warm upper layer is called the epilimnion; it is well-oxygenated (absorbs oxygen from the atmosphere and from algal photosynthesis), warm, and the site of most biological activity. (3) The cold, dense lower layer is called the hypolimnion; it is separated from the epilimnion by the thermocline, a zone of rapid temperature change (often 1 degree Celsius per metre) that acts as a physical barrier to vertical mixing. (4) As the hypolimnion is cut off from the surface, its oxygen is consumed by decomposers breaking down organic matter sinking from above; no photosynthesis occurs here; the hypolimnion becomes progressively depleted in oxygen (hypoxic or anoxic) and accumulates nutrients released by decomposition. (5) In temperate lakes, autumn cooling causes the epilimnion to cool and become as dense as the hypolimnion; the



two layers can then mix (seasonal overturn), bringing nutrient-rich bottom water to the surface and triggering algal blooms.

3. River zonation from source to mouth: (1) Headwater/source zone (upper reaches): the river begins as a small, steep, fast-flowing stream in highland or hilly terrain; the gradient is steep so water flows rapidly and turbulently; turbulence mixes atmospheric oxygen into the water, producing high dissolved oxygen levels; the fast flow prevents sedimentation, leaving a coarse substrate of boulders, cobbles, and gravel; the water is cold (from underground springs or highland catchment), clear (low sediment load), and oligotrophic (nutrient-poor from low catchment soil development); primary productivity is low (algae growing on rock surfaces, mosses); invertebrates are specialised to fast flow: mayfly larvae (Ephemeroptera) with flattened bodies; caddisfly larvae (Trichoptera) in weighted cases; stonefly larvae (Plecoptera) clinging to rocks. (2) Middle reaches: the gradient decreases; flow becomes slower and less turbulent; the river widens and receives tributary inputs; substrate changes from gravel to sand and fine gravel; water warms and becomes less clear as it carries more sediment; nutrient levels rise from tributary runoff; algae and aquatic macrophytes become more abundant; fish diversity increases (dace, carp, barbel, perch); invertebrates change to burrowing species in the softer substrate. (3) Lower/lowland reach (lower course): very gentle gradient; slow, meandering flow; wide channel; high sediment load (turbid, brown water); warm temperature; lower dissolved oxygen due to decomposition consuming oxygen and less turbulence to replenish it; fine silt and mud substrate; nutrient-rich from agricultural and urban runoff; catfish, tilapia, and mudfish dominate; floodplain connects during the wet season; mangroves and swamp forests at the tidal lower limit.
4. Three horizontal zones of a lake: (1) Littoral zone (nearshore, shallow): the zone where sunlight penetrates to the lake bottom; typically extends to a depth of 1 to 5 m in turbid tropical lakes; receives sufficient light for rooted aquatic plants (macrophytes) to grow from the bottom; characteristic plants include *Nymphaea* (water lily; floating leaves), *Typha* (bulrush; emergent), and *Ceratophyllum* (submerged); the littoral zone is the most productive and biologically diverse zone of the lake; it supports diverse invertebrates (snails, insects, worms, crustaceans), amphibians, nesting waterbirds, juvenile fish, and the feeding activities of wading birds; this is also where water hyacinth



(*Eichhornia crassipes*) grows as an invasive weed in Nigerian lakes. (2) Limnetic zone (open water zone): the open water away from the shore, extending to the depth limit of effective photosynthesis (photic zone limit); dominated by free-floating microscopic organisms (phytoplankton: cyanobacteria, diatoms, green algae; and zooplankton: rotifers, cladocerans, copepods); pelagic fish feeding on zooplankton are characteristic; productivity is lower than in the littoral zone but the limnetic zone makes up most of the volume of large lakes. (3) Profundal zone (deep zone): the zone below light penetration in large, deep lakes; receives no sunlight; no photosynthesis; organisms depend entirely on organic matter (dead plankton, faeces) sinking from above; typically hypoxic or anoxic in productive lakes; characterised by benthic invertebrates adapted to anaerobic or low-oxygen conditions: Chironomus (bloodworm; midge larva with haemoglobin for O₂ binding); Tubifex worms; anaerobic bacteria.

5. The profundal zone is anaerobic because: (1) it lies below the depth of light penetration (aphotic zone), so no photosynthesis occurs there to produce oxygen; (2) it is separated from the oxygenated surface epilimnion by the thermocline during thermal stratification, preventing mixing of well-oxygenated surface water downward; (3) the profundal sediments receive a continuous rain of organic matter (dead plankton, faeces) sinking from the productive upper zones; decomposing bacteria consume this organic matter using aerobic respiration, which rapidly consumes the limited oxygen dissolved in the cold hypolimnion water; (4) because oxygen supply (from the isolated hypolimnion water) is limited and consumption by decomposers is continuous, oxygen is depleted completely; conditions then become anaerobic; in very productive (eutrophic) lakes, the hypolimnion and profundal zone are anoxic for most of the summer stratification period; only during seasonal turnover (when stratification breaks down) is oxygen-rich surface water mixed to the bottom.

Part 2.4

1. Three abiotic features of the marine habitat: (1) High and relatively constant salinity: seawater has a mean salinity of approximately 35 parts per thousand (3.5% dissolved



salts, dominated by sodium chloride); this salinity is relatively constant across most of the open ocean (34 to 37 ppt); marine organisms are osmoregulated or osmoconformed to this salinity, and most cannot tolerate the large salinity fluctuations found in estuaries; salinity is lower near river mouths and higher in enclosed seas with high evaporation rates. (2) Temperature decreasing with depth: surface temperature in the tropical Gulf of Guinea is 26 to 30 degrees Celsius; temperature decreases with depth, falling through the thermocline to approximately 2 to 4 degrees Celsius at depth; this creates permanent stratification in tropical and subtropical oceans; cold, nutrient-rich water upwells in some areas (e.g. off the West African coast) creating highly productive zones. (3) Pressure increasing with depth: pressure increases by approximately one atmosphere (101 kPa) for every 10 metres of depth; at the bottom of the deepest ocean trenches (approximately 11,000 m), pressure is over 1,000 atmospheres; only highly specialised organisms with pressure-resistant biochemistry and anatomy (deep-sea fish, invertebrates, bacteria) can survive at these depths.

2. Ocean zonation from intertidal to abyssal: (1) Intertidal zone (between high and low tide marks): regularly exposed to air at low tide and submerged at high tide; the most physically stressful marine zone; organisms must tolerate wave impact, desiccation (drying out), temperature extremes, and variable salinity; characteristic organisms: barnacles (*Balanus*; cemented to rocks), limpets (*Patella*; cling to rocks with muscular foot), mussels (*Mytilus*; attached by byssus threads), and rockweed algae (*Fucus*); zonation within the intertidal (splash zone, upper, mid, and lower intertidal) reflects decreasing submersion time. (2) Subtidal zone (just below low tide): permanently submerged; far less physically stressful; richer community; seagrass beds (*Thalassia*, *Zostera*) on sandy bottoms; diverse fish and invertebrate communities; in Nigeria, includes shallow nearshore areas of the Gulf of Guinea. (3) Continental shelf (0 to 200 m; photic zone): the shallowest and most productive offshore zone; sufficient light for photosynthesis; phytoplankton primary production supports zooplankton, fish, and higher trophic levels; most commercial fishing in the Gulf of Guinea occurs on the Nigerian shelf (approximately 150 to 200 km wide); continental shelf productivity is enhanced where cold, nutrient-rich deep water upwells to the surface. (4) Continental slope (200 to 2,000 m; mesopelagic twilight zone): little or no light; declining temperature; bioluminescent organisms common; adapted fish with large eyes or light-



producing organs. (5) Abyssal zone (4,000 to 6,000 m): total darkness; extreme pressure (400 to 600 atmospheres); near-freezing temperature (2 to 3 degrees Celsius); no photosynthesis; organisms feed on marine snow (organic particles sinking from above); hydrothermal vent communities supported by chemolithotrophy (sulphur-oxidising bacteria as primary producers).

3. An estuary is a semi-enclosed body of coastal water with free connection to the open sea, where freshwater from one or more rivers mixes with tidal salt water. Productivity: estuaries are among the most productive ecosystems on Earth for three reinforcing reasons: (1) Continuous nutrient subsidy: river water carries dissolved nutrients (nitrate, phosphate, silicate) eroded from agricultural soils and organic material from river catchments into the estuary; simultaneously, tidal marine water brings additional nutrients and organic matter from the sea; the estuary receives these dual subsidies continuously. (2) Shallow, well-lit water: the tidal mixing keeps nutrients in the shallow photic zone where light is available for photosynthesis; nutrients are not lost by sinking into deep, dark water as they are in the open ocean. (3) Productive benthic environment: the fine sediments of estuaries are rich in detrital organic matter; benthic organisms (worms, bivalves, crustaceans) process this organic matter with high efficiency; waterbirds exploit the dense benthic invertebrate communities; in Nigerian estuaries (Niger Delta, Cross River estuary), this combination supports very high phytoplankton biomass, dense submerged and fringing macrophytes, and abundant shrimp and fish populations.
4. Coral reefs are marine ecosystems built by reef-building (hermatypic) corals: colonial cnidarians (Order Scleractinia) whose polyps secrete massive calcium carbonate (CaCO_3) skeletons; over thousands of years, the accumulated skeletons of successive coral generations build up a reef structure of solid calcium carbonate rock; the living corals form only a thin veneer on the outside of this massive structure. Conditions required: (1) Warm, clear, shallow water: hermatypic corals require water temperatures between 18 and 28 degrees Celsius; they cannot survive temperatures above 30 degrees Celsius for extended periods (causing bleaching); they require clear (low turbidity) water with good light penetration to the reef surface because their symbiotic zooxanthellae (photosynthetic dinoflagellate algae living in their tissues) need light for photosynthesis; reef-building corals are therefore confined to depths less than



- approximately 50 metres. (2) High salinity: reef-building corals require normal marine salinity (28 to 40 ppt); they cannot tolerate the low salinity of river runoff; therefore reefs do not develop near river mouths or in estuaries. (3) Low nutrient concentrations: paradoxically, the most diverse coral reefs grow in nutrient-poor (oligotrophic) tropical waters; high nutrients cause blooms of phytoplankton that cloud the water and shade the zooxanthellae; they also promote the growth of algae that overgrow and kill coral.
5. Coral bleaching is the whitening of corals caused by the expulsion of their symbiotic zooxanthellae (photosynthetic dinoflagellate algae that normally live within the coral tissue). The zooxanthellae provide the coral with up to 90% of its energy through photosynthesis, and their pigments give corals their characteristic brown, yellow, and green colours; when the zooxanthellae are expelled, the coral appears white or pale (bleached) because only the white calcium carbonate skeleton remains visible through the transparent tissue. Main cause: ocean warming from climate change. When seawater temperature rises even 1 to 2 degrees Celsius above the seasonal maximum for 3 to 4 weeks, the zooxanthellae produce damaging reactive oxygen species; in response, the coral polyps expel the zooxanthellae; if the temperature stress ends quickly (within 2 to 4 weeks), corals can re-acquire zooxanthellae and recover; if high temperature persists, the coral dies of starvation. Climate change is increasing the frequency and severity of bleaching events: mass bleaching events that were once once-per-century events now occur every 5 to 6 years on average globally; in Nigeria and the Gulf of Guinea, periodic ocean warming events threaten the small patch reefs and coral communities in shallow coastal waters.



References and Attributions [Series 2]

Textual References (Books and External Sources)

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Figures, Plates, Tables, and Boxes

- Figure 2.1: Tropical rainforest vertical stratification diagram and photograph Attribution: AI generated. Suggested OER search string: "tropical rainforest vertical stratification emergent canopy understorey shrub floor layers diagram photograph Nigeria OER".
- Figure 2.2: Hadejia-Nguru freshwater wetland ecosystem diagram and photograph Attribution: AI generated. Suggested OER search string: "freshwater wetland ecosystem Nigeria Hadejia-Nguru zonation diagram photograph OER".
- Figure 2.3: River zonation diagram from headwater to lower reaches Attribution: AI generated. Suggested OER search string: "river zonation headwater middle lower reaches diagram organisms substrate flow speed water quality OER".
- Figure 2.4: Ocean zonation cross-section diagram Attribution: AI generated. Suggested OER search string: "ocean zonation diagram intertidal subtidal continental shelf abyssal photic zone characteristic organisms OER".
- Box 2.1: Comparison of major Nigerian habitat types Attribution: AI generated. Suggested OER search string: "Nigerian habitat types comparison table rainfall temperature vegetation animals OER box".

Course code: BIO 202

Course title: Introductory Ecology



Series 3: Community Ecology and Natural Cycles

- **Part 3.1: Community Structure and Organisation**

- Sub Part 3.1.1: Definition and characteristics of ecological communities
- Sub Part 3.1.2: Species diversity and community composition
- Sub Part 3.1.3: Trophic structure and food webs

- **Part 3.2: Species Interactions**

- Sub Part 3.2.1: Competition and predation
- Sub Part 3.2.2: Symbiotic relationships
- Sub Part 3.2.3: Coevolution and keystone species

- **Part 3.3: The Carbon and Oxygen Cycles**

- Sub Part 3.3.1: The global carbon cycle
- Sub Part 3.3.2: The oxygen cycle
- Sub Part 3.3.3: Human impacts on the carbon and oxygen cycles

- **Part 3.4: The Nitrogen, Water, and Phosphorus Cycles**

- Sub Part 3.4.1: The nitrogen cycle
- Sub Part 3.4.2: The water (hydrological) cycle
- Sub Part 3.4.3: The phosphorus cycle



Introduction

A community is all the species living together in an ecosystem. Communities have emergent properties such as diversity, trophic structure, and species interactions that cannot be understood by studying individual populations alone. Alongside these biological relationships, biogeochemical cycles continuously move essential elements through living organisms and the abiotic environment, sustaining all life on Earth.

This Series covers community structure, species diversity, trophic organisation, species interactions (competition, predation, symbiosis), and the major biogeochemical cycles: carbon, oxygen, nitrogen, water, and phosphorus. These topics link directly to Series 4 (community dynamics) and Series 5 (population ecology) and apply to every Nigerian ecosystem studied in Series 2.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 3.1** describe the structure and organisation of ecological communities (Linked to Part 3.1),
- **SLO 3.2** define species diversity and explain how community composition is measured and described (Linked to Part 3.1),
- **SLO 3.3** describe the major types of species interactions (competition, predation, mutualism, commensalism, parasitism) and their ecological effects (Linked to Part 3.2),
- **SLO 3.4** explain the concept of keystone species and coevolution (Linked to Part 3.2),
- **SLO 3.5** describe the carbon and oxygen cycles and explain human impacts on them (Linked to Part 3.3), and
- **SLO 3.6** describe the nitrogen, water, and phosphorus cycles and explain the roles of microorganisms in each (Linked to Part 3.4).



3.1 Community Structure and Organisation

3.1.1 Definition and characteristics of ecological communities

An ecological community is all the populations of different species occupying the same area at the same time and interacting with one another. Communities have emergent properties not found in single populations: species richness, diversity, dominance, and trophic structure.

Communities are described by their composition (which species are present), abundance (how many of each), and the interactions among species.

Key community characteristics: dominance (one or a few species account for most of the biomass or cover; e.g. guinea grass dominates the understorey of Nigerian guinea savanna); relative abundance (the proportion each species contributes to total number or biomass); species richness (the total number of species present); evenness (how equally individuals are distributed among species). Communities also show physical structure: vertical layering (as in the rainforest canopy) and horizontal patchiness across the landscape.

Fill in the blank: A community's _____ is the total number of species present; its evenness is how equally individuals are distributed among those species; together they determine species diversity.

3.1.2 Species diversity and community composition

Species diversity combines two components: species richness (the number of species) and species evenness (how equal the abundances are). A community with many species but one dominant species has lower diversity than one with fewer species but equal abundances. The Shannon diversity index (H) is the most widely used diversity measure; it increases with both richness and evenness.

Community composition is influenced by: historical factors (which species have colonised the area); abiotic conditions (climate, soil, water); biotic interactions (competition, predation, facilitation); and disturbance regime (frequency and severity of fires, floods, storms). Dominant species exert the greatest influence on community structure; indicator species signal the health of



the ecosystem; invasive species (e.g. water hyacinth *Eichhornia* in Nigerian waterways) can fundamentally change community composition.

Fill in the blank: The _____ diversity index (H) is the most widely used measure of community species diversity; it increases with both the number of species (richness) and the equality of their abundances (evenness).

3.1.3 Trophic structure and food webs

Trophic structure describes the feeding relationships in a community, organised by trophic level: producers (level 1), primary consumers (level 2), secondary consumers (level 3), and tertiary consumers (level 4). A food web is a network of interconnected food chains in a community; it more accurately represents feeding relationships than a single food chain because most organisms eat more than one food source and are eaten by more than one predator.

Ecological pyramids represent trophic structure graphically. Pyramid of numbers: number of organisms at each level (usually narrows upward; exceptions: one oak tree supports many caterpillars). Pyramid of biomass: total dry mass at each level (usually narrows upward in terrestrial systems; may be inverted in aquatic systems where phytoplankton turns over rapidly). Pyramid of energy: always narrows upward because of the 10% transfer efficiency; never inverted; the most accurate representation of trophic structure.

Fill in the blank: The pyramid of _____ always narrows upward because only approximately 10 per cent of energy is transferred between trophic levels; it is never inverted and is the most accurate ecological pyramid.



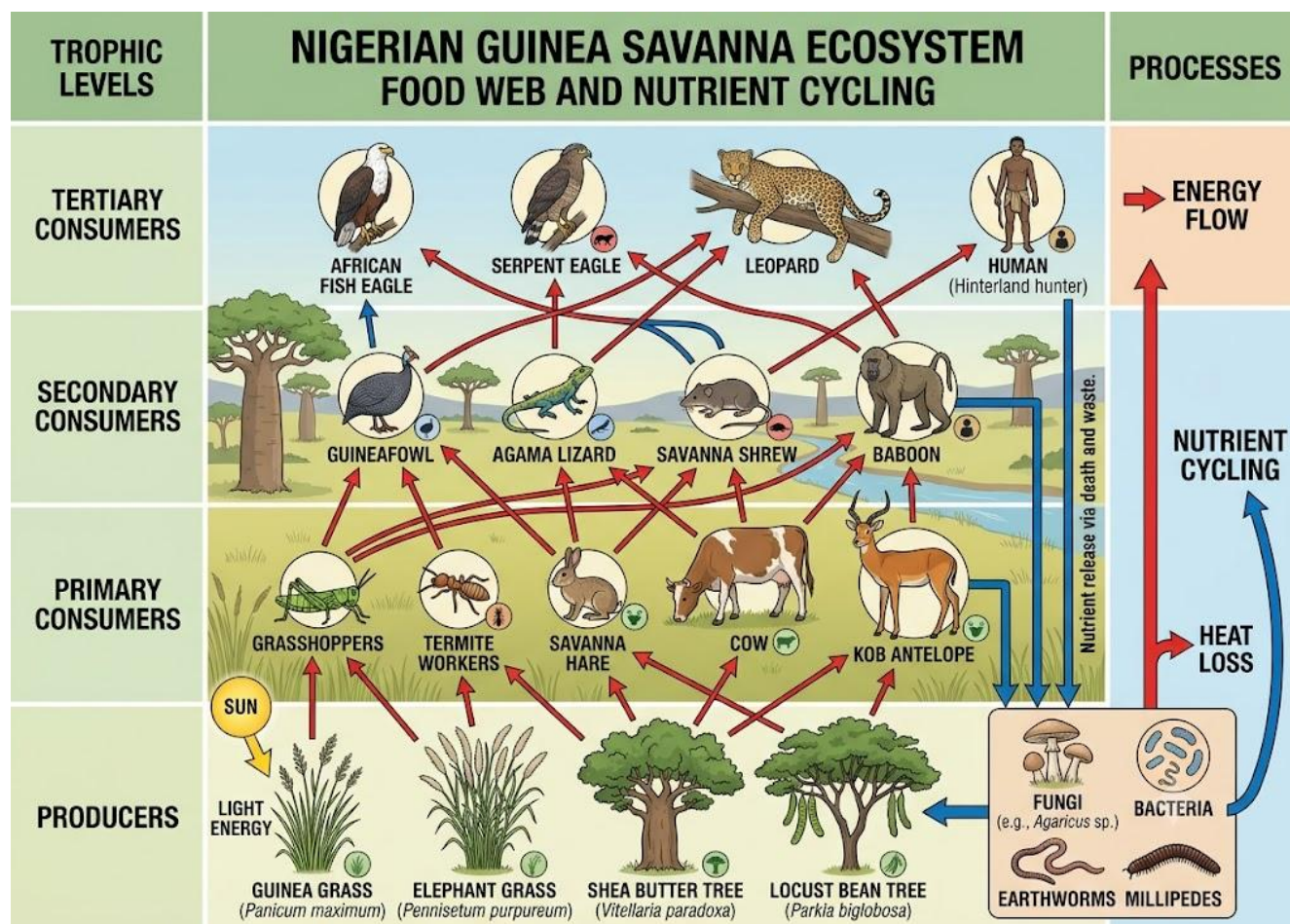


Figure 3.1: Diagram of a food web in a Nigerian guinea savanna ecosystem

Pilot questions 3.1

1. Define an ecological community and list four of its characteristics.
2. Distinguish between species richness and species evenness.
3. Explain why the pyramid of energy never inverts.
4. Distinguish between a food chain and a food web.
5. Explain how an invasive species can alter community composition.



3.2 Species Interactions

3.2.1 Competition and predation

Competition occurs when two or more organisms require the same limited resource; both are harmed by the interaction. Interspecific competition: between different species (e.g. cattle and wild herbivores competing for savanna grass in northern Nigeria). Intraspecific competition: within the same species (more intense; same niche requirements). Competitive exclusion principle (Gause's Law): two species cannot occupy identical niches in the same community indefinitely; one will be excluded.

Predation: a predator kills and consumes a prey organism; the predator benefits and the prey is harmed. Predation regulates prey population size and drives the evolution of prey defences (camouflage, spines, toxins, warning colouration) and predator counter-adaptations. Herbivory is a form of predation in which animals consume plants; parasitoidism is specialised predation in which the parasitoid larva slowly consumes the host from inside. Nigerian examples: Martial eagle (*Polemaetus bellicosus*) preying on monitor lizards; African wild dog preying on kob.

Fill in the blank: Gause's competitive _____ principle states that two species with identical niches cannot coexist indefinitely in the same community; the inferior competitor will be excluded or forced to shift its niche.

3.2.2 Symbiotic relationships

Symbiosis is any close, long-term biological interaction between two species. Three main types. Mutualism: both species benefit. Examples: Rhizobium bacteria fixing nitrogen in legume root nodules (both gain); mycorrhizal fungi increasing mineral uptake for forest trees; oxpecker birds removing ticks from cattle; fig wasps pollinating fig trees. Mutualism is widespread and often essential: mycorrhizal associations are found in over 90% of land plants.

Commensalism: one species benefits; the other is unaffected. Examples: cattle egrets following Nigerian cattle and eating insects disturbed by their hooves; epiphytic orchids growing on rainforest trees for support. Parasitism: the parasite benefits at the expense of the host, which is



harmful but not immediately killed. Nigerian examples: *Plasmodium falciparum* (malaria parasite) in human red blood cells; *Striga* (witch weed; a parasitic plant on maize and sorghum roots; a major crop pest in Nigeria); tapeworms in cattle.

Fill in the blank: _____ bacteria form mutualistic associations with the roots of legumes (cowpea, soyabean, groundnut), fixing atmospheric nitrogen into ammonia that the plant uses; the bacteria receive carbohydrates from the plant in return.

3.2.3 Coevolution and keystone species

Coevolution is the reciprocal evolutionary change in two or more interacting species, each acting as a selective force on the other. Classic examples: predator-prey arms races (cheetah speed vs gazelle speed); flower-pollinator coevolution (flower shape and colour matching pollinator anatomy and sensory abilities); host-parasite coevolution (host immune resistance vs parasite virulence). Coevolution produces tight ecological partnerships and explains much of the extraordinary diversity of flowering plants.

A keystone species has a disproportionately large effect on its community relative to its own biomass. Removing a keystone species causes dramatic changes in community structure (trophic cascade). Examples: elephants in Nigerian savanna open grassland gaps by uprooting trees, creating habitat for smaller animals; fig trees (*Ficus*) provide critical food for fruit bats, birds, and primates in the dry season when other fruits are scarce; sea otters in the Pacific control sea urchin populations, allowing kelp forests to persist.

Fill in the blank: A _____ species has a disproportionately large effect on its community relative to its biomass; removing it triggers a trophic cascade and causes dramatic changes in community structure.

Pilot questions 3.2

1. Distinguish between interspecific and intraspecific competition.
2. State Gause's competitive exclusion principle and explain its ecological significance.



3. Distinguish between mutualism, commensalism, and parasitism with one Nigerian example of each.
4. Explain what a keystone species is and give one Nigerian example.
5. Define coevolution and give one example.

3.3 The Carbon and Oxygen Cycles

3.3.1 The global carbon cycle

Carbon is the backbone of all organic molecules. The global carbon cycle moves carbon between four main reservoirs: atmosphere (as CO₂ and methane; approximately 860 GtC); biosphere (living organisms and organic matter in soil; approximately 2,300 GtC in soils; approximately 550 GtC in living biomass); hydrosphere (dissolved inorganic and organic carbon in oceans; the largest active reservoir); and lithosphere (fossil fuels, carbonate rocks; the largest total carbon store).

Key carbon cycle processes: photosynthesis removes CO₂ from the atmosphere and fixes it into organic molecules; respiration (by all organisms) releases CO₂ back to the atmosphere; decomposition releases CO₂ from dead organic matter; combustion of fossil fuels and biomass releases stored carbon; ocean uptake of CO₂ (approximately 25-30% of annual human emissions); carbonate formation in marine shells (long-term geological cycling). In Nigeria, the carbon cycle is disrupted by deforestation, savanna burning, and oil flaring in the Niger Delta.

Fill in the blank: Photosynthesis removes CO₂ from the atmosphere and fixes it into organic molecules; _____ (by all organisms) releases CO₂ back to the atmosphere, completing the short-term carbon cycle.



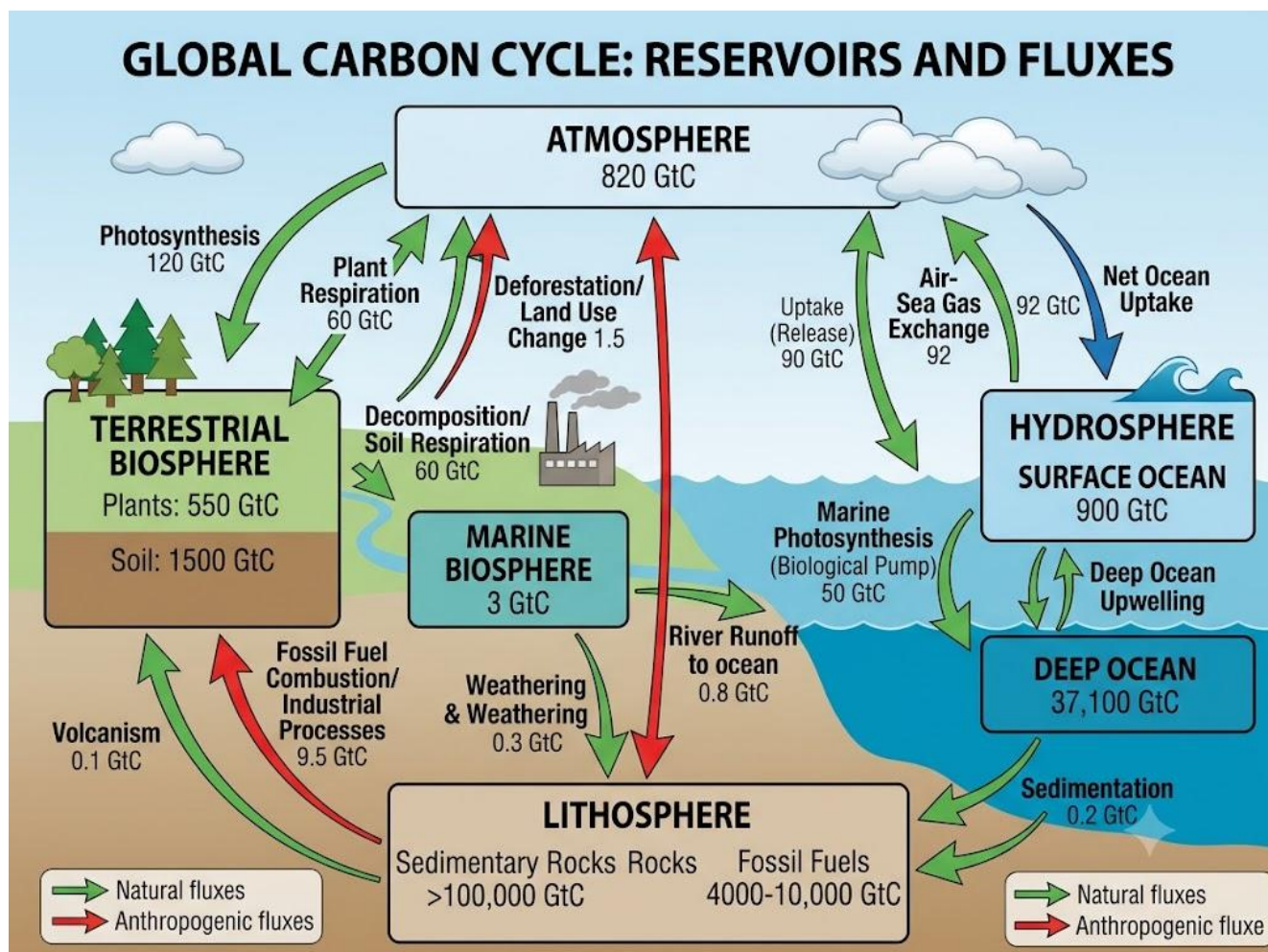


Figure 3.2: Diagram of the global carbon cycle showing reservoirs and fluxes

3.3.2 The oxygen cycle

Oxygen (O_2) makes up approximately 21% of the atmosphere. Oxygen is produced by photosynthesis (light energy splits water molecules: $2H_2O \rightarrow 4H^+ + 4e^- + O_2$) and consumed by aerobic respiration ($C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$). On geological timescales, oxygen also comes from photolysis of water vapour by ultraviolet radiation in the upper atmosphere, but photosynthesis is overwhelmingly the dominant source.

The oxygen cycle is tightly coupled to the carbon cycle: every CO_2 molecule removed by photosynthesis releases one O_2 molecule; every O_2 molecule consumed by respiration returns one CO_2 . Atmospheric O_2 remains nearly constant because photosynthesis and respiration are globally balanced. Dissolved oxygen in water is critical for aquatic life; it decreases with rising



temperature and with nutrient enrichment (eutrophication), which increases the respiration of decomposers.

Fill in the blank: Atmospheric oxygen is maintained at approximately 21 per cent because the global rates of _____ (which produces O₂) and respiration plus combustion (which consume O₂) are in long-term balance.

3.3.3 Human impacts on the carbon and oxygen cycles

Human activities are disrupting the carbon and oxygen cycles at an unprecedented rate. Fossil fuel combustion: burning coal, oil, and natural gas releases approximately 10 GtC per year to the atmosphere, raising atmospheric CO₂ from pre-industrial 280 ppm to over 420 ppm currently; CO₂ is a greenhouse gas that drives global warming. Deforestation: clearing forests removes the largest terrestrial carbon sink; burning or decomposing forest biomass releases stored carbon; deforestation also reduces O₂ production.

In Nigeria, oil flaring in the Niger Delta releases CO₂ and methane continuously; it is one of the highest sources of gas flaring in the world. Savanna burning at the start of each dry season releases large quantities of CO₂ and particulates. Rapid forest clearance for agriculture, logging, and charcoal production in southern Nigeria is reducing the country's carbon sink capacity. Globally, rising CO₂ drives climate change, ocean acidification, and sea level rise, all of which affect Nigerian ecosystems.

Fill in the blank: Fossil fuel combustion has raised atmospheric CO₂ from approximately 280 ppm before industrialisation to over _____ ppm currently; CO₂ is a greenhouse gas that traps heat and drives global warming and climate change.

Pilot questions 3.3

6. Name the four main carbon reservoirs and state which is largest.
7. State the key processes that add CO₂ to the atmosphere and those that remove it.
8. Explain why the oxygen and carbon cycles are coupled.
9. State three ways humans disrupt the carbon cycle in Nigeria.



10. Explain what ocean acidification is and how it relates to the carbon cycle.

3.4 The Nitrogen, Water, and Phosphorus Cycles

3.4.1 The nitrogen cycle

Nitrogen (N_2) makes up 78% of the atmosphere but cannot be used directly by most organisms. The nitrogen cycle has five key processes. Nitrogen fixation: atmospheric N_2 converted to ammonia (NH_3) by free-living bacteria (Azotobacter, Clostridium) and by symbiotic bacteria (Rhizobium in legume root nodules; Frankia in alder root nodules); lightning also fixes small amounts. Nitrification: ammonia oxidised to nitrite (NO_2^-) by Nitrosomonas, then to nitrate (NO_3^-) by Nitrobacter.

Assimilation: plants absorb nitrate and ammonium from the soil and incorporate nitrogen into amino acids and proteins. Ammonification (mineralisation): decomposers (bacteria and fungi) break down dead organic nitrogen into ammonium (NH_4^+); makes nitrogen available again in the soil. Denitrification: anaerobic bacteria (Pseudomonas, Thiobacillus) reduce nitrate back to N_2 gas, returning it to the atmosphere; occurs in waterlogged soils. Nitrogen cycle disruption by humans: synthetic fertiliser production (Haber-Bosch process); nitrogen pollution of waterways causing eutrophication.

Fill in the blank: _____ bacteria in the root nodules of legumes fix atmospheric N_2 into ammonia; this mutualistic relationship is the most important biological nitrogen fixation pathway in agricultural and natural ecosystems.



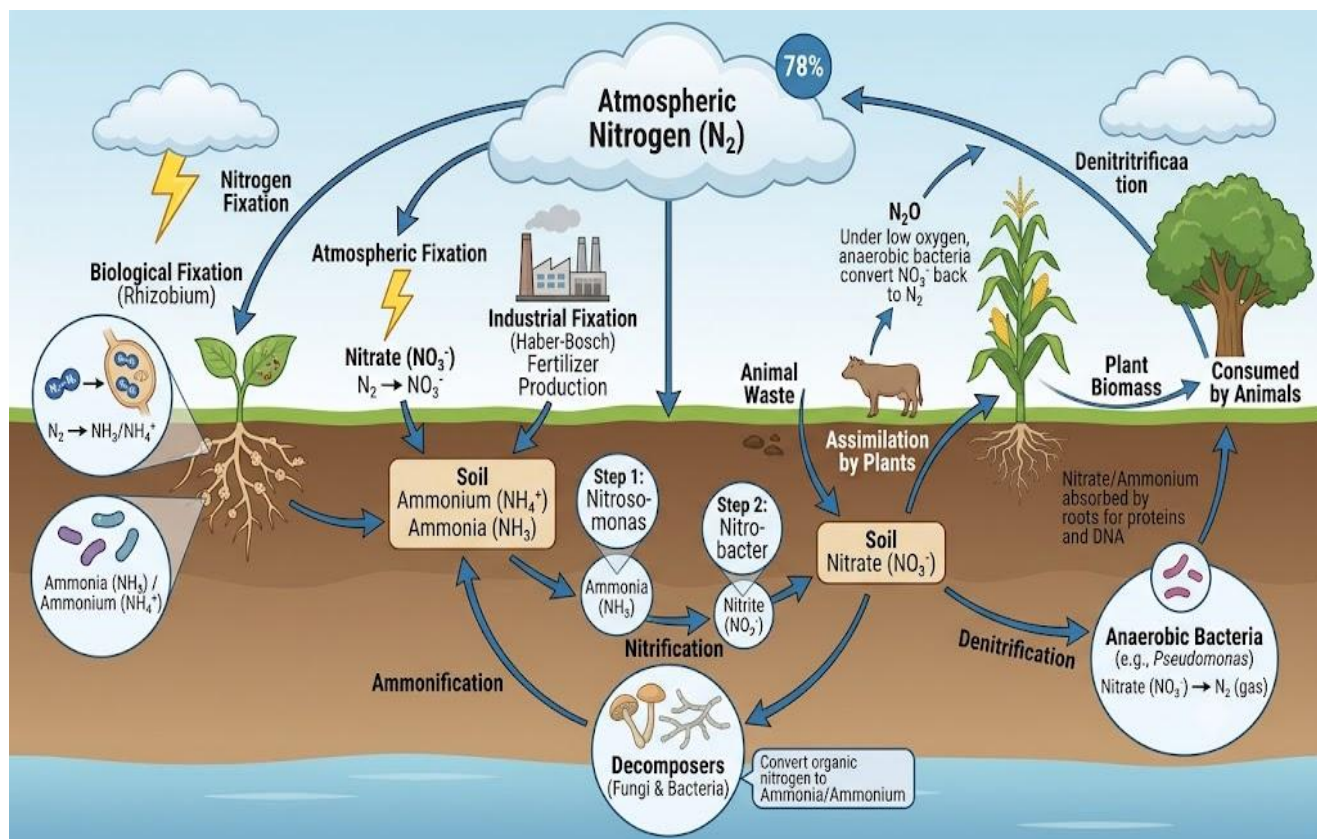


Figure 3.3: Diagram of the nitrogen cycle showing all five key processes

3.4.2 The water (hydrological) cycle

The water cycle describes the continuous movement of water through the atmosphere, land surface, soil, and oceans. Key processes: evaporation (liquid water to water vapour from ocean, lake, and land surfaces; driven by solar energy); transpiration (water vapour released from plant leaves through stomata); evapotranspiration (combined evaporation and transpiration); condensation (water vapour cools and forms clouds); precipitation (rain, snow, hail falling from clouds); surface runoff (water flowing over land into rivers and lakes); infiltration and percolation (water entering and moving through soil); groundwater flow (water moving slowly through aquifers).

In Nigeria, the water cycle is dominated by the seasonal rainfall pattern: the long rains (April to October in the south; July to September in the north) recharge rivers, lakes, wetlands, and groundwater. The harmattan dry season results in very high evapotranspiration that dries out



soils and reduces river flow. Deforestation reduces transpiration (a major component of atmospheric moisture recycling) and increases surface runoff, causing flooding and soil erosion. Loss of vegetation cover in the Sahel contributes to reduced rainfall and desertification.

Fill in the blank: _____ is the combined release of water vapour from soil and water surfaces (evaporation) and from plant leaves through stomata (transpiration); it is the major pathway returning water to the atmosphere from land surfaces.

3.4.3 The phosphorus cycle

Phosphorus (P) is an essential nutrient for ATP, DNA, RNA, and cell membranes; it is often the limiting nutrient in aquatic ecosystems. Unlike carbon and nitrogen, phosphorus has no significant gaseous phase; it cycles only through the lithosphere, soil, water, and biosphere. Geological weathering of phosphate rocks (apatite) releases phosphate ions (H_2PO_4^- , HPO_4^{2-}) into soil and water; this is the primary natural input of phosphorus to ecosystems.

Plant roots absorb inorganic phosphate from the soil; mycorrhizal fungi greatly enhance phosphate uptake by extending the effective root surface area. Organic phosphorus in dead organisms is mineralised by decomposers (bacteria and fungi) back to inorganic phosphate. In aquatic systems, phosphorus released from agricultural runoff drives eutrophication (algal blooms, oxygen depletion, fish kills). Unlike nitrogen, there is no atmospheric reservoir of phosphorus; losses to deep ocean sediments are effectively permanent on human timescales.

Fill in the blank: Unlike the carbon and nitrogen cycles, the phosphorus cycle has no significant _____ phase; phosphorus moves only between rocks, soil, water, and organisms; it is often the limiting nutrient in freshwater and marine ecosystems.

<u>Cycle</u>	<u>Reservoirs</u>	<u>Atmospheric Phase</u>	<u>Key Organisms</u>	<u>Human Impacts</u>
<u>Carbon</u>	Atmosphere (CO_2), oceans, fossil fuels, biomass	Present (CO_2 , CH_4)	Plants (photosynthesis), animals (respiration), decomposers	Burning fossil fuels, deforestation, climate change



<u>Oxygen</u>	Atmosphere (O ₂), water, rocks	Present (O ₂)	Plants (photosynthesis), animals (respiration), microbes	Pollution, reduced forest cover, eutrophication
<u>Nitrogen</u>	Atmosphere (N ₂), soil, biomass	Present (N ₂ , NO _x)	Nitrogen-fixing bacteria, plants, decomposers	Fertilizer use, industrial emissions, acid rain
<u>Water</u>	Oceans, rivers, lakes, glaciers, groundwater	Present (water vapor)	Plants (transpiration), animals, microbes	Dams, irrigation, pollution, climate change altering rainfall
<u>Phosphorus</u>	Rocks, soil, sediments, biomass	Absent (no gaseous phase)	Plants (uptake), animals, decomposers	Mining, fertilizer use, eutrophication of water bodies

Box 3.1: Summary of the five major biogeochemical cycles

Pilot questions 3.4

1. Name the five key processes of the nitrogen cycle.
2. Explain the role of Rhizobium in the nitrogen cycle.
3. Name five key processes of the water cycle.
4. Explain why deforestation disrupts the water cycle.
5. Explain why the phosphorus cycle has no atmospheric phase.



Series Summary

This Series examined the structure and dynamics of ecological communities and the biogeochemical cycles that sustain them. Community properties were described through species richness, evenness, dominance, and trophic structure, with food webs presented as networks of food chains through which energy flows upward at approximately ten percent efficiency per trophic level. The major interspecific interactions were surveyed: competition and competitive exclusion, predation and its role in driving evolutionary arms races, mutualism illustrated by the *Rhizobium*-legume nitrogen-fixing partnership, commensalism, and parasitism. Keystone species were identified as those whose disproportionate influence on community structure far exceeds their numerical abundance, and coevolution was introduced as the process generating tightly coupled species partnerships across these interaction types.

The four major biogeochemical cycles were then examined in turn. The carbon cycle operates across atmospheric, biotic, hydrospheric, and lithospheric reservoirs, with photosynthesis removing carbon dioxide, respiration and decomposition returning it, and fossil fuel combustion, deforestation, and gas flaring disrupting the natural balance. The oxygen cycle was described as intimately coupled to the carbon cycle through photosynthesis and respiration. The nitrogen cycle, driven primarily by microorganisms, was traced through fixation, nitrification, assimilation, ammonification, and denitrification. The water cycle was described through evaporation, transpiration, condensation, precipitation, runoff, and infiltration, and the phosphorus cycle was distinguished from the others by its absence of an atmospheric phase and its susceptibility to disruption through agricultural runoff causing eutrophication of freshwater systems.

Glossary of Terms

- **Ammonification:** the decomposition of organic nitrogen in dead organisms into ammonium (NH_4^+) by bacteria and fungi; makes nitrogen available for uptake by plant roots.
- **Assimilation:** the uptake and incorporation of mineral nutrients (e.g. nitrate, phosphate) into the organic molecules of living organisms.



- **Coevolution:** reciprocal evolutionary change between two interacting species; each acts as a selective force on the other; e.g. predator-prey arms races, flower-pollinator partnerships.
- **Commensalism:** a symbiotic relationship in which one species benefits and the other is neither helped nor harmed; e.g. cattle egrets following Nigerian cattle.
- **Competitive exclusion principle (Gause's Law):** two species with identical niches cannot coexist indefinitely; the inferior competitor will be excluded or forced to shift its niche.
- **Community:** all the populations of different species occupying the same area at the same time and interacting with one another.
- **Denitrification:** the reduction of nitrate (NO_3^-) to nitrogen gas (N_2) by anaerobic bacteria (e.g. *Pseudomonas*) in waterlogged soils; returns nitrogen to the atmosphere.
- **Dominance:** the disproportionate influence of one or a few species in a community by virtue of their high biomass, cover, or abundance.
- **Eutrophication:** the over-enrichment of a water body with nutrients (especially nitrate and phosphate), causing algal blooms, oxygen depletion, and fish kills.
- **Evapotranspiration:** the combined loss of water vapour from land surfaces through evaporation and from plants through transpiration.
- **Food web:** a network of interconnected food chains in a community; represents the complexity of feeding relationships more accurately than a single food chain.
- **Hydrological cycle:** the continuous movement of water through the atmosphere, land surface, soil, and oceans; driven by solar energy and gravity.
- **Infiltration:** the movement of water from the soil surface into the soil; the first step in groundwater recharge.
- **Interspecific competition:** competition between individuals of different species for the same limited resource.
- **Intraspecific competition:** competition between individuals of the same species; generally more intense than interspecific competition because of identical resource requirements.
- **Keystone species:** a species that has a disproportionately large effect on its community relative to its own biomass; its removal triggers dramatic community change (trophic cascade).



- **Mutualism:** a symbiotic relationship in which both species benefit; e.g. Rhizobium in legume root nodules; mycorrhizal fungi and plant roots.
- **Nitrification:** the two-step oxidation of ammonium to nitrite by Nitrosomonas, then to nitrate by Nitrobacter; makes nitrogen available to plants in the form most readily absorbed.
- **Nitrogen fixation:** the conversion of atmospheric N₂ into ammonia (NH₃) by nitrogen-fixing bacteria (Rhizobium, Azotobacter); the entry point of atmospheric nitrogen into the biosphere.
- **Parasitism:** a symbiotic relationship in which the parasite benefits at the expense of the host, which is harmed but not immediately killed.
- **Predation:** an interaction in which one organism (the predator) kills and consumes another (the prey); the predator benefits and the prey is harmed.
- **Pyramid of energy:** a graphic representation of energy stored at each trophic level; always narrows upward; never inverted; the most accurate ecological pyramid.
- **Shannon diversity index (H):** a mathematical measure of community diversity that combines species richness and evenness; $H = -\sum (p_i \times \ln p_i)$ for all species, where p_i is the proportion of individuals of species i .
- **Species evenness:** the degree to which individuals in a community are equally distributed among all species; a community with all species at equal abundance has maximum evenness.
- **Species richness:** the total number of different species present in a defined area or community.
- **Striga:** a genus of parasitic flowering plants (witch weed) that attach to the roots of host crops (maize, sorghum, millet, cowpea) and divert water and nutrients; a major agricultural pest in Nigeria.
- **Trophic cascade:** the indirect effects on lower trophic levels caused by changes in top predator abundance; removing a top predator or keystone species can cause dramatic increases in herbivore populations and corresponding decreases in plant biomass.
- **Trophic level:** the position of an organism in a food chain, defined by the number of energy-transfer steps between it and the primary producers.



Concept Check Questions [Series 3]

Objective Questions

6. A community's _____ is the total number of species present; its evenness is how equally individuals are distributed among those species. (Linked to SLO 3.2)
7. The pyramid of _____ always narrows upward and is never inverted because only approximately 10 per cent of energy is transferred between trophic levels. (Linked to SLO 3.1)
8. Gause's competitive _____ principle states that two species with identical niches cannot coexist indefinitely in the same community. (Linked to SLO 3.3)
9. Photosynthesis removes CO₂ from the atmosphere and fixes it into organic molecules; _____ by all organisms returns CO₂ to the atmosphere. (Linked to SLO 3.5)
10. _____ bacteria in legume root nodules fix atmospheric N₂ into ammonia; this is the most important biological nitrogen fixation pathway in agricultural ecosystems. (Linked to SLO 3.6)

Short-Answer Questions

11. Distinguish between species richness and evenness and explain how they both contribute to species diversity. (Linked to SLO 3.2)
12. Distinguish between mutualism, commensalism, and parasitism with one Nigerian example of each. (Linked to SLO 3.3)
13. Name the five key processes of the nitrogen cycle and state the organisms responsible for each. (Linked to SLO 3.6)
14. State three ways in which humans disrupt the carbon cycle in Nigeria. (Linked to SLO 3.5)
15. Explain why the phosphorus cycle has no atmospheric phase. (Linked to SLO 3.6)

Long-Answer Questions

14. Describe the structure and organisation of ecological communities; define species diversity; and describe the trophic structure of a community including food webs and ecological pyramids. (Linked to SLOs 3.1, 3.2)



15. Describe the major types of species interactions (competition, predation, symbiosis); explain coevolution; and define and give examples of keystone species. (Linked to SLOs 3.3, 3.4)
16. Describe the carbon, oxygen, nitrogen, water, and phosphorus cycles; explain the role of microorganisms in each; and discuss human impacts on the carbon and nitrogen cycles in Nigeria. (Linked to SLOs 3.5, 3.6)

Answers to Concept Check Questions [Series 3]

Objective Questions

1. Richness.
2. Energy.
3. Exclusion.
4. Respiration.
5. Rhizobium.

Short-Answer Questions

1. Species richness is the number of species present; evenness is how equally individuals are distributed among species. High richness and high evenness together produce high diversity; a community dominated by one species has low diversity even if many species are present.
2. Mutualism: both benefit (Rhizobium in cowpea root nodules; both plant and bacterium gain). Commensalism: one benefits, other unaffected (cattle egret eating insects disturbed by cattle hooves). Parasitism: parasite benefits, host harmed (Striga witch weed on maize roots in northern Nigeria).
3. Nitrogen fixation (N_2 to NH_3): Rhizobium and free-living bacteria. Nitrification (NH_3 to NO_3^-): Nitrosomonas then Nitrobacter. Assimilation (NO_3^- absorbed): plant roots.



- Ammonification (organic N to NH_4^+): decomposer bacteria and fungi. Denitrification (NO_3^- to N_2): anaerobic bacteria e.g. *Pseudomonas*.
4. Fossil fuel combustion (oil and gas extraction; oil flaring in Niger Delta); deforestation and forest clearance for agriculture reducing the carbon sink; savanna burning at the start of the dry season releasing CO_2 and particulates.
 5. Phosphorus has no gaseous form at ambient temperatures and pressures; it exists only as solid phosphate minerals in rocks or as dissolved phosphate ions in soil water and aquatic systems; without a gaseous phase it cannot enter the atmosphere and is cycled only through the lithosphere, soil, biosphere, and hydrosphere.

Long-Answer Questions

1. Community: all species in an area interacting with one another. Characteristics: species richness (number of species); evenness (equal distribution); dominance (one species dominates); relative abundance; physical structure (vertical layering, patchiness). Shannon index (H) measures diversity combining richness and evenness. Composition influenced by abiotic conditions, biotic interactions, history, and disturbance. Trophic structure: producers (level 1), primary consumers (level 2), secondary consumers (level 3), tertiary consumers (level 4). Food web: network of interconnected food chains; more realistic than single food chain; most organisms eat multiple prey. Ecological pyramids: numbers (organisms per level; may be inverted e.g. one oak, many caterpillars); biomass (dry mass; usually narrows upward; may invert in aquatic systems with fast phytoplankton turnover); energy (always narrows upward; never inverted; 10% efficiency; most accurate).
2. Competition: both species harmed when sharing a limited resource. Interspecific (between species): cattle vs wild herbivores on savanna grass. Intraspecific (within species): more intense; same niche. Competitive exclusion (Gause's Law): two species with identical niches cannot coexist; one is excluded or shifts its niche. Predation: predator benefits; prey harmed; drives evolution of defences (camouflage, spines, toxins) and predator counter-adaptations; regulates prey populations. Herbivory is a form of predation (plant as prey). Mutualism: both benefit (*Rhizobium* and legumes; mycorrhizal fungi and trees). Commensalism: one benefits, other unaffected (cattle egrets). Parasitism: parasite benefits; host harmed (*Plasmodium*; *Striga*; tapeworms).



Coevolution: reciprocal evolutionary change between interacting species; each is a selective force on the other; predator-prey arms races; flower-pollinator partnerships.

Keystone species: disproportionately large community effect relative to biomass; removal causes trophic cascade; Nigerian examples: elephants opening grassland gaps; fig trees providing dry-season food for frugivores.

3. Carbon cycle: four reservoirs (atmosphere, biosphere, hydrosphere, lithosphere); photosynthesis removes CO₂; respiration, decomposition, and combustion return CO₂; fossil fuel burning adds 10 GtC/year; CO₂ risen from 280 ppm to over 420 ppm; driving global warming. Oxygen cycle: 21% of atmosphere; produced by photosynthesis; consumed by respiration and combustion; coupled to carbon cycle; dissolved O₂ critical for aquatic life; reduced by eutrophication. Human impacts in Nigeria: oil flaring (Niger Delta; continuous CO₂ and methane); deforestation (carbon sink loss); savanna burning (CO₂ and particulates). Nitrogen cycle: fixation (N₂ to NH₃ via Rhizobium and free-living bacteria); nitrification (NH₃ to NO₃⁻ via Nitrosomonas then Nitrobacter); assimilation (plant roots absorb NO₃⁻); ammonification (decomposers return organic N to NH₄⁺); denitrification (anaerobic bacteria return N₂ to atmosphere). Human disruption: synthetic fertilisers via Haber-Bosch process; nitrate runoff causing eutrophication of rivers and lakes. Water cycle: evaporation (solar energy drives water from surfaces); transpiration (plants release water through stomata); condensation (cloud formation); precipitation (rainfall); surface runoff (into rivers); infiltration (into soil and groundwater). Deforestation disrupts water cycle by reducing transpiration, increasing runoff, and causing flooding and soil erosion. Phosphorus cycle: no atmospheric phase; weathering of phosphate rocks releases PO₄ to soil and water; plant roots absorb phosphate (aided by mycorrhizal fungi); decomposers mineralise organic P back to phosphate; eutrophication from agricultural runoff in Nigerian rivers and lakes.



Answers to Pilot Questions [Series 3]

Part 3.1

1. An ecological community is all the populations of different species occupying the same area at the same time and interacting with one another. Four characteristics: species richness (total number of species); species evenness (equality of abundances); dominance (one or few species with greatest biomass or cover); trophic structure (organisation of feeding relationships by trophic level).
2. Species richness is simply the count of species present in a community; two communities can have the same richness but very different diversities. Species evenness describes how equally individuals are distributed among the species; a community where one species accounts for 90% of individuals and nine others share the remaining 10% has low evenness despite having ten species.
3. The pyramid of energy never inverts because energy is always lost at each trophic level transfer; only approximately 10% of the energy stored in one level is converted into biomass at the next, with the remaining 90% lost as metabolic heat and waste; this irreversible energy loss means the energy available always decreases moving up the food chain, producing a pyramid that always narrows at the top.
4. A food chain is a single linear sequence showing energy transfer from producer to successive consumers (e.g. grass → grasshopper → lizard → eagle). A food web is a network of many interconnected food chains within a community; it more accurately represents reality because most organisms eat multiple prey items and are eaten by multiple predators, creating a complex interconnected network of feeding relationships.
5. An invasive species that arrives in a community can outcompete native species for resources, predatorily suppress native species, or alter habitat structure; because native species did not evolve with the invader, they may lack defences against it. Water hyacinth (*Eichhornia crassipes*) in Nigerian waterways, for example, forms dense floating mats that block light to submerged aquatic plants, reduce dissolved oxygen (causing fish kills), obstruct navigation, and displace native aquatic vegetation.



Part 3.2

1. Interspecific competition: competition between individuals of different species for the same limited resource (e.g. Nigerian savanna cattle and kob antelope competing for grass); both species are harmed but usually to unequal degrees. Intraspecific competition: competition between individuals of the same species; generally more intense because individuals have identical resource requirements and niche positions; it regulates population density and drives natural selection for competitive ability within species.
2. Gause's competitive exclusion principle states that two species with identical niches cannot coexist indefinitely in the same community; the superior competitor will ultimately eliminate the inferior one unless the inferior competitor can shift its resource use (niche differentiation) or is kept below competitive exclusion levels by predation or disturbance. Ecological significance: it explains the tendency for species to partition resources (character displacement) and explains why species diversity is maintained by niche differentiation rather than all species competing for identical resources.
3. Mutualism: both species benefit; Nigerian example: Rhizobium bacteria in root nodules of cowpea (*Vigna unguiculata*), fixing N₂ into ammonia for the plant while receiving carbohydrates. Commensalism: one benefits, other unaffected; Nigerian example: cattle egrets (*Bubulcus ibis*) following Fulani cattle herds and feeding on insects disturbed by the cattle's hooves; the bird benefits and the cattle are unaffected. Parasitism: parasite benefits; host harmed; Nigerian example: *Striga hermonthica* (witch weed) attaching to maize and sorghum roots and extracting water and nutrients, severely reducing crop yields.
4. A keystone species has a disproportionately large effect on its community relative to its own biomass; removing it causes a trophic cascade (dramatic restructuring of the community). Nigerian example: the African elephant (*Loxodonta africana*) in savanna ecosystems; elephants uproot trees and create open grassland gaps that are then colonised by grasses and used by smaller herbivores; without elephants, bush encroachment reduces open habitat and the species diversity that depends on it.
5. Coevolution is reciprocal evolutionary change in two interacting species, each acting as a selective pressure on the other's evolution. Example: the fig tree (*Ficus*) and fig wasp



(Agaonidae) relationship; figs can only be pollinated by specific fig wasp species that enter the enclosed fig inflorescence (syconium) to lay eggs; the wasp larvae develop inside the fig and adult wasps carry fig pollen to the next tree; this tight mutualistic coevolution has produced extreme morphological matching between each fig species and its specific wasp pollinator over millions of years.

Part 3.3

1. The four main carbon reservoirs: atmosphere (CO₂ and CH₄; approximately 860 GtC); biosphere (living biomass approximately 550 GtC; soil organic matter approximately 2,300 GtC); hydrosphere (dissolved inorganic and organic carbon in oceans; the largest active reservoir at approximately 38,000 GtC); lithosphere (fossil fuels, carbonate rocks; the largest total carbon store; approximately 100,000,000 GtC in carbonate rocks). The lithosphere is the largest overall.
2. Processes adding CO₂ to the atmosphere: aerobic respiration (all organisms); decomposition of dead organic matter (bacteria and fungi); combustion of fossil fuels; burning of biomass (forests, savanna). Processes removing CO₂ from the atmosphere: photosynthesis (primary removal; all photoautotrophs); ocean uptake as dissolved CO₂ and bicarbonate (approximately 25-30% of human emissions); formation of carbonate minerals in marine shells (long-term geological removal).
3. The oxygen and carbon cycles are coupled because they share the same key processes in opposite directions: photosynthesis simultaneously removes CO₂ from the atmosphere and adds O₂ ($6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$); aerobic respiration simultaneously consumes O₂ and returns CO₂ to the atmosphere ($\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O}$); the net fluxes of CO₂ and O₂ in the atmosphere therefore move together in equal and opposite amounts.
4. Three human disruptions to the carbon cycle in Nigeria: (1) Oil and gas flaring in the Niger Delta continuously releases CO₂ and methane, making Nigeria one of the highest gas-flaring countries in the world. (2) Deforestation and forest clearance for agriculture, logging, and charcoal production in southern Nigeria removes the forest carbon sink and releases stored carbon from biomass and soil. (3) Annual dry-season savanna



burning across the guinea and sudan savanna zones releases large amounts of CO₂ and carbon-containing particulates into the atmosphere.

5. Ocean acidification occurs when atmospheric CO₂ dissolves in seawater to form carbonic acid ($\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \rightarrow \text{H}^+ + \text{HCO}_3^-$); the increase in H⁺ concentration (acidity) reduces seawater pH. This is directly driven by rising atmospheric CO₂ from fossil fuel combustion; ocean pH has fallen from 8.2 to approximately 8.1 since industrialisation. It harms marine organisms (corals, molluscs, echinoderms) that build calcium carbonate shells and skeletons, because acidic water dissolves CaCO₃, threatening reef ecosystems and shellfish fisheries.

Part 3.4

1. The five key processes: (1) Nitrogen fixation: N₂ converted to NH₃ by Rhizobium (symbiotic) and free-living bacteria (Azotobacter, Clostridium); (2) Nitrification: NH₃ oxidised to NO₂⁻ by Nitrosomonas, then to NO₃⁻ by Nitrobacter; (3) Assimilation: plants absorb NO₃⁻ and NH₄⁺ and incorporate N into amino acids; (4) Ammonification: decomposers break down organic N in dead matter into NH₄⁺; (5) Denitrification: anaerobic bacteria (Pseudomonas) reduce NO₃⁻ back to N₂.
2. Rhizobium bacteria form a mutualistic symbiosis with the roots of leguminous plants (cowpea, soyabean, groundnut, Acacia); the bacteria colonise root cells and form root nodules; within the nodules, the enzyme nitrogenase reduces atmospheric N₂ to ammonia (NH₃); the plant converts this ammonia into amino acids; in return, the plant provides the bacterium with carbohydrates (sugars) from photosynthesis and O₂-buffering by leghaemoglobin; this process converts biologically unavailable N₂ into plant-usable nitrogen without requiring synthetic fertiliser.
3. Five key water cycle processes: (1) Evaporation (water vaporises from ocean, lake, and soil surfaces using solar energy); (2) Transpiration (water vapour released through plant stomata); (3) Condensation (water vapour rises, cools, and forms clouds and mist); (4) Precipitation (water falls as rain, dew, or dew onto land and ocean); (5) Surface runoff (water flows over land surface into streams and rivers when infiltration is exceeded by rainfall intensity).



4. Deforestation disrupts the water cycle in three main ways: (1) it reduces transpiration, a major pathway returning water vapour to the atmosphere; less atmospheric moisture reduces local and regional rainfall; (2) it exposes bare soil, which reduces infiltration capacity and increases surface runoff, causing flash flooding, accelerated soil erosion, and silting of rivers; (3) it eliminates the intercepting canopy that slows rainfall reaching the soil surface, so heavy rainfall hits the soil directly and compacts it, further reducing infiltration and increasing runoff.
5. Phosphorus exists naturally only as phosphate ions (PO_4^{3-} , HPO_4^{2-} , H_2PO_4^-) in solid mineral form (apatite rock) or dissolved in soil water and aquatic systems; it has no stable gaseous compound that can accumulate significantly in the atmosphere at normal temperatures and pressures; unlike nitrogen (which can exist as N_2 , NO , N_2O gases) or carbon (CO_2 , CH_4), phosphorus cannot enter a gaseous atmospheric phase; therefore it must cycle through strictly physical and biological pathways: rock weathering, soil uptake by plants, consumption by animals, and mineralisation by decomposers.



References and Attributions [Series 3]

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Figures, Plates, Tables, and Boxes

- Figure 3.1: Nigerian guinea savanna food web diagram Attribution: AI generated. Suggested OER search string: "Nigerian guinea savanna food web diagram producers consumers trophic levels decomposers energy flow OER".
- Figure 3.2: Global carbon cycle diagram Attribution: AI generated. Suggested OER search string: "global carbon cycle diagram reservoirs atmosphere biosphere hydrosphere lithosphere photosynthesis respiration decomposition OER".
- Figure 3.3: Nitrogen cycle diagram Attribution: AI generated. Suggested OER search string: "nitrogen cycle diagram fixation nitrification assimilation ammonification denitrification Rhizobium OER".
- Box 3.1: Summary comparison of five biogeochemical cycles Attribution: AI generated. Suggested OER search string: "biogeochemical cycles comparison table carbon oxygen nitrogen water phosphorus reservoirs human impacts OER box".



Course code: BIO 202

Course title: Introductory Ecology

Course credit load: 2 Units

Series 4: Natural Destruction and Community Dynamics

- **Part 4.1: Natural Disturbances**

- Sub Part 4.1.1: Definition and types of natural disturbance
- Sub Part 4.1.2: Fire as an ecological disturbance
- Sub Part 4.1.3: Flood, drought, and other disturbances

- **Part 4.2: Ecological Succession**

- Sub Part 4.2.1: Definition and types of succession
- Sub Part 4.2.2: Primary succession
- Sub Part 4.2.3: Secondary succession

- **Part 4.3: The Climax Community**

- Sub Part 4.3.1: Concept of the climax community
- Sub Part 4.3.2: Factors that prevent or delay climax
- Sub Part 4.3.3: Gap dynamics and patch mosaic

- **Part 4.4: Human-Induced Disturbance and Conservation**

- Sub Part 4.4.1: Deforestation and habitat fragmentation
- Sub Part 4.4.2: Pollution and its ecological effects
- Sub Part 4.4.3: Conservation strategies in Nigeria



Introduction

Communities are not static: they change continuously in response to disturbance, succession, and long-term environmental change. Natural disturbances such as fire, flood, and drought reset communities to earlier successional stages, while ecological succession describes the predictable sequence of community change that follows. Understanding these dynamics is essential for managing Nigeria's ecosystems and biodiversity.

This Series covers natural disturbances (fire, flood, drought), the two types of ecological succession (primary and secondary), the climax community concept, factors preventing climax, gap dynamics, and the major human-induced disturbances affecting Nigerian ecosystems: deforestation, habitat fragmentation, and pollution, with an introduction to conservation strategies.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 4.1** define disturbance and describe the major types of natural disturbance and their ecological effects (Linked to Part 4.1),
- **SLO 4.2** explain the role of fire as an ecological disturbance in Nigerian ecosystems (Linked to Part 4.1),
- **SLO 4.3** define ecological succession and distinguish between primary and secondary succession (Linked to Part 4.2),
- **SLO 4.4** describe the climax community concept and explain the factors that prevent or delay climax (Linked to Part 4.3),
- **SLO 4.5** describe the ecological effects of deforestation, habitat fragmentation, and pollution in Nigeria (Linked to Part 4.4), and
- **SLO 4.6** describe major conservation strategies applicable to Nigeria (Linked to Part 4.4).



4.1 Natural Disturbances

4.1.1 Definition and types of natural disturbance

A disturbance is a discrete event that disrupts the structure of an ecosystem, community, or population, and changes the availability of resources. Disturbances vary in frequency, intensity, spatial extent, and predictability. They are a normal and necessary part of ecosystem dynamics: disturbances create gaps, release resources, and reset communities to earlier successional stages, maintaining diversity across the landscape.

Types of natural disturbance in Nigeria: fire (annual dry-season burns across savanna; covered in 4.1.2); flood (seasonal river flooding of the Niger-Benue floodplain; coastal storm surge); drought (prolonged rainfall failure; critical in the Sahel); wind (harmattan storms; isolated tornado events); pest and disease outbreaks (locust swarms; epidemic tree disease); volcanoes and earthquakes (rare in Nigeria; more relevant to East African rift ecosystems).

Fill in the blank: A _____ is a discrete event that disrupts community structure and changes resource availability; disturbances maintain biodiversity by creating gaps and resetting communities to earlier successional stages.

4.1.2 Fire as an ecological disturbance

Fire is the single most important natural disturbance in Nigerian savanna ecosystems. Dry-season fires (November to March) are driven by dried grass biomass, low humidity, and the harmattan wind. Fire effects: kills above-ground parts of shrubs and young trees, favouring grasses with below-ground regeneration points; releases nutrients rapidly as ash; removes the previous year's litter, exposing bare soil; stimulates the germination of fire-adapted seeds.

Ecologically, fire maintains the savanna biome: without fire, guinea savanna grassland progressively succeeds to woodland and eventually closed forest. The frequency and intensity of fire are critical; low-frequency, high-intensity fires cause more tree mortality than frequent, low-intensity burns. In Nigerian national parks (Yankari, Kainji Lake), fire management is a key



conservation tool. Some forest tree species (e.g. *Isoperlinia* and *Daniellia*) have thick bark that protects them from fire; these are the dominant trees in fire-maintained woodland savanna.

Fill in the blank: Dry-season fire in Nigerian savanna prevents _____ by killing above-ground woody vegetation; without fire, savanna progressively succeeds toward closed forest over decades.

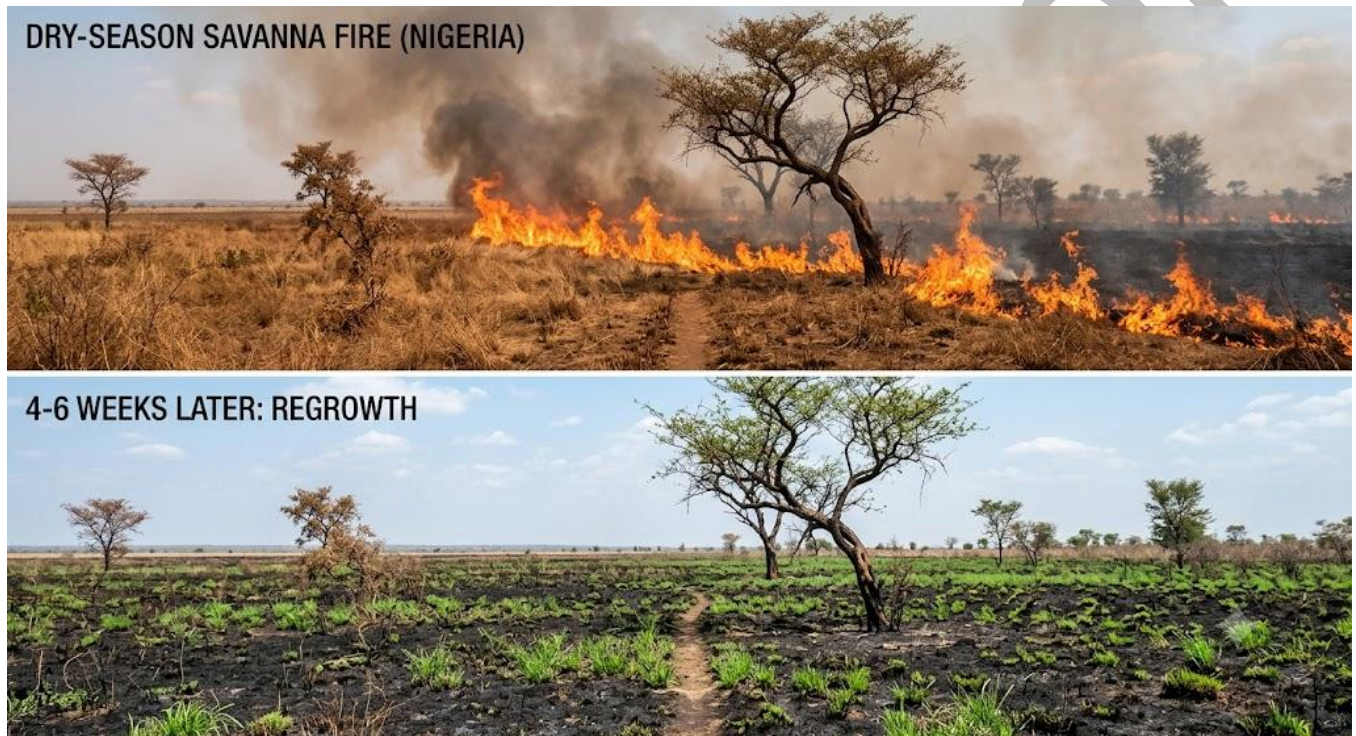


Figure 4.1: Photographs showing savanna fire and post-fire regeneration in Nigeria

4.1.3 Flood, drought, and other disturbances

Flood: seasonal flooding of the Niger and Benue river floodplains deposits nutrient-rich silt, recharges wetlands, and drives the growth of floodplain crops in Nigeria. Extreme floods destroy crops and infrastructure but also flush accumulated salts and create habitat variation. The Hadejia-Nguru Wetlands depend on annual flooding; reduced flooding from upstream dams (Kainji, Jebba, Shiroro) has significantly reduced their extent and productivity.



Drought: prolonged below-average rainfall causes vegetation dieback, crop failure, and livestock mortality; in the Sahel, multi-year droughts trigger desertification and human displacement. The 1972-1974 and 1983-1984 Sahelian droughts caused catastrophic agricultural losses across northern Nigeria. Wind disturbances: the harmattan causes physical desiccation of vegetation and increases fire risk; rare windstorms topple large trees and create canopy gaps that initiate secondary succession. Pest outbreaks: locust swarms (*Schistocerca gregaria*) devastate crops and natural vegetation.

Fill in the blank: Reduced flooding of the Hadejia-Nguru Wetlands caused by upstream _____ (Kainji, Jebba, Shiroro) has significantly reduced the extent and productivity of this critical wetland ecosystem.

Pilot questions 4.1

1. Define disturbance and state four types that occur in Nigeria.
2. Explain three ecological effects of dry-season fire in savanna.
3. Explain why fire is necessary to maintain the savanna biome.
4. Describe the ecological effects of seasonal flooding of the Niger floodplain.
5. Explain how upstream dams affect the Hadejia-Nguru Wetlands.

4.2 Ecological Succession

4.2.1 Definition and types of succession

Ecological succession is the predictable, directional change in the species composition of a community over time, following a disturbance or the colonisation of a new habitat. Each stage (seral stage) modifies the environment in ways that make it more suitable for the next community and less suitable for itself, driving community change. The process continues until a relatively stable community (the climax) is reached.

Two types: Primary succession begins on bare substrate with no soil or organic matter (e.g. bare rock after lava flow, sand dune, newly exposed lake bed); it is slow because soil must be built



from scratch. Secondary succession begins on a site that already has soil and sometimes a seed bank, following disturbance that removes the existing vegetation (e.g. abandoned farmland, burned forest, cleared savanna); it is faster because soil and propagule sources already exist.

Fill in the blank: _____ succession begins on bare substrate with no pre-existing soil; it is slower than secondary succession because soil must be built from scratch by pioneer organisms.

4.2.2 Primary succession

Primary succession on bare rock proceeds through recognisable seral stages. Pioneer stage: lichens (algae and fungi in symbiosis) colonise bare rock, secreting acids that begin weathering; mosses follow. Soil-building stage: lichens and mosses trap windblown particles and organic matter; thin soil develops; small annuals and grasses colonise. Herb and shrub stage: deeper soil supports herbaceous plants and shrubs; increasing organic matter and soil depth.

Woodland stage: shrubs give way to pioneer trees (e.g. Acacia species in savanna; Cecropia in rainforest); shade suppresses early pioneers. Climax stage: the community is dominated by long-lived species suited to the prevailing climate; canopy closes; pioneer species disappear. On Nigerian sand dunes (e.g. along the Lake Chad shore and the Borno dunes), similar primary succession stages can be observed, from bare sand colonised by annual grasses to eventual savanna or woodland.

Fill in the blank: _____ are the pioneer organisms of primary succession on bare rock; their symbiotic combination of algae and fungi allows them to colonise bare surfaces, and their acid secretions begin the weathering of rock into soil particles.



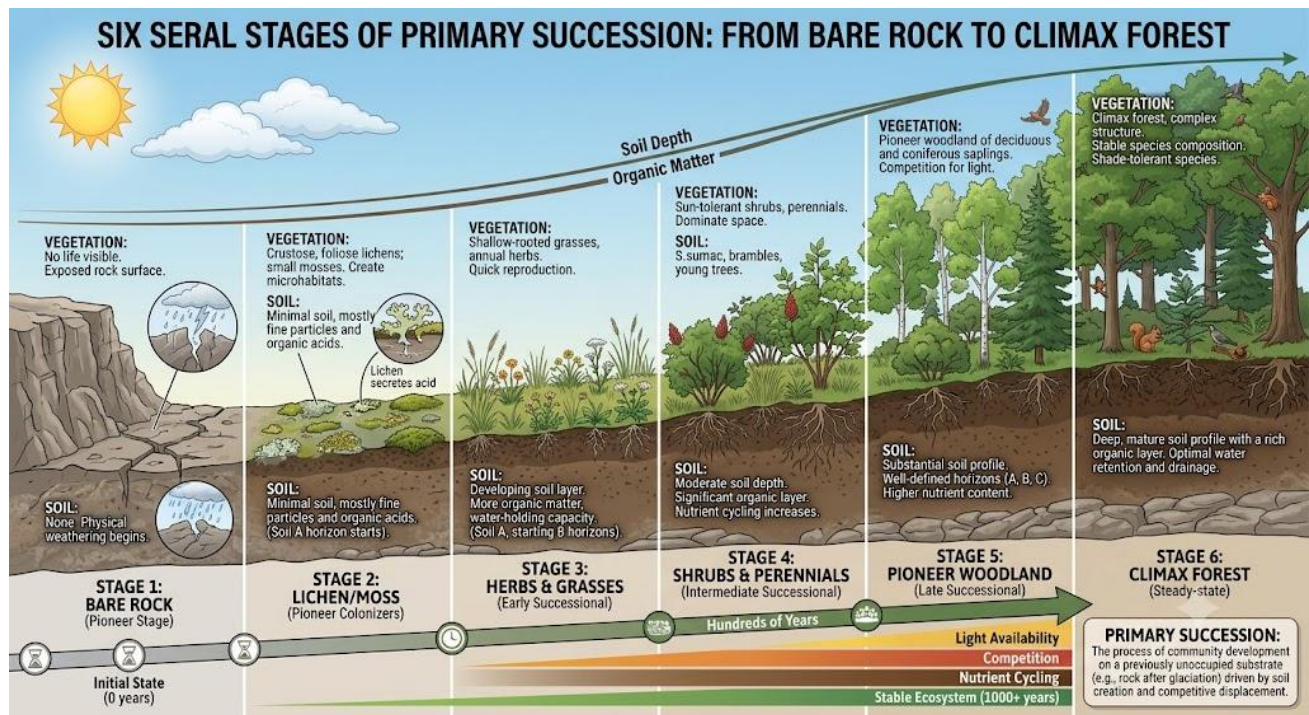


Figure 4.2: Diagram of primary succession from bare rock to climax woodland

4.2.3 Secondary succession

Secondary succession is faster than primary succession because soil, seeds, and vegetative propagules survive the disturbance. Classic example: abandoned farmland in southern Nigeria. Year 1 to 2: annual weeds and grasses (*Imperata cylindrica*, *Chromolaena odorata*) colonise. Year 3 to 5: perennial grasses, shrubs, and pioneer trees (e.g. *Musanga cecropioides* in forest zone). Year 5 to 15: secondary forest with fast-growing light-demanding tree species.

Year 15 to 50+: forest canopy closes; shade-tolerant species establish in the understorey; pioneer species die off as light decreases. Over decades to centuries, the community gradually approaches the climax forest composition for that area. In Nigerian savanna, a burned or cleared area returns through grass to shrubland and eventually woodland in 10 to 30 years depending on rainfall. Secondary succession is the dominant dynamic in Nigeria's highly fragmented landscapes where farming, logging, and fire frequently reset communities.



Fill in the blank: In secondary succession on abandoned farmland in southern Nigeria, _____ (e.g. *Chromolaena odorata*) typically colonise within the first two years, followed by pioneer trees and eventually secondary forest over decades.

Pilot questions 4.2

1. Define ecological succession and explain what drives each seral stage to change.
2. Distinguish between primary and secondary succession.
3. Describe the seral stages of primary succession on bare rock.
4. Describe secondary succession on abandoned farmland in Nigeria.
5. Explain why secondary succession is faster than primary succession.

4.3 The Climax Community

4.3.1 Concept of the climax community

The climax community is the final, relatively stable stage of ecological succession in a given region, dominated by species best adapted to the prevailing long-term climate. Frederic Clements (1916) proposed the monoclimate theory: a single regional climax community (the climatic climax) determined solely by climate. This was later refined: ecologists now recognise that multiple stable states (polyclimax) may exist within the same climate depending on soil, topography, and disturbance history.

The climax is characterised by: long-lived, slow-growing, shade-tolerant dominant species; high species diversity in forest climaxes; high biomass and deep soil; a closed canopy (in forest); and slow rates of net community change. It is not truly static; it is dynamic at a fine scale through gap dynamics and small-scale disturbances. In Nigeria, the climatic climax for the southern rainforest zone is tropical moist forest; for the Middle Belt it is guinea savanna woodland; for the north it is Sudan savanna or Sahel.



Fill in the blank: Frederic Clements proposed the _____ theory that each region has a single climatic climax community; this has been refined to a polyclimax view recognising multiple stable endpoints influenced by soil, topography, and disturbance.

4.3.2 Factors that prevent or delay climax

Several factors prevent a community from reaching climax: Recurring disturbance: frequent fire, flooding, or grazing resets the community to earlier seral stages and prevents the establishment of climax species; many Nigerian savanna areas are maintained at a fire sub-climax well below their potential forest climax. Edaphic limitations: poor soils (waterlogged, nutrient-deficient, or shallow) may prevent the development of the climax vegetation that climate alone would predict.

Chronic grazing: heavy livestock grazing selectively removes palatable plants, maintains an open sward, and suppresses tree regeneration; the resulting plagioclimax is maintained by grazing rather than reflecting the natural climatic climax. Human activities: deforestation, cultivation, and urbanisation permanently prevent or delay climax communities from re-establishing. Biotic resistance: invasive species (e.g. *Chromolaena odorata*) can arrest succession by outcompeting native pioneer and mid-successional species.

Fill in the blank: A _____ is a community maintained below its potential climatic climax by persistent human activities such as grazing, burning, or cultivation; it is stable only as long as the deflecting activity continues.

4.3.3 Gap dynamics and patch mosaic

Even in a mature climax forest, individual trees die and fall, creating canopy gaps. Gap dynamics is the process by which individual tree falls create local patches of high light intensity within an otherwise shaded forest; these gaps are colonised by light-demanding pioneer species; as the gap closes, shade-tolerant species gradually replace them. Gap dynamics allows pioneer species to coexist with climax species and maintains species diversity within mature forests.

At the landscape scale, the result is a patch mosaic: a heterogeneous landscape with patches in different successional stages, reflecting the different times since disturbance at each location.

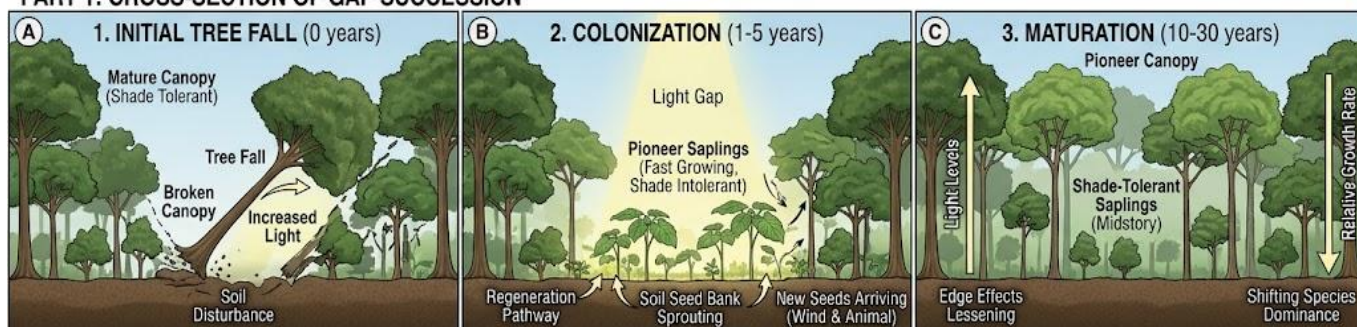


The patch mosaic maximises overall landscape diversity (beta diversity) by providing habitats for species of different successional stages simultaneously. In Nigerian forests, natural tree fall gaps, logged areas, and farmed patches create a mosaic that supports both forest-interior and gap-specialist species.

Fill in the blank: _____ dynamics describes the colonisation of light gaps created by falling trees in a mature forest; it allows pioneer species to persist within climax forest and maintains high species diversity.

FOREST GAP DYNAMICS: A CROSS-SECTION AND PATCH MOSAIC DIAGRAM

PART 1: CROSS-SECTION OF GAP SUCCESSION



PART 2:

BIRD'S EYE PATCH MOSAIC MAP: TROPICAL FOREST LANDSCAPE

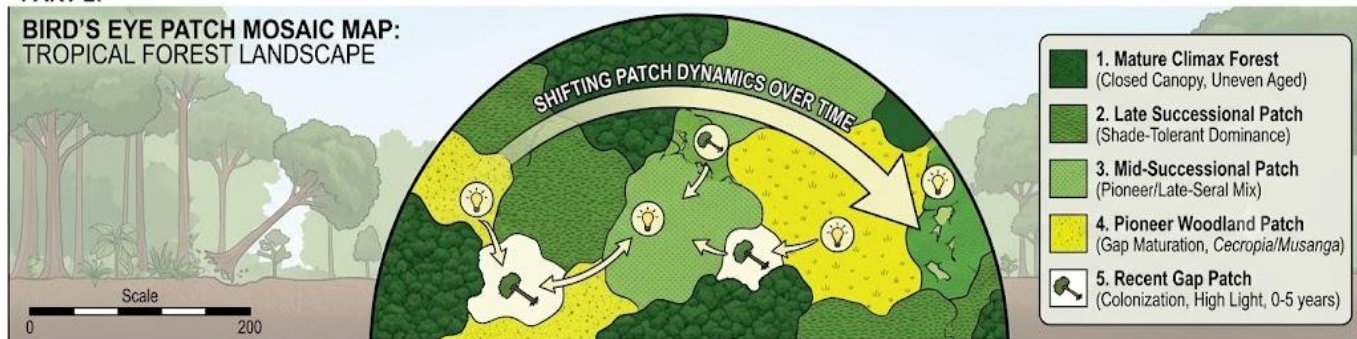


Figure 4.3: Diagram of gap dynamics and patch mosaic in a Nigerian tropical forest

Pilot questions 4.3

1. Define the climax community and distinguish between monocl climax and polyclimax theories.
2. Explain what a plagioclimax is and give a Nigerian example.
3. State four factors that can prevent a community from reaching its climatic climax.
4. Explain what gap dynamics is and state its ecological importance.



5. Define a patch mosaic and explain how it promotes landscape biodiversity.

4.4 Human-Induced Disturbance and Conservation

4.4.1 Deforestation and habitat fragmentation

Nigeria has one of the highest deforestation rates in Africa. Between 1990 and 2015, Nigeria lost approximately 96% of its primary forest cover; only fragments remain in Cross River and Edo States. Causes: agricultural clearance (especially slash-and-burn for subsistence farming); commercial timber extraction; charcoal production; urban expansion. Ecological consequences: loss of biodiversity; disruption of water and carbon cycles; soil erosion; reduced rainfall (local-scale deforestation reduces evapotranspiration).

Habitat fragmentation occurs when continuous habitat is divided into smaller, isolated patches by roads, farms, or urban development. Fragmentation effects: smaller patches support fewer species (species-area relationship); edge effects increase (habitat edges have different microclimates; interior-specialist species are displaced); populations become isolated, reducing genetic diversity and increasing extinction risk; dispersal between patches is reduced (barrier effect). In Nigeria, the fragmented forests of the south are severely affected; forest-interior species (forest elephants, chimpanzees, white-throated monkeys) are particularly vulnerable.

Fill in the blank: Habitat _____ divides continuous habitat into smaller isolated patches; it reduces species richness (species-area relationship), increases edge effects, and isolates populations, increasing local extinction risk.



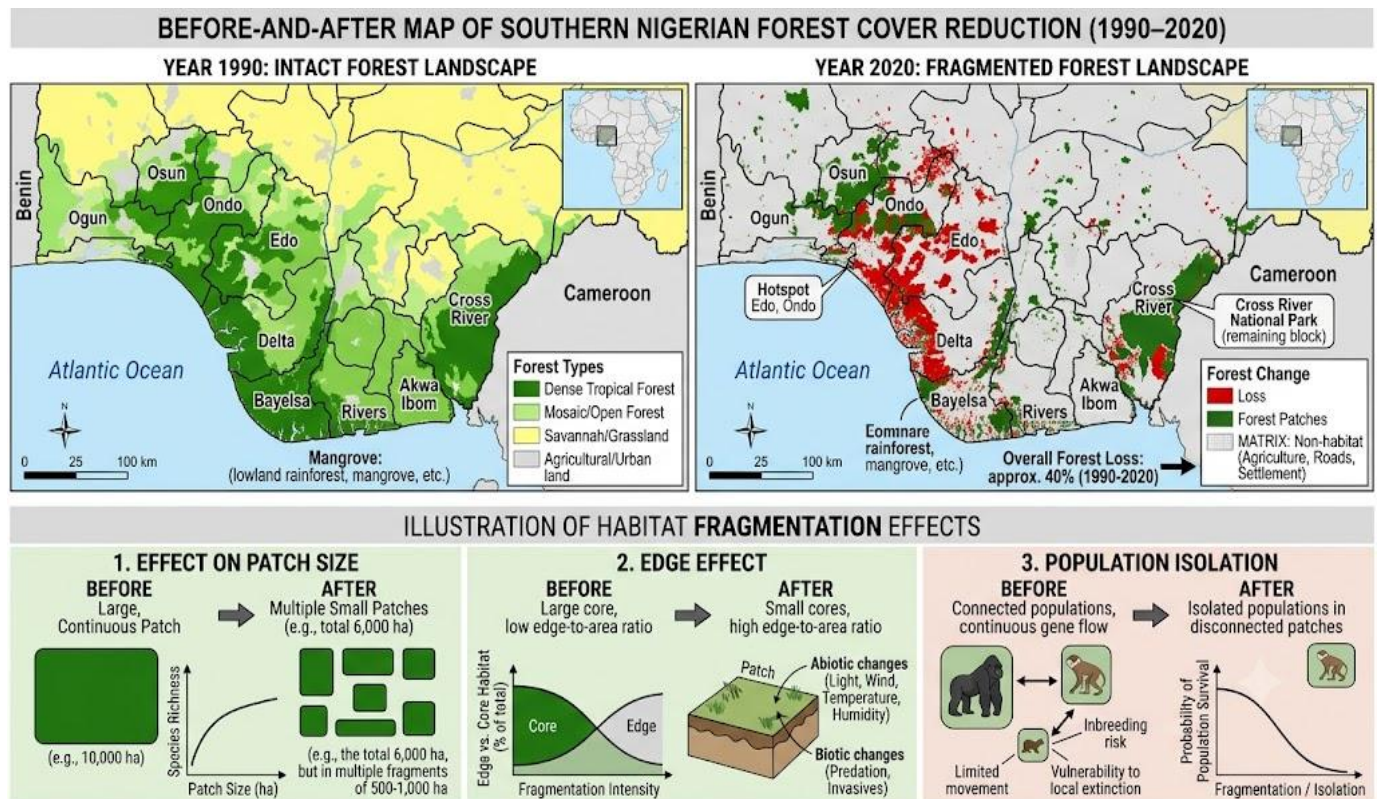


Figure 4.4: Map and diagram showing deforestation and habitat fragmentation in southern Nigeria

4.4.2 Pollution and its ecological effects

Oil pollution in the Niger Delta is the most severe ecological disaster in Nigerian history. Decades of oil spills (from pipeline ruptures, oil bunkering, and well blowouts) have contaminated mangrove soils, freshwater, and farmland. Oil smothers mangrove pneumatophores (blocking gas exchange), kills invertebrates and fish, prevents mangrove regeneration, and contaminates fish consumed by local communities. UNEP (2011) estimated it would take 25 to 30 years and over \$1 billion to remediate Ogoniland alone.

Water pollution: industrial and domestic effluents, agricultural runoff (fertilisers and pesticides), and untreated sewage entering Nigerian rivers and lakes cause eutrophication, oxygen depletion, and loss of aquatic biodiversity. Air pollution: burning of fossil fuels, biomass burning, and gas flaring release CO₂, methane, SO₂, and particulates; Nigeria is one of the world's largest sources



of gas flaring. Soil pollution: overuse of agrochemicals and illegal dumping of industrial waste degrade soil health and reduce agricultural productivity.

Fill in the blank: Oil spills in the Niger Delta smother mangrove _____ (aerial roots), blocking gas exchange to submerged roots; the oil also kills invertebrates and fish and prevents mangrove regeneration for decades.

4.4.3 Conservation strategies in Nigeria

Nigeria has several categories of protected areas: National Parks (Yankari, Kainji Lake, Cross River, Gashaka-Gumti, Chad Basin, Old Oyo; managed by NCWS); Game Reserves; Forest Reserves (managed by state governments); and Strict Nature Reserves. Protected areas cover approximately 4% of Nigeria's land surface; this is below the Convention on Biological Diversity target of 17%. Key legislation: the National Parks Act; the Endangered Species Act; the Environmental Impact Assessment Act.

Other conservation strategies: ex-situ conservation (zoos, botanic gardens, seed banks; e.g. Ibadan Botanic Garden, University of Ibadan); community-based conservation (local communities as stewards of forest resources; REDD+ programmes); ecological restoration (replanting degraded mangroves in the Niger Delta; afforestation of degraded savanna); biodiversity corridors (linking isolated forest patches to allow wildlife movement); environmental education and awareness. Effective conservation in Nigeria requires addressing the drivers of habitat loss: poverty, land tenure insecurity, and governance failures.

Fill in the blank: Nigeria's National Parks are managed by the _____ (National Conservation and Wildlife Service); they currently cover approximately 4 per cent of Nigeria's land surface, below the global Convention on Biological Diversity target of 17 per cent.

<u>Threat</u>	<u>Affected Habitat</u>	<u>Ecological Effect</u>	<u>Conservation Response</u>
<u>Deforestation</u>	Tropical rainforests, savannas	Loss of biodiversity, soil erosion, climate change	Afforestation programs, forest reserves, community forestry



<u>Oil Pollution</u>	Niger Delta wetlands, mangroves	Water contamination, fish kills, habitat destruction	Environmental clean-ups, stricter regulation, community monitoring
<u>Gas Flaring</u>	Niger Delta, coastal zones	Air pollution, acid rain, greenhouse gas emissions	Enforcement of anti-flaring laws, adoption of gas capture technologies
<u>Overgrazing</u>	Savannas, semi-arid zones	Desertification, loss of vegetation cover	Controlled grazing, reforestation, rotational grazing systems
<u>Urbanization</u>	Wetlands, forests, savannas	Habitat fragmentation, pollution, reduced green spaces	Urban planning, creation of green belts, environmental impact assessments
<u>Unsustainable Farming</u>	Savannas, semi-arid zones	Soil degradation, reduced fertility, erosion	Promotion of sustainable agriculture, soil conservation practices
<u>Climate Change</u>	All habitats	Altered rainfall, flooding, drought, species migration	Climate adaptation strategies, renewable energy, conservation awareness

Box 4.1: Summary of major threats to Nigerian ecosystems and corresponding conservation responses

Pilot questions 4.4

1. State four causes and three ecological consequences of deforestation in Nigeria.
2. Explain three effects of habitat fragmentation on biodiversity.
3. Describe the ecological effects of oil pollution in the Niger Delta.
4. Name four types of protected area in Nigeria and state the national body that manages national parks.
5. State three conservation strategies other than protected areas that are applicable in Nigeria.



Series Summary

This Series examined natural disturbances and the successional dynamics they drive in ecological communities. Fire, flood, and drought were established as the principal natural disturbance agents in Nigerian ecosystems: fire maintains the grass-tree balance of savanna and prevents forest succession; seasonal flooding recharges wetlands such as the Hadejia-Nguru system, whose degradation following upstream dam construction illustrates the ecological cost of disrupted flood regimes; and drought drives the progressive desertification encroaching on the Sahel. Ecological succession was then covered as the directional change in community composition over time, distinguishing primary succession on bare substrate, beginning with lichen pioneers and proceeding slowly, from secondary succession on previously occupied disturbed soil, which proceeds more rapidly through weed and grass pioneers toward the climax community. The climax was defined as the stable endpoint determined by regional climate, with the concept of plagioclimax introduced for communities held at earlier successional stages by persistent fire, grazing, or human activity.

Human disturbances and their conservation responses formed the second major theme. Nigeria has lost approximately 96 percent of its primary forest since 1990, with habitat fragmentation isolating populations in reduced patches across the landscape. The Niger Delta faces compounding pressures from oil pollution and gas flaring, while eutrophication threatens freshwater systems. Against this backdrop, conservation responses were surveyed: national parks including Yankari, Cross River, and Gashaka-Gumti, protected areas covering approximately four percent of national land, afforestation programmes, the REDD+ carbon finance mechanism, biodiversity corridors, and community-based conservation approaches that engage local people as active partners in habitat and wildlife protection.

Glossary of Terms

- **Biodiversity corridor:** a strip of habitat connecting two isolated patches of wildlife habitat; allows animals to move between patches for feeding, breeding, and genetic exchange.



- **Chromolaena odorata:** an invasive shrub (Siam weed) that rapidly colonises disturbed land in southern Nigeria; it can arrest succession by outcompeting native pioneer species.
- **Climatic climax:** the final stable community determined entirely by the prevailing climate; the endpoint of succession in an area not subject to persistent disturbance.
- **Climax community:** the relatively stable, self-perpetuating final stage of ecological succession; dominated by long-lived species best adapted to the prevailing climate.
- **Deflecting factor:** any agent (fire, grazing, cultivation) that prevents a community from reaching its climatic climax and maintains it at an earlier successional stage (plagioclimax).
- **Disturbance:** a discrete event that disrupts community structure and changes resource availability; types include fire, flood, drought, windstorm, and disease outbreak.
- **Ecological succession:** the predictable, directional change in species composition of a community over time, following a disturbance or the colonisation of new habitat.
- **Edge effect:** the phenomenon whereby the boundary (edge) between two habitats has a different microclimate and species composition from either habitat interior; fragmentation increases edge-to-interior ratio.
- **Eutrophication:** over-enrichment of a water body with nutrients, causing dense algal growth, oxygen depletion, and loss of aquatic biodiversity; driven by agricultural runoff.
- **Gap dynamics:** the cycle of canopy tree death, gap formation, pioneer colonisation, and eventual gap closure that maintains species diversity within mature forests.
- **Habitat fragmentation:** the division of a continuous habitat into smaller, isolated patches by roads, farms, or urban development; reduces species richness and isolates populations.
- **Monoclimax theory:** Clements's proposal that each region converges on a single climax community determined by climate; largely replaced by the polyclimax view.
- **Patch mosaic:** a landscape composed of patches in different successional stages, reflecting different disturbance histories; maximises landscape-level species diversity.
- **Pioneer species:** the first colonisers of a disturbed or bare site; typically r-selected; fast-growing; short-lived; tolerant of harsh conditions; e.g. lichens on rock, annual weeds on abandoned farmland.



- **Plagioclimax:** a community held below its potential climatic climax by a persistent deflecting factor such as grazing, fire, or cultivation.
- **Polyclimax theory:** the view that multiple stable climax communities can exist within the same climate, depending on soil type, topography, water availability, and disturbance history.
- **Primary succession:** ecological succession beginning on bare substrate with no pre-existing soil or organic matter; slow; pioneer organisms are lichens and mosses.
- **REDD+:** Reducing Emissions from Deforestation and Forest Degradation; an international climate mechanism that compensates developing countries for conserving forests.
- **Secondary succession:** ecological succession on a site that already has soil and sometimes a seed bank, following disturbance; faster than primary succession.
- **Seral stage:** one of the transitional communities in a successional sequence, from pioneer to climax; also called a sere.
- **Species-area relationship:** the ecological principle that larger habitat patches support more species; the basis for the prediction that habitat fragmentation reduces species richness.
- **Trophic cascade:** indirect effects on lower trophic levels caused by changes at higher levels; removing a top predator or keystone species causes dramatic changes throughout the community.

Concept Check Questions [Series 4]

Objective Questions

1. A _____ is a discrete event that disrupts community structure and changes resource availability; disturbances maintain diversity by creating gaps and resetting communities. (Linked to SLO 4.1)
2. Dry-season fire in Nigerian savanna prevents _____ by killing above-ground woody vegetation and maintaining the grass-tree balance. (Linked to SLO 4.2)
3. _____ succession begins on bare substrate with no pre-existing soil; pioneer organisms include lichens and mosses that begin weathering rock. (Linked to SLO 4.3)



4. A _____ is a community held below its potential climatic climax by persistent grazing, burning, or cultivation. (Linked to SLO 4.4)
5. Habitat _____ divides continuous habitat into smaller isolated patches, reducing species richness and isolating populations. (Linked to SLO 4.5)

Short-Answer Questions

1. Explain three ecological effects of dry-season fire in Nigerian savanna. (Linked to SLO 4.2)
2. Distinguish between primary and secondary succession. (Linked to SLO 4.3)
3. Define the climax community and explain the polyclimax theory. (Linked to SLO 4.4)
4. State three effects of habitat fragmentation on biodiversity. (Linked to SLO 4.5)
5. State three conservation strategies applicable to Nigeria beyond protected areas. (Linked to SLO 4.6)

Long-Answer Questions

1. Describe the major types of natural disturbance in Nigeria; explain the ecological role of fire; and describe the effects of flood and drought. (Linked to SLOs 4.1, 4.2)
2. Define ecological succession; describe the seral stages of primary succession; and describe secondary succession on abandoned farmland in southern Nigeria. (Linked to SLO 4.3)
3. Explain the climax community concept; describe factors preventing climax; explain gap dynamics; and describe the ecological effects of deforestation, fragmentation, and pollution in Nigeria with relevant conservation strategies. (Linked to SLOs 4.4, 4.5, 4.6)

Answers to Concept Check Questions [Series 4]

Objective Questions

1. Disturbance.
2. Forest succession (woodland encroachment).



3. Primary.
4. Plagioclimax.
5. Fragmentation.

Short-Answer Questions

- (1) Prevents forest succession by killing above-ground woody vegetation, maintaining open grassland. (2) Releases nutrients as ash, stimulating rapid post-fire grass growth. (3) Removes litter, exposing bare soil and stimulating the germination of fire-adapted seeds.
- (2) Primary succession begins on bare substrate with no soil; pioneers are lichens and mosses; it is slow because soil must be built from scratch. Secondary succession begins on disturbed soil that already has organic matter and seeds; pioneers are annual weeds and grasses; it is faster.
- (3) The climax community is the relatively stable final stage of succession dominated by species best adapted to the regional climate. The polyclimax theory recognises that multiple stable endpoints may exist within the same climate, depending on soil type, topography, disturbance history, and water availability.
- (4) Smaller patches support fewer species (species-area relationship); populations become isolated, reducing gene flow and increasing local extinction risk; increased edge-to-interior ratio displaces interior-specialist species into unsuitable edge microclimate.
- (5) Ecological restoration (mangrove replanting in Niger Delta; savanna afforestation); biodiversity corridors (linking isolated forest patches for wildlife movement); community-based conservation and REDD+ (incentivising local communities to protect forests).

Long-Answer Questions

- (1) Disturbance: a discrete event disrupting community structure and changing resource availability; maintains biodiversity by creating gaps. Types in Nigeria: fire (dominant in savanna; annual dry-season burns); flood (seasonal Niger-Benue floodplain inundation; deposits nutrient-rich silt; recharges wetlands; reduced by upstream dams at Kainji,



Jebba, Shiroro); drought (Sahelian droughts 1972-74, 1983-84; crop failure; desertification); wind (harmattan desiccation; increases fire risk; rare windstorms topple trees); pest outbreaks (locust swarms). Fire: kills above-ground woody vegetation (favouring grasses with underground regeneration points); releases nutrients as ash; stimulates fire-adapted seed germination; removes litter; prevents forest succession; maintained by dried grass biomass, low humidity, and harmattan winds; fire frequency and intensity determine tree mortality; fire management in national parks (Yankari, Kainji Lake). Flood: nutrient-rich silt deposition; recharges Hadejia-Nguru Wetlands and floodplain agriculture; extreme floods destroy crops; reduced upstream flooding severely degraded wetlands. Drought: vegetation dieback; crop failure; livestock mortality; Sahel desertification; human displacement.

- (2) Succession: predictable, directional community change over time, each seral stage modifying the environment to favour the next. Primary succession on bare rock: pioneer stage (lichens then mosses colonise; acid weathering begins soil formation); herb stage (thin soil supports annuals and grasses); shrub stage (deeper soil; shrubs establish); pioneer woodland (fast-growing trees: Acacia in savanna; Musanga in forest); climax (shade-tolerant species dominate; canopy closes; pioneers excluded). On Nigerian dunes (Lake Chad shore): bare sand colonised by annual grasses, then perennial grasses and Acacia, eventually savanna woodland. Secondary succession on abandoned farmland in southern Nigeria: Year 1-2: annual weeds and grasses (*Imperata cylindrica*, *Chromolaena odorata*); Year 3-5: perennial grasses, shrubs, pioneer trees (*Musanga cecropioides*); Year 5-15: secondary forest canopy (light-demanding pioneer trees); Year 15-50+: canopy closes, shade-tolerant species establish, pioneers die off; over decades approaches climax forest. Faster than primary succession because soil, seeds, and vegetative propagules already present.
- (3) Climax community: final, relatively stable stage of succession; dominated by long-lived, shade-tolerant species best adapted to regional climate; high biomass; closed canopy; slow net change. Monoclimax: one regional climax per climate (Clements). Polyclimax: multiple stable states within same climate depending on soil, topography, disturbance. Nigerian climaxes: tropical moist forest (south); guinea savanna woodland (Middle Belt); Sudan/Sahel savanna (north). Factors preventing climax: recurring fire (fire sub-climax in savanna); edaphic limitations (poor soils prevent tree



establishment); chronic grazing (plagioclimax maintained by livestock overgrazing); human activities (deforestation, cultivation, urbanisation); invasive species (Chromolaena arrests succession). Gap dynamics: individual tree falls create light gaps; pioneers colonise; shade-tolerants gradually replace them; maintains pioneer-climax species coexistence; creates patch mosaic across landscape. Human disturbances: deforestation (Nigeria lost approximately 96% of primary forest since 1990; causes: agricultural clearance, logging, charcoal, urban expansion; consequences: biodiversity loss, carbon release, erosion, reduced rainfall); fragmentation (smaller patches, edge effects, population isolation, reduced gene flow); oil pollution in Niger Delta (smothers pneumatophores blocking gas exchange; kills invertebrates and fish; prevents mangrove regeneration; UNEP: 25-30 years to remediate Ogoniland); gas flaring (CO₂ and methane; air pollution); eutrophication (agricultural runoff; algal blooms; fish kills). Conservation: national parks managed by NCWS (Yankari, Cross River, Gashaka-Gumti, Kainji Lake, Chad Basin, Old Oyo); cover approximately 4% of Nigeria vs 17% CBD target; ecological restoration (Niger Delta mangrove; savanna afforestation); biodiversity corridors; REDD+; community-based conservation; ex-situ (botanic gardens, seed banks); environmental education.

Answers to Pilot Questions [Series 4]

Part 4.1

(1) A disturbance is a discrete event that disrupts community structure and changes resource availability; it maintains biodiversity by creating gaps and resetting communities to earlier successional stages. Four types in Nigeria: fire (annual dry-season savanna burns); flood (seasonal Niger-Benue floodplain inundation); drought (prolonged Sahelian rainfall failure); pest outbreaks (locust swarms, *Schistocerca gregaria*).

(1) Fire kills above-ground parts of shrubs and young trees, favouring grasses with below-ground regeneration points, which resprout rapidly. (2) Fire releases nutrients locked in the previous year's dry grass biomass as ash, providing a



rapid nutrient pulse that stimulates the post-rain grass flush. (3) Fire removes accumulated litter and stimulates the germination of fire-adapted seeds, initiating the new growing season.

- (2) In the absence of fire, guinea savanna progressively succeeds toward woodland and eventually closed forest because shrubs and trees gradually grow taller and close the canopy, shading out grasses. Annual dry-season fires kill the above-ground parts of trees and shrubs, preventing them from reaching the height needed to suppress the grass layer and maintaining the open structure that defines savanna.
- (3) Seasonal flooding of the Niger floodplain deposits nutrient-rich silt that fertilises floodplain farmland, sustaining the livelihoods of millions of Nigerian farmers growing flood-recession crops; it also recharges floodplain wetlands, maintains fish breeding grounds, and provides water for livestock. Extreme floods can destroy crops and infrastructure but even these deposit valuable new silt.
- (4) Upstream hydroelectric dams (Kainji 1968, Jebba 1985, Shiroro 1990) on the River Niger impound water and reduce the peak flood discharge downstream; the reduced flood pulse has dramatically decreased the area of the Hadejia-Nguru Wetlands that is inundated each wet season; smaller floods support fewer fish, waterbirds, and aquatic plants and reduce the area available for flood-recession farming, undermining the livelihoods of local communities who depend on the wetland.

Part 4.2

1. Ecological succession is the predictable, directional change in species composition of a community over time, following disturbance or colonisation. Each seral stage drives change to the next because the dominant organisms modify the environment (building soil, increasing shade, changing humidity) in ways that favour the next community over themselves; pioneer species create conditions that allow mid-successional species to establish, which in turn are replaced by late-successional species, until the climax is reached.
2. Primary succession begins on bare substrate with no pre-existing soil or organic matter (e.g. bare rock, sand dune); it is slow because soil must be built by pioneer organisms



- from scratch. Secondary succession begins on disturbed substrate that already has soil, organic matter, and usually seeds or vegetative propagules (e.g. abandoned farmland, burned forest); it is faster because the essential growing medium already exists.
3. Seral stages of primary succession on bare rock: (1) Pioneer stage: lichens colonise bare rock and secrete acids that weather rock; mosses establish in the organic film; (2) Herb stage: windblown soil particles and decomposed lichen matter form thin soil that supports annual herbs and small grasses; (3) Shrub stage: deeper soil accumulation allows perennial grasses and shrubs to establish; (4) Pioneer woodland: fast-growing, light-demanding trees (Acacia in savanna zone) establish; (5) Climax: slow-growing, shade-tolerant canopy trees dominate; soil is deep and humus-rich; pioneer species are absent.
 4. Secondary succession on abandoned farmland in southern Nigeria: Years 1-2 (annual weeds and grasses colonise rapidly from seeds; *Imperata cylindrica* and *Chromolaena odorata* are typical; these are fast-growing species that disperse well into open ground); Years 3-5 (perennial grasses and shrubs establish; pioneer trees such as *Musanga cecropioides* begin to appear; grass cover declines under increasing shade); Years 5-15 (secondary forest canopy forms; pioneer trees dominate; shade-tolerant species establish in the understorey; light-demanding species decline); Years 15-50+ (canopy closes; shade-tolerant species of late secondary and climax forest gradually dominate; biodiversity approaches that of mature forest).
 5. Secondary succession is faster because: (1) soil is already present with its physical structure, water-holding capacity, mineral nutrients, and organic matter; pioneer organisms do not need to build soil from bare rock over decades; (2) a seed bank of dormant native plant seeds often persists in the soil after the disturbance, allowing rapid re-establishment of multiple plant species simultaneously; (3) vegetative propagules (roots, rhizomes, tubers, stumps) of many plants survive the disturbance and resprout immediately, providing an instant food and shade resource that speeds the succession process.



1. The climax community is the final, relatively stable stage of ecological succession dominated by long-lived species best adapted to the prevailing regional climate. Monoclimax theory (Clements, 1916): each region converges on a single climatic climax determined solely by climate; only one endpoint is possible regardless of disturbance history or soil. Polyclimax theory: multiple stable climax communities can exist within the same climate depending on soil type, topography, water availability, and disturbance history; this is the widely accepted modern view.
2. A plagioclimax is a community maintained below its potential climatic climax by a persistent deflecting factor such as grazing, burning, or cultivation; it is stable only as long as the deflecting factor continues. Nigerian example: the heavily grazed Sahel and Sudan savanna grasslands of northern Nigeria, where overgrazing by cattle, sheep, and goats prevents the establishment of trees and shrubs that would naturally colonise; remove the grazing pressure and woody species begin to establish within a few years.
3. Four factors that can prevent a community reaching its climatic climax: (1) Recurring fire (annual savanna burns reset the community to the grass stage before woody plants reach reproductive maturity); (2) Edaphic limitations (waterlogged soils, shallow soils over hardpan laterite, or nutrient-deficient soils prevent the growth of climax tree species even when climate would support them); (3) Chronic overgrazing (livestock selectively remove palatable plant species and compact soil, suppressing tree regeneration and maintaining a degraded grassland plagioclimax); (4) Human land use (continuous cultivation, charcoal production, logging, or urbanisation permanently prevents climax vegetation from re-establishing).
4. Gap dynamics is the process by which individual tree deaths and falls create local openings (gaps) in the canopy of a mature forest; these gaps allow sunlight to reach the forest floor, creating conditions for light-demanding pioneer species to establish and grow. Ecological importance: gap dynamics allows pioneer species to coexist with climax species within the same forest, maintaining higher species diversity than a perfectly uniform canopy would support; it continuously generates patches of different successional stages within the forest.
5. A patch mosaic is a landscape composed of patches at different successional stages reflecting different histories of disturbance. Each patch differs in age since last disturbance, species composition, vegetation height, and light availability. The mosaic



promotes landscape-level (beta) diversity because it simultaneously provides habitat for species characteristic of different successional stages: open-habitat species in recently disturbed patches; mid-successional species in intermediate patches; forest-interior species in mature patches; this heterogeneity supports more total species than a uniformly mature landscape would.

Part 4.4

1. Four causes of deforestation in Nigeria: (1) agricultural clearance (slash-and-burn subsistence farming; clearing for commercial plantations); (2) commercial timber extraction (logging of valuable hardwoods: Iroko, African mahogany, Obeche); (3) charcoal production (trees felled for charcoal used as domestic cooking fuel); (4) urban expansion (city growth consuming peri-urban forest and farmland). Three ecological consequences: loss of species (plants, animals, fungi, microorganisms dependent on forest habitats); disruption of the carbon and water cycles (release of stored carbon; reduced evapotranspiration and local rainfall); severe soil erosion (tree roots hold soil; bare soil is rapidly eroded by high-intensity tropical rainfall).
2. Three effects of habitat fragmentation: (1) Reduced species richness: smaller patches support fewer species due to the species-area relationship ($S = cA^z$); species requiring large home ranges (elephants, large predators) cannot persist in small isolated patches. (2) Increased edge effects: fragmentation increases the ratio of edge to interior; edge microclimate (higher light, temperature extremes, wind penetration, desiccation) is unsuitable for forest-interior specialist species (e.g. forest elephants, chimpanzees, white-throated monkeys in southern Nigeria) which retreat toward patch centres. (3) Population isolation: fragmentation cuts dispersal corridors between patches; populations become genetically isolated, reducing gene flow; inbreeding depression reduces fitness and adaptive capacity; isolated small populations are more vulnerable to local extinction from stochastic events (disease, drought).
3. Ecological effects of oil pollution in the Niger Delta: oil smothers mangrove pneumatophores (aerial roots of *Avicennia*) and prop roots (of *Rhizophora*), blocking gas exchange to submerged anaerobic roots, causing root death and tree mortality; oil



coats the bodies of invertebrates (fiddler crabs, periwinkles, mudskippers), killing them and disrupting the food web; toxic polycyclic aromatic hydrocarbons (PAHs) in crude oil contaminate fish and shellfish, making them unsafe for human consumption and reducing catches for local fishing communities; oil prevents mangrove seedling establishment by coating the mud surface, preventing regeneration for decades after a spill; oil pollution of freshwater sources contaminates drinking water and crops irrigated from contaminated streams.

4. Four types of protected area: National Parks (managed by NCWS: Yankari, Cross River, Gashaka-Gumti, Kainji Lake, Chad Basin, Old Oyo); Game Reserves (managed by state governments; permit regulated hunting); Forest Reserves (state forestry departments; primarily managed for sustainable timber); Strict Nature Reserves (no exploitation permitted). National parks are managed by NCWS (National Conservation and Wildlife Service, formerly NCFR/Nigerian Conservation Foundation framework).
5. Three conservation strategies beyond protected areas: (1) Ecological restoration: replanting degraded mangroves in the Niger Delta using locally collected propagules of *Rhizophora* and *Avicennia*; afforestation of degraded savanna with native *Acacia* and shea butter tree species; these activities recover ecosystem services (carbon sequestration, coastal protection) and biodiversity. (2) Biodiversity corridors: establishing strips of native vegetation connecting isolated forest fragments in Cross River and Edo States to allow wildlife (forest elephants, chimpanzees) to move between patches for feeding, breeding, and genetic exchange. (3) REDD+ and community-based conservation: paying local communities to protect and sustainably manage forests under international REDD+ (Reducing Emissions from Deforestation and Forest Degradation) schemes, which transfer carbon finance from developed countries to forest communities in Nigeria.



References and Attributions [Series 4]

Textual References (Books and External Sources)

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Figures, Plates, Tables, and Boxes

- Figure 4.1: Nigerian savanna fire photograph and post-fire regeneration Attribution: AI generated. Suggested OER search string: "Nigerian savanna dry season fire photograph post-fire grass regeneration OER".
- Figure 4.2: Primary succession from bare rock to climax woodland diagram Attribution: AI generated. Suggested OER search string: "primary succession stages bare rock lichen moss herbs shrubs woodland climax diagram OER".
- Figure 4.3: Forest gap dynamics and patch mosaic diagram Attribution: AI generated. Suggested OER search string: "forest gap dynamics patch mosaic diagram tropical forest pioneers gap succession OER".
- Figure 4.4: Deforestation and habitat fragmentation map and diagram Attribution: AI generated. Suggested OER search string: "deforestation habitat fragmentation southern Nigeria forest loss map diagram species area relationship OER".
- Box 4.1: Major threats to Nigerian ecosystems and conservation responses Attribution: AI generated. Suggested OER search string: "Nigerian ecosystem threats conservation responses table deforestation oil pollution gas flaring OER box".

Course code: BIO 202



Course title: Introductory Ecology

Course credit load: 2 Units

Series 5: Population Factors and Ecological Change

- **Part 5.1: Population Characteristics**

- Sub Part 5.1.1: Definition and properties of a population
- Sub Part 5.1.2: Population density and dispersion
- Sub Part 5.1.3: Age structure and sex ratio

- **Part 5.2: Population Growth**

- Sub Part 5.2.1: Exponential (geometric) growth
- Sub Part 5.2.2: Logistic growth and carrying capacity
- Sub Part 5.2.3: Density-dependent and density-independent factors

- **Part 5.3: Life History Strategies and Population Regulation**

- Sub Part 5.3.1: r-selected and K-selected species
- Sub Part 5.3.2: Predator-prey cycles
- Sub Part 5.3.3: Metapopulations

- **Part 5.4: Ecological Change and Global Issues**

- Sub Part 5.4.1: Climate change and its ecological effects
- Sub Part 5.4.2: Invasive species and biodiversity loss
- Sub Part 5.4.3: Sustainable use of ecological resources in Nigeria



Introduction

A population is a group of individuals of the same species in the same area. Populations are the units of evolution and the basic ecological level at which resources are competed for, reproduction occurs, and numbers change through time. Understanding what regulates population size is central to both ecological theory and the practical management of wildlife and crop pests.

This final Series covers population properties (density, dispersion, age structure), growth models (exponential and logistic), regulatory factors, life history strategies, predator-prey cycles, metapopulations, and closes the course with major global ecological issues: climate change, invasive species, biodiversity loss, and sustainable resource use in Nigeria.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 5.1** describe the key properties of populations and explain how they are measured (Linked to Part 5.1),
- **SLO 5.2** describe exponential and logistic population growth models and explain the concept of carrying capacity (Linked to Part 5.2),
- **SLO 5.3** distinguish between density-dependent and density-independent population regulating factors (Linked to Part 5.2),
- **SLO 5.4** distinguish between r-selected and K-selected life history strategies and describe predator-prey cycles (Linked to Part 5.3),
- **SLO 5.5** explain the metapopulation concept (Linked to Part 5.3), and
- **SLO 5.6** describe the ecological effects of climate change and invasive species; and explain the principles of sustainable resource use in Nigeria (Linked to Part 5.4).



5.1 Population Characteristics

5.1.1 Definition and properties of a population

A population is a group of individuals of the same species living in the same geographic area at the same time and potentially interbreeding. Populations have properties that individual organisms do not: birth rate (natality), death rate (mortality), immigration, and emigration.

Population size changes when: births plus immigration exceed deaths plus emigration (growth); or deaths plus emigration exceed births plus immigration (decline).

Key population parameters: population size (N): total number of individuals; population density: number of individuals per unit area or volume; birth rate (b): number of births per individual per unit time; death rate (d): number of deaths per individual per unit time; intrinsic rate of natural increase (r): $r = b - d$; when r is positive the population grows; when r is zero it is stable; when r is negative it declines.

Fill in the blank: The intrinsic rate of natural increase (r) equals birth rate minus _____ rate; when r is positive the population grows; when r is zero the population is stable.

5.1.2 Population density and dispersion

Population density is the number of individuals per unit area (e.g. per km² or per hectare). It is measured by: direct counting (census); mark-recapture (capture a sample, mark and release, recapture a second sample; the Lincoln-Petersen method estimates $N = n_1 \times n_2 / m$, where n_1 is first sample, n_2 is second sample, and m is number of marked individuals in second sample); quadrat sampling (count individuals in randomly placed sample plots); transect sampling.

Population dispersion (spatial pattern): how individuals are distributed in space. Three patterns: random (individuals are placed independently of one another; rare in nature; e.g. seeds dispersed by wind in open habitat); uniform (individuals are regularly spaced; results from strong intraspecific competition for space; e.g. territorial birds; trees in a managed plantation); clumped (individuals aggregate in groups; the most common pattern; results from resource patches, social



behaviour, or clonal reproduction; e.g. cattle around a water point; termite colonies; clonal grasses).

Fill in the blank: _____ dispersion, in which individuals are aggregated in groups, is the most common pattern in nature; it results from resource patchiness, social behaviour, or clonal reproduction.

5.1.3 Age structure and sex ratio

Age structure is the distribution of individuals among different age classes (young, pre-reproductive; reproductive adults; post-reproductive). It determines the future trajectory of population growth. A population with a large proportion of young individuals (broad base pyramid) is growing rapidly; one with equal proportions (rectangular) is stable; one with more older individuals (narrow base) is declining. Age pyramids are widely used to visualise human and wildlife population trends.

Sex ratio: the proportion of males to females in a population. Most wildlife populations have a 1:1 sex ratio at birth; this may change with age due to differential mortality. In many species, females are limiting because each female can produce offspring with multiple males, but each male can only fertilise a limited number of females. Hunting or poaching that targets large males (trophy hunting) can skew sex ratios and reduce reproductive rates in hunted populations.

Fill in the blank: A population age pyramid with a broad base (many young individuals) indicates a _____ population; a narrow base (few young individuals) indicates a declining population.



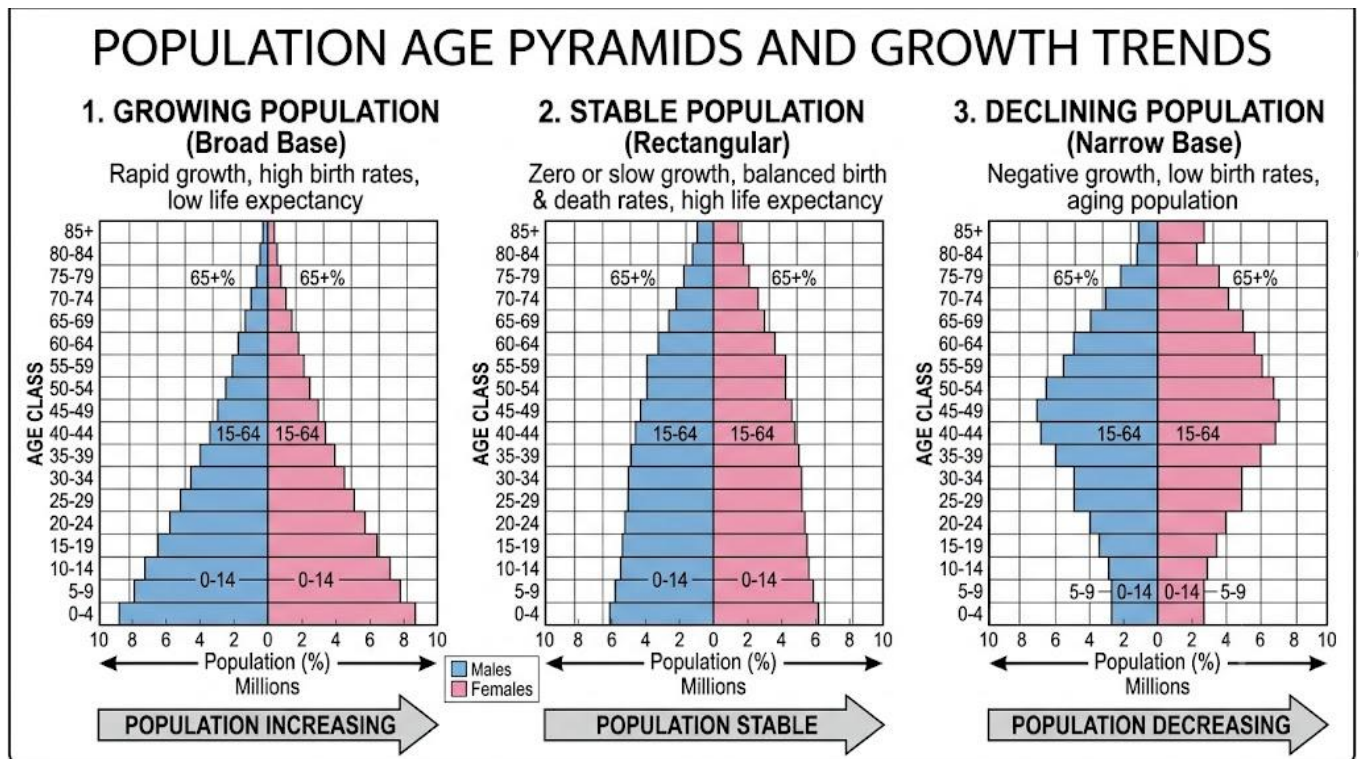


Figure 5.1: Population age pyramids showing growing, stable, and declining populations

Pilot questions 5.1

1. Define a population and list four key population parameters.
2. Describe the mark-recapture method of estimating population density.
3. Describe the three patterns of population dispersion with one example of each.
4. Explain how age structure predicts the future growth of a population.
5. Explain how trophy hunting of large males can affect population growth.



5.2 Population Growth

5.2.1 Exponential (geometric) growth

Exponential growth occurs when resources are unlimited and every individual reproduces at the same rate regardless of population size. The equation is: $dN/dt = rN$, where N is population size, t is time, and r is the intrinsic rate of increase. This produces a J-shaped growth curve: growth accelerates as population size increases because more individuals are reproducing. The population doubles in time $t = \ln(2)/r = 0.693/r$.

Exponential growth is rarely sustained in nature because resources (food, space, water) are always finite. It is observed in: populations newly colonising an empty habitat; pest populations after a crop planting; bacteria in culture media; and exotic invasive species that escape their natural predators and diseases. In Nigeria, the introduced water hyacinth (*Eichhornia crassipes*) initially showed near-exponential growth in waterways before environmental resistance slowed its spread.

Fill in the blank: Exponential population growth produces a _____ -shaped curve; it occurs when resources are unlimited and produces accelerating growth because more individuals are reproducing at each time step.

5.2.2 Logistic growth and carrying capacity

Logistic growth occurs when resource limitations slow population growth as population size increases. The equation is: $dN/dt = rN [(K \text{ minus } N)/K]$, where K is the carrying capacity (the maximum population size the environment can sustainably support). When N is small, growth is nearly exponential; as N approaches K , growth slows and stops at K . This produces an S-shaped (sigmoidal) growth curve.

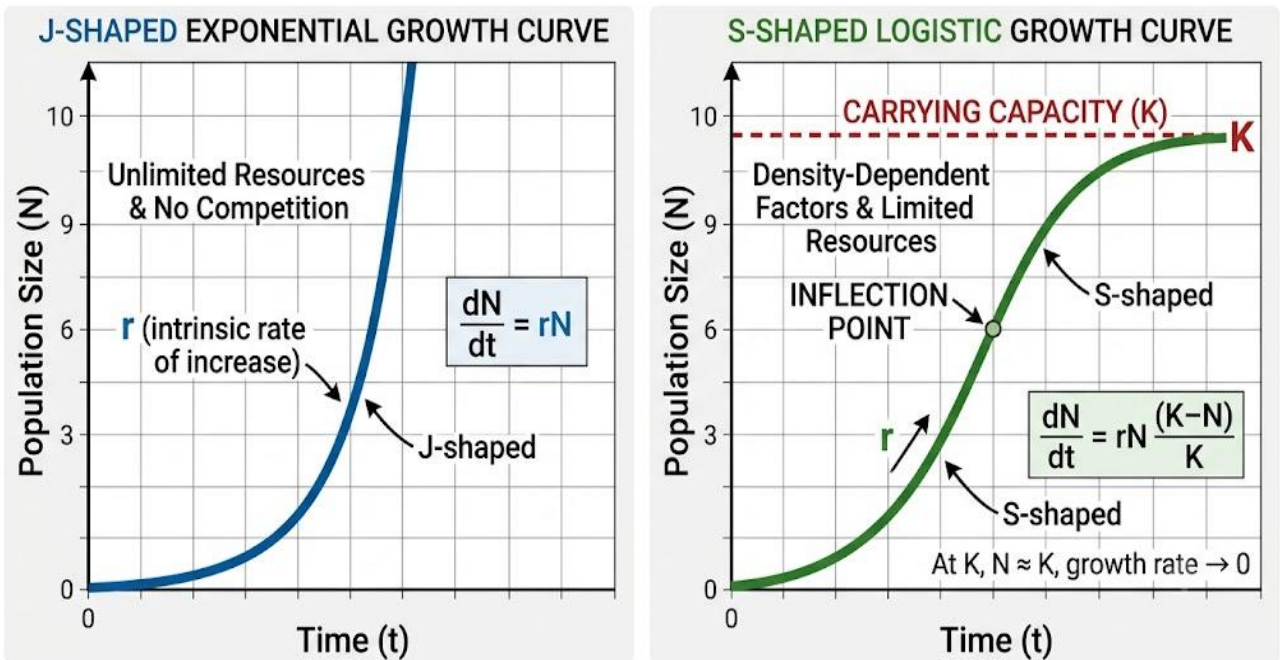
The carrying capacity K is set by the availability of the most limiting resource (food, nesting sites, water, or territory). It is not fixed: it increases when habitat conditions improve (e.g. after good rainfall) and decreases when conditions deteriorate (drought, habitat loss). In a managed wildlife reserve such as Yankari National Park, the carrying capacity for elephants is determined



by the availability of water, vegetation, and space; exceeding K leads to overgrazing and environmental degradation.

Fill in the blank: The _____ capacity (K) is the maximum population size that the environment can sustainably support; logistic growth produces an S-shaped curve as population growth slows when N approaches K.

POPULATION GROWTH MODELS: EXPONENTIAL vs. LOGISTIC



Adapted for Open Educational Resources

Figure 5.2: Graphs of exponential and logistic population growth

5.2.3 Density-dependent and density-independent factors

Density-dependent factors are those whose effect on population growth rate changes with population density. As density increases, competition for food and space intensifies, predation increases (predators concentrate where prey is abundant), disease spreads more easily, and reproductive rates fall. These are the main regulators of population size near K in the logistic model. They act as negative feedback mechanisms, reducing r as N increases and preventing indefinite population growth.



Density-independent factors affect the population regardless of its density. They are typically abiotic: extreme weather events (drought, flood, harmattan cold nights), fire, and pollution. A catastrophic drought kills a proportion of animals whether the population is large or small. In Nigeria, the 1983 to 1984 Sahel drought killed large numbers of livestock and wildlife regardless of population density. Most real populations are regulated by a combination of both density-dependent and density-independent factors.

Fill in the blank: _____-dependent factors such as food competition and disease regulate populations through negative feedback: their effect intensifies as population density rises, preventing indefinite growth.

Pilot questions 5.2

1. Describe exponential growth and state the conditions under which it occurs.
2. Describe logistic growth and explain the significance of the carrying capacity K .
3. Distinguish between density-dependent and density-independent population factors with one example of each.
4. Explain why population growth slows as N approaches K in the logistic model.
5. Explain how the carrying capacity of a wildlife reserve can change over time.

5.3 Life History Strategies and Population Regulation

5.3.1 r-selected and K-selected species

Life history theory predicts that natural selection favours different reproductive strategies in different environments. r-selected species: inhabit unpredictable or disturbed habitats; reproduce early; produce many small offspring with little parental care; high mortality in early stages; short lifespan; high intrinsic rate of increase (r); opportunistic; examples: annual weeds (*Chromolaena*, *Striga*), locusts, rats, mosquitoes, most bacteria. When conditions are favourable they grow rapidly; they are r-strategists exploiting temporary resource abundance.



K-selected species: inhabit stable environments near carrying capacity; reproduce late; produce few large offspring with extensive parental care; low mortality; long lifespan; low intrinsic rate of increase; competitive; examples: forest elephants, chimpanzees, lions, large forest trees, humans. K-selected species invest heavily in each offspring's survival and are regulated by competition for resources near K. r/K selection exists as a continuum; most species fall between the extremes.

Fill in the blank: _____-selected species invest heavily in few offspring with extensive parental care; they live in stable environments, have long lifespans, and low intrinsic rates of increase; examples include elephants, chimpanzees, and large forest trees.

5.3.2 Predator-prey cycles

Predator and prey populations are linked through density-dependent interactions: as prey increases, more food is available for predators; predator population grows; increased predation reduces prey; fewer prey means less food for predators; predator population falls; prey recovers. This produces coupled oscillations in both populations. The classic model is the Lotka-Volterra model, which produces regular, out-of-phase population cycles.

The Lotka-Volterra model predicts that predator and prey populations oscillate continuously, with prey peaks occurring slightly before predator peaks. In practice, cycles are modified by other factors: prey refuges; alternative prey; predator-caused evolution of prey defences; and environmental variation. In Nigeria, populations of kob antelope and leopard in Kainji Lake National Park show fluctuations consistent with predator-prey dynamics, though habitat change and human hunting complicate the pattern.

Fill in the blank: In the Lotka-Volterra predator-prey model, predator and prey populations show coupled _____; prey peaks occur slightly before predator peaks because prey must increase before predators can respond.



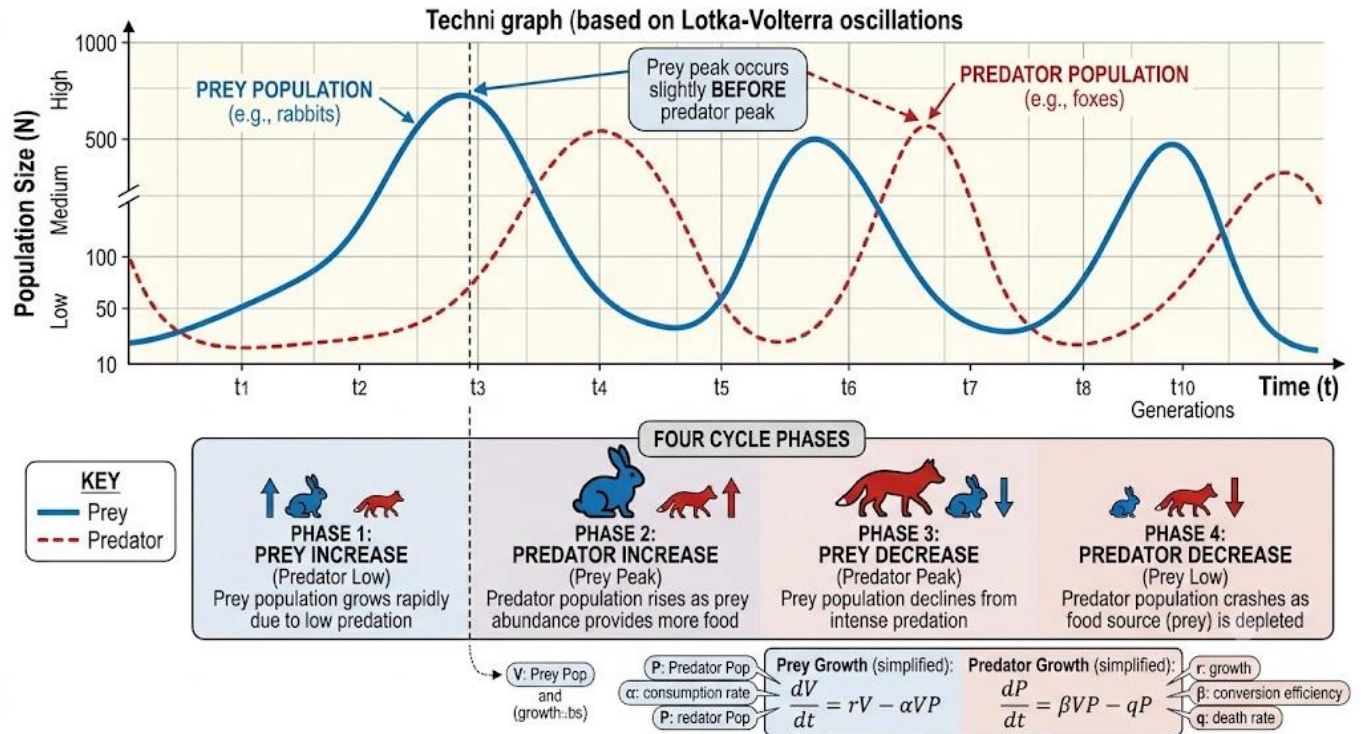


Figure 5.3: Lotka-Volterra predator-prey cycle graph

5.3.3 Metapopulations

A metapopulation is a set of spatially separated local populations of the same species that are linked by occasional dispersal (immigration and emigration) between patches. Individual local populations may go extinct (local extinction) but the metapopulation persists because extinction is balanced by recolonisation from other patches. This concept is central to understanding how species persist in fragmented landscapes.

The metapopulation concept has direct applications in conservation biology: isolated nature reserves function as habitat patches; local populations in smaller reserves have higher extinction risk; connectivity between patches (via biodiversity corridors) reduces extinction risk by allowing recolonisation. In Nigeria, the fragmented forests of Cross River State contain chimpanzee (*Pan troglodytes vellerosus*) subpopulations connected by forest corridors; loss of these corridors would isolate populations, accelerating local and eventually regional extinction.



Fill in the blank: A _____ is a set of spatially separated local populations linked by occasional dispersal; local populations may go extinct but the metapopulation persists through recolonisation from other patches.

Pilot questions 5.3

1. Distinguish between r-selected and K-selected species with two examples of each.
2. Describe the Lotka-Volterra predator-prey model and explain the resulting population cycles.
3. Define a metapopulation and explain its relevance to conservation in Nigeria.
4. Explain why K-selected species are more vulnerable to extinction than r-selected species.
5. Explain what happens in a predator-prey system when prey numbers fall very low.

5.4 Ecological Change and Global Issues

5.4.1 Climate change and its ecological effects

Global mean temperature has risen approximately 1.1 degrees Celsius above pre-industrial levels, driven by rising greenhouse gas concentrations (CO₂, methane, nitrous oxide). In Nigeria, climate change effects are already evident: increasing frequency and intensity of drought in the Sahel; more intense and unpredictable rainfall in southern Nigeria; rising sea levels threatening Niger Delta coastal communities and mangroves; Lake Chad has shrunk to approximately 10% of its 1960s size.

Ecological effects of climate change: species range shifts (species moving poleward or to higher altitude as their climate envelope moves); phenological mismatch (flowering, insect emergence, and bird breeding seasons shift at different rates, disrupting pollination and food web timing); coral bleaching (ocean warming expels zooxanthellae); increased fire frequency and intensity in savannas; loss of Sahel vegetation and accelerated desertification; rising sea levels drowning



mangroves and coastal wetlands. Climate change interacts with and amplifies all other threats to biodiversity.

Fill in the blank: _____ mismatch occurs when different species in a food web respond to climate change at different rates; for example, insects may emerge before the birds that feed on them have arrived, breaking a critical ecological timing relationship.

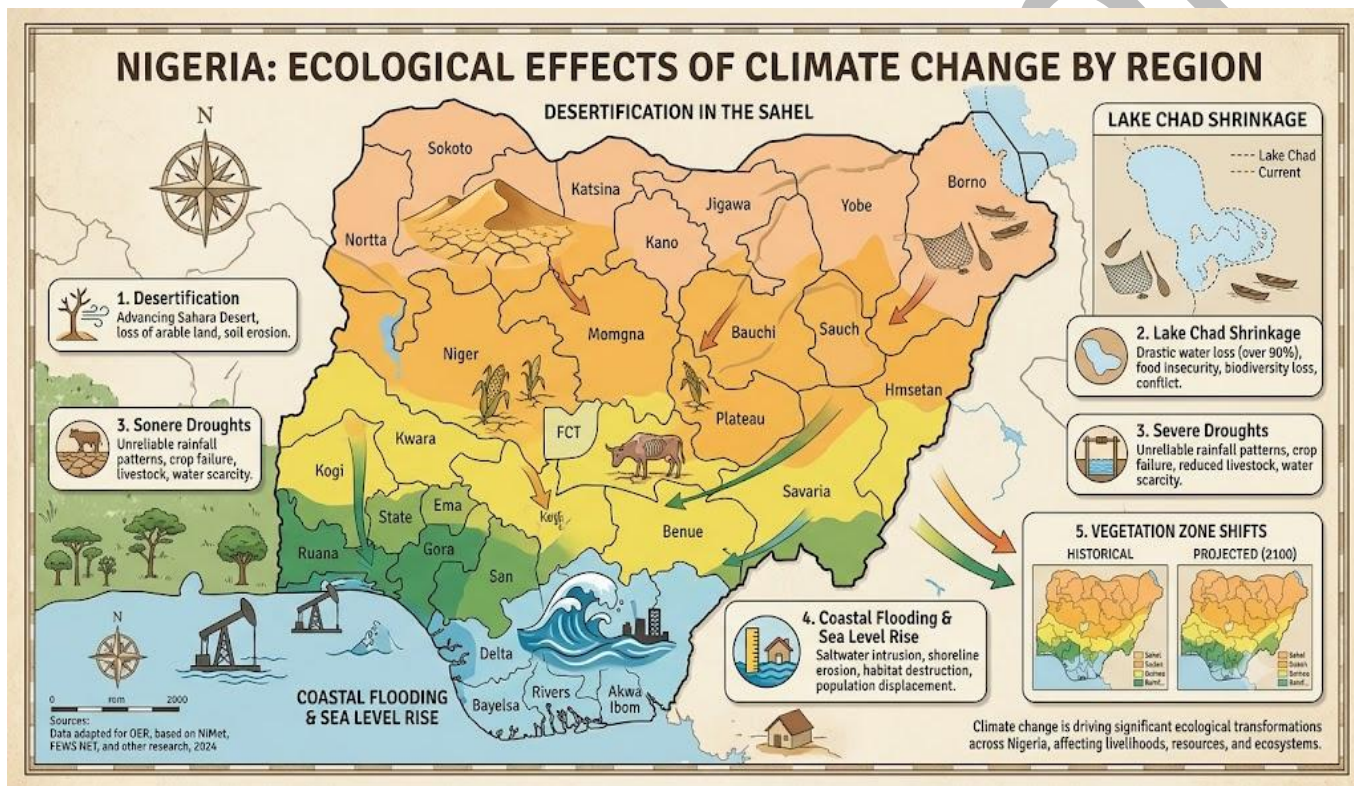


Figure 5.4: Map showing ecological effects of climate change in Nigeria

5.4.2 Invasive species and biodiversity loss

An invasive species is a non-native species that establishes and spreads in a new environment, causing ecological or economic harm. Invasions succeed because the invasive species is released from its natural predators and pathogens (enemy release hypothesis). Major invasive species in Nigeria: water hyacinth (*Eichhornia crassipes*; clogs waterways, blocks fishing, reduces dissolved oxygen, displaces native aquatic plants); Siam weed (*Chromolaena odorata*; invades disturbed land and suppresses crop and native plant growth); water lettuce (*Pistia stratiotes*); American cockroach (*Periplaneta americana*).



Global biodiversity loss is occurring at a rate estimated to be 100 to 1,000 times the natural background extinction rate; scientists call the current period the sixth mass extinction event. Main drivers (in order of importance globally): habitat loss and fragmentation; overexploitation (hunting, fishing, collection); invasive species; pollution; and climate change. In Nigeria, wildlife populations have declined dramatically since 1960: elephants, chimpanzees, lions, African wild dogs, and many bird species are now restricted to protected areas. Biodiversity loss undermines ecosystem services that underpin human livelihoods.

Fill in the blank: The _____ release hypothesis explains why invasive species often succeed: they have been freed from the predators, parasites, and pathogens that controlled their populations in their native range, giving them a competitive advantage over native species.

5.4.3 Sustainable use of ecological resources in Nigeria

Sustainable use means using natural resources at a rate that does not exceed the rate of their natural renewal, so that the resource base is maintained for future generations. Key principles: harvest below the maximum sustainable yield (the point where the population growth rate and harvest rate balance; for fisheries, this is usually at $N = K/2$ where logistic growth rate is maximum); maintain habitat quality and connectivity; reduce pollution; involve local communities as resource stewards.

Nigerian examples of sustainable resource use: sustainable fisheries management in the Kainji Lake and coastal waters through closed seasons and gear restrictions; non-timber forest product harvesting (shea butter, dawadawa, gum arabic) that provides income without clearing trees; sustainable charcoal production using fast-growing native species on managed woodlots; ecotourism in national parks (Yankari, Gashaka-Gumti) providing income to local communities as an incentive for wildlife protection. Sustainable use requires strong governance, community participation, and reliable scientific monitoring.

Fill in the blank: The _____ sustainable yield is the maximum harvest rate at which a population can be exploited without long-term decline; in a logistic model it occurs at $N = K/2$ where the population growth rate is greatest.



<u>Concept</u>	<u>Definition</u>	<u>Example</u>
<u>N</u>	Population size – the total number of individuals in a population	Number of tilapia fish in a Nigerian pond
<u>r</u>	Intrinsic rate of natural increase – maximum growth rate under ideal conditions	Bacteria doubling every 20 minutes
<u>Exponential Growth</u>	Growth pattern where population increases rapidly without limits	Yeast in nutrient-rich medium
<u>Logistic Growth</u>	Growth pattern slowed by limiting factors, forming an S-shaped curve	Goat population in a fenced pasture
<u>K</u>	Carrying capacity – maximum population size an environment can sustain	Maximum number of cattle supported by savanna grassland
<u>Density-Dependent Factors</u>	Limiting factors whose effects increase with population density	Competition for food, spread of disease
<u>Density-Independent Factors</u>	Limiting factors that affect populations regardless of density	Floods, droughts, fires
<u>r-Selected Species</u>	Species with high reproductive rate, short lifespan, little parental care	Insects, weeds
<u>K-Selected Species</u>	Species with low reproductive rate, long lifespan, high parental care	Elephants, humans

Box 5.1: Summary of population growth models and key population ecology concepts

Pilot questions 5.4

1. Describe three ecological effects of climate change already observed in Nigeria.
2. Define an invasive species and name three invasive species in Nigeria.
3. Explain the enemy release hypothesis.
4. Define sustainable use and explain the concept of maximum sustainable yield.
5. State three examples of sustainable use of ecological resources in Nigeria.



Series Summary

This final Series covered population ecology and its application to ecological change and conservation. Population properties including size, density, the three dispersion patterns, age structure, and sex ratio were established as the descriptive framework for understanding population dynamics. Growth models were then examined: exponential growth produces a J-shaped curve under unlimited resources described by the equation $dN/dt = rN$, while logistic growth produces an S-shaped curve as populations approach carrying capacity K , described by $dN/dt = rN[(K-N)/K]$. Density-dependent factors such as competition, predation, and disease regulate populations near K by intensifying with increasing density, while density-independent factors such as drought and fire affect populations regardless of their size. Life history strategies were contrasted between r -selected species producing many small offspring in unstable habitats and K -selected species investing heavily in few offspring in stable environments, and predator-prey coupled oscillations were described through the Lotka-Volterra model in which prey populations peak ahead of predator populations.

The Series then addressed ecological change at local and global scales. Metapopulation theory was introduced as a framework directly relevant to the conservation of species in Nigeria's fragmented forest landscapes, where local extinction and recolonisation through dispersal determine long-term population persistence. Global ecological threats were surveyed: climate change driving desertification, Lake Chad shrinkage, sea level rise, and phenological mismatches; invasive species such as water hyacinth and *Chromolaena* expanding through enemy release; and the ongoing sixth mass extinction. Sustainable use principles concluded the Series, centred on harvesting below the maximum sustainable yield at population size K divided by two, supported by strong governance and genuine community participation in resource management.

Glossary of Terms

- **Age structure:** the distribution of individuals among different age classes in a population; determines the future growth trajectory.



- **Biodiversity loss:** the decline in the variety of life on Earth at the genetic, species, and ecosystem levels; currently occurring at 100 to 1,000 times the natural background extinction rate.
- **Birth rate (natality):** the number of births per individual per unit time in a population; symbolised b.
- **Carrying capacity (K):** the maximum population size that the environment can sustainably support given the available resources.
- **Clumped dispersion:** a spatial pattern in which individuals aggregate in groups; the most common pattern in nature; results from resource patchiness, social behaviour, or clonal reproduction.
- **Death rate (mortality):** the number of deaths per individual per unit time; symbolised d.
- **Density-dependent factor:** a population regulating factor whose effect on population growth rate intensifies as population density increases; e.g. competition, predation, disease.
- **Density-independent factor:** a factor that affects the population regardless of its density; typically abiotic; e.g. drought, flood, fire.
- **Enemy release hypothesis:** the explanation for invasive species success: in the new range, the invasive species escapes the predators, parasites, and pathogens that controlled its population in its native range.
- **Exponential growth:** population growth when resources are unlimited; produces a J-shaped curve; described by $dN/dt = rN$.
- **Intrinsic rate of natural increase (r):** the difference between birth rate and death rate ($r = b$ minus d); the per capita rate of population growth under unlimited resources.
- **Invasive species:** a non-native species that establishes and spreads in a new environment, causing ecological or economic harm.
- **K-selected species:** a species characterised by few large offspring with extensive parental care, late reproduction, long lifespan, and populations living near carrying capacity; adapted to stable, competitive environments.



- **Lincoln-Petersen method:** a mark-recapture technique for estimating population size: $N = n_1 \times n_2 / m$, where n_1 is the first sample size, n_2 is the second sample size, and m is the number of marked individuals in the second sample.
- **Local extinction:** the disappearance of a population from a particular patch while the species persists elsewhere; a normal part of metapopulation dynamics.
- **Logistic growth:** population growth in which growth rate slows as N approaches K ; produces an S-shaped (sigmoidal) curve; described by $dN/dt = rN[(K - N)/K]$.
- **Lotka-Volterra model:** a mathematical model predicting coupled oscillations in predator and prey populations; prey peaks occur slightly before predator peaks.
- **Mark-recapture:** a method for estimating population size: a sample is captured, marked, and released; after mixing, a second sample is taken; population size is estimated from the proportion of marked individuals in the second sample.
- **Maximum sustainable yield:** the maximum harvest rate at which a population can be exploited without long-term decline; in the logistic model it occurs at $N = K/2$ where growth rate is greatest.
- **Metapopulation:** a set of spatially separated local populations of the same species that are linked by occasional dispersal; persistence depends on extinction-colonisation balance.
- **Phenological mismatch:** a disruption to ecological timing caused by different species responding to climate change at different rates; can break pollination relationships or predator-prey food web timing.
- **Population:** a group of individuals of the same species living in the same geographic area at the same time and potentially interbreeding.
- **Population density:** the number of individuals per unit area or volume.
- **Population dispersion:** the spatial arrangement of individuals within a population: random, uniform, or clumped.
- **r-selected species:** a species characterised by high intrinsic rate of increase, many small offspring with little parental care, early reproduction, short lifespan, and populations that exploit temporary resource abundances.



- **Sex ratio:** the proportion of males to females in a population; usually approximately 1:1 at birth in most species.
- **Sixth mass extinction:** the current period of accelerated global biodiversity loss, driven by human activities; extinction rates are 100 to 1,000 times the natural background rate.
- **Sustainable use:** harvesting natural resources at a rate that does not exceed the rate of their natural renewal; maintaining the resource base for future generations.
- **Uniform dispersion:** a spatial pattern in which individuals are regularly and evenly spaced; results from strong intraspecific competition for territory or space; e.g. territorial birds.



Concept Check Questions [Series 5]

Objective Questions

1. The intrinsic rate of natural increase (r) equals birth rate minus _____ rate; when r is positive the population grows. (Linked to SLO 5.1)
2. Exponential population growth produces a _____ -shaped curve; it occurs when resources are unlimited. (Linked to SLO 5.2)
3. The carrying capacity (K) is the maximum population size the environment can sustainably support; logistic growth levels off when N approaches _____. (Linked to SLO 5.2)
4. _____ -selected species invest heavily in few offspring with extensive parental care; examples include elephants and chimpanzees. (Linked to SLO 5.4)
5. The _____ release hypothesis explains why invasive species often succeed: they escape the predators, parasites, and pathogens of their native range. (Linked to SLO 5.6)

Short-Answer Questions

1. Describe the three patterns of population dispersion with one example of each. (Linked to SLO 5.1)
2. Distinguish between density-dependent and density-independent factors with one example of each. (Linked to SLO 5.3)
3. Distinguish between r -selected and K -selected species with two examples of each. (Linked to SLO 5.4)
4. Define a metapopulation and explain its relevance to conservation. (Linked to SLO 5.5)
5. State three ecological effects of climate change already observed in Nigeria. (Linked to SLO 5.6)

Long-Answer Questions



17. Describe the key properties of a population; explain exponential and logistic growth; and distinguish between density-dependent and density-independent regulatory factors.
(Linked to SLOs 5.1, 5.2, 5.3)
18. Distinguish between r- and K-selected life history strategies; describe the Lotka-Volterra predator-prey model; and explain the metapopulation concept with reference to conservation in Nigeria. (Linked to SLOs 5.4, 5.5)
19. Describe the ecological effects of climate change and invasive species in Nigeria; and explain the concept of sustainable use of ecological resources. (Linked to SLO 5.6)

Answers to Concept Check Questions [Series 5]

Objective Questions

1. Death.
2. J.
3. K.
4. K.
5. Enemy.

Short-Answer Questions

1. Random: individuals placed independently; rare in nature; e.g. wind-dispersed seeds.
Uniform: regular spacing from strong intraspecific competition; e.g. territorial birds.
Clumped: aggregated groups; most common; results from resource patches or social behaviour; e.g. cattle around water points.
2. Density-dependent: effect intensifies as density rises; acts as negative feedback; e.g. food competition reducing reproductive rates as population grows. Density-independent: effect is the same regardless of density; e.g. drought killing a fixed proportion of livestock whether the population is large or small.
3. r-selected: many small offspring; little parental care; early reproduction; unstable habitats; e.g. Striga weed, locusts. K-selected: few large offspring; extensive parental care; late reproduction; stable habitats near K; e.g. African elephant, chimpanzee.



4. A metapopulation is a set of spatially separated local populations linked by occasional dispersal; local extinctions are balanced by recolonisation from other patches.
Conservation relevance: fragmented Nigerian forest reserves function as habitat patches; biodiversity corridors between reserves allow chimpanzees and other K-selected species to recolonise patches after local extinction.
5. Sahel desertification advancing southward; Lake Chad has shrunk to approximately 10% of its 1960s area; more frequent and intense droughts across northern Nigeria; rising sea levels threatening Niger Delta mangroves and coastal communities.

Long-Answer Questions

1. Population: group of same species in same area potentially interbreeding. Properties: size (N), density (N per unit area), dispersion (random, uniform, clumped), birth rate (b), death rate (d), $r = b \text{ minus } d$. Age structure: broad-base pyramid = growing; rectangular = stable; narrow base = declining. Mark-recapture: $N = n_1 \times n_2 / m$. Exponential growth: unlimited resources; $dN/dt = rN$; J-shaped curve; rarely sustained. Logistic growth: resource-limited; $dN/dt = rN[(K-N)/K]$; S-shaped curve; levels off at K (carrying capacity); K set by most limiting resource; K changes with habitat conditions. Density-dependent: food competition, predation, disease; effect intensifies with density; negative feedback near K; main regulator in logistic model. Density-independent: drought, fire, flood; affect population regardless of density; can override density-dependent regulation.
2. r-selected species: high r; many small offspring; little parental care; short lifespan; unstable or unpredictable habitats; opportunistic; e.g. annual weeds (*Chromolaena*), locusts, rats, mosquitoes; populations grow rapidly when conditions favour them. K-selected species: low r; few large offspring; extensive parental care; long lifespan; stable environments near K; competitive; vulnerable to over-exploitation; e.g. forest elephant, chimpanzee, large forest trees. Lotka-Volterra predator-prey model: predator and prey populations show coupled oscillations; prey increases first providing food for predators; predator population then grows; predation reduces prey; fewer prey reduces predator numbers; prey recovers; cycle repeats with prey peaks slightly before predator



- peaks. Metapopulation: spatially separated local populations linked by dispersal; local extinctions balanced by recolonisation; persistence depends on patch connectivity. Nigerian conservation relevance: Cross River chimpanzee subpopulations depend on forest corridors; loss of corridors isolates populations and accelerates extinction; biodiversity corridors between fragmented forest reserves maintain metapopulation viability.
3. Climate change: global temperature risen approximately 1.1 degrees Celsius above pre-industrial; driven by greenhouse gas accumulation. Nigerian effects: Sahel desertification and southward advance; Lake Chad shrunk to approximately 10% of 1960s area; more frequent intense droughts in northern Nigeria; unpredictable intense rainfall in south; sea level rise threatening Niger Delta mangroves and coastal communities; coral bleaching in Gulf of Guinea; phenological mismatch disrupting pollinator-plant and predator-prey timing; species range shifts; increased savanna fire frequency. Invasive species: non-native species causing ecological or economic harm in new range; enemy release hypothesis: success results from escape from native predators and pathogens. Nigerian invasives: water hyacinth (*Eichhornia crassipes*: clogs waterways, kills fish by oxygen depletion, blocks fishing); *Chromolaena odorata* (arrests succession on disturbed land; suppresses crops); water lettuce (*Pistia*). Biodiversity loss: sixth mass extinction; 100 to 1,000 times background rate; drivers: habitat loss, overexploitation, invasive species, pollution, climate change. Sustainable use: use resources at or below natural renewal rate. Maximum sustainable yield: harvest at $N = K/2$ where logistic growth rate is maximum. Nigerian examples: closed fishing seasons in Kainji Lake and coastal waters; non-timber forest products (shea butter, dawadawa, gum arabic); ecotourism in national parks; community-based forest management under REDD+.

Answers to Pilot Questions [Series 5]

Part 5.1



1. A population is a group of individuals of the same species in the same geographic area at the same time and potentially interbreeding. Four key parameters: population size (N: total number of individuals); population density (individuals per unit area or volume); birth rate (b: births per individual per unit time); death rate (d: deaths per individual per unit time); and intrinsic rate of increase ($r = b - d$: positive means growing, zero means stable, negative means declining).
2. Mark-recapture method: (1) Capture a first sample (n_1), mark each individual (e.g. with a tag, dye, or ear punch), and release them back into the population; (2) after sufficient time for marked individuals to mix with the unmarked population, capture a second sample (n_2); count how many in this second sample are marked (m); (3) estimate population size using the Lincoln-Petersen formula: $N = (n_1 \times n_2) / m$. The method assumes equal catchability, no births or deaths between samples, and complete mixing of marked individuals.
3. Random: individuals distributed independently with no attraction or repulsion; rare in nature; e.g. seeds dispersed by wind in an open field with uniform soil. Uniform: individuals regularly and evenly spaced; results from strong intraspecific competition for territory; e.g. nesting territory in weaver bird colonies. Clumped: individuals aggregated into groups; the most common pattern; caused by resource patches, social behaviour, or clonal reproduction; e.g. cattle clustering around a single water point in dry-season savanna.
4. A population with a broad base (many young individuals) has a large proportion of pre-reproductive individuals that will soon enter the reproductive age class; this means birth rates will rise in future even if current conditions remain unchanged, producing rapid population growth. A rectangular pyramid (equal age classes) indicates current births roughly equal current deaths, predicting stability. A narrow base (few young relative to adults) indicates low current recruitment and predicts future population decline as the older cohorts die without replacement.
5. Trophy hunting that specifically targets the largest males selectively removes the most genetically successful and reproductively dominant males from the population, skewing the sex ratio toward females. Fewer reproductively experienced males reduces fertilisation rates and can lower the quality of genetic material available to females. In K-selected species like lions or elephants that invest heavily in each offspring, even



small reductions in reproductive rate can significantly slow population recovery and increase extinction vulnerability.

Part 5.2

1. Exponential growth is population growth at a constant per capita rate regardless of population size, described by $dN/dt = rN$; it produces a J-shaped curve that accelerates continuously over time as more individuals reproduce. Conditions: unlimited food, space, and water; no predation, disease, or competition; the population is well below carrying capacity. It occurs in newly colonising populations, pest populations after crop planting, bacteria in culture, and invasive species that have escaped their natural enemies.
2. Logistic growth is population growth that decelerates as population size approaches the carrying capacity K , described by $dN/dt = rN[(K-N)/K]$; it produces an S-shaped (sigmoidal) curve. K is the maximum population size the environment can sustainably support, set by the most limiting resource (food, water, nesting sites). As N approaches K the term $(K-N)/K$ approaches zero, slowing growth to zero; the population stabilises at K . K can increase when habitat conditions improve (e.g. good rainfall season) or decrease when conditions deteriorate (drought, habitat loss).
3. Density-dependent: a factor whose effect on the per capita growth rate intensifies as population density increases; examples include food competition (as density rises, food per individual falls, reducing birth rates and increasing starvation mortality), disease transmission (spreads more rapidly through dense populations), and predation (predators concentrate where prey is densest). Density-independent: a factor that kills or removes a fixed proportion or absolute number of individuals regardless of population density; examples include drought (kills a proportion of animals in very low or very high density populations equally), fire, and extreme cold spells.
4. As N approaches K , the logistic growth term $(K-N)/K$ becomes very small (approaching zero): for example, if $K = 1,000$ and $N = 950$, $(K-N)/K = 50/1000 = 0.05$; the growth rate is only 5% of its maximum; this is because as density rises, intraspecific competition for food, space, and mates intensifies (density-dependent regulation); reproductive rates



fall and death rates rise; the net per capita growth rate (r) declines; when $N = K$, growth stops entirely ($r_{\text{effective}} = 0$).

5. K changes as the habitat quality and quantity of limiting resources change. It increases when: good rainfall improves grass biomass (increasing food K for herbivores); new habitats are created (e.g. dam construction creating Kainji Lake increased carrying capacity for fish and waterbirds); conservation interventions reduce competition or predation. K decreases when: drought reduces vegetation and water availability; habitat is lost through deforestation or overgrazing; pollution reduces food quality; competing species increase pressure on shared resources.

Part 5.3

1. r -selected: high r ; many small offspring; little parental care; early reproduction; short lifespan; unstable or disturbed habitats; opportunistic colonisers; e.g. (1) *Chromolaena odorata* (Siam weed): produces thousands of wind-dispersed seeds; colonises any disturbed land within one growing season; (2) desert locust (*Schistocerca gregaria*): lays hundreds of eggs per female in soil; populations erupt rapidly when conditions suit.
 K -selected: low r ; few large offspring; extensive parental care; late reproduction; long lifespan; stable habitats; competitive; e.g. (1) African forest elephant (*Loxodonta cyclotis*): one calf per female every 4 to 5 years; 22-month gestation; extensive maternal care; (2) chimpanzee (*Pan troglodytes*): one infant every 4 to 6 years; 3 to 5 years of maternal dependence.
2. The Lotka-Volterra model describes the coupled dynamics of a predator and a prey population. Prey grows exponentially in the absence of predators; predator growth depends on prey availability; as prey increases, predators have more food and increase; rising predation reduces prey; declining prey starves predators, reducing their numbers; with fewer predators, prey recovers; the cycle repeats. This produces continuous coupled oscillations in both populations, with prey peaking slightly before predators. The model assumes no other limiting factors; in reality, prey refuges, alternative prey, and environmental variation modify the cycles.



3. A metapopulation is a set of spatially separated local populations of the same species linked by occasional dispersal (immigration and emigration) between habitat patches; the key feature is that local populations go extinct and are recolonised from other patches, so the metapopulation persists even though individual patches turn over. Conservation relevance in Nigeria: the fragmented forests of Cross River State contain isolated subpopulations of Nigeria-Cameroon chimpanzees (*Pan troglodytes vellerosus*); connectivity between forest fragments through biological corridors allows chimpanzees to disperse, recolonise locally extinct patches, and maintain gene flow; severing these corridors by converting forest to farmland would isolate subpopulations and accelerate regional extinction.
4. K-selected species are more vulnerable to extinction because: (1) they have low intrinsic rates of increase (r); recovering from any population reduction takes many years or decades; a chimpanzee population halved by poaching or disease takes decades to recover, while a rat population recovers in weeks; (2) each reproductive event represents a huge investment for the individual and the species; loss of breeding adults (especially breeding females in polygynous species) causes disproportionately large reductions in population growth rate; (3) they typically have small total populations, live in stable specialised habitats, and have restricted ranges; any permanent habitat loss directly and irreversibly reduces the carrying capacity available to them.
5. When prey numbers fall very low in a predator-prey system, the predator population also collapses (because it depends on prey for food); with few predators, predation pressure on prey is greatly reduced; the prey population begins to recover; this is the beginning of a new oscillation cycle. In practice, if prey numbers fall below a minimum viable population size due to predator pressure combined with other stresses (disease, habitat loss), the prey may go locally extinct rather than recovering; this collapses the predator population as well since its food base is gone.

Part 5.4



6. Three climate change effects already observed in Nigeria: (1) Sahel desertification and southward encroachment: the southern boundary of the Sahel is advancing approximately 0.5 to 1 km per year southward into the Sudan savanna due to reduced rainfall reliability and increased evapotranspiration; this is displacing farming communities and increasing conflict between farmers and Fulani herders over diminishing productive land. (2) Lake Chad shrinkage: the lake has declined to approximately 10% of its 1960s area due to reduced rainfall, increased irrigation withdrawal, and higher evaporation rates driven by warming; fisheries and the livelihoods of millions of people around the lake have collapsed. (3) Sea level rise and coastal flooding: Nigerian coastal communities and Niger Delta mangrove forests are experiencing increased coastal flooding and erosion; the low-lying Niger Delta is especially vulnerable as both sea levels rise and the Delta subsides due to oil extraction.
7. An invasive species is a non-native species introduced to a new region that establishes, spreads, and causes ecological or economic harm. Three invasive species in Nigeria: (1) Water hyacinth (*Eichhornia crassipes*): a free-floating South American aquatic plant that forms dense mats on Nigerian waterways (Niger River, Benue, Lagos lagoons), blocking navigation, reducing dissolved oxygen and light, killing fish, and displacing native aquatic vegetation. (2) *Chromolaena odorata* (Siam weed): a Central American shrub that rapidly colonises disturbed land throughout southern Nigeria, suppressing native vegetation regrowth and competing with crops. (3) Water lettuce (*Pistia stratiotes*): another invasive floating aquatic plant blocking drainage canals and fish ponds in southern Nigeria.
8. The enemy release hypothesis proposes that invasive species succeed in their new range because they have been released from the biological control agents (predators, parasites, pathogens, and herbivores) that regulated their populations in their native range; without these natural enemies, the invasive population can grow more rapidly and reach higher densities than in its native habitat; native species in the invaded range may lack evolutionary defences against the new invader and are displaced by the competitively released invader.
9. Sustainable use means harvesting natural resources at a rate that does not exceed the rate of natural renewal, maintaining the resource base indefinitely for future generations.
- Maximum sustainable yield (MSY): in a logistic population model, the highest harvest rate that can be maintained without causing long-term population decline occurs at $N = K/2$,



where the logistic growth rate ($dN/dt = rN[(K-N)/K]$) is at its maximum; harvesting at exactly this rate removes as many individuals as the population produces; harvesting above MSY causes the population to decline below $K/2$, reducing growth rate and eventually leading to collapse.

10. Three sustainable use examples in Nigeria: (1) Fisheries closed seasons: the Nigerian Institute for Oceanography and Marine Research (NIOMR) recommends seasonal closures of the Kainji Lake and coastal waters to allow fish stocks to recover during breeding periods; these closed seasons allow fish populations to remain above the level of maximum sustainable yield. (2) Non-timber forest product harvesting: collection of shea butter (*Vitellaria paradoxa* nuts), dawadawa (*Parkia biglobosa* pods), and gum arabic (*Acacia senegal* exudate) provides income to rural communities in northern Nigeria without requiring tree felling; this incentivises communities to protect tree populations. (3) Ecotourism in national parks: Yankari National Park receives tourists who pay fees to see wildlife; this income provides an economic rationale for maintaining natural habitats and wildlife populations rather than converting them to agriculture.



References and Attributions [Series 5]

Textual References (Books and External Sources)

- Odum, E. P., & Barrett, G. W. (2005). Fundamentals of ecology (5th ed.). Thomson Brooks/Cole.
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- Vitousek, P. M., Mooney, H. A., Lubchenco, J., & Melillo, J. M. (1997). Human domination of Earth's ecosystems. *Science*, 277(5325), 494-499.
- FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable agriculture. FAO.

Figures, Plates, Tables, and Boxes

- Figure 5.1: Population age pyramids (growing, stable, declining) Attribution: AI generated. Suggested OER search string: "population age pyramid growing stable declining broad narrow base diagram OER".
- Figure 5.2: Exponential (J-shaped) and logistic (S-shaped) growth curves Attribution: AI generated. Suggested OER search string: "exponential logistic population growth J-shaped S-shaped curve carrying capacity K diagram OER".
- Figure 5.3: Lotka-Volterra predator-prey cycle graph Attribution: AI generated. Suggested OER search string: "Lotka-Volterra predator prey cycle graph oscillations population size time OER".
- Figure 5.4: Map of climate change ecological effects in Nigeria Attribution: AI generated. Suggested OER search string: "Nigeria climate change ecological effects map desertification Lake Chad sea level rise vegetation zone shifts OER".
- Box 5.1: Summary of population growth models and key population ecology concepts Attribution: AI generated. Suggested OER search string: "population ecology concepts table exponential logistic growth carrying capacity r K selection density dependent OER box".

