

AP Environmental Science

Every topic handout in one volume

exercises.lol

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The Living World: Ecosystems

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Introduction to Ecosystems

An **ecosystem** is all the living things (biotic) and non-living things (abiotic) in an area, interacting together. Organisms depend on each other and on their physical environment, and interactions like **predation**, **competition**, and **symbiosis** (mutualism, commensalism, parasitism) shape the community.

Terrestrial Biomes

A **biome** is a large region defined by its climate and characteristic life. **Terrestrial biomes** (deserts, grasslands, tropical rainforest, temperate forest, taiga, tundra) are determined mainly by temperature and **precipitation**. Each has plants and animals adapted to those conditions.

The two images below sit at opposite ends of the precipitation scale, which is why their life looks so different:



A tropical rainforest : hot and wet all year, giving dense layered plant life and the richest biodiversity of any land biome



A desert : very low precipitation, so only sparse drought-adapted life survives

Aquatic Biomes

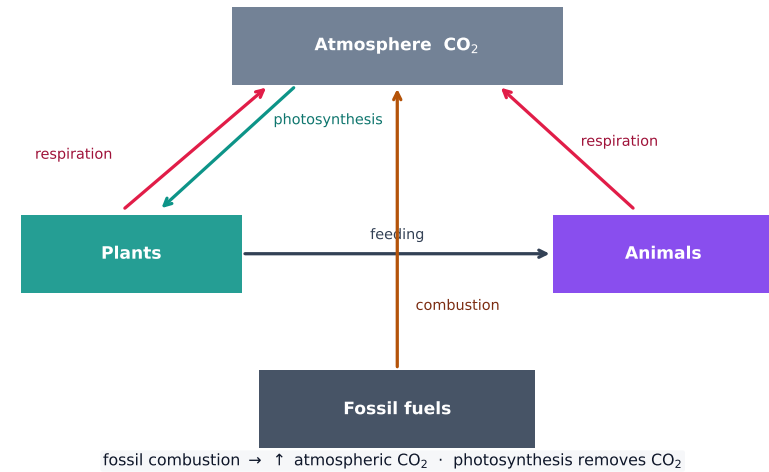
Aquatic biomes cover more of Earth than land. Freshwater (streams, lakes, wetlands) and marine (open ocean, coral reefs, estuaries) systems differ in **salinity**, sunlight, and nutrients. **Estuaries** (where rivers meet the sea) and coral reefs are especially productive and biodiverse.



A coral reef : warm, sunlit, shallow water makes it one of the most productive and biodiverse of all biomes

The Carbon Cycle

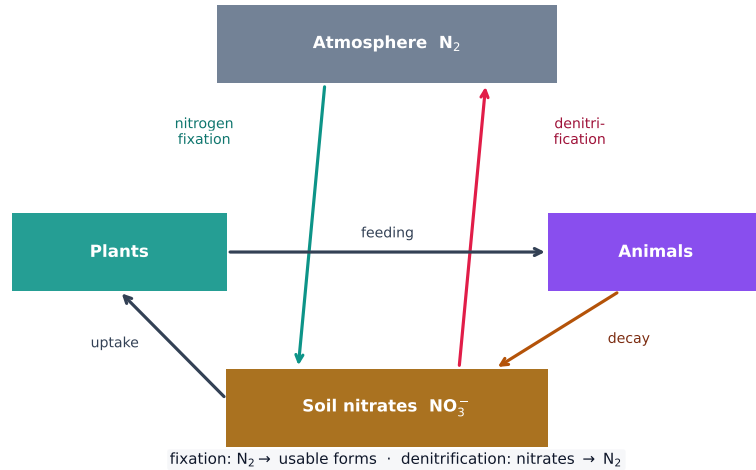
The **carbon cycle** moves carbon between the atmosphere, organisms, oceans, and rocks. **Photosynthesis** removes CO_2 ; **respiration**, **decomposition**, and burning **fossil fuels** return it. Burning fossil fuels adds carbon far faster than natural processes remove it.



The carbon cycle moves carbon among the atmosphere, living things, and fossil fuels

The Nitrogen Cycle

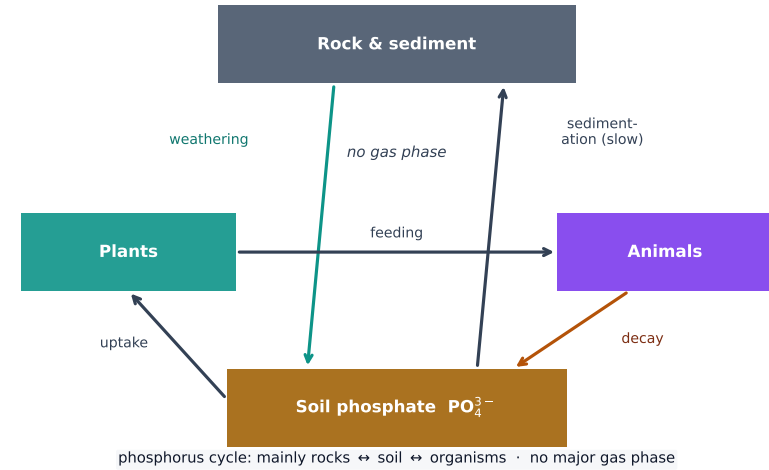
The **nitrogen cycle** makes nitrogen usable for life. **Nitrogen fixation** (by bacteria) converts atmospheric N_2 to ammonia; nitrification and assimilation pass it through organisms; **denitrification** returns N_2 to the air. Fertilizer adds reactive nitrogen, which can pollute water.



The nitrogen cycle: N_2 is fixed into soil nitrates, passed through food, and returned to the air by denitrification

The Phosphorus Cycle

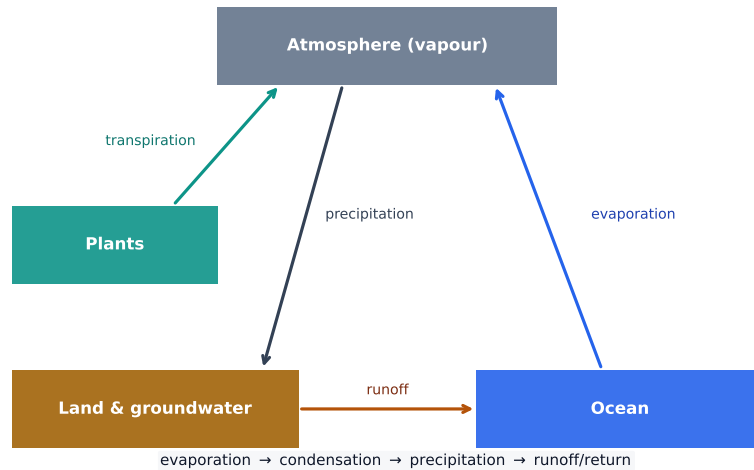
The **phosphorus cycle** has **no atmospheric (gas) stage** – phosphorus moves through rock, soil, water, and organisms. It is slow and often the **limiting nutrient** for growth, so added phosphorus (fertilizer, detergents) can trigger algal blooms.



The phosphorus cycle: rock weathers to soil phosphate and slowly sediments back, with no gas phase

The Hydrologic (Water) Cycle

The **water cycle** moves water by **evaporation**, **transpiration** (from plants), **condensation**, **precipitation**, and runoff. It distributes fresh water and shapes climate; human use and land changes can alter its flow.



The water cycle: evaporation and transpiration lift water to the air; precipitation and runoff return it

Primary Productivity

Primary productivity is the rate at which producers capture energy (usually by photosynthesis). **Gross primary productivity (GPP)** is the total captured; **net primary productivity (NPP)** is what remains after the producers' own respiration – the energy available to the rest of the ecosystem. Warm, wet, sunlit systems (rainforests, reefs) are most productive.

Worked example. If producers in a grassland capture $20,000 \text{ kcal/m}^2/\text{yr}$ of energy (GPP) and burn $8,000 \text{ kcal/m}^2/\text{yr}$ in their own respiration, then $\text{NPP} = \text{GPP} - R = 20,000 - 8,000 = 12,000 \text{ kcal/m}^2/\text{yr}$. Only that NPP – not the full GPP – is available to the consumers above.

Trophic Levels

Organisms occupy **trophic levels**: **producers** (make their own food), then primary, secondary, and tertiary **consumers**, with **decomposers** recycling nutrients at every level. Each level depends on the energy captured below it.

Energy Flow and the 10% Rule

Energy flows **one way** through an ecosystem and is lost as heat at each transfer. The **10% rule**: only about 10% of the energy at one trophic level passes to the next; the other 90% powers life processes and escapes as heat. This is why food chains are short and top predators are few.

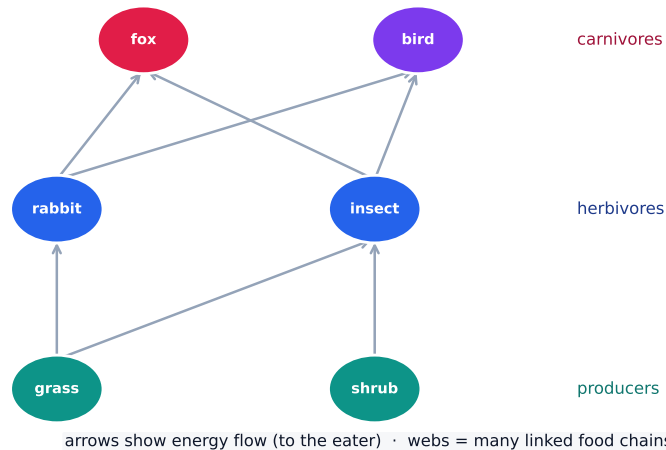
Worked example. Continuing from $12,000 \text{ kcal/m}^2/\text{yr}$ of NPP at the producer level, the primary consumers receive about $10\% = 1,200 \text{ kcal}$, secondary consumers $\approx 120 \text{ kcal}$, and tertiary consumers only $\approx 12 \text{ kcal}$. After three transfers the energy has shrunk a thousand-fold – the arithmetic reason a fourth or fifth trophic level rarely has enough to support it.



An energy pyramid: only about 10% of energy passes to the next trophic level

Food Chains and Food Webs

A **food chain** is a single line of who-eats-whom; a **food web** links many chains into a realistic picture of feeding relationships. Because species are interconnected, removing one (especially a **keystone species**) can disrupt the whole web.



A food web links many food chains; arrows point the way energy flows

Exam tips

- Remember **energy flows and is lost** (the 10% rule) while **matter cycles** (carbon, nitrogen, phosphorus, water).
- Apply the 10% rule down a food chain and know **$NPP = GPP - \text{respiration}$** (only NPP is available to consumers).
- Learn each biogeochemical cycle's stores and how humans disturb it (burning fossil fuels adds CO_2 ; fertiliser adds nitrogen/phosphorus).
- Producers are most abundant because so little energy reaches the top.
- Use correct units and show your arithmetic on the free-response math questions (no calculator — keep numbers round).

The Living World: Biodiversity

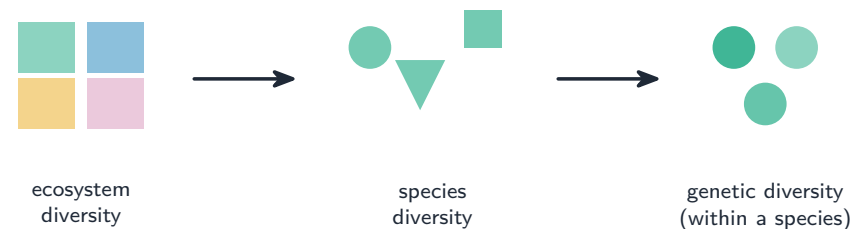
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Introduction to Biodiversity

Biodiversity is the variety of life, measured at three levels:

- Genetic diversity** – variety of genes *within* a species. More genetic variety means a population can better respond to **environmental stressors**; a **population bottleneck** (a sharp drop in numbers) throws that variety away and leaves the survivors vulnerable.
- Species diversity** – the number of species (**species richness**) and how evenly individuals are spread among them.
- Habitat diversity** – the variety of habitats in a region.

More species-rich ecosystems are more **resilient**: they recover from disruption more readily, because varied species can fill roles when conditions change. Habitat loss removes species in a predictable *order* – **specialist** species (narrow needs) go first, then the hardier **generalist** species, and species that need large territories decline as their range shrinks.



Biodiversity has three levels: genetic, species, and habitat



A coral reef: high biodiversity concentrates species and ecosystem services in a small area

Ecosystem Services

Ecosystem services are the free benefits nature gives people, in four categories:

- **Provisioning** – products: food, fresh water, timber, fibre.
- **Regulating** – processes that keep conditions stable: climate regulation, water filtration, pollination, flood control.
- **Cultural** – non-material value: recreation, beauty, spiritual and educational value.
- **Supporting** – the services that make the others possible: nutrient cycling, soil formation, photosynthesis.

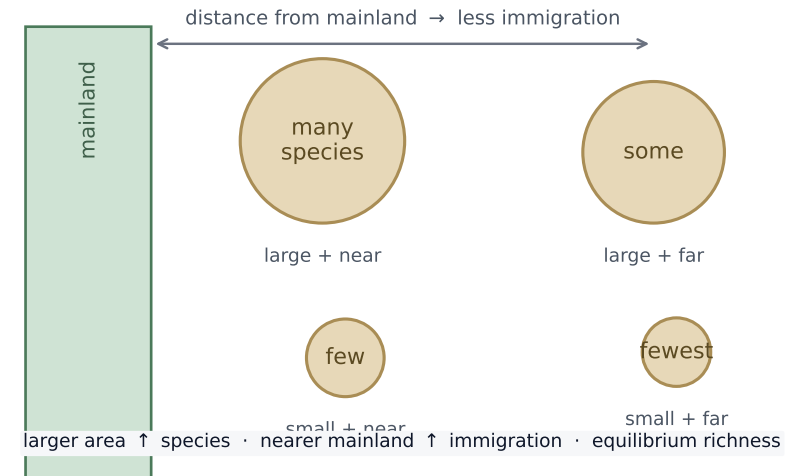
Anthropogenic (human-caused) activities can disrupt these services, with real economic *and* ecological costs – for example, losing pollinators forces farmers to pay for pollination that bees once did for free.

Island Biogeography

Island biogeography studies how many species an island (or any isolated habitat patch) holds. The number settles at a balance between two rates:

- **Immigration** of new species – higher for islands **closer** to the mainland.
- **Extinction** of resident species – lower on **larger** islands.

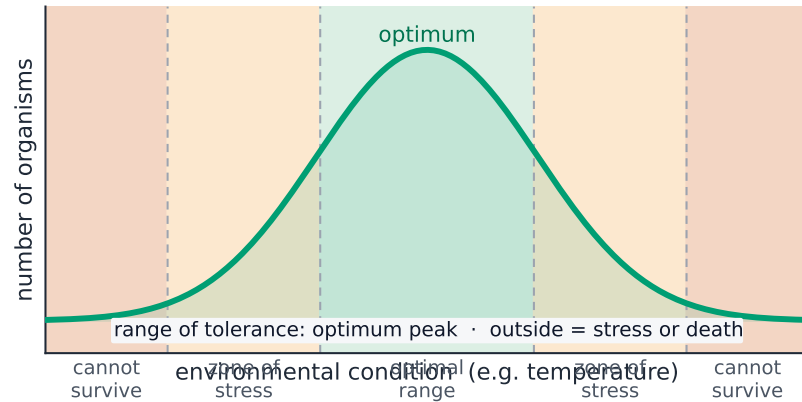
So big, near islands hold the most species; small, remote ones the fewest. Isolation also drives evolution: island species often become **specialists** because resources are limited, and many are **endemic** – found nowhere else. That makes them fragile. When an **invasive species** (usually a tough generalist) arrives, it can outcompete the specialists, which have nowhere else to go.



Larger and nearer islands hold more species, balancing immigration against extinction

Ecological Tolerance

Every species has a **range of tolerance** – the span of conditions (temperature, salinity, pH, sunlight) it can survive. Near the middle is an **optimal range** where individuals thrive; toward the edges are **zones of stress** where they survive but struggle to grow or reproduce; beyond the limits they die. **Ecological tolerance** applies both to a single individual and to a whole species, and it decides where an organism can live and how it copes with change.



Within its optimal range a species thrives; toward the limits it is stressed, then cannot survive

Natural Disruptions to Ecosystems

Natural events disrupt ecosystems across every timescale, and a single natural event can rival or exceed a human-made one. Earth's processes come in three timing patterns:

- **Periodic** – regular cycles (seasons, tides).
- **Episodic** – occasional, irregular events (fires, floods, volcanic eruptions).
- **Random** – no pattern (a meteor strike).

Over geological time, Earth's climate has shifted for many reasons, and sea level has risen and fallen with the amount of glacial ice – each change reshaping large swaths of habitat. Wildlife responds by **migration**, moving short or long distances to follow conditions.



A crown fire sweeping through a forest. Fire is a natural episodic disturbance, and many species are adapted to it

Adaptations

An **adaptation** is an inherited trait that improves survival and reproduction in an environment. Adaptations arise through **natural selection** – incremental genetic change accumulating over generations, not within a single lifetime. When the environment changes, individuals must alter their behaviour, move, or die; if change comes faster than a population can adapt, it declines. A periodic disturbance such as fire is often part of a healthy cycle, and many species are adapted *to* it (some pine cones open only in a fire's heat).

Ecological Succession

Ecological succession is the gradual, orderly change in a community over time:

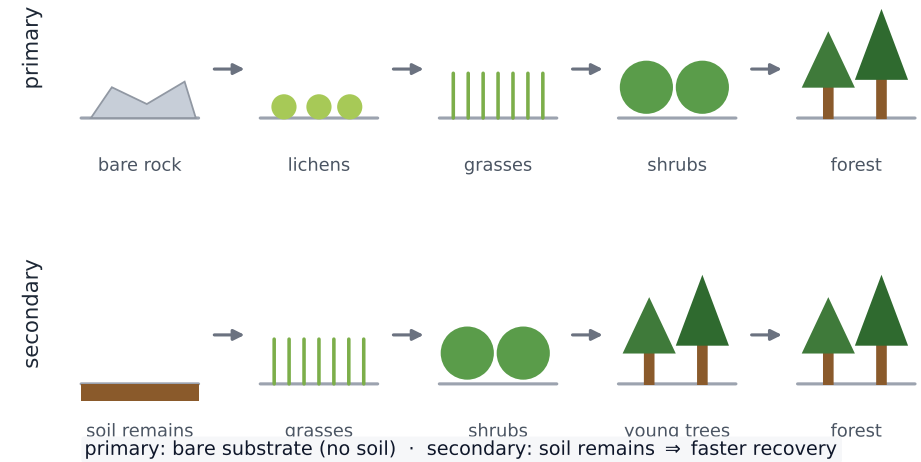
- **Primary succession** starts on bare rock with **no soil** – after a glacier retreats or lava cools. **Pioneer species** such as **lichens** arrive first and slowly build soil. It is slow.



Lichens growing straight on bare rock. As pioneer species they slowly break the rock down and build the first thin soil

- **Secondary succession** follows a disturbance that leaves the soil intact – after a fire or abandoned farming – so it is much faster.

Succession tends toward a relatively stable **climax community**. Two special roles shape a community out of proportion to their numbers: a **keystone species**, whose activities hold the community structure together (remove it and the community collapses – sea otters keeping urchins in check), and an **indicator species**, whose presence or health signals the condition of the whole ecosystem (lichens vanish where the air is polluted).



Primary succession builds from bare rock; secondary succession regrows from surviving soil

Worked example. A pond holds 3 fish species with 5, 3, and 2 individuals ($N = 10$). Simpson's Diversity Index = $1 - \sum \left(\frac{n}{N}\right)^2 = 1 - [(0.5)^2 + (0.3)^2 + (0.2)^2] = 1 - 0.38 = 0.62$. A value near 1 means high diversity; near 0 means one species dominates. Adding a fourth, evenly-sized species would push the index higher.

Exam tips

- Describe biodiversity at three levels: **genetic, species, and habitat**, and link higher diversity to greater **resilience**.
- **Specialist** species (narrow needs) are more vulnerable than **generalists** when a habitat changes.
- Distinguish **primary** succession (bare rock, no soil, slow) from **secondary** (soil intact, faster).
- Explain a **keystone species** (outsized effect) and an **indicator species** (signals ecosystem health).
- Name the four **ecosystem services** (provisioning, regulating, cultural, supporting) with examples.

Populations

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Generalist and Specialist Species

A **generalist** can live in many habitats and eat many foods (raccoon, cockroach) – flexible, so it copes well with change. A **specialist** needs specific conditions or foods (panda, koala) – efficient in a stable habitat but very vulnerable if that habitat changes.

K-Selected and r-Selected Species

Two reproductive strategies:

- **r-selected** species produce **many** offspring with little care, mature fast, and have short lives (insects, weeds). They colonize quickly and boom-and-bust.
- **K-selected** species produce **few** offspring with much care, mature slowly, and live long (elephants, humans). They do well near **carrying capacity** in stable environments but recover slowly from losses.



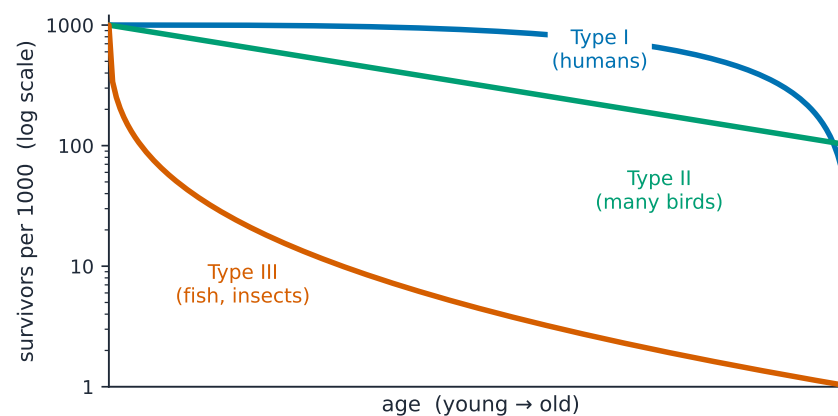
An elephant with its single calf: a K-selected species has few young but invests heavily in each one, so it recovers slowly if numbers fall



A young rabbit: r-selected species produce many offspring quickly with little parental investment

Survivorship Curves

A **survivorship curve** plots how many individuals survive at each age (on a log scale). **Type I** (humans): most survive to old age, then die – a convex curve. **Type II** (many birds): a constant death rate at all ages – a straight line. **Type III** (r-selected: fish, insects): most die young, a few survive – a concave curve.

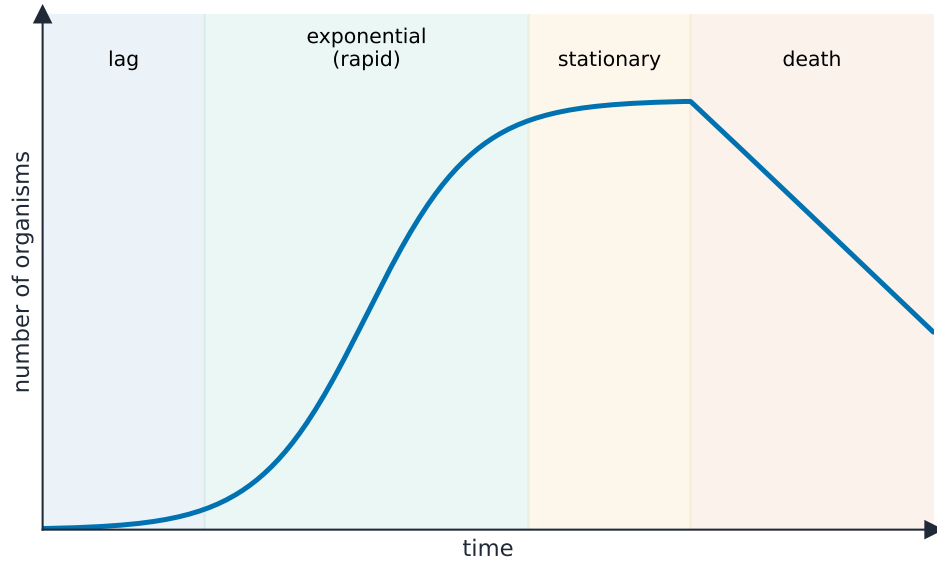


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Type I, II, and III survivorship curves on a log scale

Carrying Capacity

The **carrying capacity** (K) is the maximum population an environment can support long-term. A population may **overshoot** K when resources are temporarily plentiful, then **crash** (**dieback**) as resources run out. Populations tend to fluctuate around K .



Population growth levels off at the carrying capacity of the environment



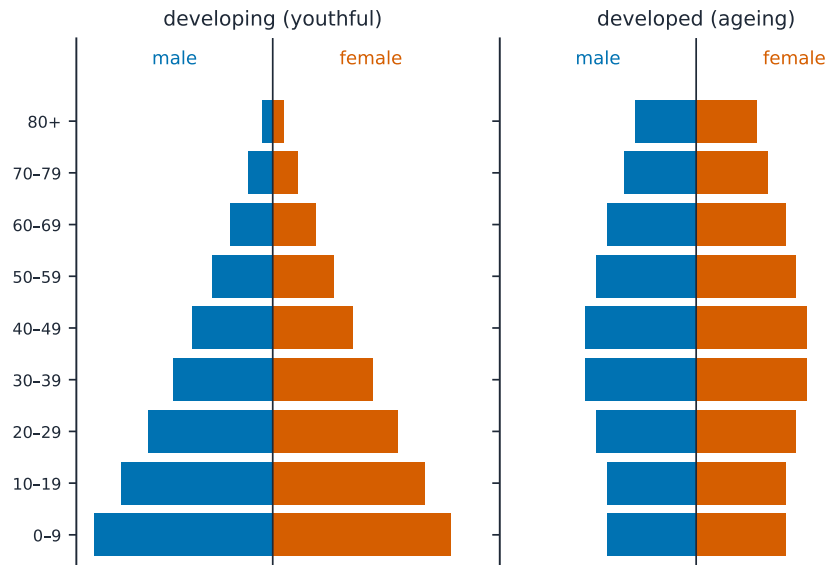
A deer herd: when a population approaches carrying capacity, resources limit further growth

Population Growth and Resource Availability

With abundant resources a population grows **exponentially** (J -curve). As resources become limited, growth slows to **logistic** (S -curve), leveling at K . **Limiting factors** (food, water, space, disease) set the ceiling.

Age Structure Diagrams

An **age-structure diagram** shows the proportion of a population in each age group. A wide base (many young) predicts **rapid growth**; even bars predict a **stable** population; a narrow base predicts **decline**. They forecast a country's future population.



Population pyramids of a developing and a developed country

Total Fertility Rate

The **total fertility rate** (TFR) is the average number of children per woman. A **replacement level** of about **2.1** keeps a population steady; above it grows, below it shrinks. TFR falls with education, access to family planning, and lower infant mortality.

Human Population Dynamics

Human population growth depends on **birth rate**, **death rate**, and **migration**. Rapid growth strains resources and increases the **ecological footprint**. Factors lowering birth rates include education (especially of women), urbanization, and economic development.

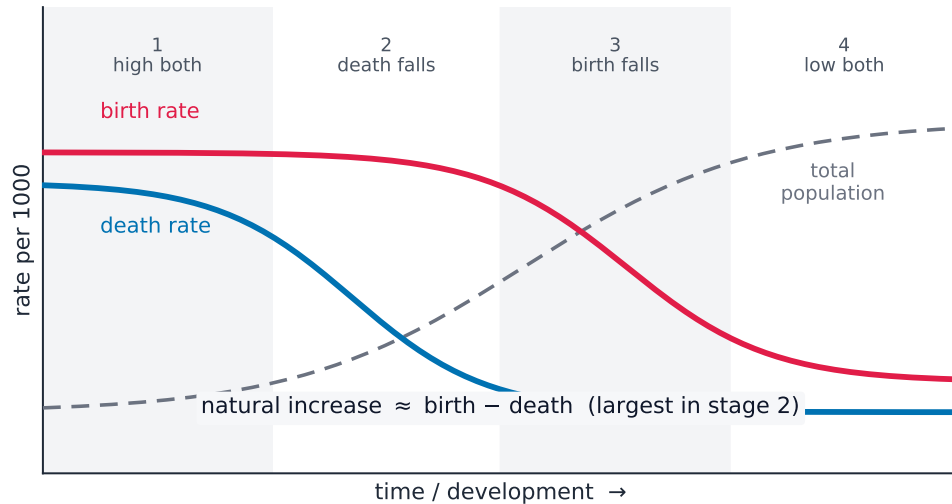
Worked example. A country has a birth rate of 30 per 1000 and a death rate of 10 per 1000. The natural growth rate is $\frac{30 - 10}{10} = 2.0\%$ per year (dividing the per-thousand difference by 10 converts it to a percent). By the **rule of 70**, the population doubles in about $\frac{70}{2.0} = 35$ years. If development cut the growth rate to 1.0%, the doubling time would stretch to $\frac{70}{1.0} = 70$ years.



A crowded city crossing: human population dynamics depend on birth rates, death rates and migration

Demographic Transition

The **demographic transition** describes how a country's growth changes as it develops, in stages: (1) high birth and death rates (slow growth); (2) death rate falls (rapid growth); (3) birth rate falls (slowing growth); (4) both low (stable). Developed nations are in later stages; many developing nations are in the rapid-growth stages.



The four stages of the demographic transition

The population grows fastest in stages 2 and 3 – the gap between a still-high birth rate and an already-fallen death rate. That lag is why a country's population keeps climbing long after its death rate drops.

Exam tips

- Use the **rule of 70**: doubling time $\approx 70 \div \text{growth-rate}(\%)$; a growth rate is (births – deaths) per 1000 $\div 10$.
- Read **age-structure diagrams**: a wide base predicts rapid growth, even bars a stable population.
- Contrast **r-selected** (many offspring, little care) and **K-selected** (few, much care) strategies.
- Know the **demographic transition** stages and what lowers birth rates (education, family planning, development).
- A falling **growth rate** still means growth — the population only shrinks when deaths exceed births.

Earth Systems and Resources

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Plate Tectonics

Earth's crust is broken into **plates** that slowly move on the mantle – **plate tectonics**. At **divergent** boundaries plates spread apart (new crust); at **convergent** they collide (mountains, volcanoes, earthquakes); at **transform** they slide past (earthquakes). Boundaries create hazards but also volcanic soils and mineral resources.



A volcano erupting at a plate boundary in Iceland. Molten rock rising between spreading plates builds new crust

Soil Formation and Erosion

Soil forms slowly as rock **weathers** and organic matter builds up. **Erosion** is the removal of soil by wind and water, sped up by removing vegetation (farming, deforestation, overgrazing). Because soil forms so slowly, erosion faster than formation depletes a vital resource.



Soil horizons form over time as parent rock weathers; erosion can strip topsoil and reverse that progress

Soil Composition and Properties

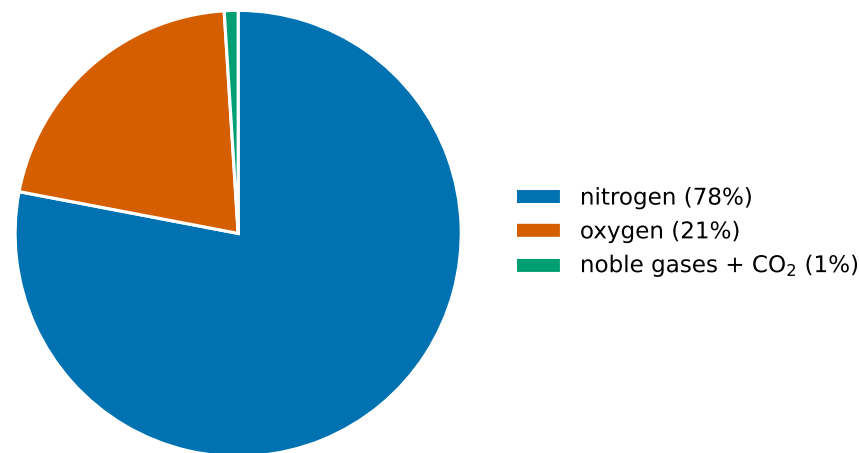
Soil is a mix of sand, silt, and clay (its **texture**), plus organic matter, water, and air, layered in **horizons** . Texture controls **porosity** and **permeability** – how well soil holds water and nutrients. **Loam** (a balanced mix) is best for plants.



A pit dug through soil shows its horizons: dark organic topsoil on top, then paler mineral layers, over broken rock (tape for scale)

Earth's Atmosphere

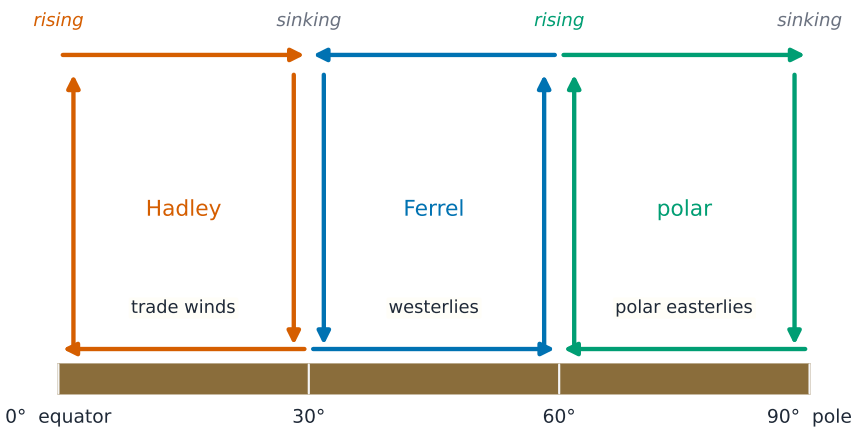
The **atmosphere** is layered: the **troposphere** (weather, where we live), the **stratosphere** (holding the ozone layer), and higher layers. It is mostly nitrogen and oxygen, with trace gases (including greenhouse gases) that regulate temperature.



Clean dry air is about 78% nitrogen, 21% oxygen, and 1% other gases

Global Wind Patterns

Uneven solar heating drives **global wind patterns**. Warm air rises at the equator and sinks at about 30°, creating **convection cells** (Hadley, Ferrel, polar) and prevailing winds (trade winds, westerlies). The spinning Earth deflects winds – the **Coriolis effect** – shaping weather and climate.



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Three circulation cells per hemisphere set the prevailing surface winds

Watersheds

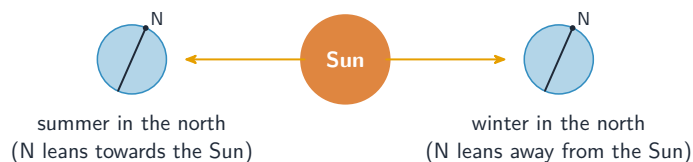
A **watershed** is all the land that drains to a common body of water. Everything that happens on the land – farming, paving, pollution – affects the water it drains into, so watersheds are key units for managing water quality.



A waterfall in a river basin: a watershed is the land that drains into a stream or lake

Solar Radiation and Earth's Seasons

Seasons come from Earth's **tilted axis** (about 23.5°), not its distance from the Sun. The hemisphere tilted toward the Sun gets more direct sunlight and longer days (summer). The tilt also makes the **tropics** warm year-round and the **poles** cold.



The tilt of the Earth's axis causes the seasons

Earth's Geography and Climate

Geography shapes climate: **latitude** (sunlight angle), **elevation** (cooler with height), proximity to **oceans** (moderating temperature), and mountains creating a **rain shadow** (wet windward side, dry leeward side). These factors decide which biome forms where.



Desert dunes: latitude, altitude and ocean currents shape Earth's climate regions

El Niño and La Niña

El Niño and **La Niña** are periodic shifts in Pacific Ocean temperatures and winds. El Niño (warm eastern Pacific) and La Niña (cool eastern Pacific) alter rainfall, storms, and fisheries **worldwide** – for example, floods in some regions and droughts in others.

Worked example. A tectonic plate moves 5 cm per year. How far does it travel in 1 million years? $5 \text{ cm/yr} \times 10^6 \text{ yr} = 5 \times 10^6 \text{ cm} = 50 \text{ km}$. A tiny yearly motion adds up to ocean-basin-scale distances over geologic time — the same slow rate that opens oceans and builds mountain ranges.

Exam tips

- **Seasons come from the Earth's tilt**, not its distance from the Sun.
- Soil forms very slowly, so **erosion faster than formation** permanently depletes it; know soil texture (sand/silt/clay) and horizons.

- Explain global wind patterns from uneven heating + the **Coriolis effect**, and a **rain shadow** (wet windward, dry leeward).
- Name the atmospheric layers (troposphere = weather, stratosphere = ozone) and air composition (~78% N₂, 21% O₂).
- **El Niño** / **La Niña** are Pacific temperature shifts that change rainfall worldwide.

Land and Water Use

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The Tragedy of the Commons

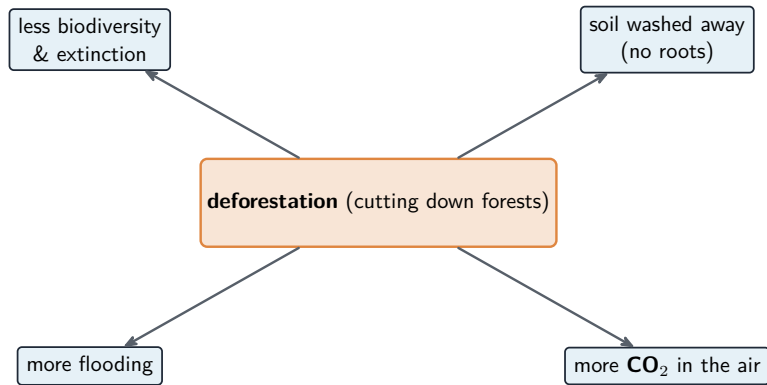
The **tragedy of the commons** : when a resource is shared and open to all (a fishery, the atmosphere, a pasture), each user takes as much as they can for private gain, and the shared resource is overused and degraded for everyone. Solutions require regulation, privatization, or cooperative management.

Clearcutting

Clearcutting removes all trees from an area at once. It is cheap and efficient but causes **erosion**, loss of habitat and biodiversity, flooding, and higher soil temperatures. Recovery is slow, and nearby streams suffer from sediment.



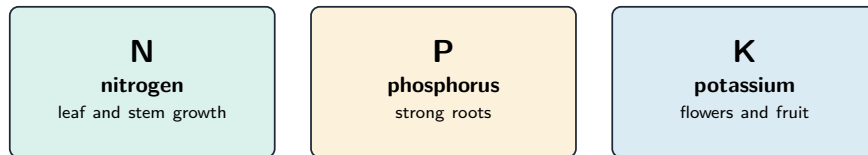
A fresh clearcut: every tree in the strip is taken at once, leaving bare soil that erodes and washes into streams



Deforestation lowers biodiversity and causes erosion, flooding, and higher CO₂

The Green Revolution

The **Green Revolution** boosted crop yields with high-yield seeds, **synthetic fertilizers**, **pesticides**, irrigation, and mechanization. It fed billions but brought costs: soil degradation, water pollution, high energy and water use, and loss of crop diversity (**monoculture**).



NPK fertilisers contain all three - ammonium salts and nitrates supply the nitrogen

NPK fertilisers supply the three elements plants need most

Impacts of Agricultural Practices

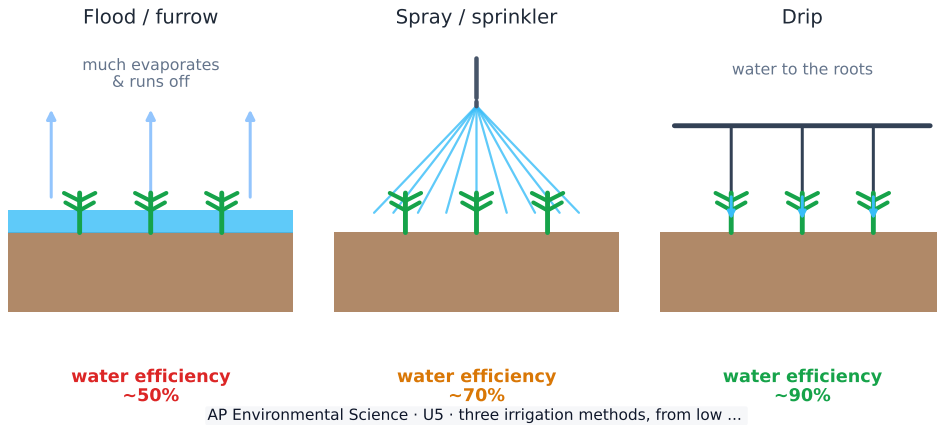
Practices such as tilling, monoculture, and heavy fertilizer/pesticide use cause **erosion**, **soil salinization**, nutrient runoff (causing **eutrophication**), and loss of biodiversity. Sustainable methods reduce these harms.



Intensive farmland: tillage, fertilisers and monocultures raise yields but can erode soil and pollute water

Irrigation Methods

Irrigation supplies water to crops, and it is by far the **largest human use of freshwater** - about **70%** of it worldwide, a figure the exam expects you to know. **Drip** irrigation is the most efficient (least evaporation); **flood** and **spray** methods waste more water and can cause **waterlogging** and **salinization** as evaporation leaves salts behind. Over-irrigation depletes **aquifers** (underground stores of freshwater) faster than they refill.



Irrigation methods compared: drip wastes the least water, flooding the most

Pest Control Methods

Pesticides kill pests and raise yields, but cause problems: they harm non-target species, pollute water, and drive **pesticide resistance** (survivors breed, so stronger doses are needed – the “pesticide treadmill”).



Aerial pesticide spraying: chemical pest control can protect yields but also harm non-target species and create resistant pests

Meat Production Methods

Producing meat, especially in **concentrated animal feeding operations** (CAFOs), uses large amounts of land, water, feed, and energy, and generates waste and **methane** (a greenhouse gas). Meat is far less energy-efficient than plant food because of the 10% rule – higher trophic levels waste more energy.

Overgrazing - letting livestock eat vegetation faster than it regrows - strips the soil of its protective cover. On dry land this can drive **desertification**: the degradation of low-precipitation regions until they become deserts. The sustainable answer is **rotational grazing**, moving livestock regularly between pastures so no single area is grazed bare.

Impacts of Overfishing

Overfishing removes fish faster than they reproduce, collapsing populations (like cod). **Bycatch** (unwanted catch) and destructive methods (bottom trawling) damage ecosystems. It is a classic tragedy of the commons in the open ocean.

Impacts of Mining

Mining extracts minerals and fuels but disturbs land, especially **surface (strip) mining** and **mountaintop removal**. Impacts include habitat destruction, **acid mine drainage**, and toxic tailings polluting water.



An open-pit mine : benches are cut ever wider and deeper to reach the ore, destroying habitat and exposing rock that pollutes water

When the easily reached deposits are gone, mining moves underground to **subsurface mining**, which is far more expensive and dangerous - the same pattern applies to coal as its accessible reserves shrink.

Impacts of Urbanization

Urbanization replaces natural land with **impervious surfaces** (roads, buildings), increasing runoff and flooding, creating **urban heat islands**, and generating pollution and waste. **Urban sprawl** consumes farmland and habitat. It also strains the **hydrologic cycle** : a dense city depletes local water, and heavy groundwater pumping near a coast draws seawater into the aquifer - **saltwater intrusion** - which can ruin a freshwater supply.



Urban sprawl : housing spreads over former farmland, sealing the soil so rain runs off instead of soaking in

Ecological Footprints

An **ecological footprint** measures the land and water a person or population needs to supply resources and absorb wastes. Wealthy, high-consumption nations have much larger footprints. If everyone's footprint exceeds Earth's capacity, resources are being used unsustainably.

Worked example. Earth provides roughly 1.6 global hectares (gha) of **biocapacity** per person. If the average person's footprint is 2.7 gha, humanity is demanding about $\frac{2.7}{1.6} \approx 1.7$ Earths – living beyond what the planet can renew. Worse, if everyone consumed like a high-income nation at 8 gha per person, it would take $\frac{8}{1.6} = 5$ Earths – exactly why footprint-per-person is the key sustainability yardstick.

Introduction to Sustainability

Sustainability means meeting present needs without harming future generations' ability to meet theirs. It balances environmental health, economic viability, and social equity, using resources no faster than they can be replaced.



Wind turbines on farmland: sustainable resource use meets present needs without locking out future generations

Methods to Reduce Urban Runoff

Reduce runoff with **permeable pavement**, **rain gardens** and **green roofs**, retention ponds, and preserved vegetation. These let water soak in, filtering pollutants and recharging groundwater instead of flooding streams.

Integrated Pest Management

Integrated pest management (IPM) combines methods – biological controls (natural predators), crop rotation, limited targeted pesticides, and monitoring – to control pests with **less** chemical use, slowing resistance and protecting non-target species.

Sustainable Agriculture

Sustainable farming protects soil and water: **crop rotation**, **cover crops**, **contour plowing**, **terracing**, reduced tillage, and **agroforestry**. These cut erosion, maintain fertility, and reduce chemical inputs.



Rice terraces cut a steep slope into level steps, so water and soil stay in place instead of eroding downhill

Aquaculture

Aquaculture (fish farming) eases pressure on wild stocks and is efficient, but can pollute water with waste and antibiotics, spread disease to wild fish, and destroy habitat (like mangroves for shrimp farms).

Sustainable Forestry

Sustainable forestry keeps forests productive: **selective cutting** instead of clearcutting, replanting, leaving buffer strips along streams, and long rotation times. It maintains habitat, prevents erosion, and lets forests keep providing ecosystem services.

Forests also absorb pollutants and store carbon dioxide, so cutting and burning them releases CO₂ and worsens climate change. Ways to **mitigate deforestation** include **reforestation** (replanting), buying wood from ecologically sustainable forestry, and reusing wood. A separate tool is the **prescribed burn**: deliberately burning a forest under controlled conditions to clear fuel, so a later wildfire cannot grow catastrophic.

Exam tips

- Explain the **tragedy of the commons** — shared, unowned resources get overused — and how rules/ownership prevent it.
- Weigh the trade-offs of the green revolution, irrigation (salinisation, aquifer depletion), and mining/urbanisation.
- Compute an **ecological footprint** in “number of Earths” (footprint $\div$ biocapacity per person); it is measured **per person**.
- List the harms of **deforestation** (erosion, flooding, lost habitat, more CO₂).
- Define **sustainability** (meeting needs without harming future generations) and give sustainable methods (IPM, crop rotation, quotas).

Energy Resources and Consumption

AP Environmental Science

Renewable and Nonrenewable Resources

A **renewable resource** replenishes on a human timescale (sun, wind, water, biomass); a **nonrenewable resource** exists in fixed amounts that take millions of years to form (fossil fuels, nuclear fuel). Nonrenewables will eventually run out and often pollute more.



Wind turbines: renewable sources replenish on human timescales; fossil fuels do not

Global Energy Consumption

Global energy use is rising, especially in developing nations. Most energy still comes from **fossil fuels**. Wealthy nations consume the most per person; access to energy shapes economic development.

Fuel Types and Uses

Different fuels suit different needs: coal and natural gas for **electricity**, oil for **transportation**, and biomass for heating and cooking in many regions. Each has trade-offs in cost, availability, and pollution.

Distribution of Natural Energy Resources

Energy resources are **unevenly** distributed – oil is concentrated in some regions, coal in others, and renewables depend on local sun, wind, or rivers. This uneven distribution drives trade, economics, and geopolitics.

Fossil Fuels

Fossil fuels (coal, oil, natural gas) formed from ancient organisms. They are energy-dense and reliable but **nonrenewable** and the main source of CO_2 and air pollution. Coal is the dirtiest; natural gas burns cleaner but leaks **methane**.



An open-pit **lignite** (brown coal) mine feeding the power station behind it — the fuel is dug from the ground and burned on the spot

Coal forms in stages, and its **rank** climbs with the heat, pressure, and depth of burial it has endured. Partly decomposed plant matter first becomes **peat** (which can itself be dried and burned), then soft brown lignite, then **bituminous** coal, and finally hard **anthracite** – each step is drier, more carbon-rich, and higher in energy, so anthracite burns hottest and cleanest.

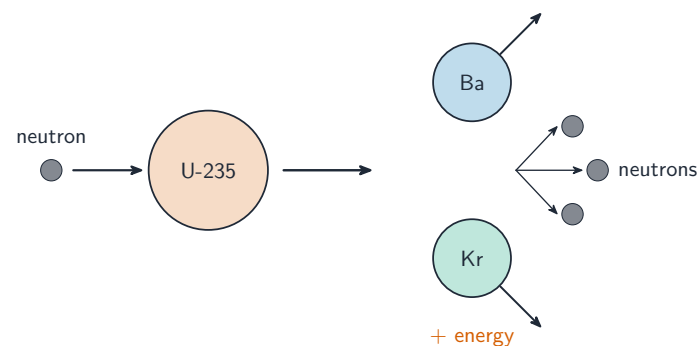
Oil and natural gas are increasingly reached by **hydraulic fracturing** (“fracking”): a high-pressure fluid is pumped into shale rock to crack it open and release the trapped fuel. It has unlocked huge reserves, but it can **contaminate groundwater** (methane and chemicals reaching drinking-water wells), release **volatile organic compounds** into the air, and trigger minor earthquakes.

Crude oil can also be recovered from **tar sands** – a mix of clay, sand, water, and thick **bitumen**. Separating the oil is energy- and water-intensive and clears large areas of land, so its environmental cost per barrel of oil is high.

Nuclear Power

Nuclear power splits uranium (**fission**) to boil water and drive turbines. It produces **no** CO_2 and lots of energy from little fuel, but risks include radioactive **waste** (long-lived), the danger of meltdowns, and high cost.

Worked example. Radioactive waste decays by its **half-life** – the time for half of it to decay. Suppose an isotope has a half-life of 30 years and a reactor leaves 100 g of it. After 30 years 50 g remains; after 60 years 25 g; after 90 years (three half-lives) $100 \times \left(\frac{1}{2}\right)^3 = 12.5$ g. Because the drop is halving, not linear, the waste stays hazardous for many half-lives – the core reason it must be stored safely for centuries.



Nuclear fission of a uranium-235 nucleus releases energy



A nuclear power station. The reactor buildings hold the fuel; the sea supplies cooling water. Notice there is no smoke — fission releases no CO₂

Energy from Biomass

Biomass (wood, crops, waste, biofuels like ethanol) is renewable and can be carbon-neutral if replanted, but burning it causes air pollution, and growing fuel crops competes with food and habitat.

Ethanol, made from crops such as corn or sugarcane, can substitute for gasoline and adds no *new* carbon when burned (the plant absorbed that CO₂ as it grew). Its drawback is a low **energy return on energy investment (EROEI)**

: growing, harvesting, and distilling the crop uses nearly as much energy as the fuel finally delivers.

Solar Energy

Solar converts sunlight to electricity (photovoltaic panels) or heat. It is renewable and clean during use, but **intermittent** (no sun at night), needs space, and has manufacturing impacts.



*A solar farm. Rows of **photovoltaic** panels are tilted toward the sun; a big output needs a large area of land*

Hydroelectric Power

Hydroelectric power uses flowing water (dams) to spin turbines – renewable and low-emission, but dams flood habitat, block fish migration, trap sediment, and displace people.



*A hydroelectric dam . The **reservoir** is held back behind the wall; water falls through the dam to spin turbines in the power house at its base*

Geothermal Energy

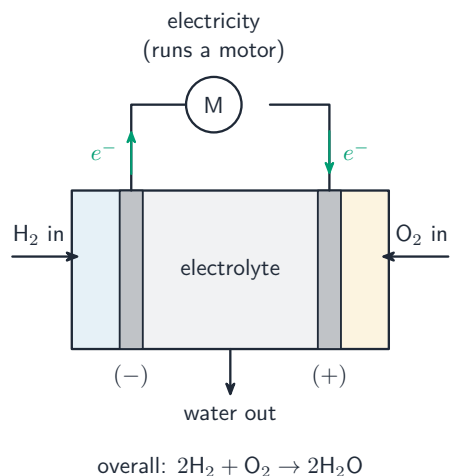
Geothermal taps Earth's internal heat for electricity and heating. It is renewable and reliable, but only practical where hot rock is near the surface (volcanic regions) and can release underground gases.



*A geothermal power station in Iceland, a volcanic region. **Steam** from hot rock below is piped up to drive the turbines*

Hydrogen Fuel Cell

A **hydrogen fuel cell** combines hydrogen and oxygen to make electricity, with **water** as the only emission at use. But producing hydrogen usually requires energy (often from fossil fuels), and storage is difficult.



A hydrogen-oxygen fuel cell makes electricity, with water as the only product

Wind Energy

Wind turbines convert moving air to electricity – renewable, clean, and low-operating-cost, but intermittent, land- or sea-intensive, and a hazard to birds and bats. Best where winds are strong and steady.



Wind turbines on farmland. They take little ground, so the land between them can still be farmed

Energy Conservation

Energy conservation reduces demand through efficiency (LED lighting, insulation, efficient appliances, public transport) and behavior. Saving energy is often the cheapest and cleanest option – the energy you do not use needs no fuel and makes no pollution.

A related efficiency gain is **cogeneration** (combined heat and power): a single fuel burn is used to make **both** electricity **and** useful heat, capturing the waste heat that an ordinary power plant simply dumps – so far more of the fuel's energy ends up doing useful work.

Worked example. Replacing a 60 W incandescent bulb with a 10 W LED that gives the same light saves 50 W. Running it 5 hours a day saves $50\text{ W} \times 5\text{ h} = 250\text{ Wh} = 0.25\text{ kWh}$ per day, or about $0.25 \times 365 \approx 91\text{ kWh}$ per year. Multiply that by every bulb in a city and conservation rivals a new power plant – at far lower cost.



A solar farm: generating more renewable energy and cutting demand are both energy-conservation strategies

Exam tips

- Separate **renewable** (sun, wind, water) from **non-renewable** (fossil fuels, nuclear) and weigh each source's trade-offs.
- Fossil fuels are energy-dense but emit CO_2 ; **nuclear** emits no CO_2 but leaves long-lived waste.
- Do **half-life** math: after n half-lives a fraction $(\frac{1}{2})^n$ remains.
- Note that solar and wind are **intermittent** and need storage or backup.
- **Conservation** (efficiency) is often the cheapest, cleanest option — the energy not used needs no fuel.
- Know the **coal ranks** (peat $\rightarrow$ lignite $\rightarrow$ bituminous $\rightarrow$ anthracite; more heat/pressure/burial $\rightarrow$ higher energy) and the unconventional fuels **fracking** (shale oil/gas; groundwater + VOC pollution) and **tar sands** (bitumen, energy-intensive).
- **Ethanol** adds no net CO_2 but has a **low EROEI**; **cogeneration** (combined heat and power) captures waste heat so one fuel gives both electricity and heat.

Atmospheric Pollution

AP Environmental Science

Introduction to Air Pollution

Air pollution is harmful substances in the atmosphere. **Primary pollutants** are emitted directly (carbon monoxide, nitrogen oxides, sulfur dioxide, particulates); **secondary pollutants** form in the air from reactions (like ozone in smog). Most come from **burning fossil fuels** in vehicles, power plants, and industry.

Photochemical Smog

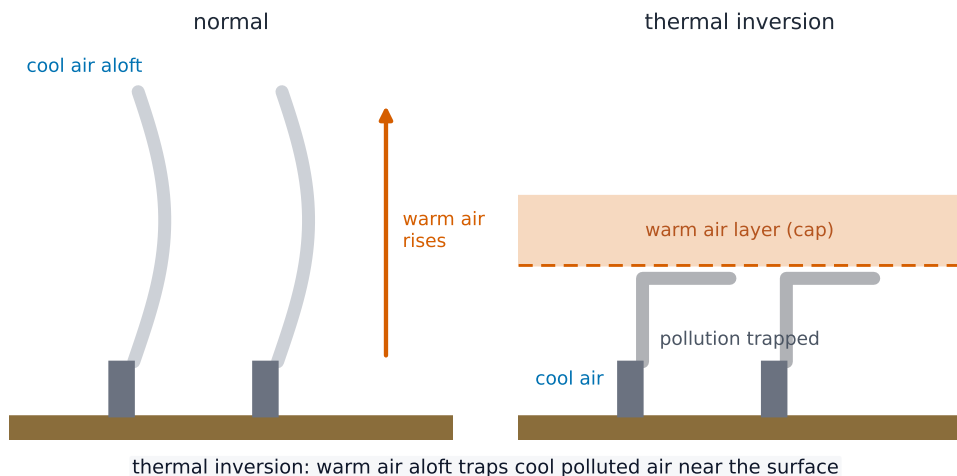
Photochemical smog forms when **sunlight** drives reactions among nitrogen oxides and volatile organic compounds from car exhaust, producing ground-level **ozone**. It is worst in sunny, car-heavy cities and harms lungs. (Ground-level ozone is a pollutant, unlike the protective ozone layer high up.)



Photochemical smog over Los Angeles: on a sunny day, car exhaust reacts in the light to make a brown haze that hides the skyline

Thermal Inversion

A **thermal inversion** traps pollution near the ground. Normally warm air rises and carries pollutants away, but in an inversion a layer of warm air sits **above** cooler air, capping it. Pollutants accumulate below – causing dangerous smog episodes, especially in valleys.



Normally warm air rises and disperses pollution; an inversion caps it near the ground

Atmospheric CO₂ and Particulates

Rising **atmospheric CO₂** from fossil fuels enhances the greenhouse effect and warms the climate. **Particulate matter** (tiny solid/liquid particles, PM_{2.5} and PM₁₀) penetrates deep into lungs, causing respiratory and heart disease, and reduces visibility.

Indoor Air Pollutants

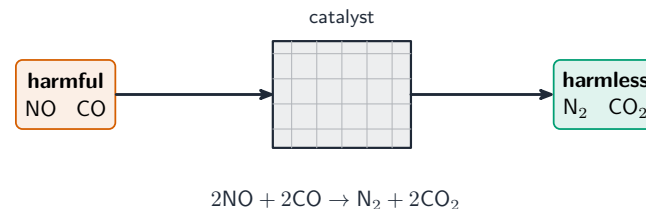
Indoor air can be more polluted than outdoor. Common **indoor pollutants** include **radon** (radioactive gas from the ground, a lung-cancer risk), **carbon monoxide**, **asbestos**, tobacco smoke, mold, and **VOCs** from paints and furnishings. Ventilation and source control reduce exposure.



An indoor cookstove: biomass smoke is a major indoor air pollutant in many homes worldwide

Reduction of Air Pollutants

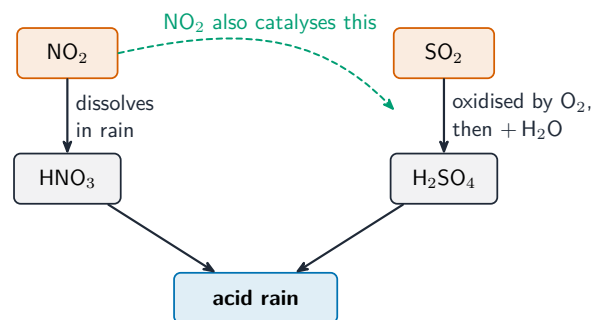
Air pollution is cut by technology and policy: **catalytic converters** on cars, **scrubbers** and **electrostatic precipitators** on smokestacks, cleaner fuels, and laws like the **Clean Air Act** setting emission limits. Reducing fossil-fuel use addresses the root cause.



A catalytic converter turns harmful NO and CO into harmless N₂ and CO₂

Acid Rain

Acid rain forms when **sulfur dioxide** and **nitrogen oxides** react with water in the air to make sulfuric and nitric acids, which fall far downwind. It acidifies lakes and soils (harming fish and trees), leaches nutrients, and corrodes buildings. Reducing SO_2 and NO_x emissions is the fix.



Nitrogen and sulfur oxides form nitric and sulfuric acid in rain



Forest dieback: acid deposition from SO_2 and NO_x can damage trees far downwind of the source

Noise Pollution

Noise pollution is unwanted or harmful sound in the environment. Major sources are road traffic, aircraft, trains, industry, and construction. In people, long or loud exposure causes **hearing loss**, **stress**, sleep loss, and higher blood pressure. It also disturbs **wildlife**: it masks the sounds animals use to communicate, navigate, and find mates, and underwater noise from ships is especially harmful to whales and dolphins. It is reduced by sound barriers, quieter engines and mufflers, and land-use planning such as buffer zones around airports.

Worked example. Normal rain has a pH of about 5.6; an acid-rain sample measures pH 3.6. Because pH is a base-10 logarithmic scale, each unit is a $10\times$ change in hydrogen-ion concentration, so pH 3.6 is $10^{(5.6-3.6)} = 10^2 = 100$ times more acidic than normal rain. That hundred-fold jump is why acid rain damages leaves, soils, and limestone so quickly.

Exam tips

- Distinguish **primary** pollutants (emitted directly: CO , NO_x , SO_2 , particulates) from **secondary** (form in the air: ground-level ozone).
- Ground-level ozone is a **pollutant**, but the ozone **layer** high up is protective — do not confuse them.
- Explain how a **thermal inversion** traps pollution near the ground.
- **Acid rain** (from SO_2 and NO_x) often falls **far downwind**, making it an international problem.
- Link control methods to pollutants (catalytic converters, scrubbers, cleaner fuels, emission laws).

Aquatic and Terrestrial Pollution

AP Environmental Science

Sources of Pollution

Pollution sources are **point** or **nonpoint**. A **point source** comes from a single, identifiable place (a factory pipe, a sewage outfall) – easy to locate and regulate. A **nonpoint source** is spread out (farm runoff, urban street runoff, car exhaust) – much harder to control because it comes from everywhere.

Human Impacts on Ecosystems

Human activities – pollution, habitat destruction, overharvesting, introducing species – degrade ecosystems and reduce biodiversity. Because species are interconnected, harming one part can ripple through the whole system.

Endocrine Disruptors

Endocrine disruptors are chemicals (some pesticides, plasticizers like BPA) that mimic or block hormones, disrupting growth, reproduction, and development in wildlife and humans even at very low doses.

Human Impacts on Wetlands and Mangroves

Wetlands and **mangroves** filter pollutants, store floodwater, and nurse young fish, but they are drained and cleared for farms, shrimp ponds, and development. Losing them removes valuable ecosystem services and coastal protection.



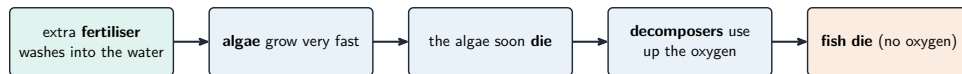
Mangrove roots: this tangle traps sediment, calms waves, and shelters young fish, all services lost when mangroves are cleared

Eutrophication

Eutrophication happens when excess nutrients (nitrogen, phosphorus from fertilizer and sewage) trigger **algal blooms**. When the algae die, decomposers use up the oxygen, creating **hypoxic** “dead zones” that suffocate fish.



A pond choked by an algal bloom: extra nutrients let algae cover the whole surface. When they die and rot, the water loses its oxygen



Extra fertiliser makes algae bloom, then the water loses its oxygen

Thermal Pollution

Thermal pollution is heat added to water, usually from power-plant cooling. Warm water holds **less dissolved oxygen** and stresses aquatic life adapted to cooler temperatures.

Persistent Organic Pollutants (POPs)

Persistent organic pollutants (POPs, like DDT and PCBs) resist breakdown, so they last for decades, travel far, and are **fat-soluble**, so they build up in organisms. This sets up bioaccumulation and biomagnification.

Bioaccumulation and Biomagnification

Bioaccumulation is the build-up of a toxin **within one organism** over its life. **Biomagnification** is the increase in concentration **up the food chain** – top predators end up with the highest levels, which is why large predatory fish carry the most mercury.

Worked example. Suppose lake water holds DDT at just 0.01 ppm. Plankton concentrate it to 0.5 ppm, small fish to 2 ppm, large fish to 10 ppm, and a fish-eating eagle to 25 ppm. From water to eagle the concentration has multiplied about $\frac{25}{0.01} = 2500$ -fold – which is why a top predator can be poisoned even when the water itself looks only lightly polluted.

Solid Waste Disposal

Solid waste is any discarded material that is not a liquid or gas, generated by homes, industry, business, and agriculture. It is buried in **sanitary landfills** (lined to limit leachate) or burned in **incinerators** (reduces volume but emits pollutants). Landfills take space and can leak; both have environmental costs, so reducing waste is preferred.

Two categories the exam names specifically: **e-waste** (discarded electronics - phones, computers, televisions - which contain toxic metals), and ocean dumping, where plastic and other waste collect into vast floating **garbage patches** far out at sea.



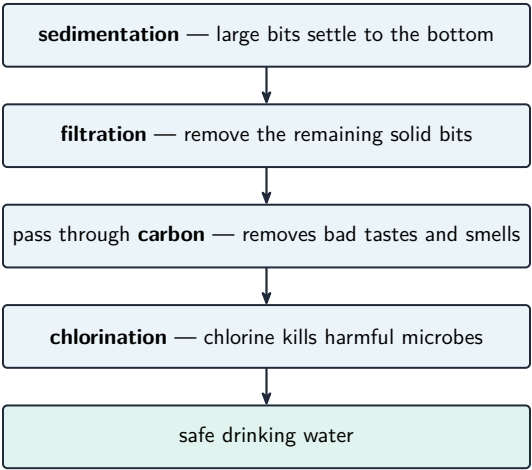
A landfill: solid waste is buried here in lined cells. It takes up land and can leak, which is why reducing waste comes first

Waste Reduction Methods

The waste hierarchy is **reduce, reuse, recycle** , plus **composting** for organic waste. Reducing consumption is best (no waste to manage); recycling and composting recover materials and cut landfill use.

Sewage Treatment

Sewage treatment cleans wastewater in stages: **primary** (settling out solids), **secondary** (bacteria break down organic matter), and sometimes **tertiary** (removing nutrients and disinfecting). This protects waterways from pathogens and nutrient pollution.



Treating water to make it safe: sedimentation, filtration, then disinfection

Lethal Dose 50% (LD50)

The **LD50** is the dose of a substance that kills **50%** of a test population. A **lower** LD50 means a **more toxic** substance (less is needed to be deadly). It is a standard way to compare toxicity.

Worked example. Chemical A has an LD50 of 5 mg per kg of body weight; chemical B, 500 mg/kg. Because A’s value is 100 times smaller, A is about 100× **more toxic**. For a 70 kg adult, the dose of A expected to be lethal to half of people is 5 mg/kg × 70 kg = 350 mg – a tiny amount, whereas B would take 500 × 70 = 35,000 mg (35 g).

Dose Response Curve

A **dose–response curve** plots the effect against the dose. Generally, a higher dose causes a greater effect. Some chemicals have a **threshold** (no effect below it); for others any exposure carries risk. These curves guide safety limits.

Pollution and Human Health

Pollution harms health directly (respiratory disease from air pollution, poisoning from contaminated water) and indirectly. **Dose, duration, and individual sensitivity** all affect the outcome. The poor are often most exposed and least protected.

Pathogens and Infectious Diseases

Pathogens (bacteria, viruses, parasites) spread through contaminated water and food. The exam names specific diseases and expects you to know **how each one is transmitted**, because the transmission route decides the defence:

Disease	Type	How it spreads
Cholera	bacterial	drinking water contaminated with sewage
Dysentery	bacterial	untreated sewage in streams and rivers
Plague	bacterial	bite of an infected organism (e.g. fleas) or contact with infected fluids
Tuberculosis (TB)	bacterial	breathing in bacteria from an infected person’s bodily fluids
Malaria	parasitic	bite of an infected mosquito (mostly sub-Saharan Africa)
West Nile / Zika	/	bite of an infected mosquito (Zika also via sexual contact)
SARS / MERS	viral	inhaling or touching infected fluids; MERS passes from animals to humans

Two big-picture ideas carry marks. **Poverty** deepens the problem - low-income areas often lack sanitary waste disposal and clean water, giving water-borne diseases a haven. And **climate change spreads disease**: as warm equatorial climate zones expand toward the poles, mosquitoes and other **vectors** - and the diseases they carry - move into temperate regions that never had them before. Clean water, sanitation, and vector control remain the main defences.

Exam tips

- Trace **eutrophication** step by step: nutrient runoff → algal bloom → decay → oxygen depletion → fish die.
- **Bioaccumulation** builds up in one organism; **biomagnification** increases up the food chain, so top predators are hit hardest.
- Read an **LD50**: a **lower** value means **more** toxic; multiply by body mass for a lethal dose.

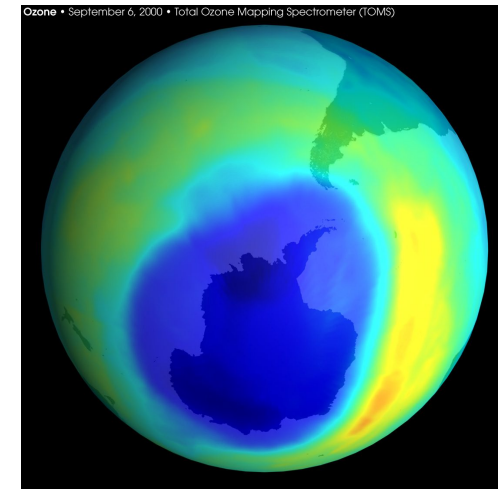
- Order the waste hierarchy **reduce** > **reuse** > **recycle**, and the stages of sewage treatment.
- Link pathogens to contaminated water and to clean-water/sanitation defences.

Global Change

AP Environmental Science

Stratospheric Ozone Depletion

The **ozone layer** high in the stratosphere absorbs harmful **ultraviolet** radiation. **CFCs** (chlorofluorocarbons, once used in coolants and sprays) drift up and release chlorine that destroys ozone, thinning it (the Antarctic “**ozone hole**”). More UV reaching the surface raises skin cancer, cataracts, and crop damage.



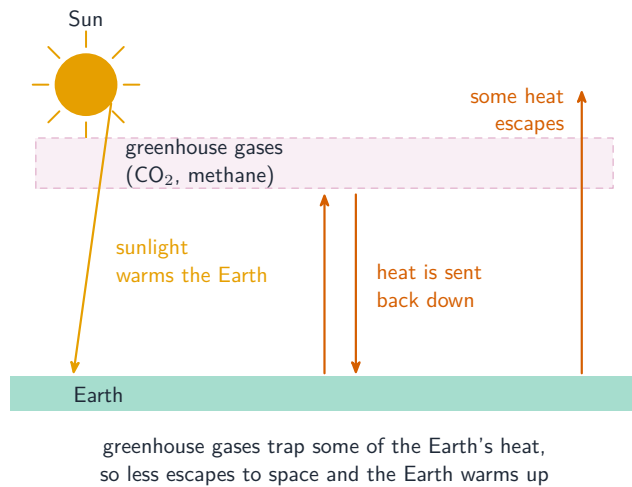
The ozone hole over Antarctica (dark blue) on a NASA map: this is where the ozone layer has thinned the most

Reducing Ozone Depletion

The **Montreal Protocol** (1987) phased out CFCs worldwide and is a rare environmental success – the ozone layer is slowly recovering. Substitutes (like HFCs and HCFCs) replaced CFCs, though some are themselves greenhouse gases.

The Greenhouse Effect

The **greenhouse effect** keeps Earth warm: **greenhouse gases** let sunlight in but trap outgoing infrared heat. This natural effect makes Earth livable. The problem is the **enhanced** greenhouse effect – humans adding extra gases that trap more heat.



Greenhouse gases absorb the heat the Earth gives off and send some back

Increases in the Greenhouse Gases

Human activities raise greenhouse gases: **CO₂** from burning fossil fuels and deforestation, **methane** from livestock, landfills, and rice paddies, and **nitrous oxide** from fertilizers. Methane traps far more heat per molecule than CO₂ but is less abundant.

To compare gases fairly, we use **global warming potential (GWP)**

- how much heat one unit of a gas traps over a set time, relative to CO₂. **CO₂ is the reference, with GWP = 1**, so every other gas is measured against it. Ranked by GWP: **CFCs** are highest, then **nitrous oxide**, then **methane** - all trap far more heat per molecule than CO₂. But GWP alone does not decide impact: CO₂ still causes the most warming overall because it is released in vastly greater **quantity**. The exam expects both ideas - a high GWP *and* how much is emitted.



Coal mining and combustion: burning fossil fuels is the main driver of rising atmospheric CO₂

Global Climate Change

Global climate change is the long-term shift in climate from the enhanced greenhouse effect: rising average temperatures, melting ice, rising **sea levels**, more extreme weather, and shifting rainfall. It disrupts ecosystems, agriculture, and human communities worldwide.



A glacier breaking apart into the sea. Warming melts land ice, which adds water to the ocean and raises sea level

Ocean Warming

As the climate warms, oceans absorb most of the extra heat. **Ocean warming** causes **coral bleaching** (corals expel their algae and can die), shifts species ranges, reduces dissolved oxygen, and – with melting ice – raises sea level through **thermal expansion**.



A bleached coral colony: warmer water made it expel its colourful algae, leaving the bare white skeleton. If the heat lasts, the coral dies

Ocean Acidification

The ocean absorbs about a quarter of our CO₂, which forms carbonic acid – **ocean acidification**. Lower pH makes it harder for corals, shellfish, and plankton to build **calcium carbonate** shells and skeletons, threatening marine food webs.

Invasive Species

An **invasive species** is a non-native species that spreads and harms its new ecosystem. With no natural predators, it outcompetes natives, spreads disease, and reduces biodiversity (kudzu, zebra mussels, Burmese pythons). Human trade and travel move them around.



The invasive vine kudzu smothering a stand of trees. With no natural predators in its new home, it blankets and kills what it covers

Endangered Species

An **endangered species** is at risk of extinction. Causes are summarized as **HIPPO**: **H**abitat loss, **I**nvasive species, **P**ollution, **P**opulation (human) growth, and **O**verharvesting. Protection includes laws (the Endangered Species Act), protected areas, and captive breeding.



A coral reef: habitat loss, warming and acidification put whole reef communities at risk of extinction

Human Impacts on Biodiversity

Together, habitat loss, climate change, pollution, invasive species, and overexploitation are driving a rapid loss of biodiversity – some call it a sixth mass extinction. Reducing these pressures, conserving habitat, and sustainable practices are the ways to slow it and protect the ecosystem services all life depends on.

A specific and heavily-tested driver is **habitat fragmentation** : large continuous habitats are broken into smaller, isolated patches by roads, pipelines, and development. Fragmentation is worse than simple area loss, because the small patches cut populations off from each other, reduce genetic diversity, and expose more **edge** to predators and invasive species.

two ways to conserve a species



In-situ and ex-situ conservation protect species

Worked example. Atmospheric CO₂ rose from about 280 ppm before industrialisation to about 420 ppm today. The percent increase is $\frac{420 - 280}{280} \times 100\% = \frac{140}{280} \times 100\% = 50\%$. This roughly 50% rise in the main long-lived greenhouse gas is the core driver of the enhanced greenhouse effect and modern warming.

Exam tips

- Keep **ozone depletion** (CFCs let in more UV) and **climate change** (greenhouse gases trap more heat) as **two different problems**.
- Explain the natural greenhouse effect and the **enhanced** version from extra CO₂ and methane.
- Connect ocean warming (coral bleaching) and **ocean acidification** (CO₂ → carbonic acid → weaker shells).
- An **invasive species** is dangerous because it has no natural predators in its new home.

- Summarise threats to biodiversity with **HIPPO** (Habitat loss, Invasive species, Pollution, Population, Overharvesting).