

Stability and change

Revision notes • IB Biology ecosystem stability: tipping points, mesocosms, keystone species, sustainability, pollution, rewilding and succession (HL).

For IB Diploma Biology, Standard Level and Higher Level (first assessment 2025). **HL only** is additional higher level content, for HL students only.

Stability and change **Spec D4.2**

Stability of natural ecosystems **Spec D4.2.1, D4.2.2**

A stable ecosystem keeps a similar community and similar processes over time, and recovers after disturbance. **Stability** is a property of natural ecosystems. There is evidence, from fossils and from pollen preserved in sediments, that some ecosystems have persisted for millions of years.

- **Tropical rainforest** in the Daintree region of north-east Australia descends from forests that covered much of Gondwana. Fossil pollen shows rainforest in Australia for tens of millions of years, and it survived here while drier climates shrank it elsewhere. (Popular figures of 135–180 million years are not firmly supported.)
- The **Namib Desert** in south-west Africa has been arid or semi-arid for at least 55 million years, and extremely dry for the last few million. Many desert species there, such as fog-basking beetles, are found nowhere else.

Requirements for stability in ecosystems

Requirement	Why it matters
Supply of energy	Sunlight captured by producers supports every trophic level; energy is not recycled, so the supply must be continuous.
Recycling of nutrients	Decomposers return carbon, nitrogen and phosphorus to the soil and air, so producers never run out.
Genetic diversity	Populations with many alleles are more likely to include individuals that survive a new disease or a change in conditions.
Climatic variables within tolerance levels	Temperature and rainfall must stay within the range the species can tolerate.

Exam tip: Linking question: over what timescales do things change in different biological systems? Ecosystems can be stable for millions of years yet collapse within decades once a requirement fails.

Amazon deforestation as a possible tipping point **Spec D4.2.3**

A **tipping point** is a critical threshold beyond which a small further change causes a large, often irreversible, shift to a different state.

How the rainforest makes its own rain

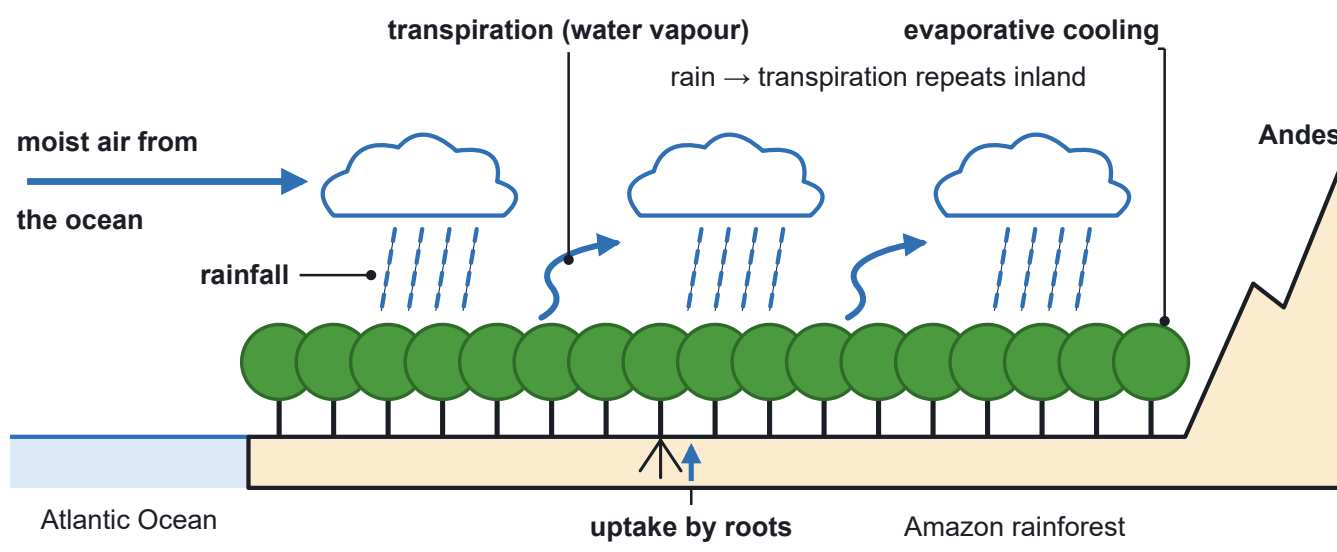
1. Trees take up water from the soil and release huge amounts of water vapour by **transpiration**.
2. Evaporation of this water absorbs heat, which cools the land surface.

3. Rising moist air and the condensation of vapour drive air flows that draw in more moist air from the Atlantic Ocean.
4. The water vapour condenses and falls as rain further inland, where it is transpired again. Water is recycled several times across the basin.

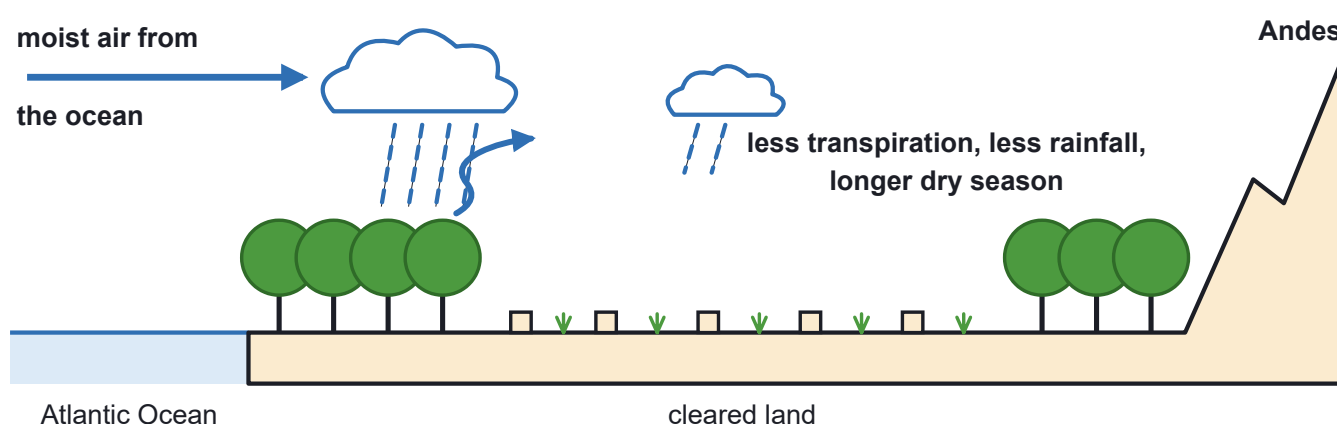
Deforestation reduces transpiration, so less rain falls and the dry season lengthens. Remaining trees become drought-stressed and fires spread more easily, killing more trees: a **positive feedback**. Beyond a tipping point, large parts of the forest could change to savannah.

A **large area** of rainforest is needed to keep these processes going, but there is uncertainty over the minimum area that is sufficient. Estimates differ between models, and climate change and fire make the threshold harder to predict.

intact rainforest



after deforestation



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The Amazon recycles its own rain by **transpiration**; clearing forest weakens the cycle.

Maths skill: The extent of deforestation can be assessed by calculating the percentage change from the original area of forest.

$$\text{percentage change} = (\text{final value} - \text{original value}) \div \text{original value} \times 100$$

Percentage change in forest area

A region originally had 4 200 000 km² of rainforest. It now has 3 486 000 km². Calculate the percentage change (practice figures).

1. Change = 3 486 000 – 4 200 000 = –714 000 km²
2. $-714\,000 \div 4\,200\,000 = -0.17$
3. $-0.17 \times 100 = -17\%$

Answer: –17%: the forest area has decreased by 17% of the original.

Mesocosms and keystone species Spec D4.2.4, D4.2.5

Using a model: mesocosms

A **mesocosm** is a small, enclosed experimental ecosystem that models a natural one, so that one variable can be changed while others are controlled. Mesocosms can be set up in open tanks, but **sealed glass vessels** are preferable: entry and exit of matter is prevented, but energy transfer is still possible, as light enters and heat leaves. Aquatic or microbial ecosystems are likely to be more successful than terrestrial ones.

1. Set up several identical sealed glass jars with pond water, sediment, aquatic plants and algae.
2. Change one variable between jars, for example light intensity, temperature or added nitrate, with at least three replicates of each.
3. Keep other variables the same and leave the jars for several weeks.
4. Monitor stability, for example dissolved oxygen, pH, water clarity and the number of organisms of each type.

Practical skill: Care and maintenance of mesocosms should follow IB experimental guidelines: avoid causing harm or distress to animals, and use plants and microorganisms where you can.

Keystone species

A **keystone species** has a disproportionate impact on community structure compared with its abundance. If it is removed, the community changes greatly and the ecosystem may collapse.

- **Sea otters** in Pacific kelp forests eat sea urchins. Where otters were hunted out, urchins multiplied and grazed the kelp away, leaving 'urchin barrens' with far fewer species.
- **Ochre starfish** (*Pisaster*) on rocky shores eat mussels. When they were removed in experiments, mussels covered the rocks and the number of species fell sharply.

Sustainable harvesting and agriculture Spec D4.2.6, D4.2.7

Wild plants and fish are **renewable resources**. Sustainability depends on the **rate of harvesting being lower than the rate of replacement** by growth and reproduction.

Assessing the sustainability of harvesting

Example	How sustainability is assessed
Brazil nut tree (<i>Bertholletia excelsa</i>), harvested from wild Amazon forest	Surveys of the size and age structure of tree populations, repeated over years. A study of 23 populations (2003) found that stands with a long history of heavy nut collection lacked young trees, so recruitment may be too low to replace old trees. Later long-term studies at some sites found stable populations despite heavy collection, so sustainability must be assessed site by site.
Atlantic cod (<i>Gadus morhua</i>), marine fish	Stock assessments estimate the mass of breeding adults from catches and research surveys; a catch dominated by young fish is a sign of overfishing. Quotas and net mesh sizes are then set. The northern cod stock off Newfoundland collapsed and a moratorium on commercial fishing began in 1992. Canada reopened a commercial fishery in 2024, which is controversial because the stock is still well below its former size.

Factors affecting the sustainability of agriculture

Factor	Problem	More sustainable practice
Soil erosion	Bare, ploughed soil is washed or blown away	Cover crops, contour ploughing, hedgerows
Leaching of nutrients	Nitrate and phosphate dissolve and drain out of the soil	Apply fertilizer in smaller amounts when crops need it
Supply of fertilizers and other inputs	Phosphate is mined from finite rock deposits; nitrogen fertilizer manufacture uses large amounts of fossil fuel	Crop rotation with nitrogen-fixing legumes, use of manure
Pollution due to agrochemicals	Pesticides and herbicides harm non-target species and water	Integrated pest management, targeted spraying
Carbon footprint	CO ₂ from machinery, transport and fertilizer manufacture; methane from livestock	Lower energy inputs, local supply chains

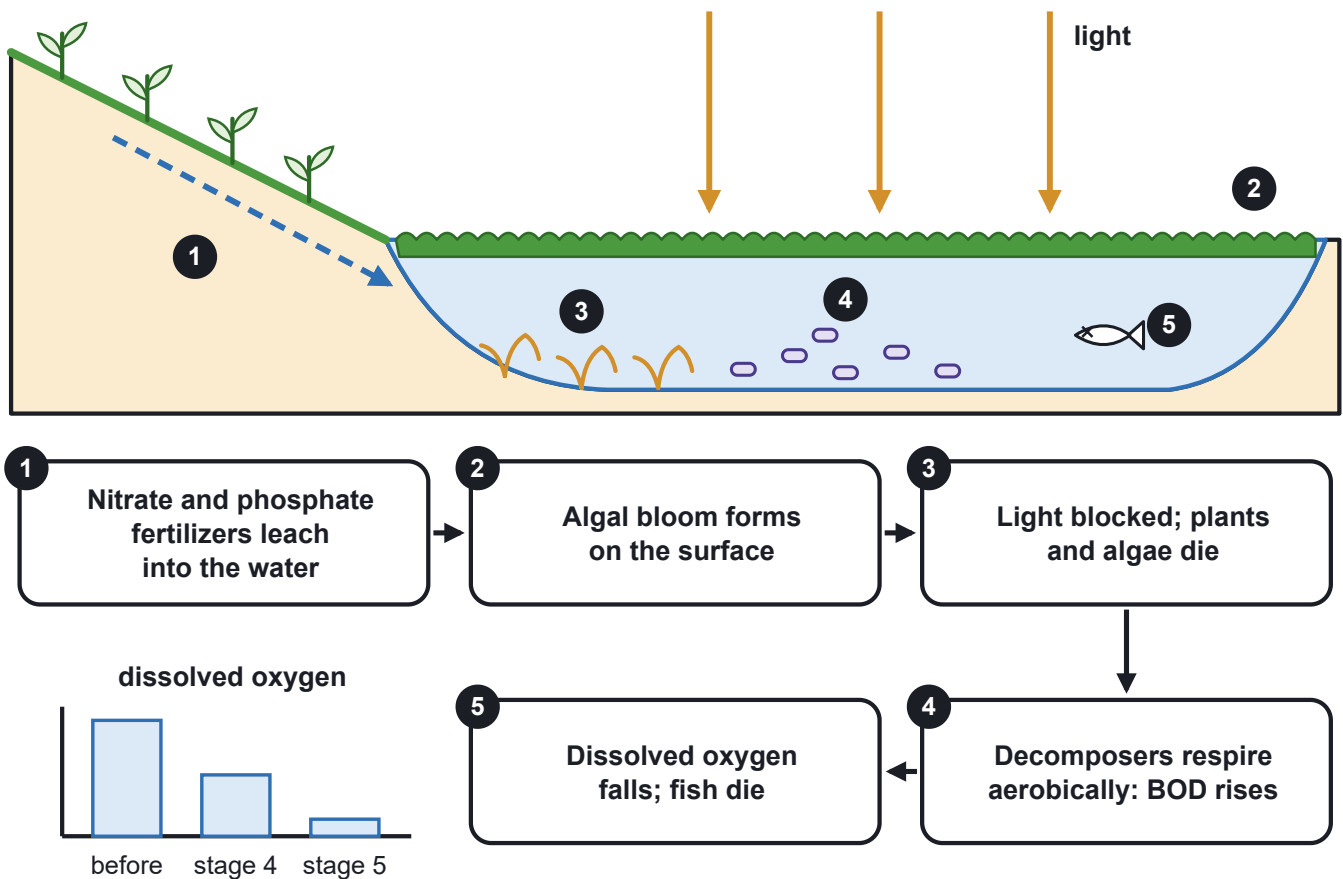
Eutrophication Spec D4.2.8

Eutrophication is the enrichment of water with nutrients. Nitrogen and phosphate fertilizers **leach** out of farmland and run into rivers, lakes and coastal seas.

1. Nitrate and phosphate leach from fields into the water.
2. Algae and other producers grow rapidly, forming an **algal bloom** at the surface.
3. The bloom blocks light, so plants below cannot photosynthesise and die; the short-lived algae die too.
4. Bacteria decompose the dead organic matter, using oxygen in aerobic respiration.
5. **Biochemical oxygen demand** rises and dissolved oxygen falls.
6. Fish and other animals that need oxygen die, forming a low-oxygen 'dead zone'.

Biochemical oxygen demand (BOD)

The amount of dissolved oxygen used by microorganisms in a water sample over a set time while breaking down organic matter. A high BOD shows heavy organic pollution.



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Eutrophication: decomposers raise **biochemical oxygen demand**, so dissolved oxygen falls and fish die.

Common mistake: Fish die from lack of oxygen used up by decomposers, not because algae 'use up the oxygen' by photosynthesis. Algae produce oxygen while alive.

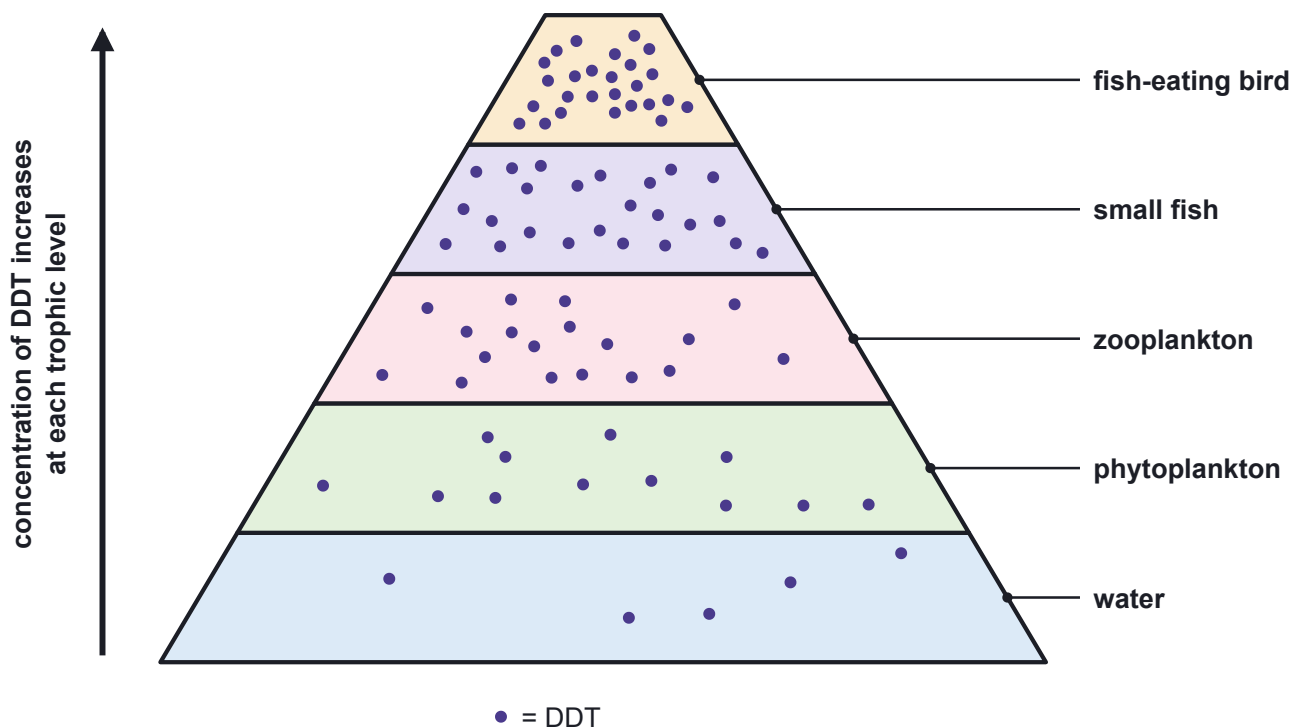
Biomagnification of pollutants Spec D4.2.9

Some pollutants are **persistent** (not broken down) and fat-soluble, so organisms store them in their tissues instead of excreting them. Their concentration builds up inside each individual over its life (bioaccumulation).

Each consumer eats many prey, taking in all the toxin they stored. So the concentration rises at each trophic level: **biomagnification**. Consumers in the highest trophic levels have the highest concentrations.

Two examples

Pollutant	Source	Effect at high trophic levels
DDT	Insecticide sprayed on crops and to control malaria mosquitoes	Birds of prey such as ospreys and peregrine falcons laid eggs with thin shells that broke, and populations crashed. Populations recovered after DDT was banned for farm use in many countries.
Mercury	Burning coal and gold mining; bacteria in sediments convert it to methylmercury	High levels in large predatory fish such as tuna and swordfish. It damages the nervous system of fish-eating mammals and birds, and of humans.



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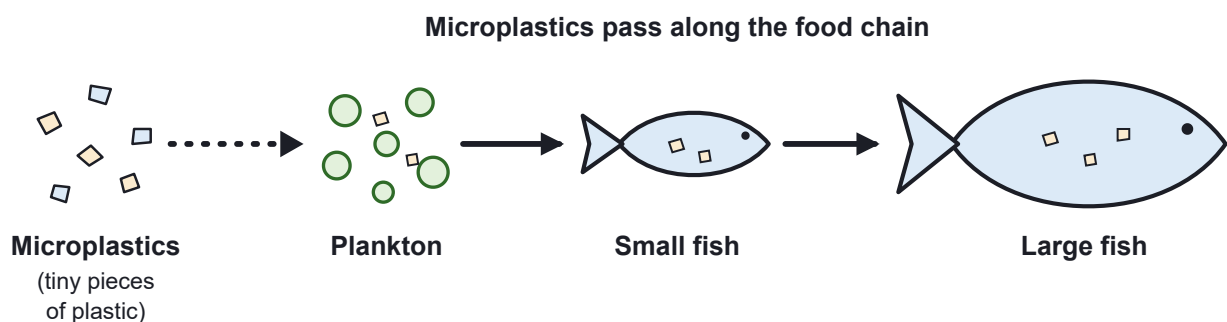
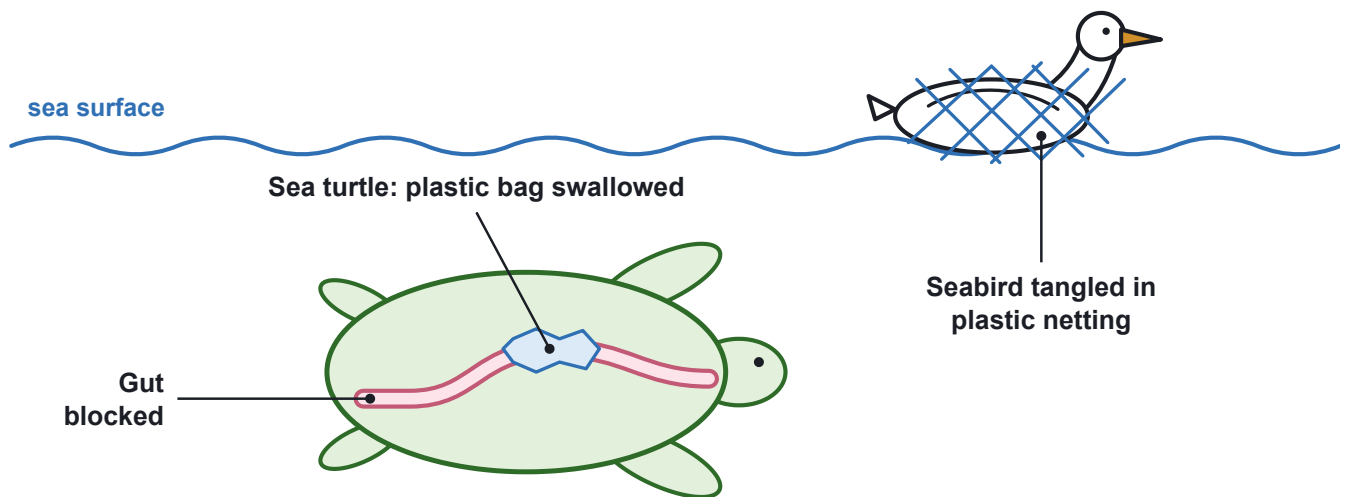
Biomagnification: DDT concentration rises at each higher trophic level.

Exam tip: Explain biomagnification with three ideas: persistent, stored in fatty tissue (not excreted), and each consumer eats many organisms from the level below.

Microplastic and macroplastic pollution of the oceans Spec D4.2.10

Most plastics are **non-biodegradable**: decomposers do not have enzymes to break them down. So plastics are **persistent** in the natural environment for decades or longer. Sunlight and waves break large pieces into smaller ones.

Type	Examples	Effects on marine life
Macroplastic (larger pieces)	Bags, bottles, packaging, lost fishing nets	Entanglement of seals, turtles and seabirds, causing drowning or injury; sea turtles swallow bags mistaken for jellyfish; albatross chicks are fed plastic, which fills their stomachs and causes starvation.
Microplastic (pieces under 5 mm)	Fragments of larger plastic, fibres from clothing	Eaten by zooplankton, filter feeders such as mussels, and fish; passed along food chains; can carry toxic chemicals that stick to their surfaces.



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Macroplastic entangles and blocks guts; **microplastics** pass along marine food chains.

Exam tip: Nature of science: scientists can influence citizens by giving clear information. Popular media coverage of plastic harming marine life changed public perception globally and drove measures such as bans on single-use bags and microbeads.

Rewilding Spec D4.2.11

Rewilding aims to restore natural processes so that an ecosystem can sustain itself with as little human management as possible.

- **Reintroduction of apex predators and other keystone species:** grey wolves were returned to Yellowstone National Park, USA, in 1995. Studies reported less browsing by elk and regrowth of willow and aspen in some areas, although the size of the effect is still debated.
- **Re-establishment of connectivity of habitats over large areas:** wildlife corridors link fragments so populations can move, find mates and exchange alleles.
- **Minimisation of human impact, including by ecological management:** removing livestock, controlling invasive species, then stepping back.

Hinewai Reserve, New Zealand

Hinewai Reserve on Banks Peninsula, South Island, is former sheep farmland that had become covered by gorse, an introduced shrub. Since 1987 it has been managed with minimal interference. Grazing animals were kept out, and the gorse was not burned or sprayed. Gorse acts as a nursery: native tree seedlings grow up through it, then overtop and shade it out. Native forest is now regenerating over more than 1 000 hectares.

Exam tip: Linking question: what is the distinction between artificial and natural processes? Rewilding uses a human decision to let natural processes take over again.

Ecological succession and primary succession Spec D4.2.12, D4.2.13 HL only

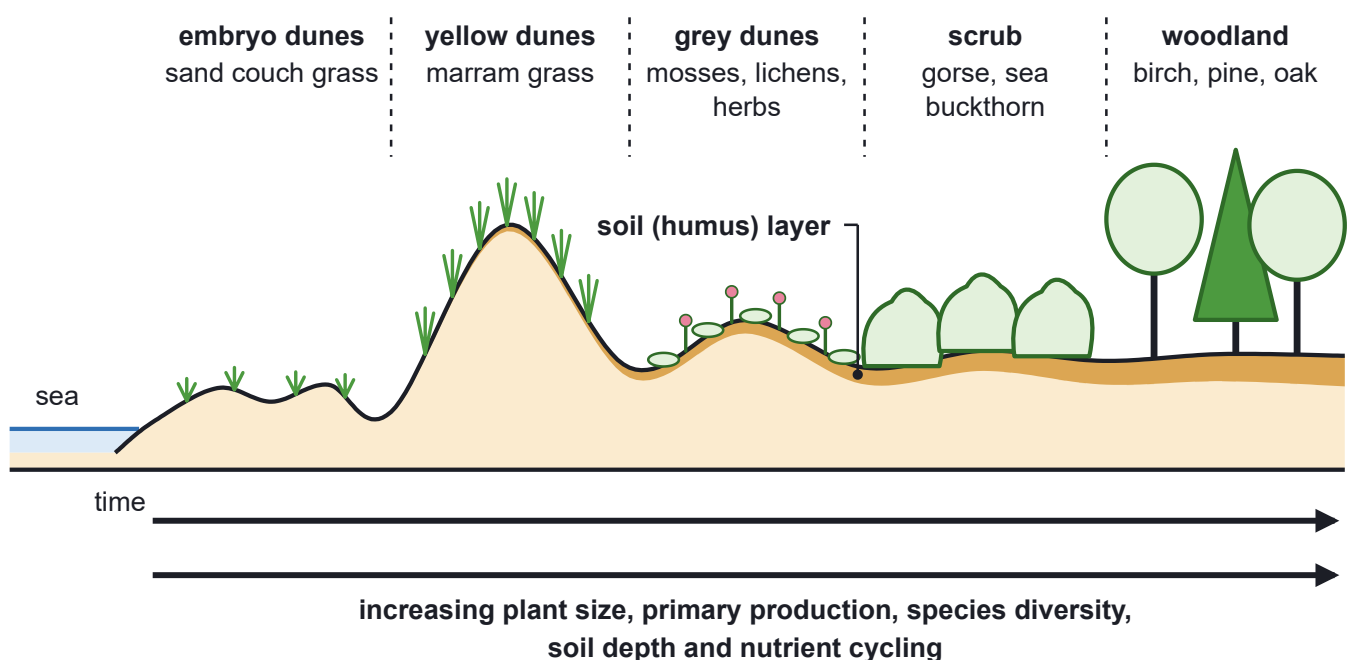
Ecological succession is a sequence of changes in the community of an area over time. It can be triggered by changes in the **abiotic environment**, for example new land exposed by a retreating glacier or deposited as sand dunes, and by **biotic factors**, for example organisms forming soil, casting shade or adding nitrogen, so that conditions suit different species.

Primary succession starts on land with no soil. **Secondary succession** starts where soil remains after a disturbance, such as a fire.

Example: sand dune succession

1. Pioneer species such as sand couch grass tolerate salt spray and wind and colonise bare sand above the high-tide line.
2. Their roots trap sand; marram grass grows up through new sand and stabilises taller dunes.
3. Dead plant matter adds humus, so the soil holds more water and nutrients; mosses, lichens and many herbs colonise.
4. Shrubs such as gorse and sea buckthorn grow in the deeper soil and shade out low plants.
5. Woodland of trees such as birch, pine and oak develops.

General changes during primary succession	
Feature	Change
Size of plants	Increases, from low pioneers to shrubs and trees
Amount of primary production	Increases
Species diversity	Increases
Complexity of food webs	Increases, with more trophic links
Amount of nutrient cycling	Increases, as more organic matter is decomposed and soil deepens



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Primary succession on sand dunes: moving inland means moving **forward in time**.

Cyclical succession, climax communities and arrested succession Spec D4.2.14, D4.2.15

HL only

Cyclical succession

In some ecosystems there is a **cycle of communities** rather than a single unchanging climax community. In heathland dominated by heather (*Calluna vulgaris*), patches go through a repeating cycle.

1. Pioneer phase: young heather plants establish in a gap.
2. Building phase: heather forms a dense canopy and dominates the patch; few other plants grow beneath it.
3. Mature phase: the plants lose vigour and the canopy starts to open in the centre.
4. Degenerate phase: old woody stems collapse outwards, leaving gaps colonised by lichens, mosses and other plants such as bearberry, then new heather seedlings, and the cycle restarts.

One full cycle takes roughly 30–40 years, so a heathland is a mosaic of patches at different phases while the heathland as a whole stays the same. This model was first described for heather in Scotland; it does not apply everywhere, for example not on wet bogs.

Climax communities and arrested succession

Given any specific environmental conditions, succession tends to lead to a particular type of **climax community**, a relatively stable community determined mainly by climate and soil, often forest where rainfall allows. Human influences can stop it from developing: **arrested succession**.

- **Grazing by farm livestock:** sheep and cattle eat tree seedlings, so grassland or moorland persists where woodland would grow.
- **Drainage of wetlands:** lowering the water table removes waterlogged conditions, so wetland and peat-forming communities are lost and the land is used for farming; the natural sequence cannot continue to its climax.

*Exam tip: A community kept by human activity at a stage short of the natural climax is called a **plagioclimax**.*

Quick check

1. Name the four requirements for ecosystem stability.
2. When is harvesting sustainable?
3. What does BOD stand for?
4. Why are sealed glass vessels preferred for mesocosms?
5. **HL only** Give two human causes of arrested succession.

Quick check answers

Stability and change

1. Supply of energy, recycling of nutrients, genetic diversity, climatic variables within tolerance levels.
2. When the rate of harvesting is lower than the rate of replacement.
3. Biochemical oxygen demand.
4. Matter cannot enter or leave, but energy transfer is still possible.
5. Grazing by farm livestock and drainage of wetlands.