IB BIOLOGY · D4.2

BIOLOGY BY BRADFORD

REVISION GUIDE

What keeps an ecosystem *going*

Stability and change

The Daintree rainforest has grown in the same place for over a hundred million years. Here is what lets an ecosystem last that long, what people do that can tip it over, and how a community rebuilds itself on bare rock.

15 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ib-biology-d4-2-stability-and-change

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By the end you can

- [ ] Give evidence that some ecosystems, such as the Daintree rainforest and the Namib Desert, have stayed stable for millions of years D4.2.1
- [ ] Explain the four requirements for a stable ecosystem: energy, nutrient recycling, genetic diversity and a climate within tolerance D4.2.2
- [ ] Explain why deforestation could tip the Amazon rainforest into savanna, and calculate percentage change in forest area D4.2.3
- [ ] Design and evaluate a sealed mesocosm to investigate the effect of a variable on ecosystem stability D4.2.4
- [ ] Explain the disproportionate effect of a keystone species, such as the sea otter, on its community D4.2.5
- [ ] Assess whether harvesting a resource is sustainable, using the Brazil nut and Atlantic cod D4.2.6
- [ ] Outline the factors that decide whether farming is sustainable D4.2.7
- [ ] Explain how leached fertilizer causes eutrophication and raises the biochemical oxygen demand D4.2.8
- [ ] Explain how DDT and mercury biomagnify up a food chain D4.2.9
- [ ] Describe the effects of macroplastic and microplastic on marine life, and how research changed what people do D4.2.10
- [ ] Describe how rewilding restores natural processes, with Hinewai Reserve as the example D4.2.11
- [ ] Explain how abiotic and biotic changes trigger ecological succession D4.2.12
- [ ] Describe the changes during primary succession, from bare rock to forest D4.2.13
- [ ] Explain cyclical succession, with the heather cycle as the example D4.2.14
- [ ] Explain climax communities and how grazing and drainage arrest succession D4.2.15

Tick each one when you can do it without the book.

D4.2.1 STABILITY AS A PROPERTY OF NATURAL ECOSYSTEMS

01 Some ecosystems last for *millions* of years

In the far north of Queensland, Australia, the Daintree rainforest grows down to the sea. Its trees stand where rainforest has grown, without a break, for well over a hundred million years, since Australia was part of the supercontinent Gondwana. Many of its plants belong to lineages that are almost gone everywhere else. One, the idiot fruit tree (*Idiospermum australiense*), is among the oldest surviving groups of flowering plants, and it was thought to be extinct until it was found there again in the 1970s.

Across the Indian Ocean, the Namib Desert in southwest Africa has been dry for at least 55 million years, which makes it the oldest desert on Earth. Its animals and plants have had all that time to adapt to almost no rain. A fog-basking beetle (*Onymacris unguicularis*) stands head down on a dune at dawn so that fog condenses on its back and runs to its mouth. *Welwitschia mirabilis*, a plant with just two leaves that grow for its whole life, can live for more than a thousand years.

Both are examples of **ecosystem stability**: the same community, with the same processes running, over a very long time. The evidence comes from fossils (fossil pollen in sediments shows which plants grew there), from the ages of the rocks and dunes, and from the DNA of living species, which shows how long their lineages have been separate.

KEY POINTS

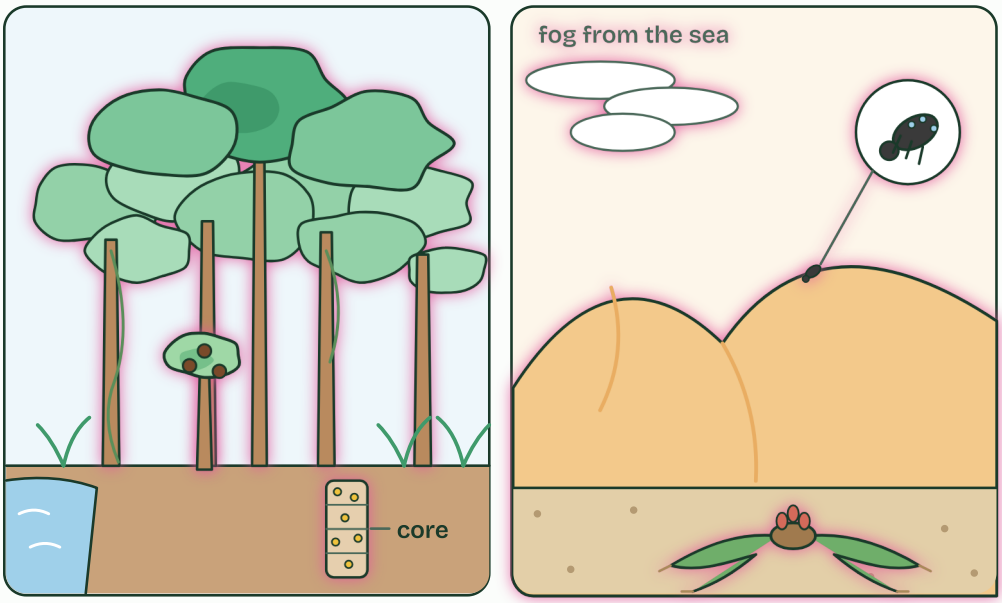
- A stable ecosystem keeps the same **community** and the same **processes** over long periods.
- **Evidence** for long-term stability: fossils such as pollen, the age of the landforms, and ancient lineages still living there.
- Stable does not mean unchanging: populations rise and fall, but the system stays within limits and recovers.

KEY TERMS

ecosystem stability
The ability of an ecosystem to keep the same structure and processes over a long time, and to return to that state after a disturbance.

Daintree rainforest

Namib Desert



The canopy Rainforest has grown here without a break for well over 100 million years, since Australia was part of Gondwana. It is often called the oldest tropical rainforest on Earth.

Fossil pollen A core drilled through old sediments holds pollen grains layer by layer, oldest at the bottom. Rainforest pollen in every layer shows the forest has been there all along.

The dunes The Namib has been dry for at least 55 million years, which makes it the oldest desert on Earth. Its species have had that long to adapt to almost no rain.

Fog-basking beetle At dawn, *Onymacris unguicularis* climbs a dune crest and stands head down into the fog. Droplets condense on its back and run down to its mouth.

Idiot fruit tree *Idiospermum australiense* belongs to one of the oldest surviving groups of flowering plants. It was thought to be extinct until it was found again in the Daintree in the 1970s.

Fog Cold water offshore makes fog that rolls inland most mornings. It is the main source of water for many Namib animals and plants, since rain may not fall for years.

Welwitschia *Welwitschia mirabilis* grows only two leaves, which keep growing from the base for its whole life while their tips fray. Some plants are more than a thousand years old.

PREDICT

Why are very old, stable ecosystems such as the Daintree so rich in species found nowhere else?

(A) The warm, wet climate makes mutations far more common there than in other places

(B) Lineages have had a very long time to diversify there, with no event that wiped them out

(C) Species that arrive from other places are kept out by the dense tangle of the old trees

Decide before you look. Answer on page 48.

02

D4.2.2 REQUIREMENTS FOR STABILITY IN ECOSYSTEMS

Four things a stable ecosystem *needs*

What did the Daintree and the Namib have that let them carry on for so long? Four things, and an ecosystem that loses any of them starts to change.

A supply of energy. Energy flows through an ecosystem and is lost as heat at every step, so it has to be supplied all the time. Almost always it arrives as sunlight, captured by producers in photosynthesis.

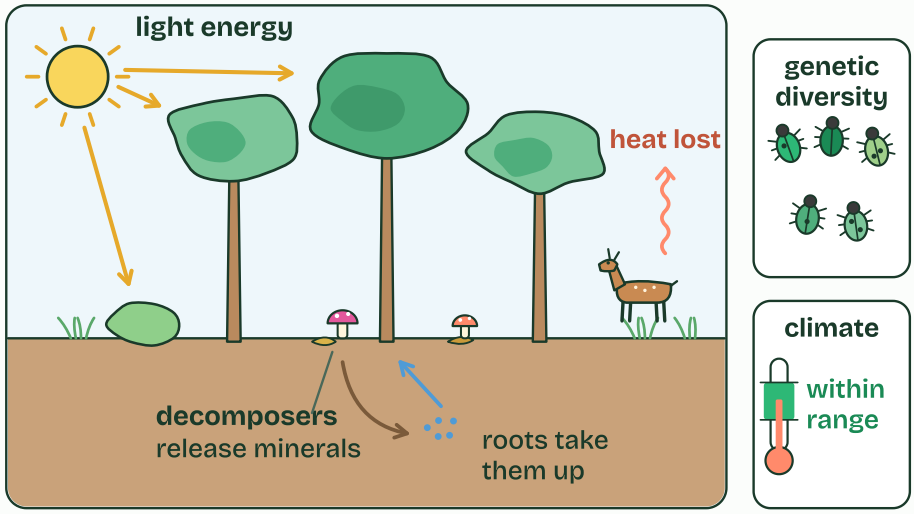
The recycling of nutrients. Unlike energy, matter is not supplied from outside: the same carbon, nitrogen and phosphorus atoms go round and round. Saprotrophs and other decomposers break down dead matter and release the nutrients for producers to take up again.

Genetic diversity. A population whose members differ has the variation that natural selection can act on, so it can adapt when conditions shift. A population of near-identical individuals can be wiped out by one new disease.

Climatic variables within tolerance. Every species has a range of temperature and rainfall it can survive. If the climate stays inside those ranges, the community stays; if it moves outside them, species die out or leave.

KEY TERMS

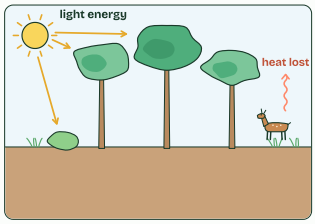
saprotrophs
Organisms that feed on dead matter by secreting enzymes onto it and absorbing the products, releasing inorganic nutrients. Most are bacteria and fungi.



STEP BY STEP

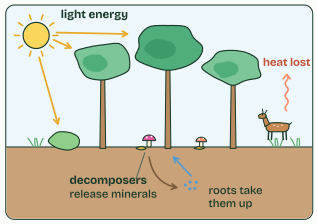
4 STEPS

1



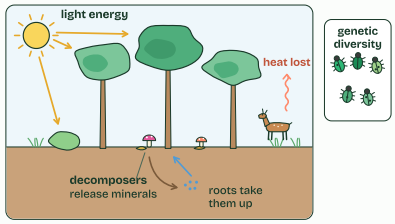
Energy. Sunlight is captured by the producers. Energy is lost as **heat** at every step, so it must be supplied all the time.

2



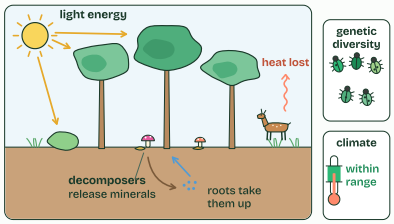
Nutrients. Decomposers break down dead leaves and bodies and release minerals, which roots take up again. Matter is recycled.

3



Genetic diversity. Members of each population differ, so some can survive a new disease or a change in conditions, and the population can adapt.

4



Climate. Temperature and rainfall stay within the range the species can **tolerate**. Every Nest Gets Care.

REMEMBER IT

The four requirements for stability

E	N	G	C
Every	**Nest**	**Gets**	**Care**
Energy	**Nutrients**	**Genetic diversity**	**Climate**
a constant supply, almost always sunlight	recycled by decomposers	variation, so populations can adapt	temperature and rainfall within tolerance

PREDICT

A forest is cut and the logs are taken away every 30 years. Which requirement for stability does this put at risk most directly?

(A) The supply of energy, because the cut trees no longer absorb the sunlight that lands on the forest

(B) The recycling of nutrients, because the nutrients locked in the logs leave the forest and never return

(C) The climate staying within tolerance, because each cut warms the whole region by a few degrees

Decide before you look. Answer on page 48.

IN THE EXAM

Requirements for ecosystem stability:

1. A continuous supply of energy, usually sunlight, for producers.
2. Recycling of nutrients by decomposers (saprotrophs).
3. Genetic diversity, so populations can adapt to change.
4. Climatic variables (temperature, rainfall) staying within the tolerance of the species.

D4.2.3 DEFORESTATION OF AMAZON RAINFOREST AS AN EXAMPLE OF A POSSIBLE TIPPING POINT IN ECOSYSTEM STABILITY

03 The forest that makes its own *rain*

Moist air blows in from the Atlantic over the Amazon basin and drops rain on the forest. The trees take the water up through their roots and release most of it again as water vapour by **transpiration**. The vapour rises, cools, condenses into clouds and falls as rain further west. The same water is recycled like this several times as the air crosses the continent, and a large tree can move hundreds of litres a day.

The forest as a whole puts billions of tonnes of water vapour into the air each day. Evaporating that water takes heat from the leaves, so transpiration also cools the land. The moist air flows on in streams that Brazilian scientists call **flying rivers**. When the Andes block them, they turn south and bring rain to the farms and cities of southern Brazil, Paraguay and Argentina.

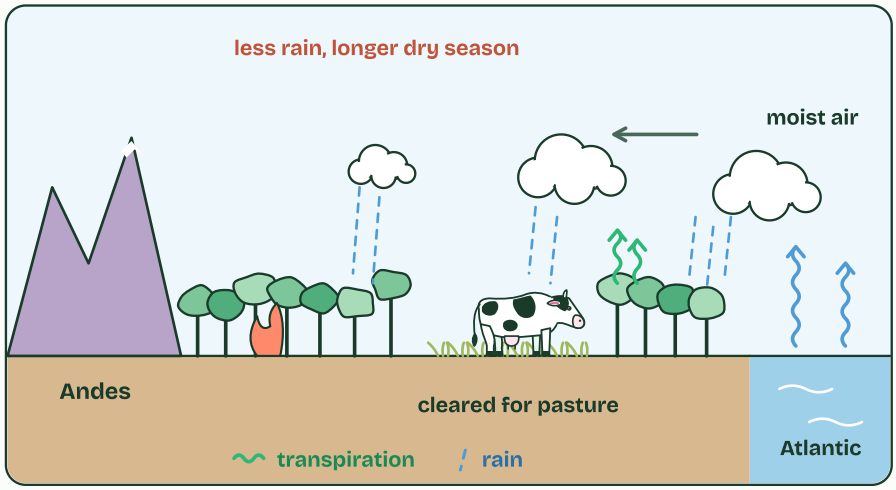
Clear the forest and the chain breaks. Pasture and soy fields transpire far less, so less rain falls downwind, the dry season grows longer, and the remaining trees are stressed and burn more easily. If enough forest is lost, the rest may be unable to make enough rain to keep itself going. It would then die back into dry savanna, even where no one cuts it. That threshold is a **tipping point**.

KEY TERMS

transpiration
The loss of water vapour from the leaves of plants, mostly through the stomata.

flying rivers
Streams of water vapour carried in the air from the Amazon rainforest to other parts of South America, where they fall as rain.

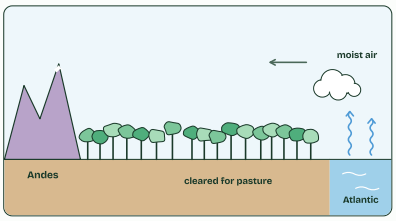
tipping point
A point beyond which a small further change pushes a system into a new state, from which it does not easily return.



STEP BY STEP

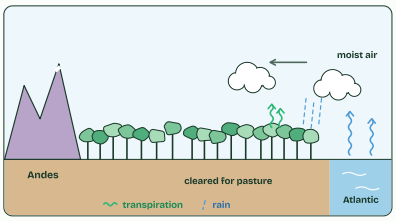
4 STEPS

1



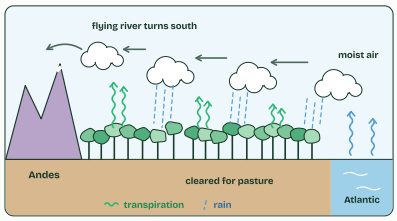
Moist air blows in from the **Atlantic** and forms clouds over the coast.

2



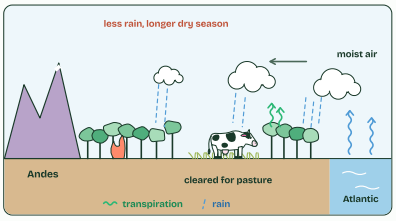
Rain falls on the forest. Trees take up the water and release it again by **transpiration**, and new clouds form further west.

3

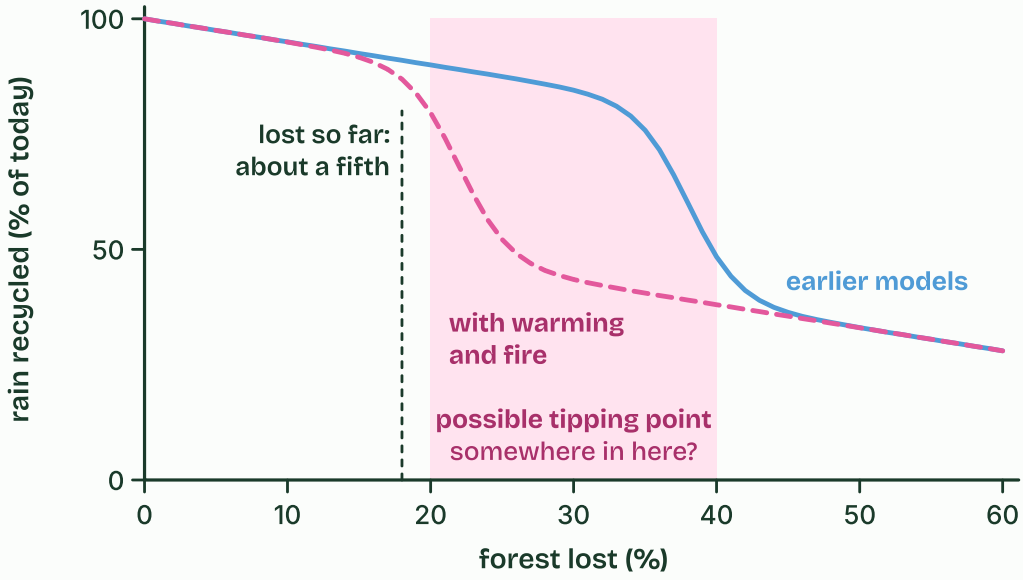


The water is recycled several times across the continent. Blocked by the Andes, the moist air flows south as a **flying river**, bringing rain to southern Brazil.

4



Clear a large area and transpiration there stops. Less rain falls downwind, the dry season lengthens and the remaining forest dries out and burns.



PREDICT

Nobody knows exactly how much forest the Amazon can lose before it tips. Why is this so hard to find out?

(A) No scientist has yet measured how much water an Amazon tree transpires each day

(B) There is only one Amazon, so models are all we have, and they depend on climate warming too

(C) The forest has already passed the threshold, and the effects are too slow to measure

Decide before you look. Answer on page 48.

PREDICT

A state had 1 250 000 km² of rainforest in 1970 and 1 000 000 km² in 2020. What is the percentage change in forest area?

(A) −25%, because 250 000 is a quarter of 1 000 000

(B) −20%, because 250 000 is a fifth of 1 250 000

(C) +20%, because the loss is a fifth of the area

(D) −80%, because 1 000 000 is four fifths of it

Decide before you look. Answer on page 48.

PERCENTAGE CHANGE

To measure deforestation, compare the area of forest now with the original area.

1. Percentage change = (new value − original value) ÷ original value × 100.
2. Example: a region had 4.0 million km² of forest and now has 3.3 million km².
3. (3.3 − 4.0) ÷ 4.0 × 100 = −0.7 ÷ 4.0 × 100 = **−17.5%**.
4. The minus sign shows a decrease: 17.5% of the original forest has gone.

IN THE EXAM

Why the Amazon may have a tipping point:

1. Trees transpire large volumes of water vapour, which falls as rain further inland.
2. Transpiration cools the land, and the moist air flows (flying rivers) bring rain across South America.
3. Deforestation cuts transpiration, so rainfall falls and dry seasons lengthen.
4. Below some minimum area the forest cannot make enough rain to sustain itself, and could turn to savanna.
5. That minimum area is uncertain: estimates range from about 20% to 40% loss.

04 An ecosystem in a *bottle*

D4.2.4 USE OF A MODEL TO INVESTIGATE THE EFFECT OF VARIABLES ON ECOSYSTEM STABILITY

In 1960, David Latimer in Surrey, England, planted a spiderwort seedling in compost in a large glass bottle. He last added water in 1972 and then sealed it with a cork. The plant has filled the bottle ever since. Light passes through the glass, the plant photosynthesizes, water evaporates and condenses on the inside of the bottle, and microbes in the compost recycle the fallen leaves.

A bottle like this is a **mesocosm**, a model ecosystem that can be controlled and repeated. Mesocosms can be open tanks, but a sealed glass vessel is the better model for stability: no matter can enter or leave, so every nutrient has to be recycled inside, while energy still crosses the glass, in as light and out as heat. A sealed vessel is a **closed system**.

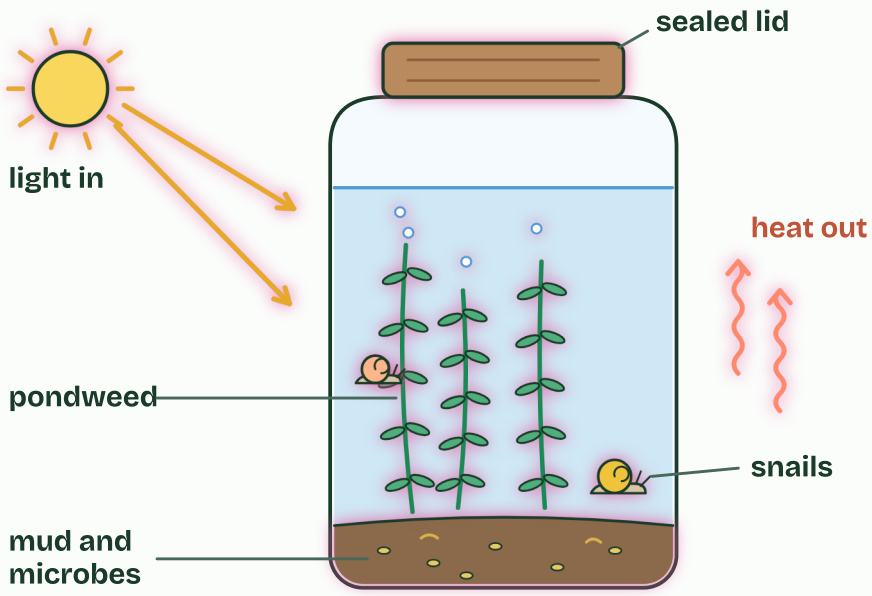
Aquatic and microbial mesocosms tend to work better than terrestrial ones. A jar of pond water with pondweed, a few snails and the microbes in some pond mud can stay balanced for months: the pondweed makes oxygen and food, the snails eat and respire, and the microbes break down wastes and return the minerals.

A mesocosm is better because	A mesocosm is worse because
its variables can be controlled and changed one at a time	it leaves out much of a real ecosystem, so the results may not apply outside
it can be replicated, with several identical jars	it cannot hold large animals, and long food chains are missing
it is small, cheap and easy to monitor	sealing animals in raises ethical concerns, so their welfare must be checked

KEY TERMS

mesocosm
A small, enclosed experimental ecosystem, set up so that its conditions can be controlled and changed, as a model of a natural ecosystem.

closed system
A system that exchanges energy, but not matter, with its surroundings.



Mud and microbes Bacteria and fungi in the mud are the decomposers. They break down dead leaves and snail waste and return minerals, such as nitrate and phosphate, for the plants to take up again.

Snails The consumers. They graze the pondweed and the algae on the glass, use oxygen in respiration and release carbon dioxide and waste. Too many and they use oxygen faster than the plants make it.

Light in Energy crosses the glass. Light from the sun, or a lamp, powers photosynthesis. Without it the jar runs down.

Pondweed The producer. In the light it photosynthesizes, adding oxygen to the water and making the sugars that the food web runs on. Day and night it also respires.

The seal Nothing gets in or out: no gas, water or food. Every atom of carbon, nitrogen and oxygen inside must be recycled. That makes it a closed system, the best model for testing stability.

Heat out Energy also leaves, as heat from respiration and from the warm glass. Energy flows through the jar while matter cycles inside it.

PREDICT

A student seals four jars with pondweed and snails and keeps one in the dark. Which jar would you expect the snails to die in first, and why?

(A) The jars in the light, because the pondweed takes the oxygen from the water for its own use

(B) The dark jar, because with no photosynthesis everything there uses oxygen and nothing makes it

(C) None of them, because a sealed jar keeps all the oxygen that was in it when it was closed

Decide before you look. Answer on page 48.

CARE OF THE ANIMALS

An investigation with live animals follows the IB's guidelines: use as few as possible, check them every day, and take them out and return them to a pond if they show signs of stress. The lab on this page lets you run the experiment as many times as you like with no snails harmed.

05 Pull out one stone and the *arch* falls

D4.2.5 ROLE OF KEYSTONE SPECIES IN THE STABILITY OF ECOSYSTEMS

In 1963 the ecologist Robert Paine began prising purple sea stars (*Pisaster ochraceus*) off the rocks of one stretch of shore in Washington State and throwing them back into the sea. Within a few years, mussels, which the sea stars had been eating, had spread over the rock and crowded out almost everything else. The number of species on the rock fell from fifteen to eight. Paine called the sea star a **keystone species**, after the wedge-shaped stone at the top of an arch, which holds the others in place.

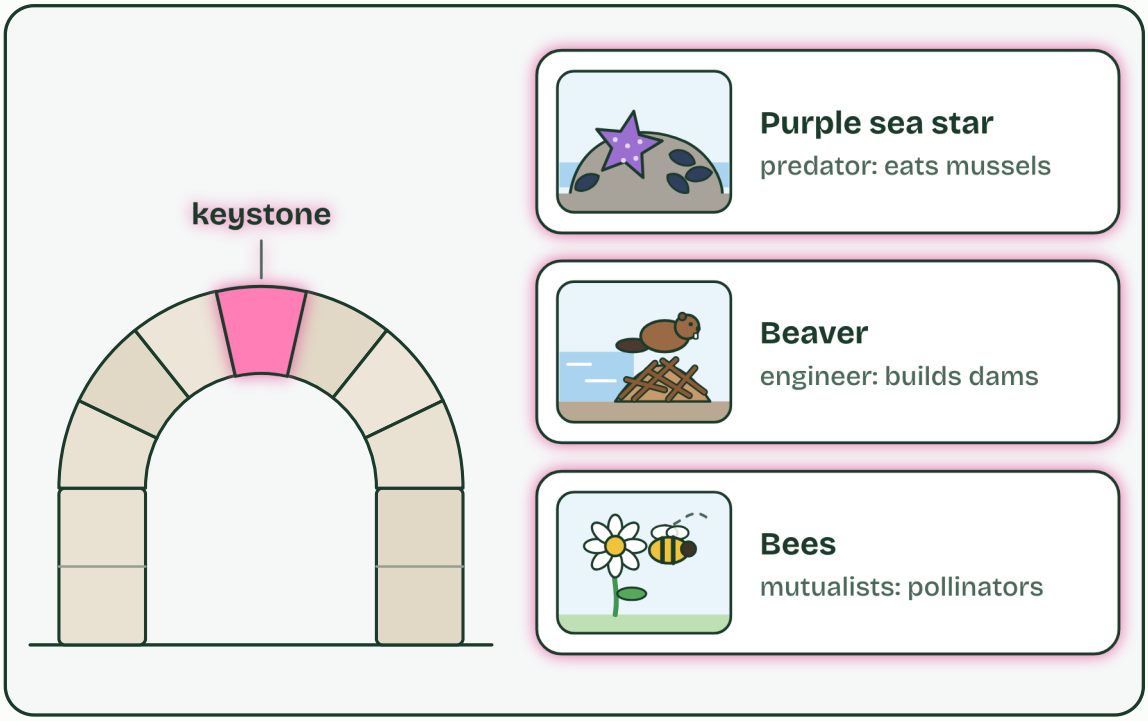
A keystone species is often not common. What matters is that its effect is **disproportionate**: far bigger than its numbers would suggest. Remove it and the community can collapse into a simpler one. Keystones work in different ways. Some are predators that keep a dominant prey in check, some are ecosystem engineers that change the habitat, and some are mutualists that many other species depend on.

Sea otters (*Enhydra lutris*) along the Pacific coast of North America were hunted for their fur until fewer than two thousand were left, by 1911. Without otters to eat them, sea urchins multiplied and grazed the giant kelp down to bare rock, leaving an **urchin barren**. The fish, crabs and seals that lived in the kelp forest went too. Where otters were protected and came back, the urchins were eaten, the kelp grew back, and so did the forest's community.

KEY TERMS

keystone species
A species that has a much larger effect on the structure of its community than its numbers or biomass would suggest.

urchin barren
A stretch of sea floor where sea urchins have eaten the kelp, leaving bare rock with few other species.



The keystone The wedge at the top of an arch holds the other stones in place. Take it out and the arch falls, though it is only one stone of many. A keystone species is like it: few in number, but holding the community together.

Purple sea star *Pisaster ochraceus* eats mussels on rocky shores. When Robert Paine removed it, mussels covered the rock and the number of species fell from fifteen to eight.

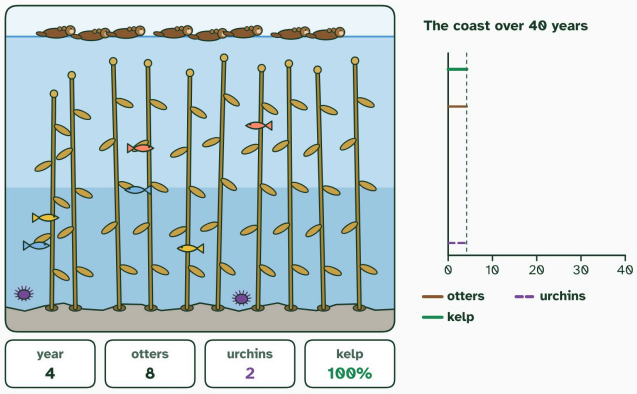
Beaver Beaver dams flood streams into ponds and wetlands, making a habitat that fish, frogs, insects and water birds use. Remove the beavers and the ponds drain.

Bees Many wild plants depend on bees to carry their pollen. Lose the bees and those plants set no seed, and the animals that eat the seeds and fruits go hungry.

ANIMATION · OTTERS, URCHINS AND KELP

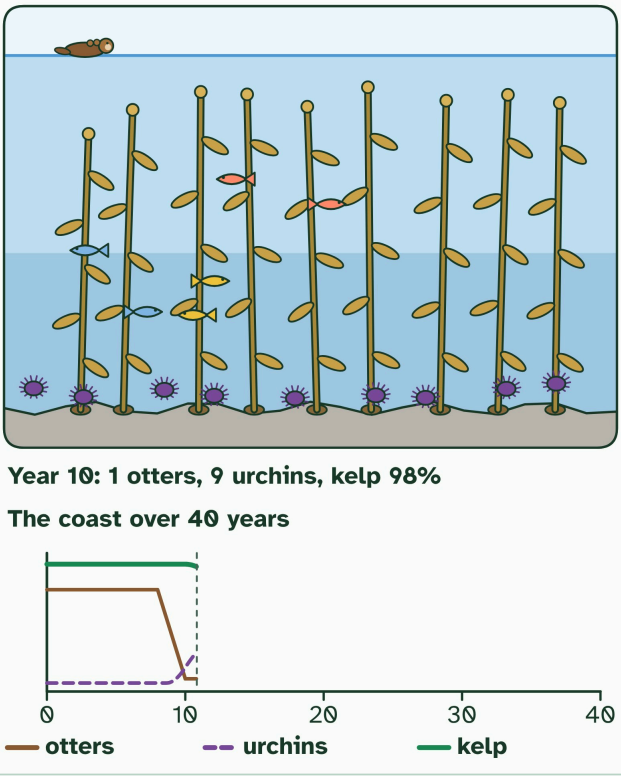
5 MOMENTS

1 YEAR 4: 8 OTTERS, 2 URCHINS, KELP COVER 100%



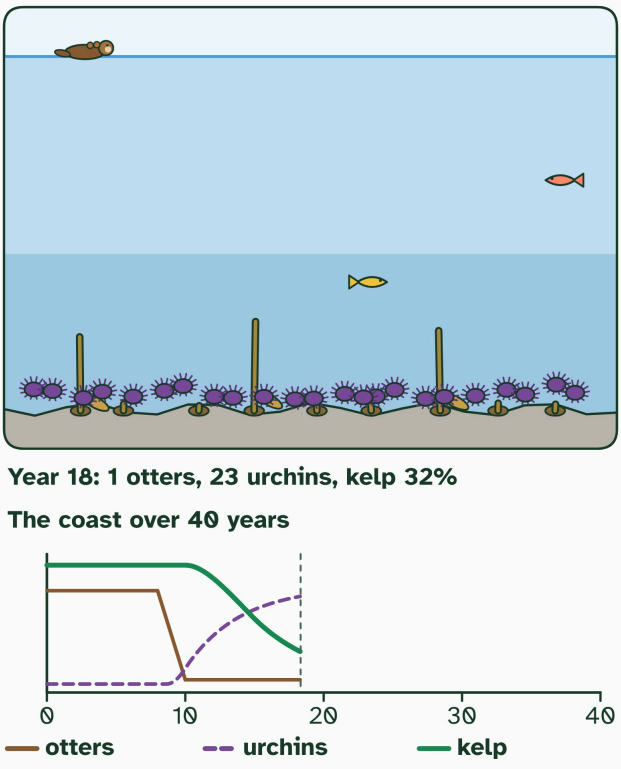
A kelp forest. **Sea otters** eat **sea urchins**, and the urchins graze on giant **kelp**.

2 YEAR 10: 1 OTTERS, 9 URCHINS, KELP COVER 98%



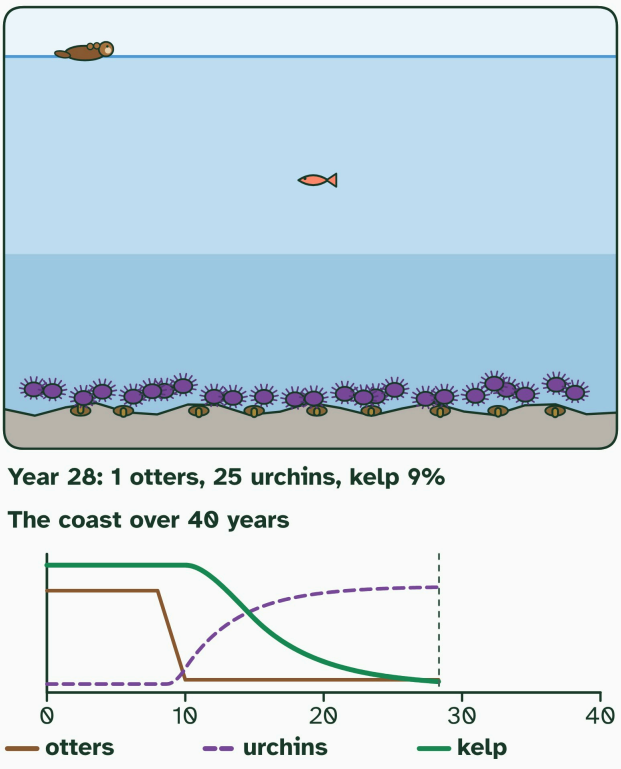
Year 8: hunting or protection changes the number of otters. Set it with the slider.

3 YEAR 18: 1 OTTERS, 23 URCHINS, KELP COVER 32%



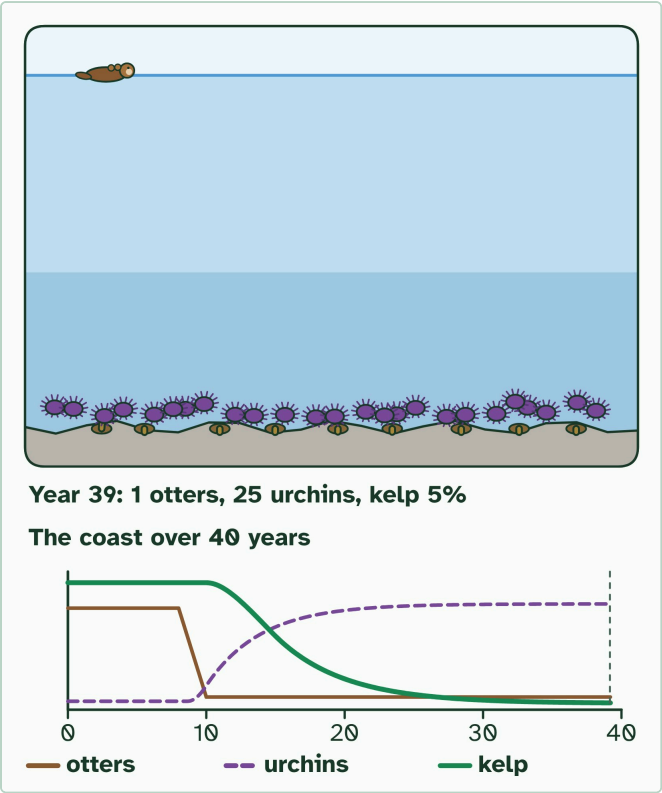
The **urchins** answer first: the fewer otters there are, the more urchins survive and multiply.

4 YEAR 28: 1 OTTERS, 25 URCHINS, KELP COVER 9%



Then the **kelp**. Urchins chew through the holdfasts and the stalks drift away. With too many urchins the forest becomes an **urchin barren**.

5 YEAR 39: 1 OTTERS, 25 URCHINS, KELP COVER 5%



The fish, crabs and seals that live in the kelp follow it. One predator decides what the whole community looks like: a **keystone species**.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-d4-2-stability-and-change#keystone

PREDICT

A seaweed is the most common organism in a rock pool. Removing it changes little. Removing a rare whelk, a predator, changes almost everything. Which is the keystone species?

(A) The seaweed, because a keystone species is the one with the most biomass in the pool

(B) The whelk, because its effect on the community is far greater than its small numbers suggest

(C) Both of them, because every species in a community is a keystone species in some way

Decide before you look. Answer on page 48.

IN THE EXAM

Keystone species:

1. Have a disproportionately large effect on community structure, relative to their abundance.
2. For example, sea otters eat sea urchins, which graze kelp.
3. Removing otters lets urchins multiply and destroy the kelp forest.
4. The many species that depend on the kelp are lost, so diversity falls and the ecosystem can collapse.

06

D4.2.6 ASSESSING SUSTAINABILITY OF RESOURCE HARVESTING FROM NATURAL ECOSYSTEMS

Take no more than *grows back*

Fish, timber and wild nuts are **renewable resources**: the population that provides them reproduces and grows. Harvesting is **sustainable** when the rate of harvesting is lower than the rate of replacement. Take more than that and the population shrinks every year, and the harvest shrinks with it.

A population grows fastest at middle densities: a small one has few parents, and a crowded one is held back by competition. The largest catch that can be taken every year without the population falling is the **maximum sustainable yield** (MSY). It is taken by keeping the population at about half its carrying capacity.

A plant on land: the Brazil nut. Brazil nuts (*Bertholletia excelsa*) are not farmed. They are gathered from wild trees in the Amazon. The trees need large orchid bees to pollinate their flowers, so they set few nuts in plantations, and agoutis to bury the seeds, some of which they forget and which then sprout. Gathering takes seeds that would have become the next trees. Ecologists assess it by counting the young trees at many sites: where people had gathered nuts heavily for decades, there were very few juveniles, so the stand was ageing with nothing to replace it. Where gathering was light, young trees were common.

A fish in the sea: the Atlantic cod. For centuries the cod (*Gadus morhua*) of the Grand Banks off Newfoundland seemed endless. From the 1960s, large factory trawlers took catches far above the replacement rate. Catches peaked in 1968, then fell, and in 1992 the stock had collapsed to around 1% of its former size. Canada banned the fishing, and about 35 000 people lost their work. Three decades on, the stock has recovered only in part.

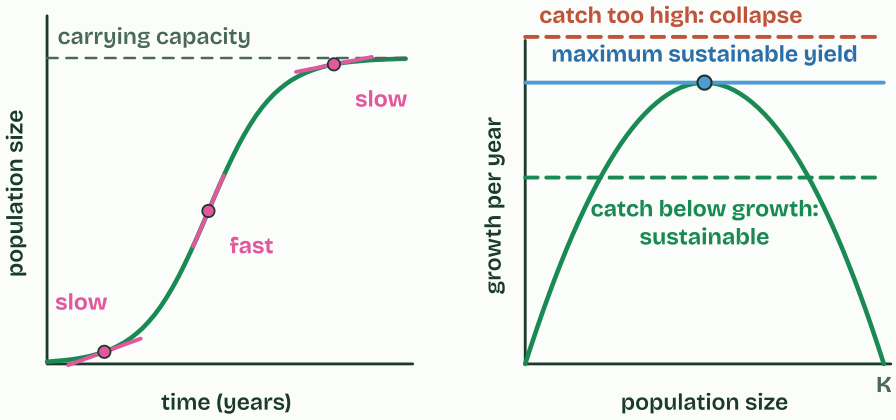
How harvesting is assessed	What it shows
Surveys of population size, such as research trawls or counts of trees	whether the stock is rising or falling year on year
Age or size structure, such as the share of young trees or of mature fish	whether enough young are joining the population to replace what is taken
Catch per unit effort, the catch for each day at sea	a falling catch for the same effort warns that the stock is shrinking

KEY TERMS

renewable resources
A resource that is replaced by natural processes, such as reproduction and growth, so it can be used indefinitely if it is not used faster than it is replaced.

sustainable
Able to continue indefinitely without depleting the resource or damaging the ecosystem.

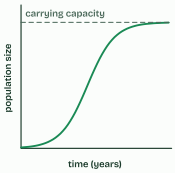
maximum sustainable yield
The largest harvest that can be taken from a population every year without it declining, taken when the population is kept at the size where it grows fastest.



STEP BY STEP

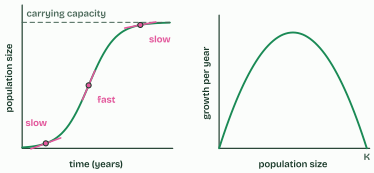
4 STEPS

1



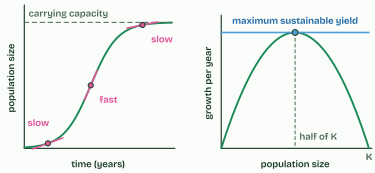
A population grows in an **S curve**, levelling off at the **carrying capacity** (K) set by food and space.

2



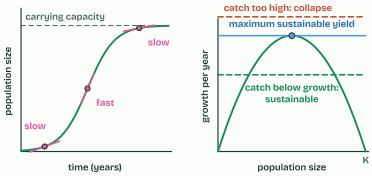
It grows **fastest** at middle sizes: a small population has few parents, and a crowded one is held back by competition.

3



The most that can be taken every year, for ever, is the growth at the peak: the **maximum sustainable yield**, with the population kept at about **half of K**.

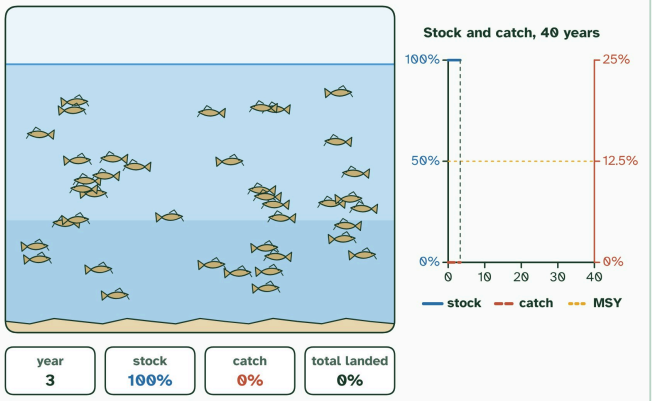
4



Take more than the population can replace and it shrinks every year until it **collapses**. Take less than its growth and it can be harvested indefinitely.

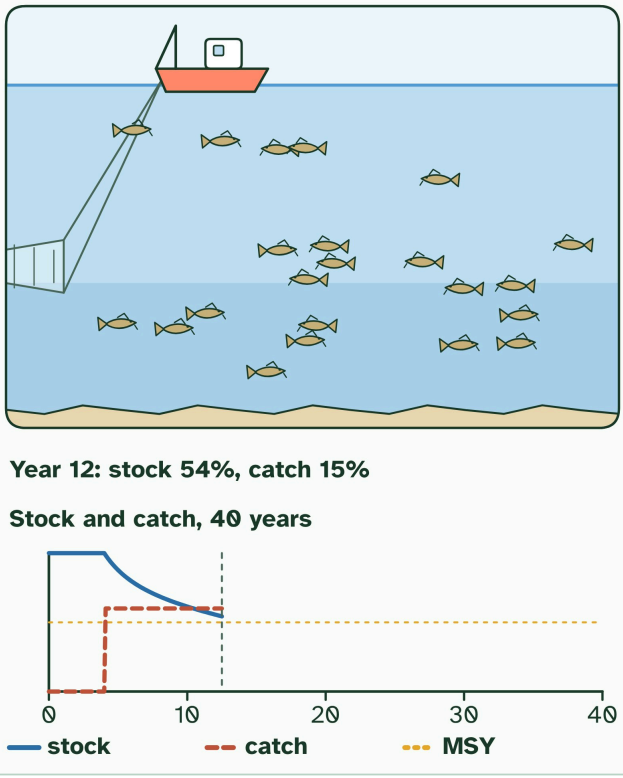
ANIMATION · FISHING A COD STOCK
4 MOMENTS

1 YEAR 3: STOCK 100% OF UNFISHED, CATCH 0% A YEAR



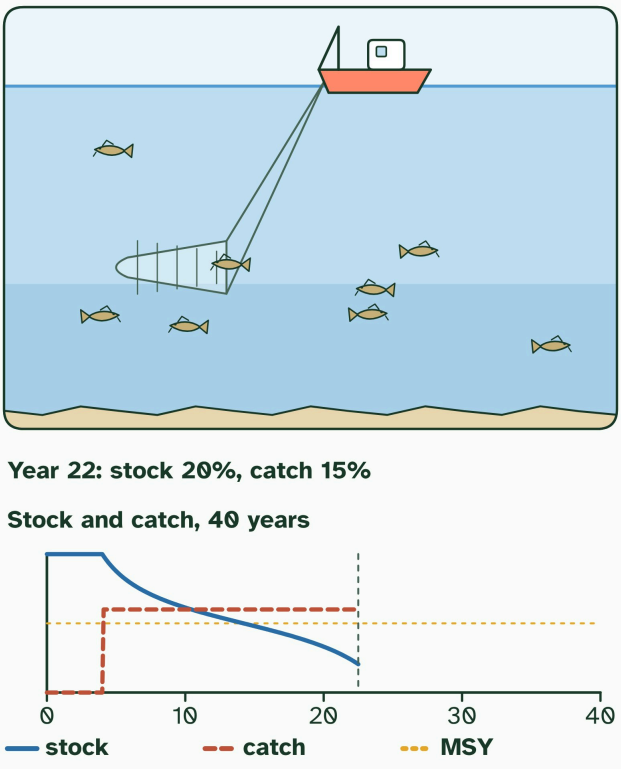
An unfished cod stock, as large as its sea can support. The boats begin taking the **same catch** every year.

2 YEAR 12: STOCK 54% OF UNFISHED, CATCH 15% A YEAR



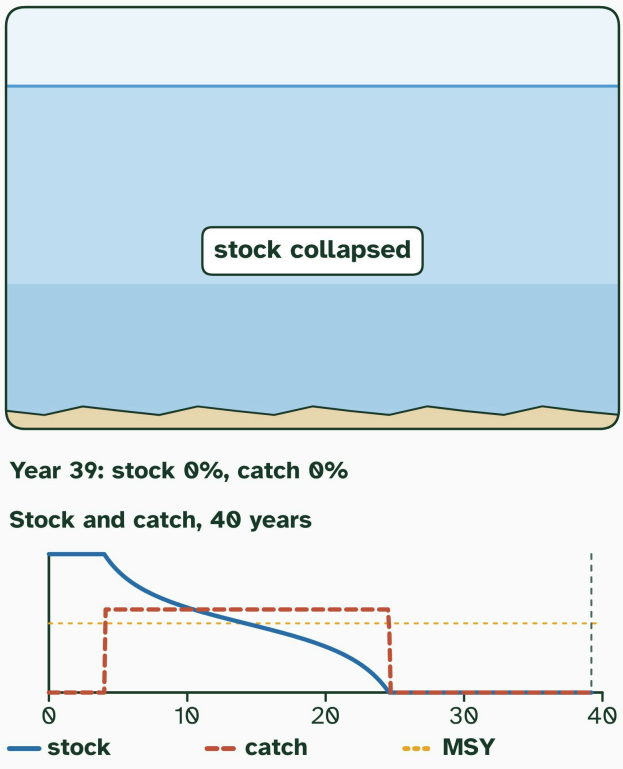
Fishing thins the stock, and a thinner stock grows faster, with less competition for food. Growth can now replace some of the catch.

3 YEAR 22: STOCK 20% OF UNFISHED, CATCH 15% A YEAR



If the catch is **lower than the replacement** rate, the stock levels off and can be fished for ever. If it is higher, the stock shrinks every year.

4 YEAR 39: STOCK 0% OF UNFISHED, CATCH 0% A YEAR



Too high a catch ends in **collapse**, as the Grand Banks cod did in 1992. The most that can be taken for ever is the **maximum sustainable yield**: 12.5% here.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-d4-2-stability-and-change#harvesting

PREDICT

Fishing boats keep catching the same tonnage of cod each year, but they need more and more days at sea to do it, and the fish landed are smaller. What does this suggest?

(A) The stock is healthy, because the total catch is holding steady from one year to the next

(B) The stock is shrinking, because the catch per day is falling and fewer fish reach full size

(C) The fish have moved to colder water, so the stock is the same size but harder to reach

Decide before you look. Answer on page 48.

IN THE EXAM

Sustainable harvesting:

1. The rate of harvesting must be lower than the rate of replacement (reproduction and growth).
2. Assess it by monitoring population size, age structure and catch per unit effort.
3. Set quotas at or below the maximum sustainable yield, with closed seasons, minimum sizes or protected areas.
4. Atlantic cod on the Grand Banks were overharvested and collapsed in 1992.

07

D4.2.7 FACTORS AFFECTING THE SUSTAINABILITY OF AGRICULTURE

Can a farm keep *going* for ever?

A farm is an ecosystem that people have simplified: one crop, cleared of its competitors, harvested and carried away every year. Whether it can go on producing food for centuries depends on five things.

Soil erosion. Bare, ploughed soil is washed off by rain and blown off by wind, and the fertile topsoil goes first. It can take centuries to form a few centimetres of soil. Keeping the ground covered, ploughing along the contours of a slope, planting hedges as windbreaks and not ploughing at all (no-till farming) all reduce erosion.

Leaching of nutrients. Nitrates and phosphates dissolved in soil water drain down past the roots and into streams. The farm loses fertility and the rivers gain it (chapter 8). Adding fertilizer little and often, when the crop is growing, and keeping a cover crop in winter both cut leaching.

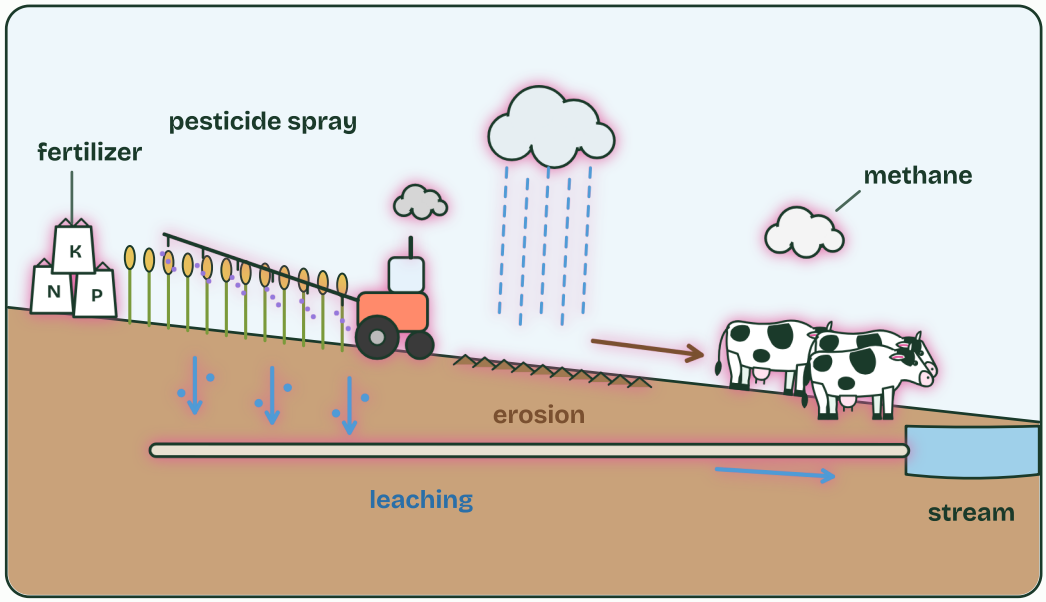
Supply of fertilizers and other inputs. Every harvest removes minerals, which must be replaced. Industrial nitrogen fertilizer is made with large amounts of fossil fuel, and phosphate is mined from rock that will run out. Growing legumes, whose root nodules hold nitrogen-fixing bacteria, and spreading manure and compost reduce the need for them.

Pollution by agrochemicals. Pesticides and herbicides can kill species other than the targets, such as pollinators and the predators of pests, and some persist and build up in food chains (chapter 9). **Integrated pest management** uses them only when needed.

Carbon footprint. Farm machinery burns diesel, fertilizer factories burn gas, ploughing releases carbon from the soil, and cattle and flooded rice fields release methane. Food that is flown across the world adds more. The carbon footprint of a farm is the total greenhouse gas released to produce its food.

KEY TERMS

integrated pest management
Using natural predators, crop rotation and targeted spraying together to control pests with as few pesticides as possible.



Inputs Every harvest carries minerals off the farm, so they must be replaced. Nitrogen fertilizer is made using a lot of fossil fuel and phosphate is mined from rock that will run out. Legumes in the rotation, manure and compost cut the need for them.

Soil erosion Bare, ploughed soil is washed away by rain and blown by wind, and the fertile topsoil goes first. Cover crops, ploughing along the contours, hedges and no-till farming keep it in place.

Carbon footprint Cattle release methane as they digest grass, tractors burn diesel, fertilizer factories burn gas and ploughing releases carbon from the soil. All add greenhouse gases for each tonne of food.

Agrochemicals Pesticides and herbicides can kill more than their targets, such as bees and the predators of pests, and some persist and build up in food chains. Integrated pest management sprays only when it is needed.

Leaching Nitrate and phosphate dissolve in soil water and drain down past the roots, into field drains and streams. The farm loses fertility and the water downstream is enriched (chapter 8). Fertilizer little and often, and winter cover crops, cut it.

PREDICT

A farmer grows clover in a field for one year in four, then ploughs it in before planting wheat. Which problem does this mainly reduce?

(A) Soil erosion, because the clover's dense roots hold the soil together for all four years

(B) The need for nitrogen fertilizer, because bacteria in the clover's root nodules fix nitrogen

(C) The carbon footprint, because clover takes in more carbon dioxide than any other crop does

Decide before you look. Answer on page 49.

REMEMBER IT

Five factors for sustainable farming

E Every	L Lazy	I Ivy	P Poisons	C Crops
Erosion of the soil by rain and wind	**Leaching** of nutrients out of the soil	**Inputs** fertilizers, fuel, water	**Pollution** by agrochemicals	**Carbon footprint** greenhouse gases from farming

08 Too much of a good *thing*

D4.2.8 EUTROPHICATION OF AQUATIC AND MARINE ECOSYSTEMS DUE TO LEACHING

Nitrate and phosphate are the minerals that most often limit the growth of algae in lakes and the sea. When rain leaches fertilizer from fields, or manure or sewage reaches a river, those limits are lifted. The enrichment of water with nutrients is **eutrophication**.

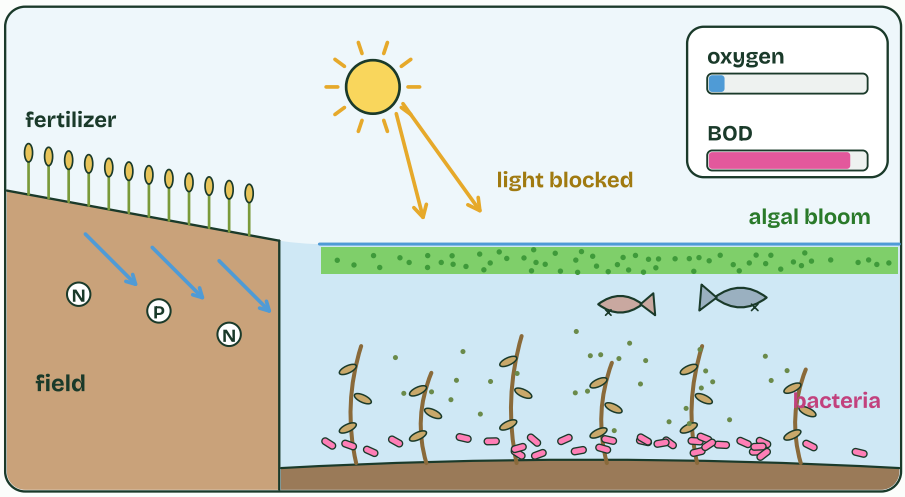
Algae multiply into a bloom that turns the water green and stops light reaching the plants on the bottom, so they die. The algae themselves are short-lived and die in huge numbers. Bacteria decompose the dead plants and algae by aerobic respiration, and they multiply too, using up the dissolved oxygen. Fish and other animals that need oxygen suffocate or swim away, and only a few tolerant species are left.

The demand for oxygen from decomposers is measured as the **biochemical oxygen demand** (BOD). A sample of water is kept sealed in the dark at 20 °C for five days, and the fall in its dissolved oxygen is measured. Clean water has a low BOD. Water full of dead organic matter has a high BOD, and the higher it is, the faster the oxygen will run out.

KEY TERMS

eutrophication
The enrichment of a body of water with mineral nutrients, especially nitrate and phosphate, which causes algae to grow rapidly and can lead to oxygen depletion.

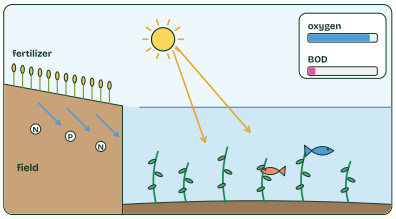
biochemical oxygen demand
The mass of dissolved oxygen used by microorganisms to break down the organic matter in a sample of water, usually measured over 5 days at 20 °C, in mg per litre.



STEP BY STEP

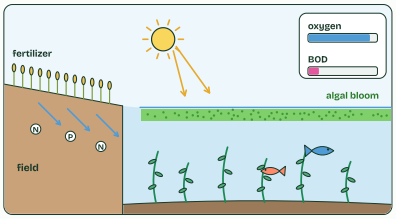
6 STEPS

1



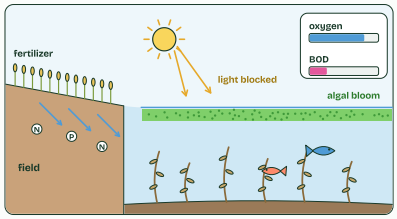
Rain **leaches** nitrate and phosphate from the fertilized field into the lake.

2



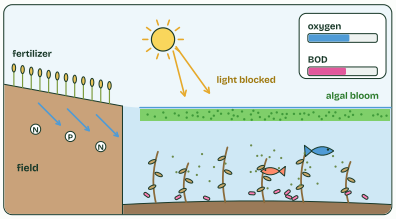
The nutrients were limiting the algae. Now they multiply into an **algal bloom** at the surface.

3



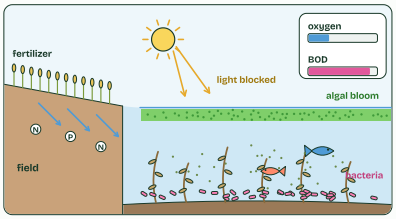
The bloom **blocks the light**, so the plants on the lake bed cannot photosynthesize and die.

4



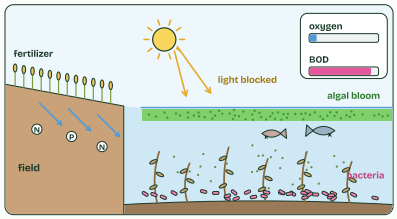
The short-lived algae **die** and sink, adding to the dead plant matter.

5



Aerobic **bacteria** decompose the dead matter and multiply. The **biochemical oxygen demand** (BOD) soars.

6

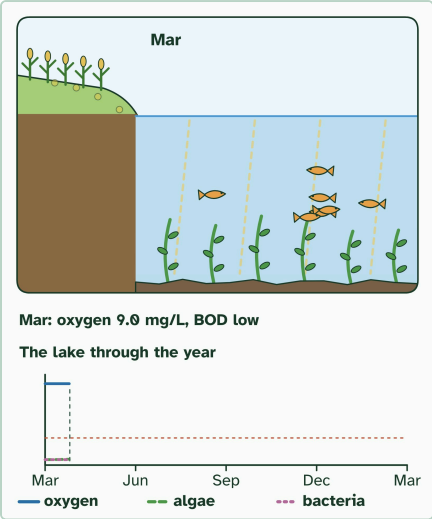


Dissolved oxygen falls so low that **fish die**. Only a few low-oxygen tolerant species remain, and diversity falls.

ANIMATION · A LAKE BELOW A FARM

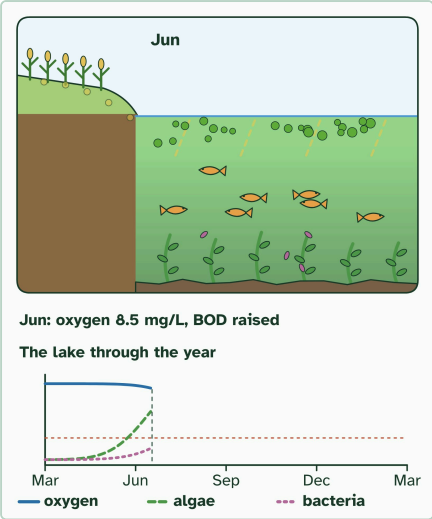
4 MOMENTS

1 MAR: DISSOLVED OXYGEN 9.0 MG/L, BOD LOW, FISH ALIVE



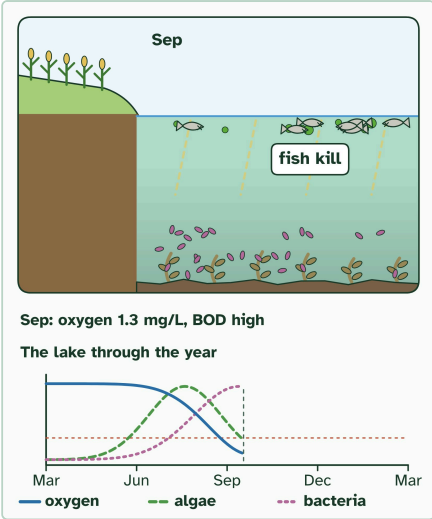
Spring rain washes **fertilizer** off the fields: nitrate and phosphate run into the lake.

2 JUN: DISSOLVED OXYGEN 8.5 MG/L, BOD RAISED, FISH ALIVE



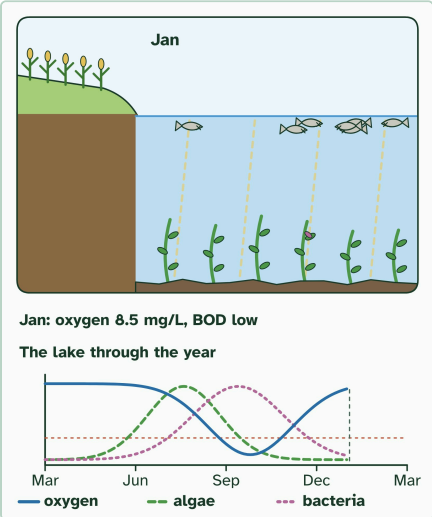
Extra nutrients feed an **algal bloom**. The green water shades out the plants on the lake bed.

3 SEP: DISSOLVED OXYGEN 1.3 MG/L, BOD HIGH, FISH DEAD



Algae and plants die. **Bacteria** decompose them and use up oxygen as they respire: a high **BOD**.

4 JAN: DISSOLVED OXYGEN 8.5 MG/L, BOD LOW, FISH DEAD



Dissolved oxygen falls below what fish need, and they suffocate. The lake recovers slowly through the winter.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-d4-2-stability-and-change#eutrophication

PREDICT

A river below a farm has a high nitrate level and a high BOD. Why does adding nitrate, which is not organic matter, raise the BOD?

(A) Nitrate reacts with the dissolved oxygen in the water and takes it out of the water directly

(B) Nitrate lets algae grow, and when the algae die, bacteria use oxygen to decompose them

(C) Nitrate is food for the fish, which then grow larger and use more of the oxygen in the river

Decide before you look. Answer on page 49.

REMEMBER IT

The steps of eutrophication

L Little	A Algae	L Love	D Dirty	D Dark	D Ditches
Leaching nitrate and phosphate wash into water	**Algal bloom** the algae multiply	**Light blocked** plants below are shaded	**Death** the plants and algae die	**Decomposers** bacteria multiply, BOD rises	**Deoxygenation** oxygen falls, fish die

IN THE EXAM

Eutrophication:

1. Nitrate and phosphate fertilizers leach from fields into rivers and lakes.
2. The nutrients cause rapid growth of algae (an algal bloom).
3. The algae block light, so plants below cannot photosynthesize and die.
4. Dead algae and plants are decomposed by aerobic bacteria, which multiply.
5. The biochemical oxygen demand rises and dissolved oxygen falls.
6. Fish and other aerobic animals die, and biodiversity falls.

09

D4.2.9 BIOMAGNIFICATION OF POLLUTANTS IN NATURAL ECOSYSTEMS

A pesticide that *climbs* the food chain

DDT is an insecticide first used widely in the 1940s, against the mosquitoes that carry malaria and the insects that eat crops. It is very stable, it is not broken down in the body, and it dissolves in fat rather than water, so it is not excreted. Whatever an animal takes in stays in its fat for the rest of its life. This build-up within one organism is **bioaccumulation**.

A small fish eats thousands of plankton in its life and keeps the DDT from all of them. A larger fish eats hundreds of small fish, and a bird of prey eats many large fish. At each trophic level the concentration rises, because most of the biomass eaten is used in respiration while the DDT stays. This rise in concentration up a food chain is **biomagnification**. In an estuary on Long Island, New York, studied in the 1960s, the water held 0.00005 parts per million of DDT, and cormorants at the top of the food chain held over 26 ppm, about half a million times more.

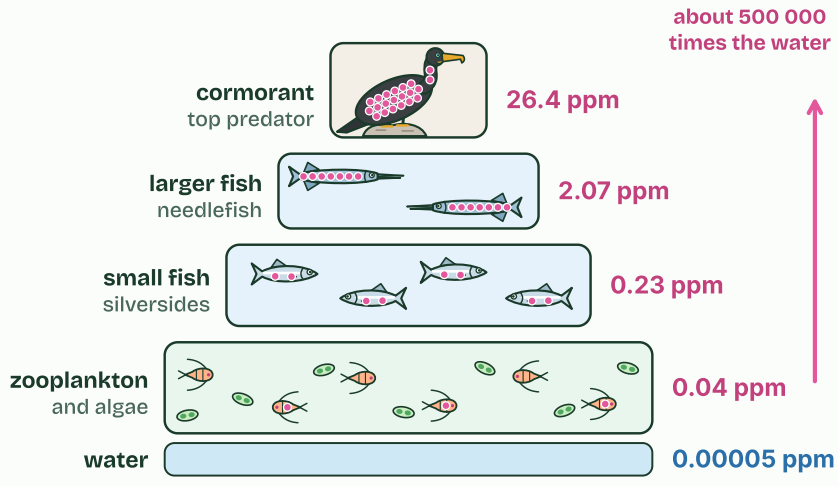
At those levels DDT made birds of prey lay eggs with thin shells, which cracked when the parents sat on them. Ospreys, peregrine falcons and bald eagles declined steeply. Rachel Carson described the damage in her book *Silent Spring* (1962), the public outcry followed, and the United States banned DDT for farm use in 1972. The birds recovered. DDT is still sprayed inside houses in some countries against malaria.

Mercury biomagnifies in the same way. It is released by burning coal and by small-scale gold mining, and bacteria in sediments turn it into methylmercury, which animals absorb and keep. Large, long-lived predatory fish such as swordfish, sharks and tuna carry the most, so pregnant women are advised to eat little of them. In the 1950s, a factory in Minamata, Japan, released mercury into the bay, and thousands of people who ate the local fish were poisoned.

KEY TERMS

bioaccumulation
The build-up of a substance in the tissues of an organism over its life, because it is taken in faster than it is broken down or excreted.

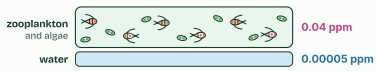
biomagnification
The increase in the concentration of a persistent pollutant in the tissues of organisms at each higher trophic level of a food chain.



STEP BY STEP

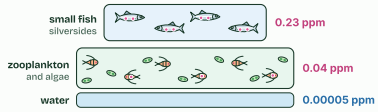
5 STEPS

1



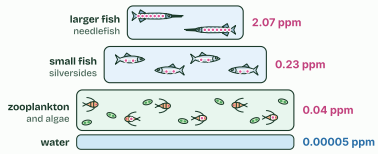
DDT in the water is barely measurable, but **plankton** absorb it and keep it in their fat: **bioaccumulation**.

2



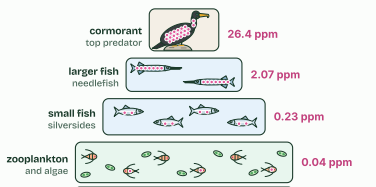
Each small fish eats many plankton. Most of their biomass is respired, but their DDT stays, so it is more **concentrated** in the fish.

3



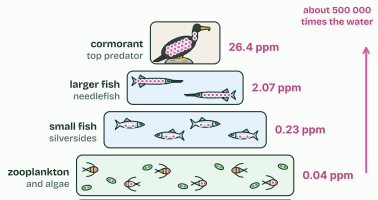
Larger fish eat many small fish, and the concentration rises again.

4



The **top predator**, a cormorant, carries the highest concentration of all.

5



From water to top predator, about half a million times more concentrated: **biomagnification**. Values from a Long Island estuary in the 1960s.

PREDICT

Why do top predators carry the highest concentration of DDT, even though they eat far less food in total than the plankton do?

(A) Top predators eat the plankton directly as well as the fish, so they take in DDT from two places

(B) Each predator keeps the DDT from many prey, while most of the prey's biomass is respired away

(C) Top predators live where the water holds more DDT, so they absorb more of it through the skin

Decide before you look. Answer on page 49.

IN THE EXAM

Biomagnification:

1. The pollutant (DDT, mercury) is persistent and fat-soluble, so it is not broken down or excreted.
2. It accumulates in each organism over its life (bioaccumulation).
3. Each consumer eats many prey, and most of the prey's biomass is lost in respiration, but the pollutant stays.
4. So its concentration rises at each trophic level and is highest in top predators.
5. DDT thinned eggshells of birds of prey; mercury harms the nervous system.

10 Plastic that never *goes away*

D4.2.10 EFFECTS OF MICROPLASTIC AND MACROPLASTIC POLLUTION OF THE OCEANS

Plastic is made to last, and in the sea it does. No decomposer has the enzymes to digest most plastics, so they are not **biodegradable**. Sunlight and waves break a bottle into smaller and smaller pieces, but the pieces are still plastic. Almost every piece of plastic ever made is still somewhere on Earth.

Macroplastic is the debris you can see, such as bags, bottles, nets and bottle caps. Animals get tangled in it, and seals, whales and turtles drown in lost fishing nets, called ghost nets. Animals also eat it: a sea turtle takes a floating bag for a jellyfish, and the plastic blocks its gut, so it starves with a full stomach.

Microplastic is debris smaller than about 5 mm (sources differ on the cut-off). It includes fragments of larger items, fibres washed out of synthetic clothes, and the pellets that plastic goods are made from. Zooplankton, mussels and small fish eat it, and the toxins that stick to its surface can then pass up food chains.

Midway Atoll, in the middle of the North Pacific, is home to about a million Laysan albatrosses (*Phoebastria immutabilis*). The parents skim food off the sea surface and carry it back to their chicks, and with it they bring bottle caps, lighters and fragments. The chicks cannot bring it up again. Many die with stomachs packed with plastic, and the plastic stays on the beach after their bodies have rotted away.

Photographs of those chicks, and television series such as *Blue Planet II* in 2017, showed the effects of plastic to millions of people who had never read the research behind them. Public opinion changed quickly, and that drove action: bans on plastic microbeads in cosmetics, charges for plastic bags, and many companies changing their packaging. This shows scientists that clear, vivid information about their findings can change what citizens and governments do.

KEY POINTS

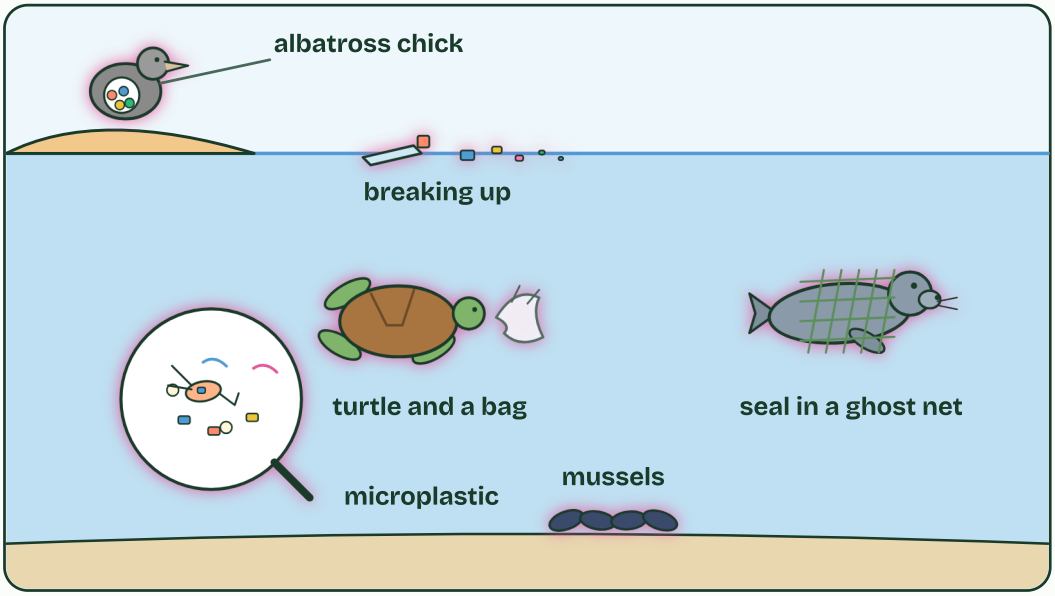
- Plastics are **persistent** because they are not biodegradable.
- **Macroplastic**: entanglement and blocked guts, as in turtles, seals and albatross chicks.
- **Microplastic**: eaten by plankton and filter feeders, and carries toxins up food chains.
- Clear coverage of research in the media changed public opinion and led to new rules.

KEY TERMS

biodegradable
Able to be broken down by decomposers into simple substances.

macroplastic
Pieces of plastic larger than about 5 mm, such as bags, bottles, nets and packaging.

microplastic
Pieces of plastic smaller than about 5 mm, such as fragments, fibres from synthetic clothes, and the pellets plastics are made from.



Laysan albatross chicks On Midway Atoll the parents scoop food off the sea and feed it to their chicks, with bottle caps, lighters and fragments mixed in. The chicks cannot bring it up, and many die with stomachs full of plastic.

Sea turtle A floating bag looks like a jellyfish, the turtle's food. Swallowed plastic can block the gut, so the turtle starves with a full stomach.

Microplastic Pieces under about 5 mm: fragments of larger items, fibres from synthetic clothes and the pellets plastics are made from. Zooplankton such as this copepod eat them, and so do mussels and small fish, and toxins stuck to the plastic can pass up the food chain.

Persistent No decomposer can digest most plastics, so they are not biodegradable. Sunlight and waves break a bottle into ever smaller pieces, but every piece is still plastic, and it stays for centuries.

Ghost nets Fishing nets lost at sea drift for years, catching and drowning seals, whales, turtles and seabirds, which then attract more animals to the same net.

Filter feeders Mussels and oysters filter large volumes of seawater and keep the microplastic they trap, which reaches anything that eats them, people included.

PREDICT

Why does breaking macroplastic into microplastic not solve the problem?

(A) The small pieces sink at once to the sea floor, where they release toxic gases into the water

(B) The pieces are still plastic, and now small enough to be eaten by plankton and filter feeders

(C) Breaking plastic up makes it biodegradable, but the decomposers that digest it are themselves poisoned

Decide before you look. Answer on page 49.

11

D4.2.11 RESTORATION OF NATURAL PROCESSES IN ECOSYSTEMS BY REWILDING

Let the land heal *itself*

Most conservation protects what is left. **Rewilding** goes further: it restores the processes that make an ecosystem work and then lets them run with as little human interference as possible. It uses three main methods.

Reintroducing apex predators and other keystone species. Grey wolves were reintroduced to Yellowstone National Park in the USA in 1995, seventy years after the last ones were killed. Elk, which had browsed the young willows and aspens along the rivers, were eaten and moved more often, and in places the trees grew back. Beavers returned to build dams. Ecologists still debate how much of the change was due to the wolves.

Reconnecting habitats over large areas. Small, isolated fragments of habitat cannot hold large animals and lose species over time. Corridors of habitat, and bridges and tunnels over and under roads, let animals move, find mates and recolonize.

Minimizing human impact. Stopping farming, logging and drainage, and managing the land only as much as the natural processes need. That may include removing invasive animals that would stop recovery.

Hinewai Reserve on Banks Peninsula, in the South Island of New Zealand, is more than a thousand hectares of former sheep farm. Much of it was covered in gorse, a spiny shrub from Europe that farmers treat as a weed and usually burn or spray. Since 1987, the botanist Hugh Wilson has managed it on a different principle: **minimal interference**. The gorse is left alone. It acts as a **nurse crop**, sheltering native seedlings from wind, frost and browsing animals. The native trees grow up through it, overtop it and shade it out, because gorse cannot grow in shade. Feral goats and deer are kept out, but nothing is planted. The native forest has returned over much of the reserve, with streams running clear and native birds back.

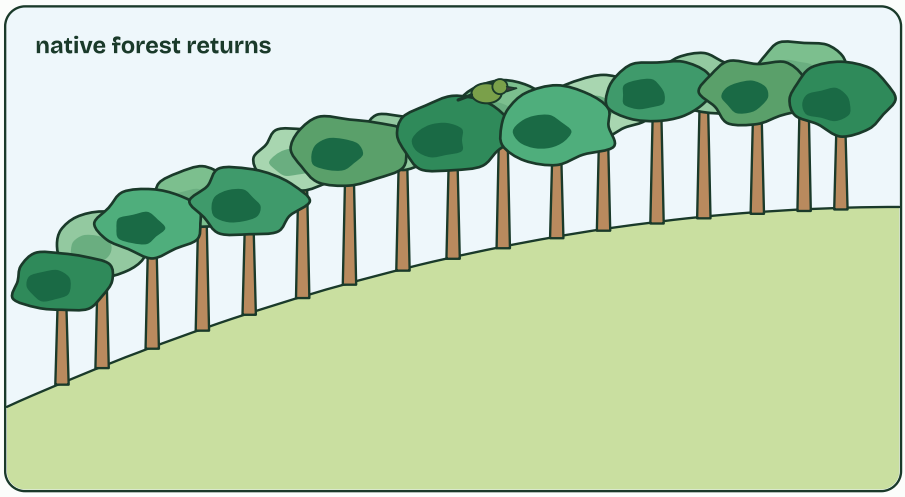
KEY POINTS

- Rewilding restores **processes**, then lets them run.
- Methods: reintroduce **apex predators and keystone species**, reconnect habitats, and **minimize human impact**.
- **Hinewai Reserve**: gorse left as a nurse crop, browsers excluded, native forest returning since 1987.

KEY TERMS

rewilding
Restoring an ecosystem by letting its natural processes run again, for example by reintroducing keystone species, reconnecting habitats and reducing human management.

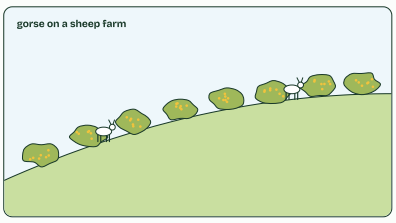
nurse crop
A plant that shelters the seedlings of other species while they establish, and is later replaced by them.



STEP BY STEP

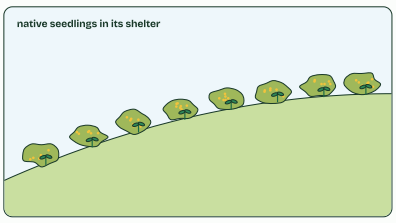
4 STEPS

1



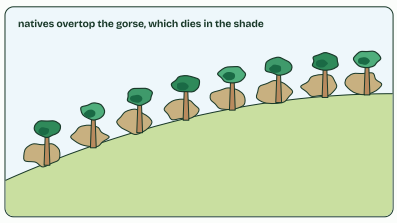
1987. A former sheep farm on Banks Peninsula, its slopes covered in **gorse**, a spiny shrub from Europe, and browsed by feral goats.

2



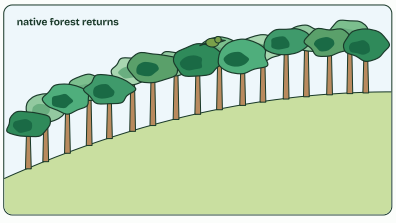
The goats and deer are kept out and the gorse is **left alone**. It acts as a **nurse crop**, sheltering native seedlings from wind, frost and browsing.

3



The native trees grow up through the gorse and **overtop** it. Gorse needs full light, so in their shade it dies back.

4



Over much of the reserve, **native forest** has returned, with nothing planted. Minimal interference let natural succession do the work.

PREDICT

At Hinewai, why does leaving the invasive gorse alone speed up the return of native forest, rather than slowing it?

(A) Gorse fixes so much carbon from the air that the soil gets warmer, and native seeds germinate faster

(B) Gorse shelters native seedlings, and then dies once they overtop it, because it cannot live in shade

(C) Gorse poisons the grass that would otherwise compete with native seedlings, so they grow faster

Decide before you look. Answer on page 49.

12 Communities that *change* in order

D4.2.12 HL ECOLOGICAL SUCCESSION AND ITS CAUSES

Stable ecosystems are not the whole story. Bare ground does not stay bare, and a field left alone does not stay a field. Over years to centuries one community replaces another in a fairly predictable sequence, called **ecological succession**. Each community in the sequence is a **seral stage**.

Succession is started by a change, and the change can be abiotic or biotic.

Abiotic changes are changes to the non-living environment. A volcano lays down new lava, a glacier retreats from bare rock, wind piles up a new sand dune, a river drops silt in a delta. Fire, floods and landslides strip a community away. Once begun, succession is driven on by the organisms themselves changing the abiotic conditions: they build soil, add nutrients, shade the ground and hold water.

Biotic changes are changes to the living community. A new species arrives, a disease kills one tree species (Dutch elm disease removed millions of elms), grazing animals are added or removed, or beavers dam a stream and flood a wood. Each new arrival can make conditions better for some species and worse for others.

Where succession begins on ground with no soil, it is **primary succession**. Where a disturbance removes the community but leaves the soil, as after a fire or when a field is abandoned, it is **secondary succession**, which is faster because the soil, seeds and roots are already there.

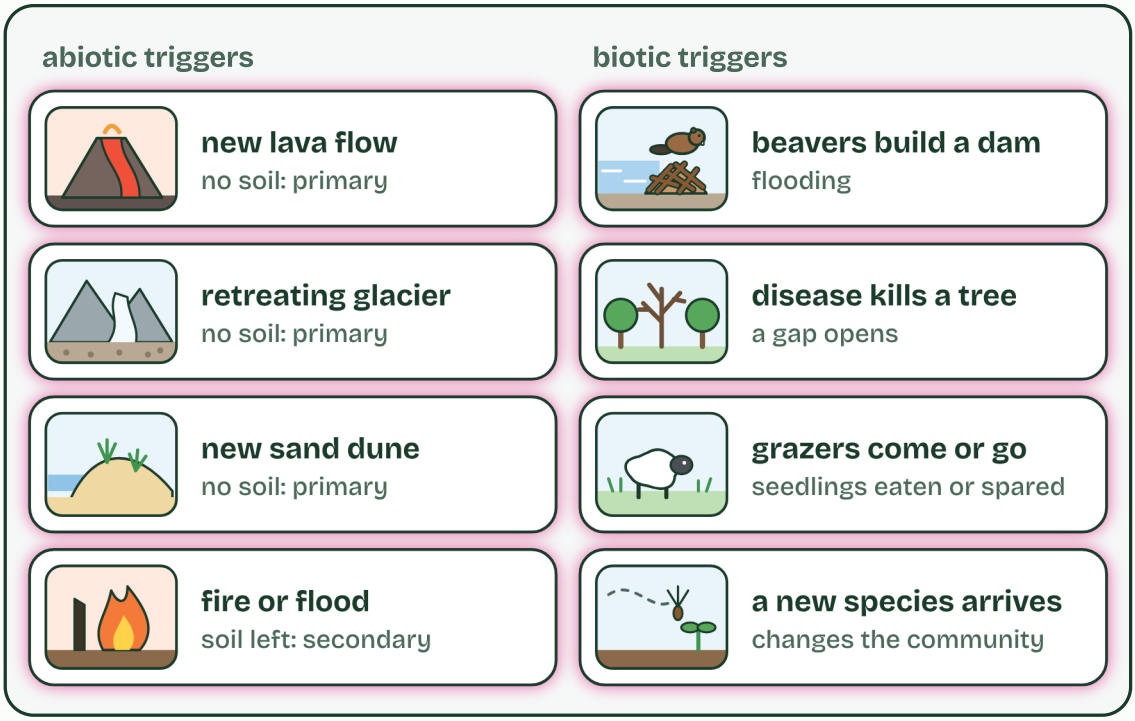
KEY TERMS

ecological succession
The sequence of changes in the species of a community over time, as each community alters the conditions and is replaced by another.

seral stage
One stage in a succession, with its own typical community.

primary succession
Succession on newly exposed ground with no soil, such as lava, bare rock or sand.

secondary succession
Succession on ground that already has soil, after an existing community has been removed or disturbed.



Lava A volcano lays down new rock. With no soil and no seeds, succession starts from bare rock with pioneers: primary succession. Hawaii and the island of Surtsey, off Iceland, are examples.

A new sand dune Wind piles up sand along a coast. Marram grass binds it, and a succession of dune communities follows, inland from the sea.

Beavers A dam floods a valley and kills the trees there. A pond, then a marsh, then, when the dam fails, a meadow follows: a biotic cause.

Grazing animals Add sheep and tree seedlings are eaten, so grassland stays. Take them away and scrub and woodland follow (chapter 15).

A retreating glacier As the ice melts back it uncovers bare rock and gravel. Glacier Bay in Alaska is the classic example (chapter 13).

Fire, flood or storm The community is removed but the soil, its seeds and many roots survive, so succession restarts quickly: secondary succession.

Disease Dutch elm disease, spread by beetles, killed millions of elm trees in Europe and North America. The gaps let light reach the ground and other species grow up.

A new arrival A species that arrives, carried by wind, animals or people, can change conditions for others: a nitrogen-fixing shrub enriches the soil, a shade tree shades out the plants below.

PREDICT

A forest fire burns a wood to the ground. A new lava flow covers another. Which will be forest again first, and why?

(A) The lava flow, because volcanic rock is so rich in the minerals that new plants need to grow

(B) The burnt wood, because its soil, buried seeds and living roots survive the fire

(C) Both at the same time, because succession runs at one fixed rate on any kind of ground

Decide before you look. Answer on page 49.

13 From bare rock to *forest*

D4.2.13 HL CHANGES OCCURRING DURING PRIMARY SUCCESSION

When the glaciers of Glacier Bay in Alaska melted back, from the 1750s on, they left bare rock and gravel. Ecologists have followed what happened since, and because the ice retreated gradually, a walk from the ice front to the mouth of the bay is also a walk through two hundred years of succession.

The first colonizers are **pioneer species**: cyanobacteria, lichens and mosses that can grip bare rock and survive drought and cold. They weather the rock, trap dust and, as they die, add the first organic matter. A thin soil forms. Then come small plants such as mountain avens (*Dryas*), which, like the alder that follows, has nitrogen-fixing bacteria in its roots and enriches the soil. Shrubs follow, then Sitka spruce, which shades out the alder, and after about two centuries a forest of spruce and hemlock.

The same five things increase in any primary succession on land.

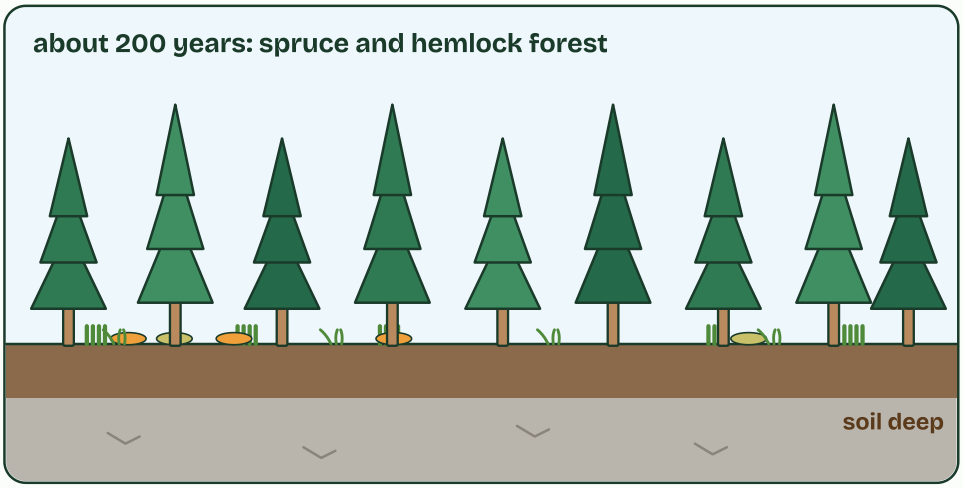
KEY POINTS

- **The size of the plants**: from mats of lichen to tall trees.
- **Primary production**: more and bigger plants capture more light energy.
- **Species diversity**: more kinds of plants give more habitats and food for animals.
- **The complexity of food webs**: more producers and consumers, with more links between them.
- **Nutrient cycling**: a deeper soil, more dead matter and more decomposers, so more nutrients cycle faster.

Diversity often peaks shortly before the end. In the final stage a few large, long-lived species can dominate and shade out some of the others.

KEY TERMS

pioneer species
The first organisms to colonize bare ground. They tolerate harsh conditions and begin forming soil.



STEP BY STEP

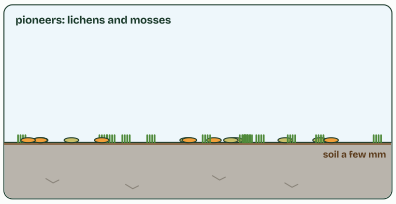
5 STEPS

1



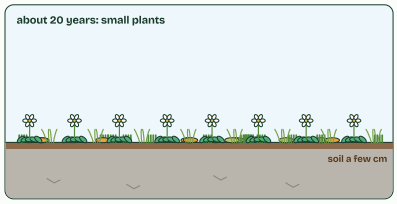
The ice has retreated and left **bare rock** and gravel: no soil, no seeds.

2



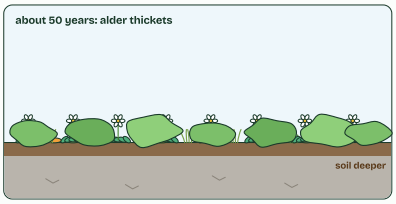
Pioneer species arrive: cyanobacteria, lichens and mosses. They weather the rock and, as they die, add organic matter. A thin soil begins.

3



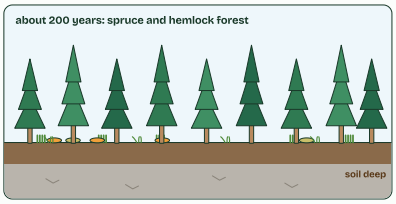
Small plants such as mountain avens (*Dryas*) and grasses colonize. Bacteria in the roots of *Dryas* fix nitrogen, and the soil deepens.

4

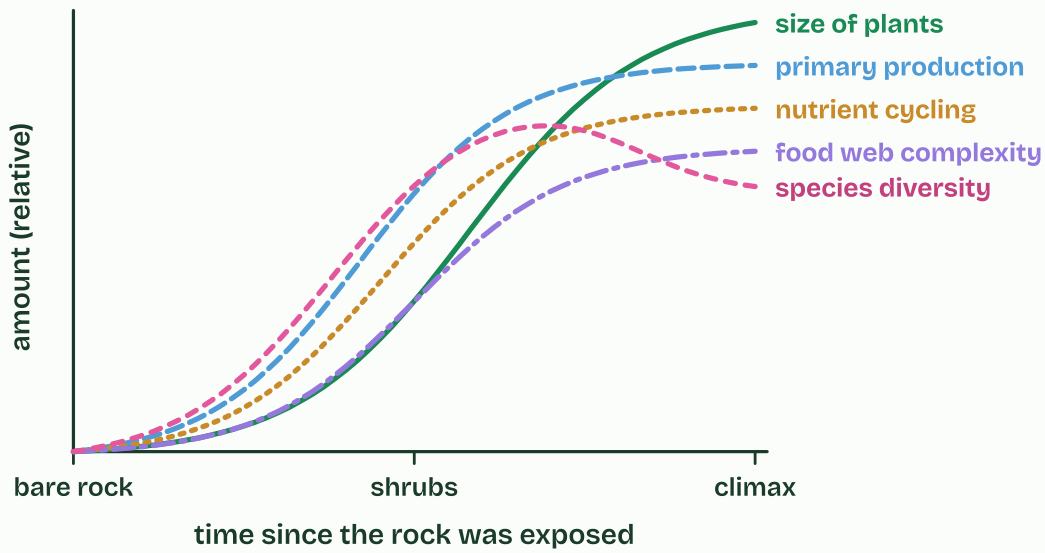


Alder shrubs, also nitrogen fixers, form thickets. More dead leaves and roots, more decomposers, deeper and richer soil.

5



Sitka spruce shades out the alder, and after about two centuries a **climax** forest of spruce and hemlock stands where the ice was.



REMEMBER IT

What increases in primary succession

S Slowly	P Plants	S Spread	F Feeding	N Nature
Size of the plants	**Production** primary production rises	**Species diversity** more species	**Food webs** more complex	**Nutrient cycling** more, and faster

PREDICT

Why does soil depth increase as succession goes on?

(A) Rain carries soil in from the land around, and it settles in the cracks of the rock over time

(B) Each community weathers the rock and adds dead matter, which decomposers turn into humus

(C) The rock under the plants softens with age, and turns into soil whether plants are there or not

Decide before you look. Answer on page 49.

IN THE EXAM

Primary succession:

1. Starts on bare ground with no soil, such as rock after a glacier retreats.
2. Pioneer species (lichens, mosses) colonize, weather the rock and add organic matter, so soil forms.
3. Each seral stage changes conditions so other species can grow and replace it.
4. Plant size, primary production, species diversity, food web complexity and nutrient cycling all increase.
5. Ends in a climax community.

D4.2.14 HL CYCLICAL SUCCESSION IN ECOSYSTEMS

14 A succession that goes round in a *circle*

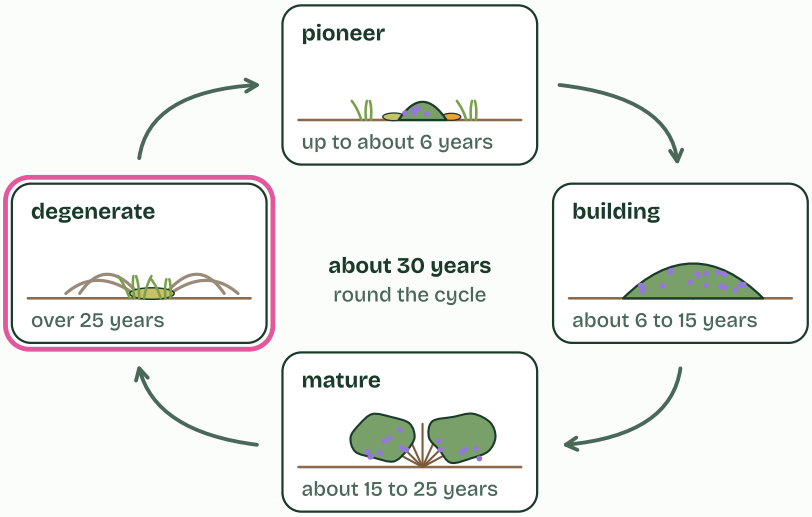
Succession is often drawn as a line that ends in one unchanging community. In some ecosystems it is a loop instead: a series of communities replace each other and then the first one comes back. This is **cyclical succession**.

The classic example is heather (*Calluna vulgaris*) on the heaths and moors of Britain, described by the ecologist Alex Watt in 1947. Each heather bush goes through four phases over about 30 years. In the **pioneer** phase a seedling grows among grasses, mosses and lichens. In the **building** phase it forms a dense dome that shades out almost everything beneath. In the **mature** phase the centre of the bush begins to open up. In the **degenerate** phase the old stems die and fall outwards, leaving a gap where lichens, mosses and grasses grow again, and then a new heather seedling starts the cycle. Across a moor, patches are at every phase at once, so the moor as a whole stays the same while each patch keeps changing.

Fire can drive cycles too. Some heaths, grasslands and dry shrublands burn every few decades, and the community that grows back after the fire replaces the one that burned until the next fire.

KEY TERMS

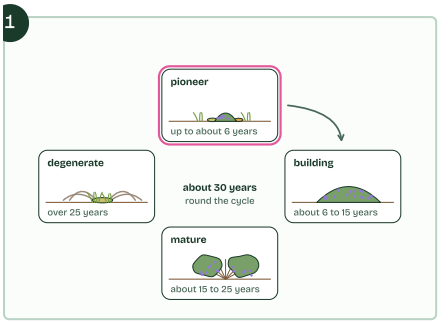
cyclical succession
A succession in which a series of communities replace one another and the cycle repeats, rather than ending in one permanent climax community.



STEP BY STEP

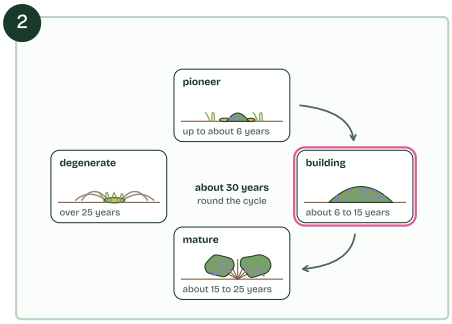
4 STEPS

1



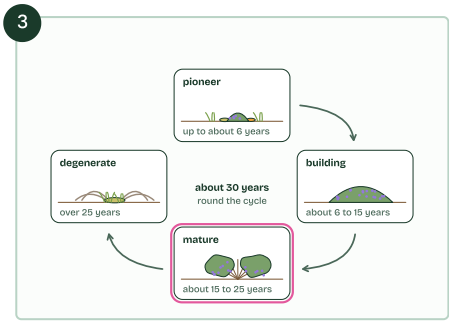
Pioneer. A heather seedling grows in a gap among grasses, mosses and lichens.

2



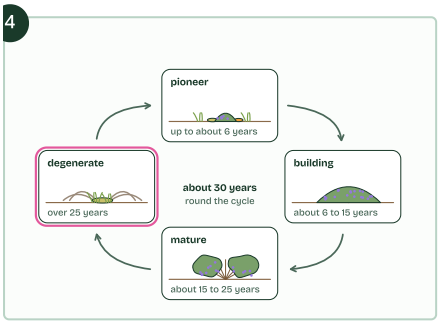
Building. The heather forms a dense dome that flowers well and shades out almost everything beneath it.

3



Mature. The bush is at its largest, and its centre starts to open up as the old stems spread.

4



Degenerate. The old stems die and fall outwards. Lichens, mosses and grasses grow in the gap, and a new seedling starts the cycle again.

PREDICT

A heather moor has patches at all four phases. Why does the moor still look much the same from year to year?

(A) Heather stops growing once the moor is covered, so the patches all stay at one phase for good

(B) The patches are out of step, so as one dies back another builds up, and the mix stays the same

(C) Heather bushes live for hundreds of years, so any change is far too slow to be seen in a year

Decide before you look. Answer on page 49.

15 Where succession *stops*

D4.2.15 HL CLIMAX COMMUNITIES AND ARRESTED SUCCESSION

Succession tends towards a **climax community**: the community that is stable under the climate and soil of that place. Which community that is depends on the conditions. In most of lowland Britain it is broadleaf woodland of oak and ash; where it is colder or wetter it may be pine forest, and where it is very dry, grassland. Given the same conditions, succession tends to end in the same type of climax.

People often stop succession before it gets there. This is **arrested succession**, and the community it leaves is sometimes called a plagioclimax.

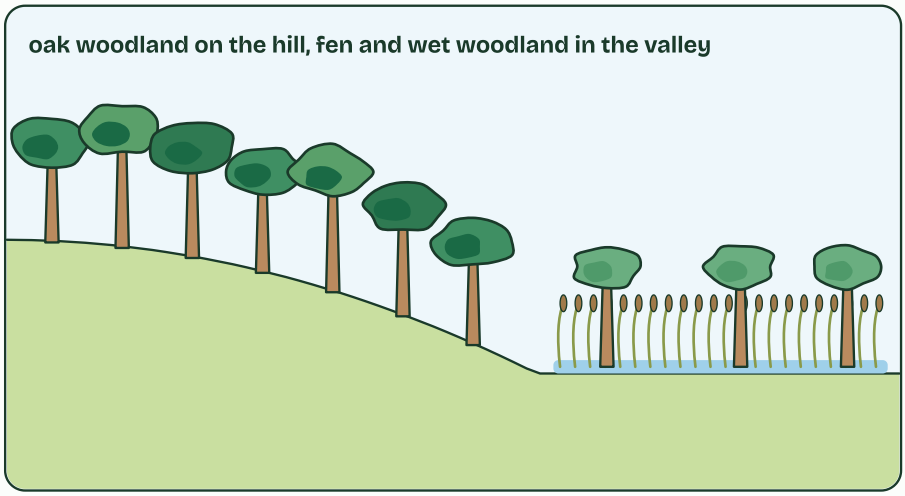
Grazing by farm livestock. Sheep and cattle eat tree seedlings along with the grass, so the trees never get started. Many of the open hills of Britain and New Zealand would be woodland if the sheep were taken off them, as at Hinewai (chapter 11).

Drainage of wetlands. A fen or marsh naturally fills with dead plant matter over time and slowly becomes wet woodland. Drained for farming, as most of the Fens of eastern England were from the 1600s on, the peat dries and shrinks, the wetland species die out, and the land is held as farmland. Ploughing, mowing and regular burning arrest succession too.

KEY TERMS

climax community
The final, stable community of a succession, which stays unless conditions change.

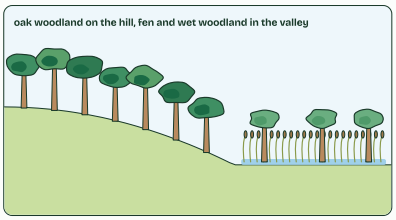
arrested succession
Succession that is prevented from reaching the climax community, usually by human activity such as grazing, mowing, burning or drainage.



SWITCH IT

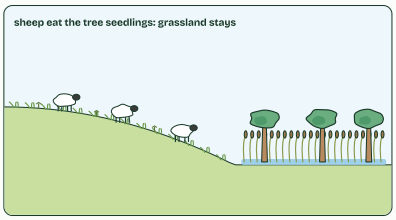
3 SETTINGS

1



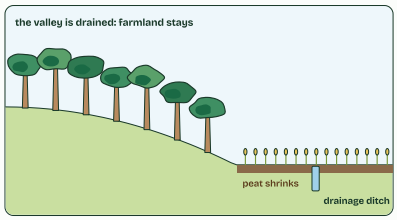
Left alone

2



Grazed by sheep

3



Valley drained

PREDICT

A sheep farm on a hillside in lowland Britain is abandoned. What would you expect to grow there after a hundred years?

(A) The same short grassland, because grassland is the climax community wherever sheep once grazed

(B) Woodland, because without grazing, tree seedlings survive and succession runs on to the climax

(C) Bare soil, because the sheep took all the nutrients and nothing larger than moss can grow there

Decide before you look. Answer on page 50.

IN THE EXAM

Climax and arrested succession:

1. Under given environmental conditions, succession tends to lead to one type of climax community.
2. Human activity can stop succession before the climax: arrested succession.
3. Grazing livestock eat seedlings, so grassland does not become woodland.
4. Draining wetlands stops their succession and holds the land as farmland.

Key terms

Every term this guide defines, A to Z, with the chapter it is in. Cover the right-hand side and test yourself.

arrested succession 15
Succession that is prevented from reaching the climax community, usually by human activity such as grazing, mowing, burning or drainage.

bioaccumulation 09
The build-up of a substance in the tissues of an organism over its life, because it is taken in faster than it is broken down or excreted.

biochemical oxygen demand 08
The mass of dissolved oxygen used by microorganisms to break down the organic matter in a sample of water, usually measured over 5 days at 20 °C, in mg per litre.

biodegradable 10
Able to be broken down by decomposers into simple substances.

biomagnification 09
The increase in the concentration of a persistent pollutant in the tissues of organisms at each higher trophic level of a food chain.

climax community 15
The final, stable community of a succession, which stays unless conditions change.

closed system 04
A system that exchanges energy, but not matter, with its surroundings.

cyclical succession 14
A succession in which a series of communities replace one another and the cycle repeats, rather than ending in one permanent climax community.

ecological succession 12
The sequence of changes in the species of a community over time, as each community alters the conditions and is replaced by another.

ecosystem stability 01
The ability of an ecosystem to keep the same structure and processes over a long time, and to return to that state after a disturbance.

eutrophication 08
The enrichment of a body of water with mineral nutrients, especially nitrate and phosphate, which causes algae to grow rapidly and can lead to oxygen depletion.

flying rivers 03
Streams of water vapour carried in the air from the Amazon rainforest to other parts of South America, where they fall as rain.

integrated pest management 07
Using natural predators, crop rotation and targeted spraying together to control pests with as few pesticides as possible.

keystone species 05
A species that has a much larger effect on the structure of its community than its numbers or biomass would suggest.

macroplastic 10
Pieces of plastic larger than about 5 mm, such as bags, bottles, nets and packaging.

maximum sustainable yield 06
The largest harvest that can be taken from a population every year without it declining, taken when the population is kept at the size where it grows fastest.

mesocosm 04
A small, enclosed experimental ecosystem, set up so that its conditions can be controlled and changed, as a model of a natural ecosystem.

microplastic 10
Pieces of plastic smaller than about 5 mm, such as fragments, fibres from synthetic clothes, and the pellets plastics are made from.

nurse crop 11
A plant that shelters the seedlings of other species while they establish, and is later replaced by them.

pioneer species 13
The first organisms to colonize bare ground. They tolerate harsh conditions and begin forming soil.

primary succession 12
Succession on newly exposed ground with no soil, such as lava, bare rock or sand.

renewable resources 06
A resource that is replaced by natural processes, such as reproduction and growth, so it can be used indefinitely if it is not used faster than it is replaced.

rewilding 11
Restoring an ecosystem by letting its natural processes run again, for example by reintroducing keystone species, reconnecting habitats and reducing human management.

saprotrophs 02
Organisms that feed on dead matter by secreting enzymes onto it and absorbing the products, releasing inorganic nutrients. Most are bacteria and fungi.

secondary succession 12
Succession on ground that already has soil, after an existing community has been removed or disturbed.

seral stage 12
One stage in a succession, with its own typical community.

sustainable 06
Able to continue indefinitely without depleting the resource or damaging the ecosystem.

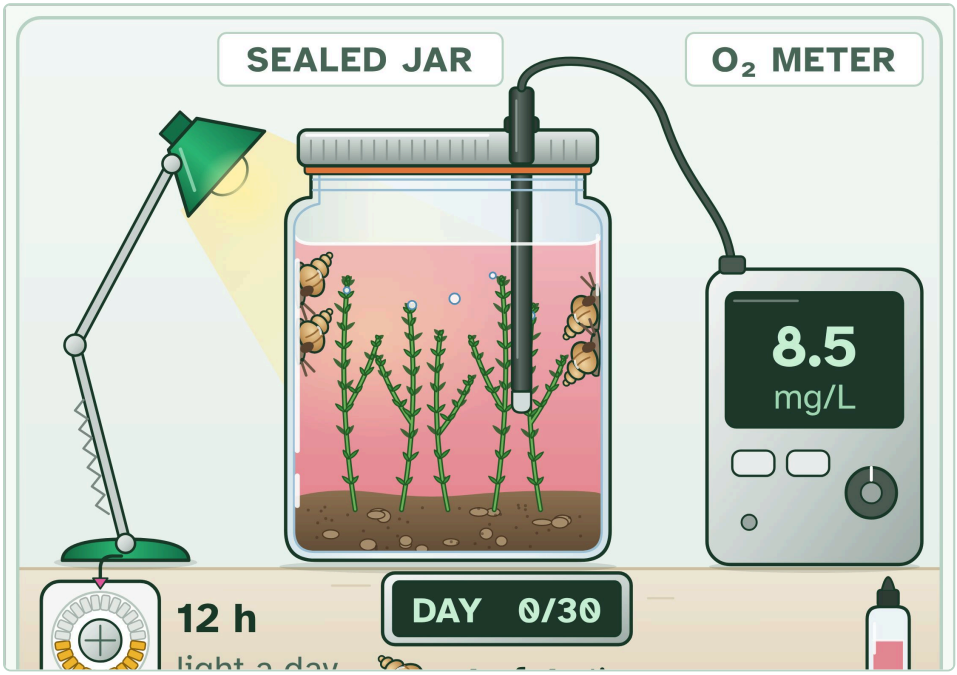
tipping point 03
A point beyond which a small further change pushes a system into a new state, from which it does not easily return.

transpiration 03
The loss of water vapour from the leaves of plants, mostly through the stomata.

urchin barren 05
A stretch of sea floor where sea urchins have eaten the kelp, leaving bare rock with few other species.

Dry lab: *Life in a sealed jar*

A sealed jar of pond water with pondweed, snails and the microbes in its mud. Change the light, the number of snails, the amount of pondweed and the lid, and follow the oxygen for 30 days to find which jars stay stable.



Run it online: change the variables, run the trials, and the table and graph fill in as you go. `biologybybradford.com/guides/ib-biology-d4-2-stability-and-change#lab`

Your question

What does a sealed jar need to keep its animals alive? Light passes through the glass but no matter gets in or out, so the plants, animals and microbes inside must balance each other. Pick one variable to change and keep the rest the same.

What you can change

The light each day (hours of light), the number of snails, the mass of pondweed and whether the jar is sealed or open. A sealed jar is the model the IB prefers: energy can enter as light, but no matter can enter or leave.

What to record

The dissolved oxygen in each jar every day, in milligrams per litre, and the day any snail dies. Repeat each jar at least three times, because every run varies a little, and use the mean. Download the CSV to plot your own graph.

Find out

- **Is the starting jar stable?** Run 12 hours of light, 10 g of pondweed and 4 snails, sealed, three times. Does the oxygen hold and do the snails live?
- **How much light does it need?** Keep everything else the same and run 0, 6, 12 and 18 hours. Which light setting is the least that keeps every snail alive?
- **Producers against consumers.** At 6 hours of light, raise the snails from 0 to 10. At what number does the jar tip over, and does more pondweed rescue it?
- **Why seal it?** Repeat one jar that failed with the lid open. What does the open lid let in, and why does that spoil the experiment as a model of a closed ecosystem?

Record

- The hours of light, the pondweed, the snails and the lid for every run (the independent and controlled variables).
- The dissolved oxygen on day 30 and the snails alive (the dependent variables), and the day the first snail died.
- At least three runs at each setting, because cloud and warmth change a little from day to day.
- The graph in your results shows oxygen through the month for your last six runs. Download the CSV to plot your own.

Your question What does a sealed jar need to keep its animals alive? Light passes through the glass but no matter gets in or out, so the plants, animals and microbes inside must balance each other. Pick one variable to change and keep the rest the same.**What you can change**The light each day (hours of light), the number of snails, the mass of pondweed and whether the jar is sealed or open. A sealed jar is the model the IB prefers: energy can enter as light, but no matter can enter or leave.**What to record**The dissolved oxygen in each jar every day, in milligrams per litre, and the day any snail dies. Repeat each jar at least three times, because every run varies a little, and use the mean. Download the CSV to plot your own graph.

Back to ecosystems

Use your results to explain what a sealed mesocosm needs to stay stable, and why it is sealed rather than left open.

QUESTIONS ON THE LAB

QUESTION 1

A sealed jar has 10 g of pondweed and 4 snails. In the dark, the snails die within a few days. Why?

(A) The snails have nothing to eat once the pondweed stops growing

(B) Without light there is no photosynthesis, but the pondweed and snails go on respiring and use up the oxygen

(C) The water cools in the dark, which kills the snails directly

(D) Carbon dioxide runs out, so the snails cannot respire any more

Answer on page 50.

QUESTION 2

A student finds that a jar with the lid open stays stable with 10 snails, but the sealed one does not. What should they conclude?

(A) Open jars are the better model, so sealing should be avoided

(B) The snails need fresh food from the air

(C) Oxygen dissolving from the air made up the shortfall, so the open jar is not testing whether the community can sustain itself

(D) Sealing the jar stops photosynthesis from happening

Answer on page 50.

Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on D4.2 each time, marked as you go, and saved to your Exam practice progress when you are signed in. Scan the code, or type the link.

biologybybradford.com/exam-maker/sit?topics=D4.2&level=HL&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

01 Why are very old, stable ecosystems such as the Daintree so rich in species found nowhere else?

B **Lineages have had a very long time to diversify there, with no event that wiped them out**

Time without a catastrophe. Over tens of millions of years, populations evolved and split into new species that stayed put, and no ice age, fire or drought destroyed them. In younger or more disturbed ecosystems, many lineages were lost and had to recolonize from elsewhere.

02 A forest is cut and the logs are taken away every 30 years. Which requirement for stability does this put at risk most directly?

B **The recycling of nutrients, because the nutrients locked in the logs leave the forest and never return**

The recycling of nutrients. The logs hold nitrogen, phosphorus and other minerals that decomposers would have returned to the soil. Taking them away removes those nutrients from the cycle, and each harvest leaves the soil poorer. The new trees still get sunlight.

03 Nobody knows exactly how much forest the Amazon can lose before it tips. Why is this so hard to find out?

B **There is only one Amazon, so models are all we have, and they depend on climate warming too**

We cannot run the experiment. The estimates come from computer models of rainfall and forest, and they differ: some put the threshold near 40% of the forest lost, while later work that adds warming and more fires puts it at 20 to 25%. Around a fifth of the Brazilian Amazon has already been cleared, which is why scientists urge caution.

03 A state had 1 250 000 km² of rainforest in 1970 and 1 000 000 km² in 2020. What is the percentage change in forest area?

B **−20%, because 250 000 is a fifth of 1 250 000**

(1 000 000 − 1 250 000) ÷ 1 250 000 × 100 = −20%. Always divide by the original value, the area before the change, not the area now. The minus sign shows a fall.

04 A student seals four jars with pondweed and snails and keeps one in the dark. Which jar would you expect the snails to die in first, and why?

B **The dark jar, because with no photosynthesis everything there uses oxygen and nothing makes it**

The dark jar. Without light, the pondweed cannot photosynthesize, but it still respires, and so do the snails and microbes. All of them use up the dissolved oxygen and none is replaced. In the light, photosynthesis adds oxygen faster than respiration uses it.

05 A seaweed is the most common organism in a rock pool. Removing it changes little. Removing a rare whelk, a predator, changes almost everything. Which is the keystone species?

B **The whelk, because its effect on the community is far greater than its small numbers suggest**

The whelk. A keystone species is defined by the size of its effect compared with its abundance, not by being common. The common seaweed is a dominant species. The rare whelk has a disproportionate effect.

06 Fishing boats keep catching the same tonnage of cod each year, but they need more and more days at sea to do it, and the fish landed are smaller. What does this suggest?

B **The stock is shrinking, because the catch per day is falling and fewer fish reach full size**

The stock is shrinking. Catch per unit effort is falling, and smaller fish mean the older, bigger ones have been fished out. This was the pattern on the Grand Banks before the collapse: modern boats kept the total catch high while the population underneath them disappeared.

07 A farmer grows clover in a field for one year in four, then ploughs it in before planting wheat. Which problem does this mainly reduce?

B **The need for nitrogen fertilizer, because bacteria in the clover's root nodules fix nitrogen**

The need for nitrogen fertilizer. Clover is a legume, and nitrogen-fixing bacteria in its root nodules turn nitrogen from the air into compounds the plant uses. Ploughing the clover in releases that nitrogen for the next crop. Crop rotation like this was used long before artificial fertilizer existed.

08 A river below a farm has a high nitrate level and a high BOD. Why does adding nitrate, which is not organic matter, raise the BOD?

B **Nitrate lets algae grow, and when the algae die, bacteria use oxygen to decompose them**

Through the algae. Nitrate feeds a bloom of algae, the algae die, and the dead algae are organic matter. Aerobic bacteria decomposing them use the oxygen, which is what BOD measures.

09 Why do top predators carry the highest concentration of DDT, even though they eat far less food in total than the plankton do?

B **Each predator keeps the DDT from many prey, while most of the prey's biomass is respired away**

DDT is kept and biomass is not. Most of the energy and biomass a predator eats is respired or excreted, but the DDT stays in its fat. So the same mass of DDT ends up in a smaller and smaller mass of animal at each level, and the concentration rises.

10 Why does breaking macroplastic into microplastic not solve the problem?

B **The pieces are still plastic, and now small enough to be eaten by plankton and filter feeders**

The pieces are still plastic. Smaller pieces are not digested any better, and they can now be eaten by animals at the bottom of the food chain, such as zooplankton and mussels. There are far more pieces, they are harder to collect, and they carry absorbed toxins.

11 At Hinewai, why does leaving the invasive gorse alone speed up the return of native forest, rather than slowing it?

B **Gorse shelters native seedlings, and then dies once they overtop it, because it cannot live in shade**

It is a nurse crop. Under the gorse, native seedlings are protected from wind, frost and grazing. Once they grow taller, they shade the gorse, which needs full light, and it dies back. Burning or spraying the gorse would kill the native seedlings too and start the process over again.

12 A forest fire burns a wood to the ground. A new lava flow covers another. Which will be forest again first, and why?

B **The burnt wood, because its soil, buried seeds and living roots survive the fire**

The burnt wood. Its succession is secondary: there is soil, a seed bank and roots that resprout, so plants return within weeks. The lava has no soil at all, and pioneers must make it first, which takes centuries.

13 Why does soil depth increase as succession goes on?

B **Each community weathers the rock and adds dead matter, which decomposers turn into humus**

The organisms make it. Pioneers and roots break up the rock, and every generation adds dead leaves, roots and bodies, which decomposers turn into humus. Deeper soil holds more water and nutrients, which lets bigger plants grow, which add more organic matter: the change feeds itself.

14 A heather moor has patches at all four phases. Why does the moor still look much the same from year to year?

B **The patches are out of step, so as one dies back another builds up, and the mix stays the same**

The patches are out of step. Each one cycles through pioneer, building, mature and degenerate, but they started at different times, so at any moment the moor holds a similar share of each. The whole community is stable even though no patch is.

15 A sheep farm on a hillside in lowland Britain is abandoned. What would you expect to grow there after a hundred years?

B **Woodland, because without grazing, tree seedlings survive and succession runs on to the climax**

Woodland. The grassland was held there by grazing, which is arrested succession. Remove the sheep and shrubs and tree seedlings survive, so the succession continues through scrub to the woodland that is the climax for that climate.

QUESTIONS ON THE DRY LAB

Q1 A sealed jar has 10 g of pondweed and 4 snails. In the dark, the snails die within a few days. Why?

B **Without light there is no photosynthesis, but the pondweed and snails go on respiring and use up the oxygen**

Plants respire day and night. With no light they only use oxygen, as the snails do, so it falls until the snails suffocate. Decomposers then use more, and the indicator turns yellow as carbon dioxide builds up.

Q2 A student finds that a jar with the lid open stays stable with 10 snails, but the sealed one does not. What should they conclude?

C **Oxygen dissolving from the air made up the shortfall, so the open jar is not testing whether the community can sustain itself**

A sealed jar lets in light but no matter, so its oxygen must come from its own producers. An open lid lets oxygen dissolve in from the air and hides the imbalance between photosynthesis and respiration.

How this was made. The course structure, the activities and the teaching choices come from my own classroom, my presentations and my years of teaching IB and AP Biology. I use Claude, an AI, to help write and build the interactive guides, lesson plans, slides and practice questions, and to draw the diagrams and code the interactives. I direct the work and review it against the IB and AP specifications before it goes live.

Written and drawn for Biology by Bradford, biologybybradford.com. Free to print and share with a class.