

Ecology and ecosystems

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1 Ecology: levels of organisation, habitat and niche

Ecology studies how organisms interact with each other and with their physical surroundings, at levels that run from a single organism up to the whole biosphere.

Core facts

- **Ecology** is the branch of biology that studies the **interactions among organisms and between organisms and their physical (abiotic) environment**.
- The word "ecology" (*Oekologie*) was coined by **Ernst Haeckel** in **1866**. It comes from the Greek *oikos* (house) and *logos* (study).
- NCERT says ecology deals with **four levels of biological organisation: organisms, populations, communities and biomes**.
- Full order, smaller to larger: **individual** → **population** → **community** → **ecosystem** → **biome** → **biosphere**.
- **Population**: individuals of the **same species** living in a defined area at the same time.
- **Community**: populations of **different species** living and interacting in an area.
- **Ecosystem**: a community together with its **abiotic** environment. The term was coined by **A.G. Tansley** in **1935**.
- **Biosphere**: the part of the Earth (land, water and air) where life exists.
- **Habitat**: the physical place where an organism lives (its "address").
- **Niche**: the functional role of a species, including what it eats, when and where it is active, and the range of conditions it tolerates (its "profession").
- **Ecotone**: a transition zone between two ecosystems, such as a mangrove between land and sea, or grassland between forest and desert.
- **Edge effect**: an ecotone often has more species, and higher density, than either neighbouring community.

Explained

Levels of organisation

Level	Made of	Example
Organism	One individual	One tiger
Population	Same species, one area	All tigers in Nallamala forest
Community	All populations in an area	Tigers, deer, trees, fungi of that forest
Ecosystem	Community + abiotic factors	The forest with its soil, water, climate
Biome	Large region with similar climate and vegetation	Tropical deciduous forest
Biosphere	All ecosystems on Earth	The living layer of the planet

Major abiotic factors

- **Temperature.** It affects enzyme activity and so the metabolism of organisms.
 - **Eurythermal** organisms tolerate a wide range of temperature. NCERT notes that only a few organisms are like this.
 - **Stenothermal** organisms tolerate only a narrow range (for example, many corals). The vast majority of organisms are stenothermal.
- **Water.** Salinity tolerance gives **euryhaline** (wide range) and **stenohaline** (narrow range) organisms. Many freshwater animals cannot live long in sea water, and the reverse.
- **Light.** Plants need it for photosynthesis. Many plants and animals use day length (photoperiod) to time flowering, breeding and migration.
- **Soil.** Its composition, grain size and water-holding capacity decide which plants can grow.

How organisms respond to stress

Response	Meaning	Example
Regulate	Keep the body constant (homeostasis)	Birds and mammals keep body temperature constant
Conform	Body changes with the surroundings	Most animals and nearly all plants
Migrate	Move away for a while	Siberian cranes to Keoladeo (Bharatpur) in winter
Suspend	Lower activity until conditions improve	Hibernation, aestivation, diapause, spores, seed dormancy

- **Hibernation** is winter sleep (bears).
- **Aestivation** is summer sleep, for example frogs, snails and some fish in burrows or mud during heat.
- **Diapause** is a stage of suspended development, as in zooplankton in lakes.

Deeper

Evolution of the niche concept

Ecologist	Year	View of niche
Joseph Grinnell	1917	Spatial or habitat niche: the place and conditions a species needs
Charles Elton	1927	Functional niche: the role of a species in the community, especially in food relations
G.E. Hutchinson	1957	n-dimensional hypervolume : all the conditions and resources that let a species survive and reproduce

- **Fundamental niche:** the full range a species could occupy with no competitors.
- **Realised niche:** the smaller range it actually occupies, because of competition and predation.
- **Gause's competitive exclusion principle:** two species with exactly the same niche cannot coexist indefinitely. One displaces the other. Coexistence happens through **resource partitioning** (see ENV-EC-06).

- **Ecological equivalents:** unrelated species that hold similar niches in different regions, such as grazing kangaroos in Australia and grazing bison in North America.
- **Ecocline:** a gradual change in community along an environmental gradient (for example, altitude). An ecotone, by contrast, is a sharper zone of transition.

Adaptations named in NCERT

- **Kangaroo rat** (North American desert) meets its water needs by internal fat oxidation, which yields water (metabolic water). It can also concentrate its urine.
- **Desert plants** have a thick cuticle and sunken stomata, which cut water loss. Many follow the **CAM** pathway: stomata stay closed in the day. In *Opuntia*, leaves become spines and the flattened stem (phylloclade) does photosynthesis.
- **Allen's rule:** mammals in cold climates tend to have shorter ears and limbs, which reduce heat loss.
- **Altitude sickness:** at high altitude, the body first breathes faster and raises heart rate, then makes more red blood cells over time.
- **Seals** in polar seas have a thick layer of fat (blubber) below the skin, which insulates them.

Common traps

✗ "Ecology was coined by Tansley." ✓ **Haeckel (1866)** coined *ecology*; **Tansley (1935)** coined *ecosystem*.

✗ "A population includes all species in an area." ✓ That is a **community**. A population is **one species**.

✗ "Habitat and niche mean the same thing." ✓ Habitat is the **place**; niche is the **role** and the range of conditions used.

✗ "Aestivation is winter sleep." ✓ Aestivation is **summer** sleep; hibernation is **winter** sleep.

✗ "An ecotone has fewer species than its neighbours." ✓ It often has **more**: this is the **edge effect**.

✗ "Elton gave the n-dimensional hypervolume." ✓ **Hutchinson (1957)** did; Elton gave the functional niche (1927).

Quick revision

- Ecology: Haeckel, 1866. Ecosystem: Tansley, 1935.
- NCERT's four levels: organisms, populations, communities, biomes.
- Order: individual → population → community → ecosystem → biome → biosphere.
- Habitat = address; niche = profession.
- Niche: Grinnell (spatial, 1917), Elton (functional, 1927), Hutchinson (hypervolume, 1957).
- Ecotone = transition zone; edge effect = more species there.
- Eurythermal (few) / stenothermal (most); euryhaline/stenohaline.

- Responses: regulate, conform, migrate, suspend.
- Hibernation = winter; aestivation = summer; diapause = suspended development.

2 Ecosystem structure: biotic and abiotic components

An ecosystem is a functional unit of nature in which living organisms interact with each other and with their non-living surroundings, linked by energy flow and nutrient cycling.

Core facts

- **Ecosystem:** a functional unit of nature where living organisms interact among themselves and with the physical environment. Term coined by **A.G. Tansley (1935)**.
- Two parts:
 - **Biotic:** producers, consumers and decomposers.
 - **Abiotic:** light, temperature, water, soil, air, minerals and dead organic matter.
- **Producers (autotrophs):** make their own food. Green plants, algae and cyanobacteria do it by **photosynthesis**; some bacteria do it by **chemosynthesis**.
- **Consumers (heterotrophs):** herbivores (primary), carnivores (secondary and tertiary) and omnivores.
- **Decomposers:** mainly **bacteria and fungi**. They break down dead matter and release nutrients.
- **Detritivores:** animals such as the **earthworm** that feed on detritus and break it into smaller pieces.
- Ecosystems are **natural** (forest, grassland, desert, pond, lake, river, estuary, sea) or **man-made** (crop field, aquarium, fish pond, plantation).
- **Four functional aspects (NCERT): productivity, decomposition, energy flow and nutrient cycling.**
- **Stratification:** the vertical layering of species, such as trees at the top, then shrubs, then herbs and grasses at the bottom. It is a **structural** feature.

Explained

Components of an ecosystem

Component	Type	Examples
Inorganic substances	Abiotic	Carbon dioxide, water, nitrogen, phosphates
Organic substances	Abiotic	Proteins, carbohydrates, lipids, humus
Climatic factors	Abiotic	Light, temperature, rainfall, humidity, wind
Edaphic and topographic factors	Abiotic	Soil type, slope, altitude
Producers	Biotic	Grass, trees, phytoplankton
Consumers	Biotic	Deer, tiger, zooplankton, fish
Decomposers	Biotic	Bacteria, fungi

The pond as a model ecosystem (NCERT's example)

- **Abiotic:** water, dissolved inorganic and organic matter, and the soil deposit at the bottom.
- **Producers:** phytoplankton, some algae, and floating, submerged and marginal plants.
- **Consumers:** zooplankton, and free-swimming and bottom-dwelling animals.
- **Decomposers:** fungi, bacteria and flagellates, which are especially plentiful at the bottom.
- The pond shows all four functions: producers convert sunlight to food, consumers eat it, decomposers mineralise dead matter, and nutrients return to the producers.

Ecosystem services

- These are the benefits people get from ecosystems.
- Examples: forests purify air and water, reduce droughts and floods, cycle nutrients, form fertile soil, provide habitat, pollinate flowers and store carbon.
- **Purification of air and water by forests** is a classic example of an ecosystem service.
- **Robert Costanza and colleagues (1997)** put the value of global ecosystem services at an average of about **US\$ 33 trillion a year**. This was nearly **twice** the global GNP of the time (about US\$ 18 trillion).
 - In NCERT's summary, **soil formation** accounts for about **50%** of the total. (Answer exam questions by NCERT's figures.)
 - Recreation and nutrient cycling were each less than 10%.
 - Climate regulation and habitat for wildlife were about 6% each.

Deeper

Millennium Ecosystem Assessment (2005) categories

Category	Meaning	Examples
Provisioning	Products obtained	Food, fresh water, timber, fibre, medicine
Regulating	Control of natural processes	Climate regulation, flood control, water purification, pollination
Cultural	Non-material benefits	Recreation, spiritual value, tourism
Supporting	Needed for all the others	Soil formation, nutrient cycling, primary production

Laws of limiting factors

- **Liebig's law of the minimum (1840):** growth is controlled by the essential nutrient in shortest supply, not by the total of resources.
- **Shelford's law of tolerance (1913):** each organism has a minimum and a maximum limit for each factor. Its range between them is its range of tolerance. Too much of a factor limits it as surely as too little.

Autotroph types

- **Photoautotrophs** use sunlight.
- **Chemoautotrophs** use energy from oxidising inorganic chemicals such as hydrogen sulphide, ammonia or iron. They support the **deep-sea hydrothermal vent** communities, the main ecosystems not driven by sunlight.

Ecosystems as open systems. Energy enters (mainly as sunlight) and leaves (as heat). Matter is largely recycled within. Ecosystems show **homeostasis**: feedback (for example, predator and prey numbers) keeps them within limits, until a disturbance crosses a threshold.

Common traps

✗ "Stratification is one of the four functional aspects." ✓ It is **structural**. The four functions are **productivity, decomposition, energy flow and nutrient cycling**.

✗ "An estuary is a man-made ecosystem." ✓ An estuary is **natural**. Crop fields, aquaria and fish ponds are man-made.

✗ "Earthworms are decomposers in the strict sense." ✓ Earthworms are **detritivores**; the true decomposers are **bacteria and fungi**.

✗ "Costanza valued ecosystem services at about US\$ 18 trillion." ✓ About **US\$ 33 trillion**; US\$ 18 trillion was global GNP.

✗ "All producers use sunlight." ✓ Chemosynthetic bacteria at hydrothermal vents use **chemical energy**.

Quick revision

- Ecosystem: Tansley, 1935; biotic + abiotic.
- Biotic: producers, consumers, decomposers.
- Decomposers: bacteria and fungi; earthworm = detritivore.
- Four functions: productivity, decomposition, energy flow, nutrient cycling.
- Stratification = vertical layering = structure.
- Man-made: crop field, aquarium, fish pond.
- Costanza (1997): about US\$ 33 trillion a year; soil formation about 50%.
- MEA 2005: provisioning, regulating, cultural, supporting.
- Liebig: law of minimum; Shelford: law of tolerance.

3 Energy flow and productivity: food chains, food webs, trophic levels and decomposition

Energy enters an ecosystem as sunlight, is fixed by producers, and flows one way through trophic levels while most of it is lost as heat; decomposers return the nutrients locked in dead matter.

Core facts

- **Primary productivity:** the rate of biomass production by plants, per unit area per unit time.
- **GPP (gross primary productivity):** the total rate of photosynthesis.
- **NPP = GPP – R**, where R is the energy plants use in respiration. NPP is the biomass available to heterotrophs (herbivores and decomposers).
- **Secondary productivity:** the rate of formation of new organic matter by **consumers**.
- **Standing crop:** the mass of living material at a trophic level at a given time.
- Productivity units: **$\text{g m}^{-2} \text{yr}^{-1}$** or **$\text{kcal m}^{-2} \text{yr}^{-1}$** . Biomass is measured as **dry weight**.
- Annual NPP of the whole biosphere is about **170 billion tonnes** (dry weight) of organic matter. **Oceans**, despite covering about **70%** of the surface, produce only about **55 billion tonnes**.
- The **Sun** is the energy source of all ecosystems, **except deep-sea hydrothermal vent** ecosystems (chemosynthesis).
- Energy flow is **unidirectional** (one-way), not cyclic. Nutrients cycle; energy does not.
- **Food chains:**
 - **Grazing food chain (GFC):** starts with living green plants.
 - **Detritus food chain (DFC):** starts with dead organic matter (detritus).
- In terrestrial ecosystems, a **much larger fraction of energy flows through the detritus food chain** than through the grazing food chain.
- **Food web:** interconnected food chains.

Explained

How much sunlight is used

- Less than **50%** of incident solar radiation is **photosynthetically active radiation (PAR)**.
- Plants capture only **2–10% of PAR**. That small amount sustains the whole living world.
- Ecosystems obey the **second law of thermodynamics**. They need a constant supply of energy to build complex molecules and to counter the natural tendency towards disorder (entropy).

Trophic levels

Trophic level	Organisms	Example
First	Producers	Grass, phytoplankton
Second	Primary consumers (herbivores)	Grasshopper, deer, zooplankton

Trophic level	Organisms	Example
Third	Secondary consumers (carnivores)	Frog, small fish
Fourth	Tertiary consumers (top carnivores)	Snake, large fish, eagle

- A species can sit at **more than one trophic level**. A sparrow is a primary consumer when it eats seeds and a secondary consumer when it eats insects. This is why a food web is more realistic than a food chain.
- The number of trophic levels is limited (usually 4–5) because energy falls sharply at each step (about 10% passes on; see ENV-EC-04).

Decomposition: the five steps

Step	What happens
Fragmentation	Detritivores such as earthworms break detritus into small particles
Leaching	Water-soluble inorganic nutrients go down into the soil and are precipitated as unavailable salts
Catabolism	Bacterial and fungal enzymes break detritus into simpler inorganic substances
Humification	A dark, amorphous, colloidal substance called humus forms. It is highly resistant to microbial action and decomposes very slowly
Mineralisation	Humus is degraded by microbes, releasing inorganic nutrients

What speeds up or slows down decomposition

- **Faster:** detritus rich in **nitrogen** and water-soluble substances such as **sugars; warm and moist** conditions.
- **Slower:** detritus rich in **lignin and chitin; low temperature** and **anaerobiosis** (lack of oxygen). This is why organic matter builds up in cold or waterlogged places.

Deeper

- **Lindeman (1942)** set out the trophic-dynamic view of ecosystems: energy is transferred between trophic levels with large losses at each step. This led to the "ten per cent law".
- **Why a larger fraction goes through the DFC on land:** most plant matter (wood, leaf litter, roots) is not eaten while alive. It dies and enters the detritus pathway. In many aquatic systems, phytoplankton are grazed quickly, so the grazing chain carries a larger share.
- **Productivity varies widely.** It depends on the plant species, the environment, nutrients and photosynthetic capacity. Tropical rain forests, estuaries, coral reefs and wetlands are among the most productive. Deserts and the open ocean are among the least, per unit area.
- **Food webs give stability.** When a consumer has several food sources, the loss of one does not collapse the system. Simple chains (for example, in the Arctic tundra) are fragile.
- **Biomagnification:** the rise in concentration of a non-degradable (persistent) substance at successive trophic levels. The substance is not broken down or excreted, so it builds up in fat.

- Classic example: **DDT** reached high levels in fish-eating birds, causing thin eggshells and breeding failure. Rachel Carson's *Silent Spring* (1962) drew attention to it.
- **Bioaccumulation** is the build-up within one organism over its lifetime; biomagnification is the increase **across** trophic levels.
- **Breaking a food chain has costs.** In the 1980s India exported frog legs on a large scale. With fewer frogs eating insects, **crop pests increased** and farmers used more pesticides. The Government then banned the export of frog legs.

Common traps

✗ "Energy flow in an ecosystem is cyclic." ✓ It is **unidirectional**. Only **nutrients** cycle.

✗ "The grazing food chain begins with dead organic matter." ✓ The **detritus** food chain does. The grazing chain begins with living plants.

✗ "NPP = GPP + R." ✓ **NPP = GPP – R.**

✗ "Oceans produce most of the world's NPP because they cover 70% of Earth." ✓ Oceans produce only about **55 of the 170 billion tonnes**.

✗ "Low temperature and anaerobic conditions speed up decomposition." ✓ They **slow** it. Warm, moist, oxygen-rich conditions speed it up.

✗ "Humification releases nutrients." ✓ **Mineralisation** releases nutrients; humification forms humus, which resists decay.

Quick revision

- $NPP = GPP - R$; NPP feeds the heterotrophs.
- Secondary productivity = new organic matter made by consumers.
- Biosphere NPP about 170 billion t; oceans about 55 billion t.
- PAR is under 50% of sunlight; plants capture 2-10% of PAR.
- Energy: one-way; nutrients: cyclic.
- On land, more energy flows through the DFC than the GFC.
- Decomposition: fragmentation, leaching, catabolism, humification, mineralisation.
- Lignin, chitin, cold and no oxygen slow decay.
- Biomagnification: persistent chemicals (DDT) rise up the food chain.
- Hydrothermal vents: the exception to sunlight-based ecosystems.

4 Ecological pyramids and the ten per cent law

Ecological pyramids show the number, biomass or energy at each trophic level; only the pyramid of energy is always upright, because only about a tenth of energy passes from one level to the next.

Core facts

- An **ecological pyramid** shows the relationship between trophic levels in terms of **number, biomass or energy**.
- The **base** is always the **producers (first trophic level)**; the **apex** is the top carnivore.
- Three types: **pyramid of numbers, pyramid of biomass, pyramid of energy**.
- The pyramid idea (first as the pyramid of numbers) was introduced by **Charles Elton (1927)**, hence the name "Eltonian pyramids". Energy pyramids came later, from trophic-dynamic work.
- **Ten per cent law**: only about **10%** of the energy at one trophic level is passed on to the next. It came from **Lindeman's** work (1942).
- The **pyramid of energy is always upright**. It can never be inverted.
- The **pyramid of biomass in the sea is generally inverted**.
- The **pyramid of numbers for a single tree** with many insects on it is **inverted**.
- Biomass is measured more accurately as **dry weight**.

Explained

The three pyramids

Pyramid	Measures	Upright or inverted
Numbers	Count of individuals at each level	Upright in grassland; inverted for a tree
Biomass	Dry weight of living matter at each level	Upright on land; generally inverted in the sea
Energy	Energy at each level per unit area per unit time	Always upright

NCERT's grassland pyramid of numbers

- Primary producers: about **5.8 million** plants (5,842,424).
- Primary consumers: 708,624.
- Secondary consumers: 354,904.
- Top carnivores: **3**.
- So nearly 6 million plants support just 3 top carnivores.

NCERT's ideal pyramid of energy

- Of 1,000,000 J of sunlight, producers convert about **1%** (10,000 J) into NPP.
- Then about 10% passes on at each step: 10,000 J → 1,000 J → 100 J → 10 J.

Why the pyramid of energy is always upright

- At each transfer, energy is lost as heat in respiration, in undigested matter and in uneaten parts.
- A higher level can never have more energy than the level that feeds it.

Why the pyramid of biomass is inverted in the sea

- Phytoplankton have a **small standing crop** at any moment, because they are eaten quickly and reproduce quickly.
- The biomass of fish feeding on them is larger at any one time.
- The pyramid of **energy** in the same sea is still upright, because the phytoplankton's yearly **production** is far larger than their standing crop.

Why the pyramid of numbers is inverted for a tree

- One large tree (producer) supports many insects, which in turn support fewer birds.
- The base is narrow and the middle is broad. Parasite chains (one host, many parasites) are also inverted.

Deeper

Limitations of ecological pyramids (NCERT)

- They do not take into account the **same species belonging to two or more trophic levels** (the sparrow eating both seeds and insects).
- They assume a **simple food chain**, which almost never exists in nature.
- They **do not accommodate a food web**.
- **Saprophytes** (decomposers) are **not given any place**, although they play a vital role in the ecosystem.

The ten per cent law in detail

- Transfer efficiency is not exactly 10%. It usually falls in a range of about 5–20%, and 10% is the rule of thumb.
- Each level loses energy:
 - in respiration (the largest loss)
 - as food not eaten
 - as food eaten but not absorbed (faeces)
- This explains:
 - why food chains rarely have more than **four or five** levels
 - why top carnivores are few, and need large territories
 - why top carnivores are most at risk from habitat loss and biomagnification

Numbers and biomass can mislead; energy does not. Numbers ignore size (a tree counts as one). Biomass is a snapshot (standing crop) and ignores turnover rate. Energy measures flow over time, so it reflects how the ecosystem works.

Common traps

✗ "The pyramid of biomass is always upright." ✓ It is **generally inverted in the sea**. Only the **energy** pyramid is always upright.

✗ "The pyramid of numbers is always upright." ✓ It is **inverted** for a tree with many insects, and for parasite chains.

✗ "The ten per cent law means 10% of energy is lost at each level." ✓ About 10% is **passed on**; about **90% is lost**.

✗ "The base of a pyramid is the top carnivore." ✓ The base is the **producers** (first trophic level).

✗ "Pyramids take full account of decomposers and food webs." ✓ They **leave out saprophytes** and **cannot show food webs**.

Quick revision

- Three pyramids: numbers, biomass, energy.
- Base = producers; apex = top carnivore.
- Energy pyramid: always upright.
- Biomass in sea: generally inverted.
- Numbers for a tree: inverted.
- Ten per cent law (Lindeman, 1942): about 10% passes on.
- NCERT grassland: about 5.8 million plants support 3 top carnivores.
- NCERT ideal energy pyramid: producers convert about 1% of sunlight into NPP.
- Limits: ignore multi-level species, food webs and saprophytes.

5 Ecological succession: primary, secondary and climax

Ecological succession is the gradual, fairly predictable change in the species of an area over time, until a stable climax community in balance with the climate is reached.

Core facts

- **Succession:** a gradual and fairly predictable change in the species composition of an area.
- **Pioneer species:** the first species to colonise a bare area.
- **Sere:** the entire sequence of communities that replace one another in an area.
- **Seral stages (seral communities):** the individual transitional communities in a sere.
- **Climax community:** the final, stable community that is in near equilibrium with the environment (mainly the climate).
- **Primary succession:** starts where **no soil or life existed before**: bare rock, newly cooled lava, newly formed sand dunes, a newly created pond or reservoir.
- **Secondary succession:** starts where a community **was destroyed but soil remains**: abandoned farmland, burned or cut forest, flooded land.
- **Secondary succession is faster** than primary succession, because soil, seeds and roots are already present.
- **Pioneers on bare rock:** usually **lichens**. They secrete acids that dissolve rock and start soil formation. Mosses follow.
- **Pioneers in water:** usually **phytoplankton**.
- **Hydrarch succession:** in water; progresses from **wet (hydric) to mesic** conditions.
- **Xerarch succession:** in dry areas; progresses from **dry (xeric) to mesic** conditions.
- The idea of succession and the climax was developed by **F.E. Clements (1916)**.

Explained

Stages of succession

Hydrarch (water)	Xerarch (bare rock)
Phytoplankton	Lichens (crustose, then foliose)
Rooted submerged plants	Mosses
Rooted floating plants	Herbs and grasses
Reed swamp and sedges (marsh-meadow)	Shrubs
Shrubs	Trees
Forest (climax)	Forest (climax)

- Both sequences lead towards **mesic** conditions (medium moisture): water bodies fill up and become drier; bare rock builds soil and holds more water.

What changes during succession

- Soil depth and organic matter increase.
- The number and diversity of species increase.
- Total biomass increases.
- Niches become more specialised and food webs more complex.
- Nutrient cycles become more closed; less is lost from the system.
- The community moves from r-selected pioneers (small, fast-growing) to K-selected climax species (large, long-lived).

Primary versus secondary succession

Feature	Primary	Secondary
Starting point	No soil, no life	Soil present, life removed
Examples	Bare rock, lava, new pond	Abandoned field, burned forest
Pioneers	Lichens, phytoplankton	Grasses and herbs, from seeds in soil
Speed	Very slow (centuries or more)	Faster (decades)

Deeper

Types by cause and energy

- **Autogenic succession:** change is driven by the community itself (for example, plants building soil and shade).
- **Allogenic succession:** change is driven by outside forces (fire, flood, siltation, climate change).
- **Autotrophic succession:** dominated by green plants from the start; biomass rises over time.
- **Heterotrophic succession:** dominated early by heterotrophs, for example on a dead log or in a sewage-rich pond; organic matter falls over time.

Views of the climax

Theory	Proposed by	Idea
Monoclimax	F.E. Clements	Each climatic region has only one climax, set by climate
Polyclimax	A.G. Tansley	Several climaxes can exist in one region, set by soil, topography, fire and so on
Climax-pattern	R.H. Whittaker	The climax is a continuous pattern that varies with the environment

Mechanisms (Connell and Slatyer, 1977)

- **Facilitation:** early species change conditions in ways that help later species.
- **Tolerance:** later species tolerate lower resource levels and simply outlast earlier ones.
- **Inhibition:** early species hold the site and block later ones until they die or are disturbed.

Disturbance resets succession. Fire, cyclones, grazing and shifting cultivation hold many Indian landscapes at a seral stage. For example, many grasslands persist only because of regular fire or grazing.

Real examples: after the 1883 eruption of Krakatoa (Indonesia) wiped out life on the island, it became a classic study of primary succession. Abandoned *jhum* (shifting cultivation) plots in north-east India show secondary succession back towards forest.

Common traps

✗ "An abandoned farm is primary succession." ✓ It is **secondary** succession, because soil remains.

✗ "Mosses are the pioneers on bare rock." ✓ **Lichens** are the pioneers; mosses follow.

✗ "Hydrarch succession moves from dry to wet." ✓ Hydrarch moves from **wet to mesic**; xerarch moves from **dry to mesic**.

✗ "Primary succession is faster because there is less competition." ✓ **Secondary** succession is faster, because soil is already present.

✗ "A sere is the final community." ✓ A sere is the **whole sequence**; the final stable stage is the **climax**.

Quick revision

- Succession: gradual, predictable change in species composition.
- Pioneer → seral stages → climax; the whole sequence = sere.
- Primary: no soil (rock, lava, new pond). Secondary: soil remains (abandoned field, burnt forest).
- Secondary is faster.
- Pioneers: lichens on rock; phytoplankton in water.
- Hydrarch: wet → mesic. Xerarch: dry → mesic.
- Clements (1916): monocl原因. Tansley: polyclimax. Whittaker: climax-pattern.
- During succession, diversity, biomass and soil increase.

6 Population and community ecology: growth, interactions and keystone species

Populations grow by births and immigration and shrink by deaths and emigration, within limits set by resources, while species in a community interact in ways that can help, harm or leave each other unaffected.

Core facts

- **Population attributes** (an individual does not have them): **birth rate (natality), death rate (mortality), sex ratio, age distribution**.
- **Population density** is written as **N**.
- **Population change**: $N_{t+1} = N_t + [(B + I) - (D + E)]$. Density rises when births plus immigration exceed deaths plus emigration.
- **Exponential growth** (unlimited resources): $dN/dt = rN$. It gives a **J-shaped** curve. **r** is the **intrinsic rate of natural increase**.
- **Logistic growth** (limited resources): $dN/dt = rN (K - N)/K$. It gives a **sigmoid (S-shaped)** curve. This is the **Verhulst–Pearl** model. **K** is the **carrying capacity**.
- **Interactions between two species:**

Interaction	Species A	Species B
Mutualism	+	+
Competition	–	–
Predation	+	–
Parasitism	+	–
Commensalism	+	0
Amensalism	–	0

- **Keystone species**: a species whose effect on the community is far larger than its numbers suggest. The classic case is the starfish *Pisaster*.

Explained

Measuring population size

- Plain **numbers** are not always meaningful. If an area has 200 *Parthenium* plants and one large banyan tree, **percent cover or biomass** describes the banyan better.
- **Relative density** is often enough. For example, the number of fish caught per trap is a measure of the fish population.
- **Birth rate example (NCERT)**: 20 lotus plants last year, 8 new ones added: birth rate = $8/20 = 0.4$ **offspring per lotus per year**.

- **Age pyramids** show the share of pre-reproductive, reproductive and post-reproductive individuals:
 - triangular (broad base): **expanding**
 - bell-shaped: **stable**
 - urn-shaped (narrow base): **declining**

Growth models

- **NCERT r values:** Norway rat **0.015**; flour beetle **0.12**; India's human population in 1981 **0.0205**.
- **Exponential:** $N_t = N_0 e^{(rt)}$. A population that doubles in 3 years has $r = \ln 2 / 3 \approx \mathbf{0.23}$ per year.
- **Logistic:** the curve has a **lag phase**, then **acceleration**, then **deceleration**, and finally an **asymptote** at K. It is more realistic, because resources are always finite.
- **Life-history patterns (NCERT):**
 - Some breed **once** in a lifetime: **Pacific salmon, bamboo**.
 - Most birds and mammals breed **many times**.
 - Some produce **many small offspring**: **oysters, pelagic fishes**.
 - Others produce **a few large offspring**: birds and mammals.
- Populations evolve to maximise **reproductive (Darwinian) fitness**, shown by a **high r**.

Examples of each interaction (NCERT)

- **Mutualism:**
 - lichens (fungus + alga or cyanobacterium)
 - mycorrhiza (fungus + roots of higher plants)
 - fig and its pollinator wasp: the female wasp lays eggs in the fruit, and the larvae feed on the developing seeds
 - the orchid *Ophrys*, pollinated through **sexual deceit** of a bee
- **Commensalism:** orchid growing on a mango branch; barnacles on a whale; **cattle egret and grazing cattle**; **sea anemone and clown fish**.
- **Amensalism:** *Penicillium* secretes penicillin, which harms bacteria while the fungus is unaffected.
- **Parasitism:** lice on humans, ticks on dogs, copepods on marine fish (ectoparasites); liver fluke (endoparasite); *Cuscuta* on hedge plants.
 - **Brood parasitism:** the **koel (cuckoo)** **lays its eggs in a crow's nest**.
- **Competition:** flamingoes and resident fishes compete for zooplankton in South American lakes.

Deeper

Predation

- Predators transfer energy, keep prey numbers in check and help keep species diversity.
- The **prickly pear cactus**, an introduced plant in Australia, had spread over millions of hectares of rangeland by the 1920s (NCERT dates the problem to the early 1920s). It was controlled only by introducing a **cactus-feeding moth** from its native area. (Biological control.)
- **Prudent predators** do not over-exploit prey. If prey went extinct, the predator would starve too.
- **Prey defences:**

- camouflage
- poison: the **Monarch butterfly** is distasteful to birds because of a chemical its caterpillar takes in from a poisonous weed
- thorns (*Acacia*, cactus)
- plant chemicals: *Calotropis* makes poisonous **cardiac glycosides; nicotine, caffeine, quinine, strychnine** and **opium** are plant defences against grazers
- Nearly **25%** of all insects are **phytophagous** (they feed on plant sap and other plant parts).

Competition

- NCERT defines competition as a process in which the fitness of one species (measured by its r) is significantly lower in the presence of another. It occurs between related and unrelated species, and even when resources are not limited.
- **Interference competition:** the feeding efficiency of one species is reduced by the interfering and inhibitory presence of the other, even when resources are plentiful.
- **Abingdon tortoise** (Galapagos) died out within a decade of goats arriving, apparently because the goats browsed more efficiently.
- **Competitive release:** a species whose range is restricted by a superior competitor expands when that competitor is removed. **Connell's** experiments on the Scottish coast showed that the larger barnacle *Balanus* excludes the smaller *Chthamalus* from the intertidal zone.
- **Gause's competitive exclusion principle:** two closely related species competing for the same resource cannot coexist indefinitely; the weaker is eventually eliminated.
- **Resource partitioning: MacArthur** showed that five closely related **warblers** live on the same tree by foraging in different parts of it.

Parasites

- Many are **host-specific**, so host and parasite **co-evolve**.
- Adaptations: loss of unnecessary sense organs, adhesive organs or suckers, **loss of the digestive system**, high reproductive capacity.
- Life cycles of **endoparasites are more complex** than those of ectoparasites.
- In brood parasitism, the parasite's eggs resemble the host's in size and colour, which **reduces the chance that the host detects and ejects them**.
- NCERT notes that the **female mosquito is not considered a parasite**, although it needs our blood to reproduce.

Keystone species

- **Robert Paine** removed all *Pisaster* starfish from an enclosed intertidal area on the American Pacific coast. Within a year, **more than 10 species of invertebrates became extinct**, because of interspecific competition once the predator was gone.
- Other examples: tigers and wolves (top predators), elephants (open up forest), fig trees (fruit through the year).

Common traps

✗ "Commensalism benefits both species." ✓ That is **mutualism**. In commensalism one benefits and the **other is unaffected**.

✗ "One harmed, the other unaffected, is commensalism." ✓ That is **amensalism**.

✗ "Endoparasites have simpler life cycles than ectoparasites." ✓ Endoparasites have **more complex** life cycles.

✗ "The logistic curve is J-shaped." ✓ Logistic is **S-shaped (sigmoid)**; exponential is **J-shaped**.

✗ "Gause showed warbler coexistence." ✓ **MacArthur** showed warbler resource partitioning; Gause gave competitive exclusion.

✗ "Lichen is commensalism." ✓ Lichen is **mutualism** between a fungus and an alga or cyanobacterium.

Quick revision

- Population attributes: birth rate, death rate, sex ratio, age distribution.
- $N_{t+1} = N_t + [(B + I) - (D + E)]$.
- Exponential: $dN/dt = rN$ (J-shaped). Logistic: $dN/dt = rN(K - N)/K$ (S-shaped, Verhulst–Pearl).
- r : Norway rat 0.015; flour beetle 0.12; India 1981 0.0205.
- Breed once: Pacific salmon, bamboo.
- $+/+$ mutualism; $-/-$ competition; $+/-$ predation, parasitism; $+/0$ commensalism; $-/0$ amensalism.
- Koel in crow's nest = brood parasitism.
- Gause: exclusion. MacArthur: warblers. Connell: barnacles.
- Pisaster removed → more than 10 invertebrate species lost: keystone species.
- Prickly pear in Australia controlled by a cactus-feeding moth.

7 Terrestrial biomes: ecology and adaptations

A biome is the largest recognisable assemblage of plants and animals on Earth, shaped mainly by temperature and rainfall, and its species show adaptations to those conditions.

Core facts

- **Biome:** the largest recognisable assemblage of plants and animals, whose distribution is controlled mainly by **climate**, chiefly **temperature and precipitation**.
- Major terrestrial biomes:
 - tropical rain forest
 - tropical deciduous (monsoon) forest
 - savanna
 - desert
 - temperate grassland
 - temperate deciduous forest
 - Mediterranean scrub
 - taiga (boreal coniferous forest)
 - tundra
- **Tropical rain forest:** hot and wet all year, very high diversity, multi-layered canopy.
- **Savanna:** tropical grassland with scattered trees; fire and grazing maintain it.
- **Desert:** very low rainfall (usually below about 25 cm a year); xerophytes and water-saving animals.
- **Taiga:** coniferous forest of the cold north, between temperate forest and tundra.
- **Tundra:** treeless; **permafrost** below the surface; lichens and mosses; reindeer (caribou).
- India's forests are classified by **Champion and Seth (1968)** into **16 type groups**.
- **Tropical dry deciduous** and **tropical moist deciduous** forests are the most widespread forest type groups in India.

Explained

Main biomes at a glance

Biome	Climate	Typical life
Tropical rain forest	Hot; heavy rain all year	Tall evergreen trees, lianas, epiphytes; Amazon, Congo, South-East Asia; in India, Western Ghats and the north-east
Tropical deciduous	Hot; seasonal (monsoon) rain	Teak, sal; trees shed leaves in the dry season
Savanna	Hot; long dry season	Grasses and scattered trees; large herds of grazers in Africa

Biome	Climate	Typical life
Desert	Very dry; extreme day–night range	Cacti, thorny shrubs; kangaroo rat, camel
Temperate grassland	Cold winters, warm summers, moderate rain	Grasses; deep fertile soils; prairies, pampas, steppes, veld, downs
Temperate deciduous	Four seasons	Oak, maple, beech
Taiga	Long cold winter, short summer	Spruce, fir, pine; moose
Tundra	Very cold; short summer	Lichens, mosses, dwarf shrubs; reindeer, Arctic fox

Temperate grasslands by region

Name	Region
Prairies	North America
Pampas	South America (Argentina)
Steppes	Eurasia
Veld	South Africa
Downs	Australia

Adaptations to desert life

- **Plants (xerophytes):** thick cuticle; sunken stomata; leaves reduced to spines; photosynthesis in a flattened stem (*Opuntia*); deep or wide roots; **CAM** photosynthesis, in which stomata open at night.
- **Animals:** the **kangaroo rat** gets water from oxidising fat and passes very concentrated urine; many animals are active at night; camels tolerate water loss.

Adaptations to cold

- **Allen's rule:** mammals from colder climates have **shorter ears and limbs**, which cut heat loss.
- **Bergmann's rule:** within a related group, animals in colder climates tend to have **larger bodies**. A larger body has less surface area per unit volume, so it loses heat more slowly.
- Thick fur, blubber (seals), hibernation and migration.

Deeper

Why the rain forest is rich but its soil is poor

- Warm, wet conditions speed decomposition. Nutrients are taken up by plants almost as soon as they are released, so most nutrients sit in the vegetation, not in the soil.
- Heavy rain leaches the soil, leaving it poor (lateritic in many places).
- So when the forest is cleared, crops fail within a few years and the land degrades. Shifting cultivation works only with long fallows.

Indian forest types (Champion and Seth)

Type group	Rainfall (approx.)	Where in India
Tropical wet evergreen	Above 250 cm	Western Ghats, north-east, Andaman and Nicobar
Tropical moist deciduous	100–200 cm	Eastern slopes of Western Ghats, Odisha, Jharkhand, Terai
Tropical dry deciduous	70–100 cm	Peninsular plateau, much of Andhra Pradesh
Tropical thorn	Below 70 cm	Rajasthan, Gujarat, dry rain-shadow parts of the Deccan
Montane temperate and alpine	Varies with altitude	Himalaya, Nilgiris

- **Whittaker's biome diagram** places biomes on two axes: mean annual temperature and mean annual precipitation. Fire, soil and grazing can shift the boundary (for example, between savanna and forest).
- **Altitude mimics latitude.** Climbing a Himalayan slope passes through tropical, temperate, coniferous and alpine zones, much like travelling from the equator to the Arctic.
- **Tundra and taiga** hold large stores of soil carbon in permafrost. Thawing releases carbon dioxide and methane, which adds to warming (see ENV-BC-02).

AP angle

- Most of Andhra Pradesh's forest is **tropical dry deciduous**, with **tropical thorn** forest in the drier Rayalaseema districts.
- The **Nallamala** and **Seshachalam** hills of the Eastern Ghats are the main forest tracts. **Nagarjunasagar–Srisailem Tiger Reserve**, in the Nallamala, is India's largest tiger reserve by area.
- **Red sanders** (*Pterocarpus santalinus*) is **endemic** to the southern Eastern Ghats, mainly in AP's Seshachalam and nearby hills. It is a dry deciduous species, now listed as endangered, and smuggling is a major problem.
- **Seshachalam Biosphere Reserve** (notified 2010) protects this dry deciduous landscape.

Common traps

✗ "Biome distribution is controlled mainly by soil." ✓ It is controlled mainly by **climate** (temperature and rainfall).

✗ "Rain forest soils are very fertile." ✓ They are generally **poor**; nutrients are held in the vegetation.

✗ "Pampas are in Australia." ✓ Pampas are in **South America**. Australia has the **Downs**; South Africa the **Veld**.

✗ "Allen's rule says cold-climate animals are larger." ✓ That is **Bergmann's** rule. **Allen's** rule is about **shorter limbs and ears**.

✗ "Tropical evergreen forest is India's most widespread type." ✓ **Tropical dry and moist deciduous** forests are the most widespread.

Quick revision

- Biome: largest assemblage; controlled by temperature and rainfall.
- Rain forest: hot, wet, diverse, poor soil.
- Savanna: grassland with scattered trees; fire maintains it.
- Taiga = boreal conifers; tundra = treeless, permafrost.
- Prairies (N. America), pampas (S. America), steppes (Eurasia), veld (S. Africa), downs (Australia).
- Allen's rule: short limbs in cold; Bergmann's rule: larger body in cold.
- Desert plants: CAM, sunken stomata, spines; kangaroo rat makes metabolic water.
- Champion and Seth (1968): 16 forest type groups.
- Deciduous forests most widespread in India.
- Red sanders: endemic to AP's southern Eastern Ghats.

8 Aquatic ecosystems: freshwater, estuarine, mangrove and marine

Aquatic ecosystems range from fresh water to salt water; estuaries, mangroves and coral reefs are among the most productive, and they protect coasts as well as feeding fisheries.

Core facts

- **Freshwater ecosystems:**
 - **Lentic:** standing water, such as ponds, lakes and wetlands.
 - **Lotic:** flowing water, such as streams and rivers.
- **Aquatic organisms by lifestyle:**
 - **Plankton:** drift with water. **Phytoplankton** are producers; **zooplankton** are consumers.
 - **Nekton:** strong swimmers, such as fish and whales.
 - **Benthos:** live on or in the bottom, such as snails, worms and crabs.
 - **Neuston:** live at the surface film.
- **Estuary:** where a river meets the sea; water is **brackish** (a mix of fresh and salt water). Estuaries are among the **most productive** ecosystems and are nurseries for fish and prawns.
- **Mangroves:** salt-tolerant trees and shrubs of tropical and subtropical tidal coasts.
- **Sundarbans** (Ganga-Brahmaputra delta, shared by India and Bangladesh) is the **largest mangrove forest in the world**.
- **Mangrove cover in India:** about **4,990 km²**, roughly **0.15%** of the country's area (ISFR 2021 and 2023). **West Bengal** has the most, then **Gujarat**, then **Andaman and Nicobar Islands**.
- **Coral reefs** in India: **Gulf of Mannar, Gulf of Kachchh, Lakshadweep, Andaman and Nicobar Islands**.
- Mangroves **slow down strong winds and waves**, so they protect coastal people from cyclones and tsunamis.

Explained

Zones of a lake

Zone	Where	Life
Littoral	Shallow water near the shore; light reaches the bottom	Rooted plants, many animals
Limnetic	Open, sunlit surface water away from shore	Phytoplankton, zooplankton, fish
Profundal	Deep water below light penetration	Few organisms; decomposers
Benthic	The bottom, at all depths	Bottom-dwellers, decomposers

Lakes by nutrient level

- **Oligotrophic:** low nutrients, clear water, high oxygen, low productivity (deep mountain lakes).
- **Eutrophic:** high nutrients, green water, high productivity, oxygen depletion near the bottom.
- **Eutrophication** is the ageing of a lake by nutrient enrichment. It is natural but slow; fertiliser and sewage run-off (nitrates and phosphates) make it fast ("cultural eutrophication"). It causes algal blooms, low oxygen and fish deaths.

Mangrove adaptations

- **Pneumatophores:** roots that grow upward out of the mud to take in air, because the mud lacks oxygen.
- **Vivipary:** seeds germinate while still on the tree, and the seedling drops ready to root.
- **Stilt or prop roots** give support in soft mud.
- **Salt management:** many species exclude salt at the roots or excrete it through leaf glands.

Marine zones

- By light: **photic** (sunlit, where photosynthesis takes place, roughly the top 200 m) and **aphotic** (dark).
- By position: **intertidal** (between high and low tide), **neritic** (over the continental shelf), **oceanic** (open ocean beyond the shelf).
- By habitat: **pelagic** (open water) and **benthic** (sea floor).

Deeper

Thermal stratification in deep temperate lakes

- In summer, a lake forms three layers:
 - **epilimnion:** warm upper layer
 - **thermocline (metalimnion):** a layer where temperature falls rapidly with depth
 - **hypolimnion:** cold bottom layer
- In autumn and spring, surface water cools or warms to about **4 °C**, the temperature at which fresh water is densest. It then sinks, and the lake mixes (**turnover**), bringing oxygen down and nutrients up.
- Water is densest at about 4 °C, and ice floats. This keeps lakes from freezing solid, so life survives under the ice.

Why estuaries and mangroves are so productive

- Rivers bring nutrients; tides mix them; shallow water lets light reach the bottom.
- Mangrove litter supports a rich **detritus food chain** (see ENV-EC-03).
- They trap sediment and stabilise shorelines.
- They store large amounts of **blue carbon** in their soils.

Coral reefs

- Corals are colonies of tiny animals (polyps) that build calcium carbonate skeletons.
- They live in a **mutualism** with algae called **zooxanthellae**, which live in their tissues, photosynthesise and supply food. The algae also give corals much of their colour.
- Reefs need warm, clear, shallow, sunlit water.

- **Coral bleaching:** under heat stress, corals expel the zooxanthellae and turn white. Long or repeated bleaching kills them. Ocean acidification also weakens their skeletons.
- Reef types: **fringing** (close to shore), **barrier** (separated from shore by a lagoon), **atoll** (a ring around a lagoon, as in **Lakshadweep**).

Deep-sea hydrothermal vents. Bacteria there make food by **chemosynthesis**, using hydrogen sulphide. They support tube worms, clams and crabs without sunlight.

AP angle

- **Coringa Wildlife Sanctuary** (Kakinada district) protects mangroves in the **Godavari** estuary, one of the largest mangrove stretches on India's east coast.
- **Krishna Wildlife Sanctuary** protects the mangroves of the **Krishna** estuary.
- **Pulicat Lake**, shared by AP and Tamil Nadu, is India's **second-largest brackish-water lagoon** after **Chilika**. Sriharikota island lies between the lagoon and the sea.
- **Kolleru Lake**, between the Godavari and Krishna deltas, is one of India's largest natural **freshwater** lakes. It was declared a **Ramsar site in 2002**. Large areas were turned into fish tanks, and the government demolished many of them in 2006 to restore the lake.

Common traps

X "Lentic means flowing water." ✓ **Lentic = standing** (ponds, lakes); **lotic = flowing** (rivers).

X "Nekton drift with the water." ✓ **Plankton** drift; **nekton** swim actively.

X "Pulicat is India's largest brackish lagoon." ✓ **Chilika** (Odisha) is the largest; **Pulicat** is second.

X "Kolleru is a brackish-water lagoon." ✓ Kolleru is a **freshwater** lake; Ramsar site since **2002**.

X "Gujarat has the largest mangrove cover in India." ✓ **West Bengal** has the most; Gujarat is second.

X "Corals make their own food by photosynthesis." ✓ Their partner algae, **zooxanthellae**, do; corals are animals.

Quick revision

- Lentic = standing; lotic = flowing.
- Plankton drift, nekton swim, benthos live at the bottom.
- Lake zones: littoral, limnetic, profundal, benthic.
- Thermocline separates the warm epilimnion from the cold hypolimnion.
- Estuary: brackish, highly productive, fish nursery.
- Sundarbans: largest mangrove forest in the world.
- India's mangroves: about 4,990 km² (ISFR 2021/2023); West Bengal > Gujarat > Andaman and Nicobar.

- Mangrove features: pneumatophores, vivipary, salt control.
- Corals + zooxanthellae = mutualism; heat causes bleaching.
- AP: Coringa (Godavari), Krishna WLS, Pulicat (2nd brackish lagoon), Kolleru (Ramsar 2002).