

ESAT

Biology

Ecosystems

Free lesson notes

Covers	B10.1 to B10.3
Format	Lesson, worked examples, self-check
Price	Free

About this lesson

An **ecosystem** is a community of living things together with the non-living environment they share. A wood, a pond, a coral reef and a field are all ecosystems. Ecology asks how the organisms in them depend on each other and on their surroundings, how energy and matter flow through them, how we measure what lives where, and what humans do to them.

This lesson builds the ideas in order. We start with the levels of organisation and the factors that decide where organisms live. We follow energy through food chains, webs and pyramids, then follow *matter* round the carbon and water cycles. We then learn how to sample a habitat with quadrats and transects, and finish with three human impacts that the specification names: fish farming, acid rain and eutrophication.

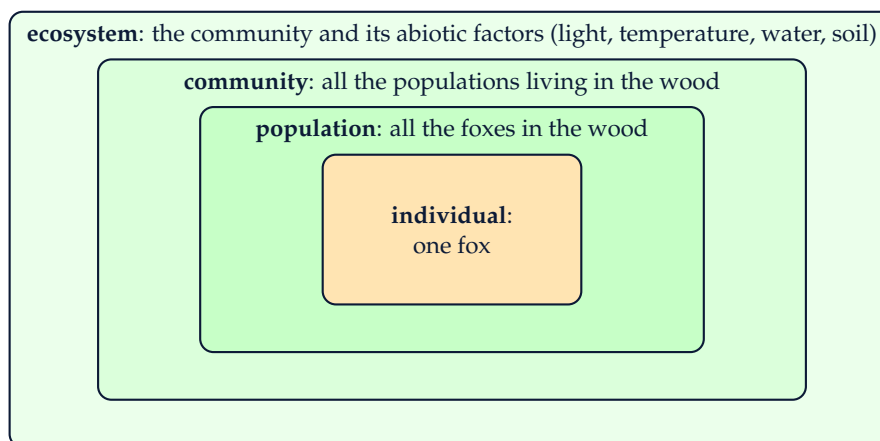
How to use it. Cover each worked example and try it first. There is no calculator in the ESAT, so the numbers are friendly, and the data questions reward careful reading of what a graph or table actually shows. Specification covered: B10.1 (organisation, abiotic and biotic factors, interdependence, competition), B10.2 (the carbon and water cycles) and B10.3 (biodiversity, sampling with quadrats and transects, and the human impacts of fish farming, acid rain and eutrophication).

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1 Organisation, abiotic and biotic factors (B10.1)

Ecologists use a set of precise words for the levels at which life is organised, and the exam expects you to use them exactly.

- An **individual** is one organism.
- A **population** is all the individuals of *one species* living in one area at one time (all the foxes in a wood).
- A **community** is all the populations of *all the species* living in one area (the foxes, rabbits, grass, insects, fungi and bacteria together).
- An **ecosystem** is the community *plus* the non-living environment: light, temperature, water, soil minerals and so on.



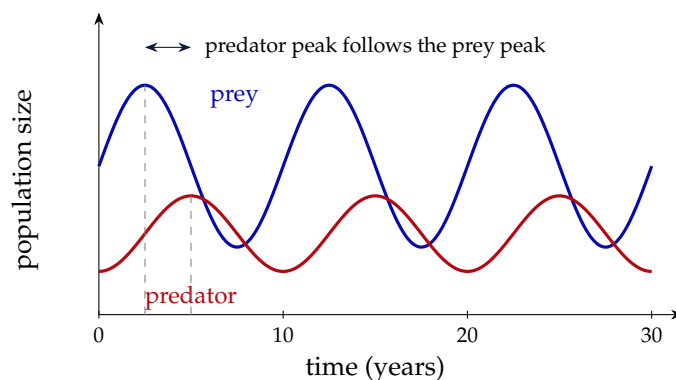
A **habitat** is the place where an organism lives (the wood). The place an organism occupies and the role it plays is sometimes called its niche, but you only need habitat.

Abiotic and biotic factors. What lives where depends on two kinds of factor. **Abiotic** factors are the non-living ones: light intensity, temperature, moisture, soil pH, wind speed, oxygen level in water, and the availability of minerals. **Biotic** factors are those caused by other living things: food supply, predation, disease, and competition. Both can change the size of a population. A hard winter (abiotic) can reduce an insect population; a new predator or disease (biotic) can do the same.

Competition. Organisms need resources, and when a resource is in short supply they *compete* for it. Plants compete for light, water, space and mineral ions from the soil. Animals compete for food, water, territory, shelter and mates. *Intraspecific* competition is between members of the *same* species (two foxes for one rabbit); *interspecific* competition is between *different* species (grey and red squirrels for acorns). Competition is usually strongest within a species, because its members need exactly the same resources. A better competitor leaves more offspring, which is why competition drives natural selection.

Interdependence. Species in a community depend on each other: for food, for shelter, for pollination and seed dispersal. Removing one species can affect many others, and a stable community is one in which the populations stay roughly constant over time because all the species, resources and abiotic factors are in balance.

Predators and prey. A predator hunts and eats prey. Their numbers are linked in a repeating pattern, shown below. When prey are plentiful, predators have plenty of food and breed, so predator numbers rise *a little later*. More predators eat more prey, so prey numbers fall. With less food, predators starve and fall in number. With fewer predators, the prey recover and the cycle begins again. The predator curve is a copy of the prey curve, shifted to the right: the predators follow the prey.



Notice that the prey peak comes *first*. A common mistake is to say that more predators “cause” the prey to rise. The *cause* of each rise is food: prey rise because predators are few, predators rise because prey are many.

Key ideas

- Individual < population (one species) < community (all species) < ecosystem (community + abiotic environment).
- Abiotic = non-living (light, temperature, water, pH). Biotic = living (food, predators, disease, competitors).
- Competition is for resources that are in short supply. In a predator–prey cycle, the predator peak follows the prey peak.

Common mistakes

- Confusing a population (one species) with a community (all the species).
- Calling the predator curve the one that peaks first. The prey curve leads and the predator curve lags.
- Describing disease or food supply as an abiotic factor. They are biotic, since they come from living organisms.
- Saying competition happens only between different species. Members of the same species compete most strongly.

2 Food chains, webs and energy (B10.1)

Almost all the energy in an ecosystem comes originally from the Sun. **Producers** (green plants and algae) capture light energy by photosynthesis and store it in organic molecules such as glucose, starch and cellulose. Everything else eats, directly or indirectly, what producers have made.

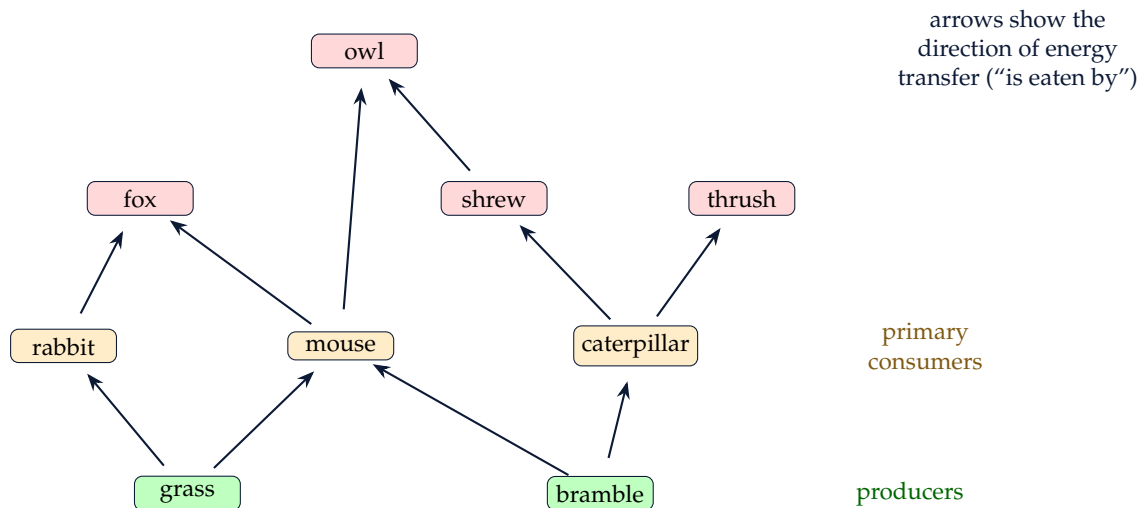
A **food chain** shows who eats whom, with each arrow meaning “is eaten by” and pointing in the direction in which energy and biomass are transferred:

grass → rabbit → fox.

The producer starts every chain. A **primary consumer** is a herbivore that eats producers. A **secondary consumer** eats primary consumers, and a **tertiary consumer** eats secondary consumers. An animal at the top, with no predators, is the

apex predator. **Decomposers** (bacteria and fungi) break down dead organisms and waste and return their minerals to the soil.

Most animals eat more than one thing, so real feeding relationships form a **food web**: many chains linked together. The web below has two producers and a number of consumers.



Read it by following arrows. Mouse eats grass and bramble; fox eats rabbit and mouse; owl eats mouse and shrew. A single organism can occupy different levels in different chains: the owl is a secondary consumer in grass → mouse → owl and a tertiary consumer in bramble → caterpillar → shrew → owl.

A web shows how the community is **interdependent**. If one population changes, others follow. For example, if a disease kills many rabbits, foxes have less food. They eat more mice, so the mouse population falls (a knock-on effect), and the grass the rabbits had been eating grows more. Such predictions use the words *more food*, *fewer predators*, *less competition*. Always say *why* a population changes.

Worked example: counting chains in a web

In the web above, how many different food chains end with the owl?

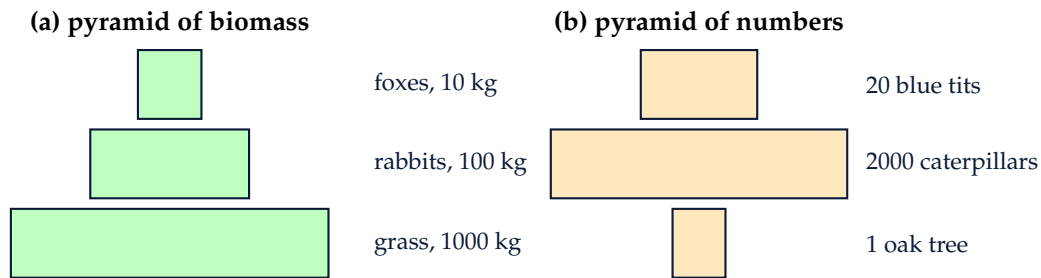
Chains must start at a producer and follow the arrows. Grass → mouse → owl. Bramble → mouse → owl. Bramble → caterpillar → shrew → owl. Grass → rabbit leads to fox, not owl. So there are 3 chains.

Common mistakes

- Drawing the arrow the wrong way. It points from the food to the eater (the direction energy flows), so grass → rabbit, not rabbit → grass.
- Starting a food chain with an animal. Every chain begins with a producer.
- Saying removing one species affects only the species that eat it. There are also knock-on effects on the species it eats and on competitors.

3 Pyramids and energy transfer (B10.1)

A **pyramid of numbers** shows the *number* of organisms at each level of a food chain, with the producers at the bottom. A **pyramid of biomass** shows the total *dry mass* of the organisms at each level. Biomass is usually the better measure, because a single oak tree and a single aphid both count as "one" in a pyramid of numbers.

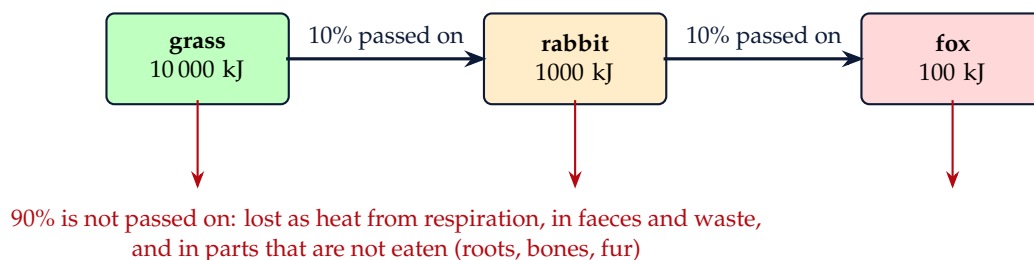


The pyramid of biomass is always a pyramid (large at the base and narrowing upwards), because mass is lost at every step. The pyramid of numbers can be a strange shape: one huge oak tree supports thousands of caterpillars, which support a few blue tits. The numbers go 1, 2000, 20, and the bar for the producers is the *narrowest*.

Why is so little passed on? Only about 10% of the energy (or biomass) at one level reaches the next. The rest is not available to the next level:

- Much is *released as heat* by respiration, which supplies the energy for movement, keeping warm, growth and so on.
- Some parts are *not eaten* (roots, bones, fur, shells, wood), or are eaten but not digested and are lost as *faeces*.
- Some energy is lost in *waste* such as urine.

Because so much is lost at each step, food chains rarely have more than four or five links. It also explains why eating plants directly supports far more people from the same land than feeding the plants to animals first.



Efficiency of transfer is

$$\text{efficiency} = \frac{\text{energy (or biomass) passed to the next level}}{\text{energy (or biomass) available at the previous level}} \times 100\%.$$

Worked example: energy down a chain

Grass in a field receives its energy from the Sun and stores 20 000 kJ in its biomass. 10% is passed to rabbits and 10% of that to foxes. How much energy do the foxes receive? What fraction of the grass's energy is that?

Rabbits: 10% of 20000 = 2000 kJ. Foxes: 10% of 2000 = 200 kJ. As a fraction of the grass's energy: $200/20000 = 1/100 = 1\%$. Each step multiplies by 0.1, so two steps multiply by 0.01.

Worked example: efficiency of transfer

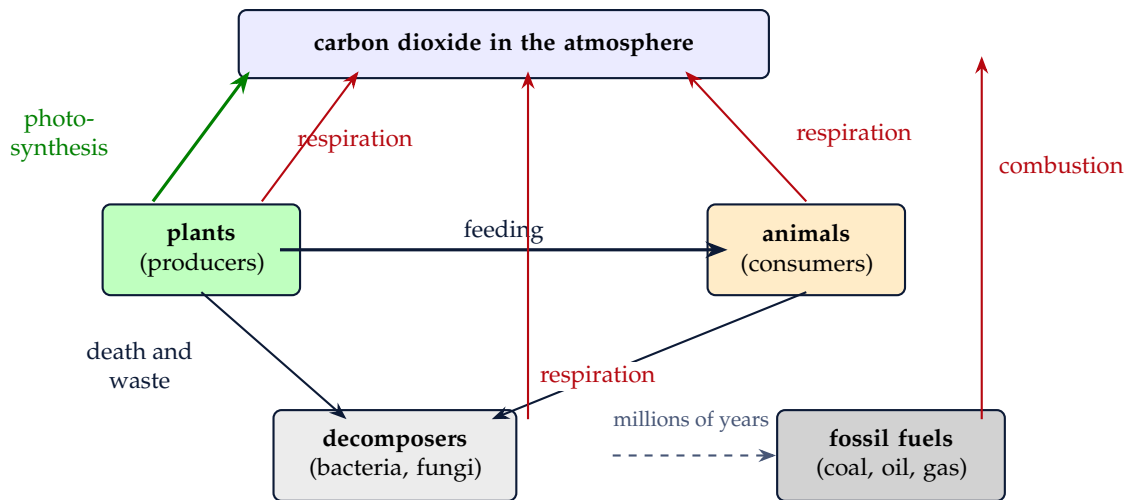
A cow eats grass containing 50 000 kJ of energy per day. Of this, 35 000 kJ is lost as undigested faeces and 10 000 kJ is released as heat in respiration. The rest is stored in growth. What percentage of the energy eaten becomes growth? Growth = $50000 - 35000 - 10000 = 5000$ kJ. Efficiency = $5000/50000 \times 100 = 10\%$.

Common mistakes

- Saying energy is "used up" or destroyed. It is transferred, and most ends up as heat in the surroundings.
- Forgetting that a pyramid of numbers can be inverted (oak tree) but a pyramid of biomass cannot.
- Giving "the animal doesn't eat all of it" as the only reason for the loss. Respiration is the largest single loss.
- Multiplying instead of dividing when finding the percentage: efficiency is output divided by input.

4 The carbon cycle (B10.2)

Living things are made of carbon compounds, but the Earth's carbon is limited, so it must be **recycled**. The **carbon cycle** describes how carbon moves between the atmosphere (as carbon dioxide), living things, soil and fossil fuels.



The processes are these.

- **Photosynthesis** removes CO_2 from the air. Plants and algae use it to make glucose, and from glucose all their other carbon compounds. This is the only way carbon enters food chains.
- **Feeding**: animals eat plants and other animals, and the carbon compounds pass along the food chain.
- **Respiration** by plants, animals and decomposers releases CO_2 back to the air.
- **Death and waste**: dead organisms, faeces and fallen leaves are broken down by **decomposers**, which respire and release CO_2 . Decay also returns minerals to the soil.
- **Fossilisation**: over millions of years, some dead material (without oxygen) becomes coal, oil and gas. **Combustion** of wood and fossil fuels releases the stored carbon as CO_2 in minutes.

In a stable ecosystem the carbon taken in by photosynthesis balances the carbon released by respiration and decay, and the level of CO_2 stays steady. Human activity upsets this: burning fossil fuels releases carbon that was locked away for millions of years, and *deforestation* removes trees that took in CO_2 . The result is a rising level of atmospheric CO_2 , which is a greenhouse gas contributing to global warming.

Worked example: a carbon balance

A woodland takes in 800 t of carbon each year by photosynthesis. Plants release 300 tonnes by respiration and animals and decomposers release 250 tonnes. What is the net change in the carbon stored in the wood each year (ignoring other processes)?

Carbon in: 800. Carbon out: $300 + 250 = 550$. Net change = $800 - 550 = +250$ tonnes, so the wood is a *store* (a "carbon sink") and is growing.

Common mistakes

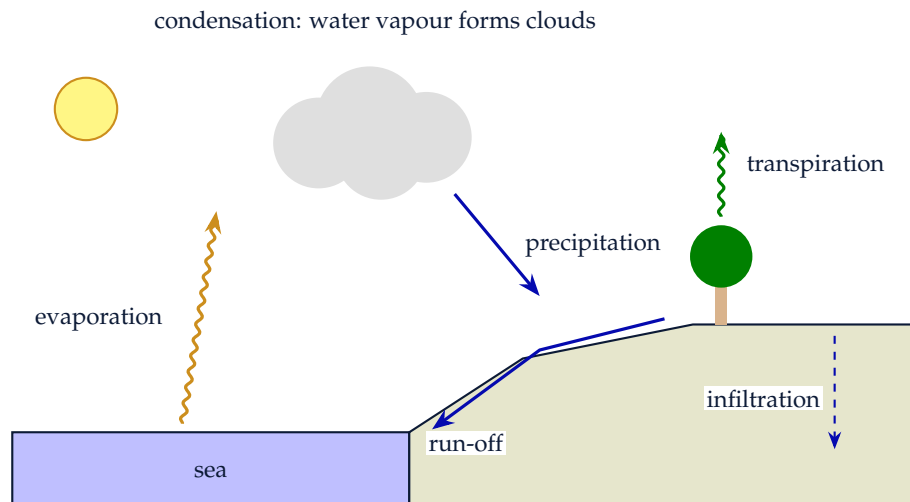
- Saying plants only photosynthesise and do not respire. Plants respire all the time, day and night.
- Saying decomposers (bacteria and fungi) are not part of the carbon cycle, or that animals are the main source of the recycled carbon. Decomposers are essential.
- Saying photosynthesis removes oxygen. It removes CO_2 and releases O_2 .
- Describing carbon as "used up". It is a recycled *element*.

5 The water cycle (B10.2)

Water is also constantly recycled, powered by the Sun's energy. The **water cycle** has the following stages.

- **Evaporation**: heat from the Sun turns liquid water in seas, lakes and soil into water vapour.

- **Transpiration:** plants take up water through their roots and lose water vapour through their leaves. A large forest returns a great deal of water to the air this way.
- **Condensation:** the rising vapour cools and turns back to liquid droplets, which form clouds.
- **Precipitation:** water falls as rain, snow or hail.
- **Run-off and infiltration:** on the ground, some water runs over the surface to streams and rivers (*run-off*) and some soaks into the soil (*infiltration*) where plants take it up or it joins groundwater. Rivers return water to the sea.



Fresh water is needed by living things and for human use (drinking, farming, industry). The cycle *purifies* the water by evaporation, because salts and most pollutants stay behind. Human actions alter it: **deforestation** reduces transpiration, so there is less water vapour and often less local rainfall, and more run-off, which carries soil away. Roads and car parks stop infiltration, which increases run-off and the risk of flooding.

Worked example: scaling a rainfall calculation

A river catchment has an area of 10 km^2 and receives 1000 mm of rain per year. 60% of this evaporates or is transpired and the rest reaches the river. How many cubic metres per year flow in the river? (Hint: 1 mm of rain over 1 m^2 is 1 litre = 0.001 m^3 .)

$10 \text{ km}^2 = 10 \times 10^6 = 10^7 \text{ m}^2$. Rain depth = 1000 mm = 1 m, so the rain volume is $10^7 \times 1 = 10^7 \text{ m}^3$. The river receives 40%: $0.4 \times 10^7 = 4 \times 10^6 \text{ m}^3$ per year.

Common mistakes

- Mixing up evaporation (liquid $\rightarrow$ gas from a surface) with transpiration (water vapour lost from plant leaves).
- Mixing up condensation (gas $\rightarrow$ liquid) with precipitation (water falling to the ground).
- Forgetting that the cycle needs energy from the Sun, and that the same water is recycled.

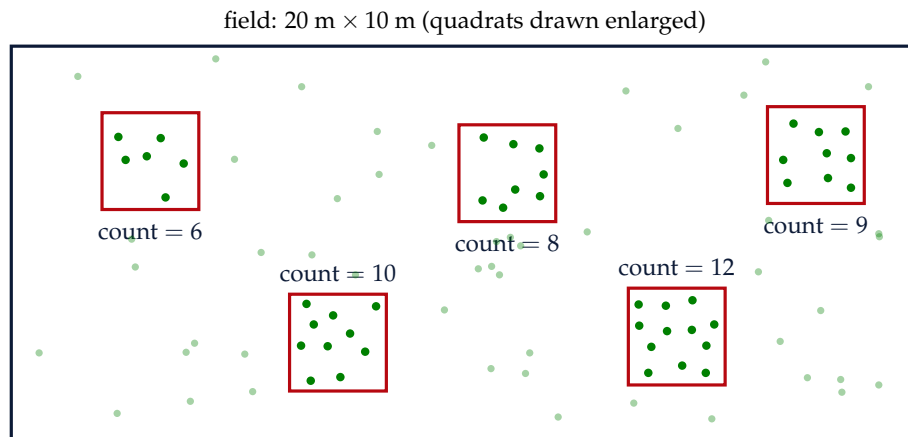
6 Biodiversity and sampling (B10.3)

Biodiversity is the variety of living things in an area: the number of different species, and the genetic variety within each. A high biodiversity ecosystem is generally more stable, as it can better cope with change, and it supplies things we depend on (food, medicines, pollination). Biodiversity is reduced by habitat destruction, pollution and invasive species.

To find out what lives where we cannot count every individual, so we **sample**. A **quadrat** is a square frame (often $1 \text{ m} \times 1 \text{ m}$ or $0.5 \text{ m} \times 0.5 \text{ m}$) placed on the ground, and the organisms inside are counted.

1. Use a measuring tape to mark out the area, and use *random* coordinates (from random numbers) to place each quadrat. This avoids bias: it stops us choosing the places where plants look most plentiful.
2. Count the organisms in each quadrat (or estimate the *percentage cover*, the share of the ground covered by a species).
3. Take many quadrats: the larger the sample, the more reliable the mean.
4. Calculate the mean number per quadrat, then scale up:

$$\text{estimated population} = \text{mean per quadrat} \times \frac{\text{total area}}{\text{area of one quadrat}}.$$



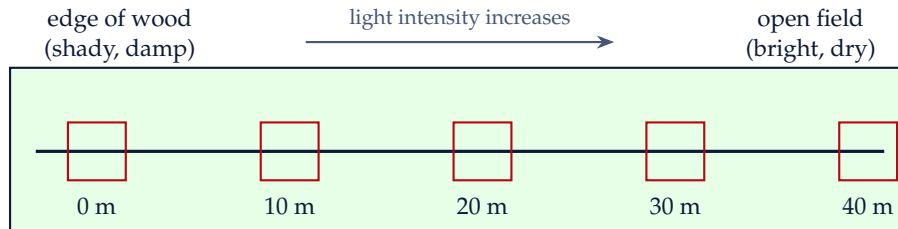
Careful: the estimate is only as good as the sampling. If the plants are not spread evenly, or too few quadrats are used, the answer may be far from the truth.

Worked example: estimating a population

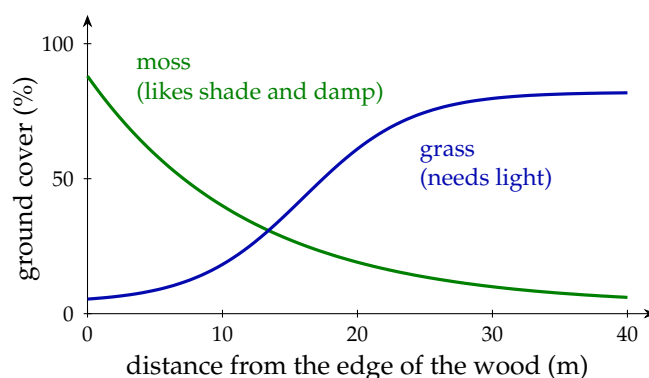
A field measures 20 m × 10 m. A student places five 1 m² quadrats at random and counts 6, 10, 8, 12 and 9 daisies. Estimate the number of daisies in the field.

Mean = $(6 + 10 + 8 + 12 + 9) \div 5 = 45 \div 5 = 9$ per m². Area of the field = $20 \times 10 = 200$ m². Estimate = $9 \times 200 = 1800$ daisies.

Transects. Random quadrats tell us how many organisms there are overall. A **transect** tells us how the distribution *changes* along an environmental gradient, such as from the shade of a wood out into an open field, or from the sea up a beach. A line (a tape or rope) is laid along the gradient and a quadrat is placed at regular intervals along it (for example every 10 m), recording the species at each.



a transect: a line across a habitat, with a quadrat placed at regular intervals along it



In the graph, moss is common in the shade and falls steadily; grass needs more light and rises. This *suggests* that light (and moisture) are important abiotic factors, but to be sure we would measure the factors as well, with a light meter, a soil moisture meter and a thermometer, at each position.

Worked example: scaling with a smaller quadrat

A $0.5\text{ m} \times 0.5\text{ m}$ quadrat is used to sample a lawn of area 100 m^2 . The mean count of clover plants is 3 per quadrat. Estimate the total number.
 Area of one quadrat = 0.25 m^2 . The lawn contains $100 \div 0.25 = 400$ quadrats' worth of area. Estimate = $3 \times 400 = 1200$ clover plants.

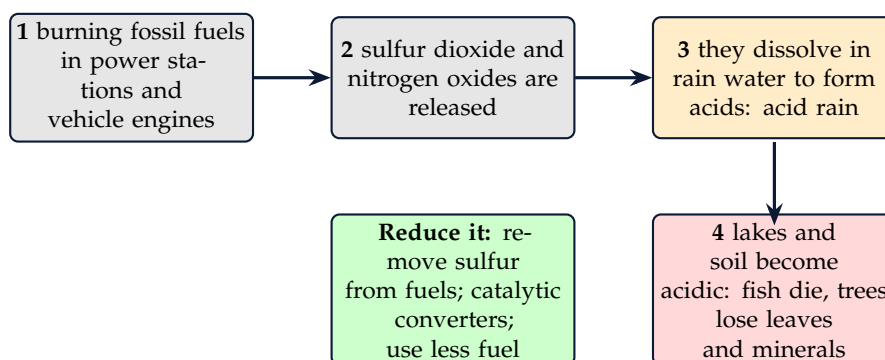
Common mistakes

- Using the area of the quadrat as 0.5 when it is $0.5 \times 0.5 = 0.25\text{ m}^2$.
- Placing quadrats where the plants look thickest (bias), instead of at random coordinates.
- Using a transect to estimate a total population. A transect shows change along a gradient; random quadrats estimate a total.
- Claiming a graph *proves* which factor is the cause, when other factors changed along the transect too.

7 Human impacts: fish farming, acid rain, eutrophication (B10.3)

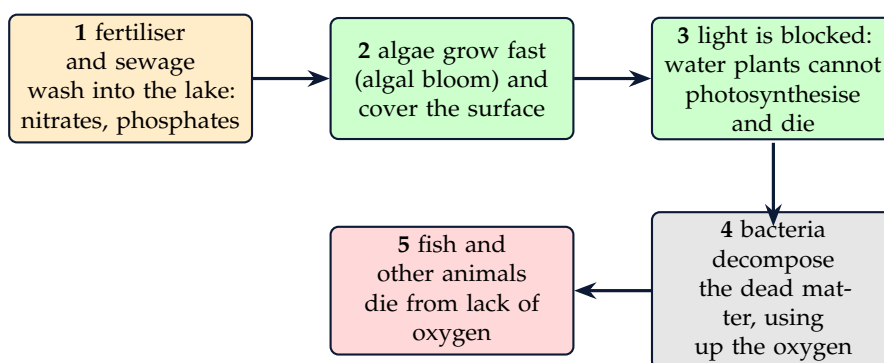
Fish farming. Wild fish stocks have been overfished, so many fish are now reared in cages or tanks. Farming can increase the *yield* and supply: the fish are fed a controlled diet, protected from predators and given medicines when ill, and they can be selected for fast growth. Because they are not allowed to swim far, less of their energy goes into movement, which makes the *transfer of energy to biomass more efficient*. But there are costs. Faeces and uneaten food pollute the water below and around the cages, leading to eutrophication. Fish living at high density spread disease and parasites (such as sea lice) to each other and to wild fish. Drugs and antibiotics used to treat them may enter the environment. Escaped farmed fish can breed with, or compete with, wild ones, and the fish are often fed on other, wild-caught fish.

Acid rain. Burning fossil fuels in power stations and vehicles releases the gases sulfur dioxide and nitrogen oxides. They dissolve in rain water to form acids, so the rain falls with a lower pH.



Acid rain makes lakes and soils acidic. Fish and other organisms die because most cannot survive at low pH; aluminium ions are released from the soil and are toxic; and trees lose leaves and minerals (such as magnesium) from the soil and die. The cure is to reduce emissions: remove sulfur from fuels before burning, use catalytic converters in vehicle exhausts, switch to renewable energy and use less fuel.

Eutrophication. *Eutrophication* means that a water body becomes over-supplied with mineral nutrients. Farmers add nitrate and phosphate fertilisers to fields. After rain, these are washed (by run-off) into rivers and lakes, and sewage adds more. The sequence is shown below.



Note that the oxygen shortage is *not* caused by the algae directly. The oxygen is used by the aerobic bacteria that decompose the huge mass of dead plants and algae. The fish die from lack of oxygen.

Worked example: explain a data trend

Nitrate levels in a lake rise sharply in April after heavy rain on nearby farmland. Two weeks later the mass of algae rises. Four weeks after that the oxygen concentration drops and fish are found dead. Explain the sequence. Fertiliser nitrates are washed into the lake by run-off (the nitrate rise). With more minerals the algae grow quickly (the algal bloom) and block the light, so submerged plants die. Dead algae and plants are decomposed by bacteria, which use oxygen in respiration, so dissolved oxygen falls and the fish die from lack of oxygen.

Exam tip

For a “how does X cause Y” question about eutrophication or acid rain, write it as a chain of linked steps, each causing the next, like the diagrams above. Marks are given for the links, not for the end result.

Common mistakes

- Saying the algae use up the oxygen. It is the *decomposing bacteria*. In daylight, algae release oxygen.
- Saying eutrophication is caused by pollution from factories. The main cause is fertiliser and sewage nitrates and phosphates.
- Confusing acid rain (sulfur dioxide, nitrogen oxides) with global warming (CO₂).
- Listing disadvantages of fish farming without linking them to a cause (for example disease spreads because the fish are crowded together).

Check yourself

Try these without looking back, then compare with the answers on the next page.

1. Distinguish between a population, a community and an ecosystem.
2. Give two abiotic and two biotic factors that could affect the numbers of a species of plant.
3. In a predator–prey graph, which population peaks first and why?
4. Explain why only about 10% of the energy passes to the next level of a food chain.
5. State two processes that remove carbon dioxide from the air and two that release it.
6. Name the processes labelled by: liquid water turning to vapour from the sea; vapour turning to cloud droplets; water falling as rain; plants losing water vapour.
7. A student counts 20 plants in a 1 m² quadrat on average, in a 50 m² area. Estimate the total and name one source of error.
8. Explain how fertiliser run-off can kill fish in a lake.

Answers to the self-check

1. A population is all the organisms of one species in an area. A community is all the populations of every species in the area. An ecosystem is the community together with its non-living (abiotic) environment.
2. Abiotic: light intensity, temperature, water, soil pH or minerals. Biotic: grazing animals (herbivores), disease, competition from other plants.
3. The prey peak first. The predators then have plenty of food and increase, so their peak follows the prey peak.
4. Much is lost as heat in respiration, some parts are not eaten or digested (faeces, bones, roots), and some is lost in waste such as urine.
5. Removed: photosynthesis (also dissolving in the oceans). Released: respiration, combustion (also decay by decomposers).
6. Evaporation, condensation, precipitation, transpiration.
7. $20 \times 50 = 1000$ plants. The sample might be too small, or not random, so it is biased.
8. Nitrates cause an algal bloom, which blocks light so plants die. Bacteria decompose the dead material and use up the oxygen. The fish die from lack of oxygen.

Next step

Heurisco's *ESAT Biology: Ecosystems Practice Set* has twenty original exam-style questions on this lesson, with food webs, population graphs and data, in order of difficulty, with a full worked solution, a common-trap note and the specification code for every question.