●●●●○ Level 4 · Science S4.3

Evolution and ecology

How living things change over many generations, and how they depend on each other and their surroundings.

Follow natural selection from variation to a changed population, and see the evidence for it in fossils and DNA. Learn how new species form and how others die out, and how scientists group living things. Then turn to ecology: the carbon and nitrogen cycles, ways to count populations, predators and prey, and what people do to biodiversity and what they can do to protect it.

YOU ARE READY FOR THIS BOOK IF

You can draw a food web with at least six living things.

One step up	S5.1 Molecules and cells
This book	**S4.3 Evolution and ecology**
One step down	S3.2 Ecosystems

Contents

S4.3.1 Natural selection

S4.3.2 Evidence for evolution

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S4.3.4 Classification

S4.3.5 The carbon and nitrogen cycles

S4.3.6 Measuring populations

S4.3.7 Interdependence

S4.3.8 Biodiversity and people

Key words, A to Z

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S4.3.1 CHAPTER 1

Natural selection

Why do so many animals look just right for the place where they live?

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** Each animal changes its body to suit its home, and its young are born with the change.
- ☐ **B** Animals that suit their home better survive and have more young, so their features become common over many generations.
- ☐ **C** Animals choose the features they want, and their young are born with them.

IF THIS FEELS HARD, READ THIS FIRST

- Level 4, Genes and inheritance, S4.2.7. It shows why the living things of one kind differ from each other.
- Level 4, Genes and inheritance, S4.2.8. It shows how a mutation makes a new allele.
- Level 3, Ecosystems, S3.2.6. It teaches what living things compete for and how they suit their homes.

BY THE END YOU CAN

- Explain natural selection in steps: variation, competition, survival and inheritance
- Use natural selection to explain antibiotic resistance in bacteria

Animals and plants often seem made for the place where they live. A sand coloured beetle is hard to see on sand. A cactus keeps water in a dry land. **Natural selection** is the process that explains this.

It begins with a **population**. This is all the living things of one kind that live in one place, such as the moths of one wood. The first step is that the moths vary. Some are dark and some are light.

You know where variation comes from. A mutation makes a new allele by chance. Sexual reproduction shuffles alleles into new sets, so no two young are exactly alike.

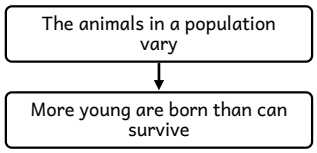
The second step is **competition**. Most kinds of living thing make far more young than can live. There is not enough food, space or safe shelter for all of them. So the young compete, and many die.

The third step is survival. Some of the young have features that suit the surroundings a little better. They are more likely to live long enough to have young. Dark moths on dark bark are hard for birds to see. Light moths on dark bark stand out.

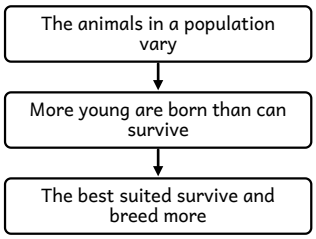
The fourth step is inheritance. The survivors pass on the alleles for their features. Their young are more likely to have those features too. Repeat this for many generations and the features become more common. This change in a population over many generations is **evolution**.

DRAW IT FIRST

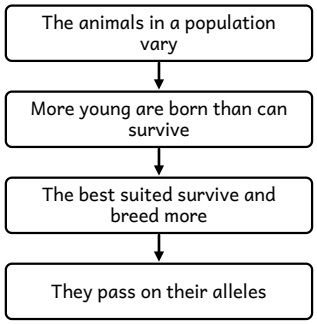
Natural selection in steps



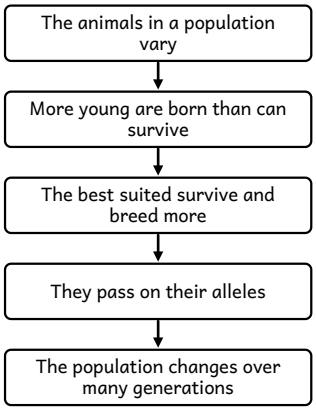
1 Living things of one kind vary, and they make more young than can live.



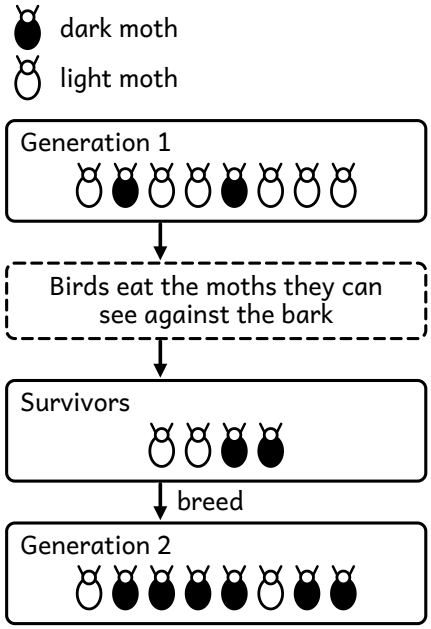
2 The young with the best suited features are more likely to survive and breed.



3 They pass on their alleles to the next generation.



4 Over many generations the population is no longer the same.



The numbers are made up to show the steps. Each moth is drawn as a simple shape. The bark is dark. The dark moths are hard to see, so more of them live and breed.

Look at what changed. No moth turned from light to dark. The change is in the population. The share of dark moths grew, because dark moths lived and bred more often than light ones.

WORKED EXAMPLE

In generation 1 there are 2 dark moths and 6 light moths. What percentage of the moths are dark?

1. There are 2 + 6 = 8 moths in all.
2. The dark moths are 2 out of 8, which is 2 ÷ 8 = 0.25.
3. As a percentage, 0.25 × 100 = 25%.

Answer: 25%

SEE IT THREE WAYS

As a picture

Generation	Dark	Light
1	2	6
2	6	2

In words

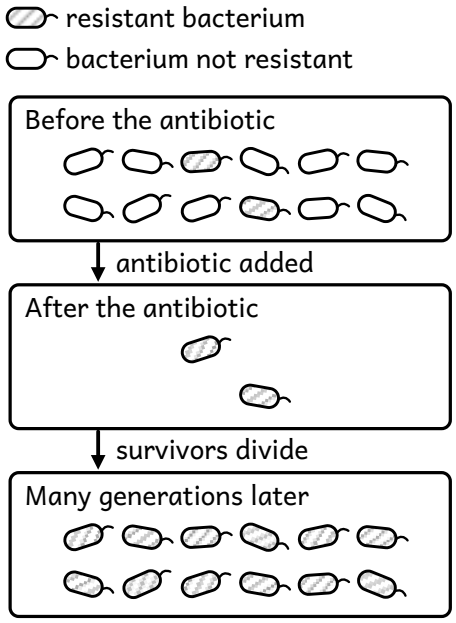
Dark moths are hard for birds to see on dark bark. They survive and breed more often, so there are more of them in generation 2.

In symbols

Dark moths: 2 out of 8 is 25%, then 6 out of 8 is 75%.

Now think about bacteria. An ***antibiotic*** is a medicine that kills bacteria. It does not work on viruses. In a large group of bacteria, a few may carry an allele that makes them **resistant**. The antibiotic does not kill a resistant bacterium.

That allele came from a mutation, by chance, before any antibiotic was used. Resistant bacteria are rare at first. The antibiotic is the pressure. It kills the bacteria that are not resistant. The resistant ones live and divide. Bacteria can also pass a resistance allele to other bacteria.



The antibiotic does not make bacteria resistant. It kills the others and leaves the resistant ones to divide.

Bacteria divide fast. Under good conditions, some kinds of bacterium can divide in about 20 to 30 minutes. So a few resistant survivors soon become a large group, and the antibiotic no longer works on them. They can also spread to other people.

WORKED EXAMPLE

One bacterium divides into two every 30 minutes. Food does not run out. How many bacteria are there after 3 hours?

1. 3 hours is 6 lots of 30 minutes, so the bacteria divide 6 times.
2. Each division doubles the number: 1, 2, 4, 8, 16, 32, 64.
3. After 6 doublings there are 2 × 2 × 2 × 2 × 2 × 2 = 64 bacteria.

Answer: 64 bacteria

In real life food runs out, so the growth stops. But at first it is this fast. This is why a person should take an antibiotic only when a health worker prescribes it. They should take the full course as the health worker says. Antibiotics do nothing for a cold or flu, which are caused by viruses.

TRY IT

Be the bird

You need: 10 light dry beans and 10 dark dry beans, a dark cloth, or a dark page of an old newspaper, a sheet of white paper, a friend and a clock with a second hand.

Be safe: Use the beans only as counters and do not eat them. Keep small beans away from babies and small children.

1. Spread the 20 beans over the dark cloth. Your friend is the bird and looks away.
2. Your friend turns round, then picks up 10 beans in 10 seconds, taking the ones they see first.
3. Count the light beans and the dark beans left on the cloth. Write the numbers down.
4. Do it again on the white paper with the same 20 beans. Compare the numbers.

What you will see: On the dark cloth, more dark beans are left. On the white paper, more light beans are left. The surroundings decide which kind is picked less often. That is selection.

If you cannot try it, this is what happens.

Surface	Light	Dark
cloth	3	7
paper	7	3

A WRONG IDEA MANY PEOPLE HAVE

~~An animal grows a feature because it needs it, and then passes the feature to its young.~~

Why it feels right: It seems natural to say that an animal "needed" to hide, so it became dark.

The test that breaks it: A person who lifts heavy loads gets strong arms. Their children are not born with strong arms. The change was made in the body, and it did not change the alleles in the sex cells.

What is true: Alleles come first, by chance. The environment does not make them. It selects among them, because some animals survive better and pass on their alleles more often.

KEY WORDS

natural selection
the process in which the living things best suited to their surroundings survive and breed more, and pass on their alleles.

population
all the living things of one kind in one place.

competition
living things trying to get the same food, space or shelter when there is not enough for all.

evolution
the change in the inherited features of a population over many generations.

antibiotic
a medicine that kills bacteria. It does not work on viruses.

resistant
not killed by something, such as an antibiotic.

BACK TO YOUR GUESS

The answer is B: Animals that suit their home better survive and have more young, so their features become common over many generations.

Animals do not choose, and a change made in one lifetime is not passed on. In each generation the ones better suited to their home are more likely to live and have young. Over many generations their features spread.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. Which of these must be true for natural selection to happen in a population?

   A The living things all have the same alleles.

   B All the young survive to have young of their own.

   C The living things vary in features that are inherited, and more young are born than can live.

   Answer at the back of the book.

2. On green leaves, some beetles are green and some are brown. Birds eat more brown beetles. After many generations most beetles are green. Which is the best explanation?

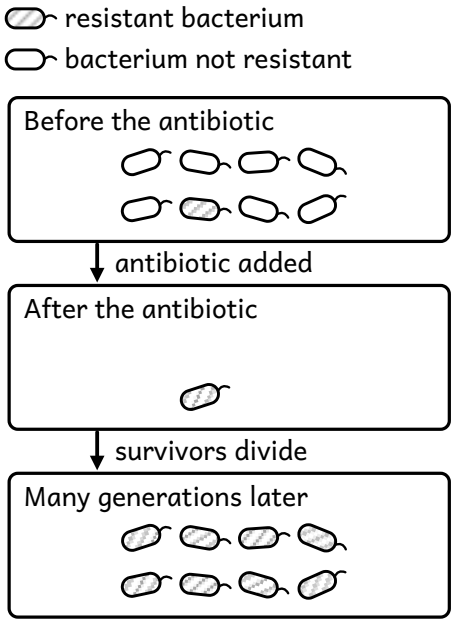
   A The brown beetles turned green because they needed to hide.

   B The birds changed the alleles of the beetles.

   C Green beetles were eaten less, so they bred more and passed on their alleles.

   Answer at the back of the book.

3. Look at the picture. Why are the hatched bacteria the only ones left after the antibiotic?



A The antibiotic turned them into resistant bacteria.

B They carried an allele for resistance, so the antibiotic did not kill them.

C The person taking the antibiotic became resistant to it.

Answer at the back of the book.

4. A health worker gives Tariq an antibiotic for a bacterial infection. After two days he feels better and stops taking it. Why is this a risk?

A Feeling better does not mean all the bacteria are dead, so some may be left to divide again.

B His body will now be resistant to the antibiotic.

C There is no risk, because the medicine is no longer needed once he feels well.

Answer at the back of the book.

5. Aisha lifts water jars every day, and her arms become strong. Will her children be born with strong arms because of this?

   A Yes, a feature gained in life is always passed on.

   B No. The change is in her body, and her alleles are not changed by it.

   C Yes, but only to her daughters.

   Answer at the back of the book.

6. Which sentence describes how a population of bacteria becomes resistant to an antibiotic?

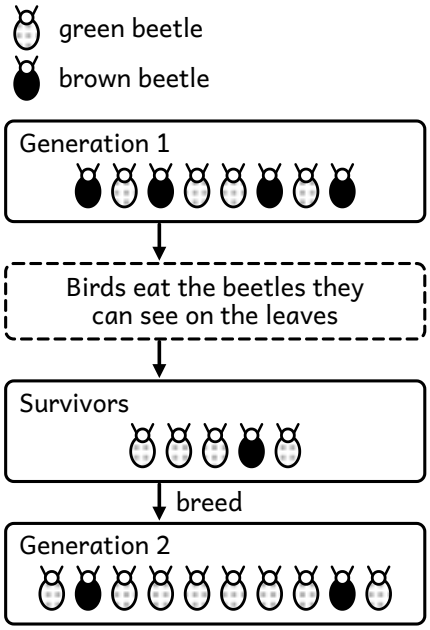
   A Each bacterium slowly learns to survive the antibiotic.

   B The antibiotic kills most of them. The few resistant ones divide, and so most of the next generation is resistant.

   C The bacteria that are killed pass on resistance to the others.

   Answer at the back of the book.

7. Look at the picture of beetles. What percentage of the beetles in generation 2 are green?



   Answer at the back of the book.

8. One bacterium divides into two every 30 minutes. Food does not run out. How many bacteria are there after 2 hours?

   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

A population varies. More young are born than live. The best suited survive, breed and pass on alleles. Over generations the population changes. Resistant bacteria survive an antibiotic and divide.

Draw: Five boxes in a line, joined by arrows: vary, compete, survive, pass on, change.

S4.3.2 CHAPTER 2

Evidence for evolution

> **How do we know that living things have changed over millions of years, when nobody was there to see it?**

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** We only know by watching living things for a few years, because the past leaves nothing behind.
- ☐ **B** Living things change so fast that new kinds can be seen forming in a single day.
- ☐ **C** The past leaves records. Fossils in rock show life of long ago, and DNA shows how closely living things are related.

IF THIS FEELS HARD, READ THIS FIRST

- Level 3, Rocks, soil and fossils, S3.11.7. It explains how a fossil forms in sedimentary rock.
- Level 3, Rocks, soil and fossils, S3.11.8. It explains why lower layers of rock are usually older.
- Level 4, Genes and inheritance, S4.2.8. It shows how DNA changes over time.

BY THE END YOU CAN

- Explain how fossils and DNA show that species are related
- Explain why the fossil record has gaps

Nobody saw the first birds or the first fish. But the past leaves records. Two of the most important are fossils and DNA. This chapter shows how they are used.

A **fossil** is the remains or the trace of a living thing from long ago, found in rock, ice or amber. There are three common kinds. The first kind is the hard parts of a body, such as shells, bones and teeth. Over a long time, minerals slowly turn them to stone.

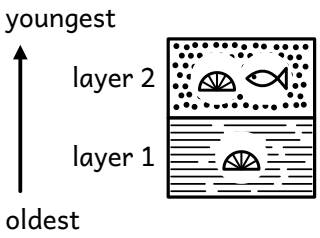
The second kind is a trace, such as a footprint, a burrow or a root hole. The third kind is the living thing itself, kept from rotting, such as an insect in amber or a plant in peat. Amber is hard tree resin.

Most dead bodies rot or are eaten. Most fossils form when a body is buried quickly in mud or sand. A fossil can also form when something stops the rotting, such as ice, amber or peat. This is rare. So fossils are only a small part of what once lived.

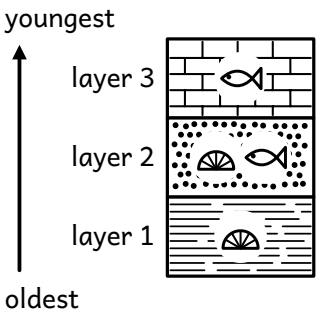
Many fossils lie in sedimentary rock. This rock forms in layers. Mud and sand settle one layer on another, then slowly harden. So in layers that have not been moved, the lowest layer is the oldest. The youngest is at the top.

DRAW IT FIRST

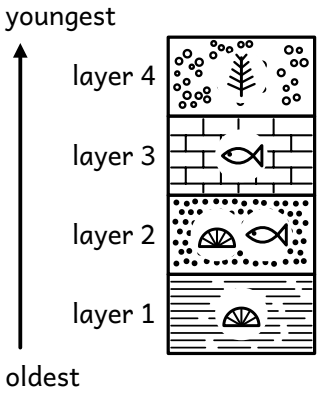
Layers build up from the bottom



1 Layer 1 is laid down first, with a shell in it. Layer 2 settles on top.



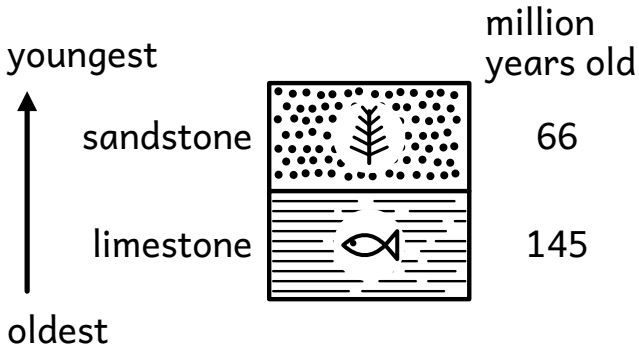
2 Layer 3 settles on top of layer 2.



3 Layer 4 settles on top. The first layer, layer 1, is the oldest and lies at the bottom.

Now line up the fossils from the oldest layer to the youngest. We see that the kinds of living thing change. Old layers hold kinds that are no longer alive. Younger layers hold kinds that look more like living species. This shows that species have changed over time.

Some fossils have features of two groups. One example is Archaeopteryx, found in rock about 150 million years old. It had feathers and wings like a bird. It also had teeth, claws on its wings and a long bony tail, like a small dinosaur.



Example ages. The older layer is at the bottom. Its age is the larger number.

WORKED EXAMPLE

A fish fossil is in rock that is 145 million years old. A fern fossil is in rock that is 66 million years old. How many million years older is the fish fossil?

1. The ages are 145 million years and 66 million years.
2. The fish is older. To find how much older, take away the smaller age.
3. 145 − 66 = 79 million years.

Answer: 79 million years older

The second record is DNA. Species that share a recent **common ancestor** have had little time to collect different mutations. So their DNA is very alike. Species that shared an ancestor long ago have had longer to change. Their DNA differs more.

Species	DNA
species 1	ATGGCCTAAGCT
species 2	ATGGCCTAAGCA
species 3	ATGACCTTAGCA
species 4	CTGACGTTAGGA

A short stretch of 12 bases from four species. These are example data. Real stretches are far longer.

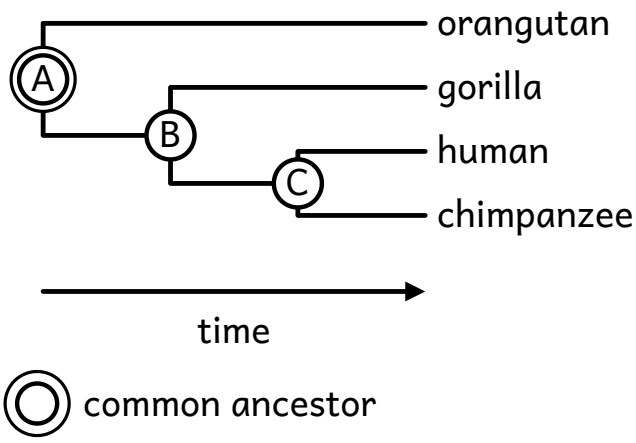
WORKED EXAMPLE

Species 1 and species 3 are compared over 12 bases. How many bases differ, and what percentage is that?

1. Compare the two stretches one base at a time.
2. The 4th, 8th and 12th bases differ. That is 3 places.
3. 3 out of 12 differ. 3 ÷ 12 = 0.25, which is 25%.

Answer: 3 bases differ, which is 25%.

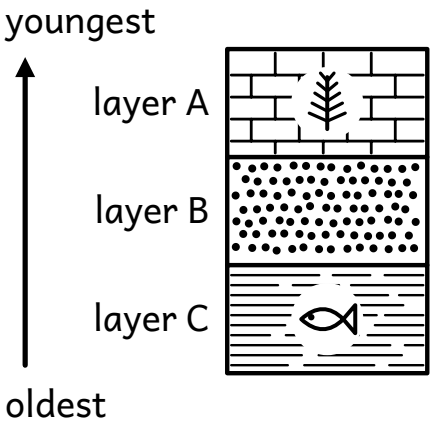
Species 1 and species 2 differ at only one place. Species 1 and species 4 differ at six. So species 1 and species 2 shared an ancestor more recently. DNA can be used to draw a family tree.



The family tree of four apes, drawn from many DNA studies. Branch points show common ancestors, and time runs to the right.

In the tree, the human and the chimpanzee share branch point C. Their latest common ancestor is more recent than any ancestor they share with the gorilla. Fossils and DNA tell the same story. Two kinds of evidence that agree are strong.

Yet the fossil record has gaps. First, soft bodies such as worms and jellyfish usually rot before they can become fossils. Second, fossils form only in rare conditions, and most dead things leave none. Third, rocks wear away, are folded, or are carried deep underground. Fourth, many fossils have not been found yet.



No fossils in layer B does not mean that nothing lived then. It means that none was kept, or none has been found.

TRY IT

Make layers like rock

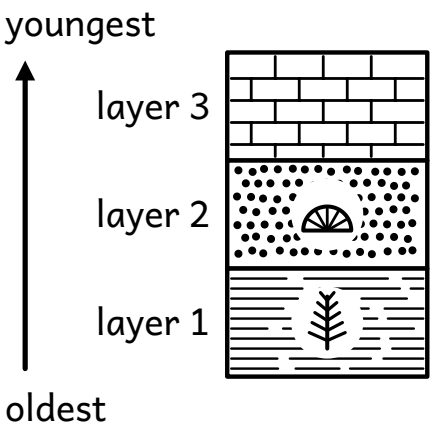
You need: a tall clear plastic cup, sand and soil, a leaf, an empty snail shell, a spoon, a little water.

Be safe: Use a plastic cup, not glass. Use only an empty snail shell, and never take a shell with a live snail in it. Wash your hands after you touch soil.

1. Put 2 cm of sand in the cup. Lay a leaf on it. This is layer 1.
2. Spoon on 2 cm of soil. Press the shell into it. This is layer 2.
3. Add 2 cm of sand as layer 3, with nothing in it. Add a little water and let it settle.
4. Look at the cup from the side. Which layer did you make first, and where is it?

What you will see: The layer you made first is at the bottom. The last layer is at the top. The layers in the cup stand for layers of rock. Rock layers form in the same way, which is why the bottom ones are the oldest.

If you cannot try it, this is what happens.



A WRONG IDEA MANY PEOPLE HAVE

~~Gaps in the fossil record show that evolution is only a guess.~~

Why it feels right: A full record would be more convincing, and the fossil record has many holes.

The test that breaks it: A diary with pages torn out still shows the order of events. The fossils we have fit in order of age. The DNA of living species gives the same family tree as the fossils.

What is true: Gaps are expected, because fossils form so rarely. Many separate records agree, and that is why scientists trust the evidence.

KEY WORDS

fossil
the remains or trace of a living thing from long ago, found in rock, ice or amber.

fossil record
all the fossils we know, and what they tell us about life long ago.

common ancestor
a living thing from which two or more kinds of living thing came.

sedimentary rock
rock made of layers of mud, sand and other pieces that settled and hardened.

BACK TO YOUR GUESS

The answer is C: The past leaves records. Fossils in rock show life of long ago, and DNA shows how closely living things are related.

Fossils and DNA are records. Fossils show what lived long ago, and DNA shows how close the relationships are. The two kinds of evidence agree with each other.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. Which of these is a fossil?

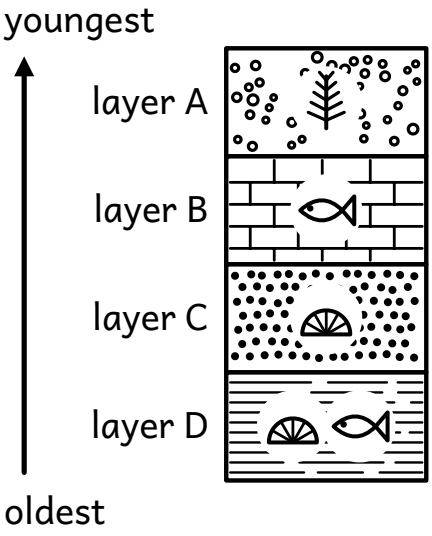
   A A footprint made in mud long ago and turned to stone

   B A shell picked up on a beach after last night's tide

   C A bone from an animal that died last year and lies in the soil

   Answer at the back of the book.

2. Look at the layers. They have not been moved. Which layer holds the oldest fossils?



   A Layer A

   B Layer D

   C They are all the same age.

   Answer at the back of the book.

3. Look at the DNA of three species. Which species is most closely related to species X?

Species	DNA
species X	CCATGGTACTGA
species Y	CCATGGTACAGA
species Z	CGATCGTACAGT

A Species Z

B Species Y

C They are equally related, because all DNA is made of the same four bases.

Answer at the back of the book.

4. Which sentence best explains why the fossil record has gaps?

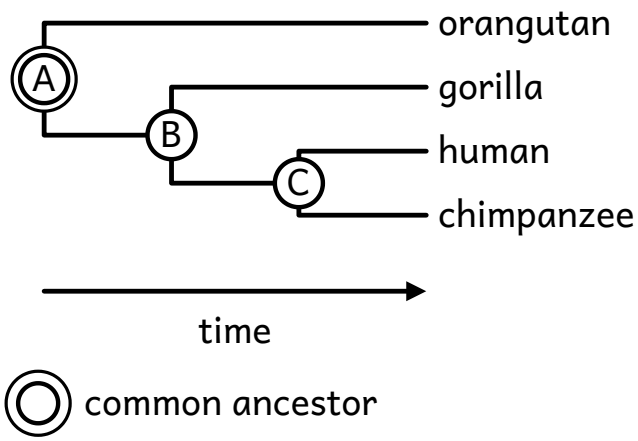
A No living things existed during the times that have no fossils.

B Most dead living things become fossils, but scientists have lost the records.

C Few dead things become fossils, and many fossils are destroyed or not yet found.

Answer at the back of the book.

5. Look at the family tree. Which two living things share the most recent common ancestor?



A The orangutan and the gorilla

B The human and the gorilla

C The human and the chimpanzee

Answer at the back of the book.

6. **From an earlier chapter**

In a wood there are dark moths and light moths on dark bark. Birds eat the light moths more often. What do you expect after many generations?

A The light moths will turn dark.

B A larger share of the moths will be dark.

C The moths will all be light, because they have been there longest.

Answer at the back of the book.

7. A shell fossil is in rock 120 million years old. A fern fossil is in rock 45 million years old. How many million years older is the shell fossil?

Answer at the back of the book.

8. The DNA of two species is compared over 200 bases. They differ at 4 bases. What percentage of the bases are the same?

Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Fossils lie in layers, the oldest at the bottom. More alike DNA means a more recent common ancestor. The record has gaps, because few things become fossils.

Draw: Three layers of rock with a fossil in each, an arrow for time pointing up, and the words oldest and youngest.

S4.3.3 CHAPTER 3

New species and extinction

How can one kind of animal become two kinds, and why do some kinds disappear for ever?

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** A barrier splits a group. The two sides have different conditions, and after many generations the two groups can no longer breed together.
- ☐ **B** Two groups of one kind become two species as soon as they live apart for a year.
- ☐ **C** Animals choose to become a new kind when they move to a new place.

IF THIS FEELS HARD, READ THIS FIRST

- Level 4, Genes and inheritance, S4.2.7. It shows why the living things of one kind differ.
- Level 2, Food chains and habitats, S2.2.8. It shows how cutting forests or dirty water harms living things.
- Level 3, Ecosystems, S3.2.8. It shows how farming, cutting trees and pollution change ecosystems.

BY THE END YOU CAN

- Explain how isolation can lead to a new species
- Give causes of extinction, past and present

A **species** is a group of living things that can breed together to give fertile young. Fertile young can have young of their own. A horse and a donkey can breed, but

their young, a mule, is almost always sterile. So a horse and a donkey are two species.

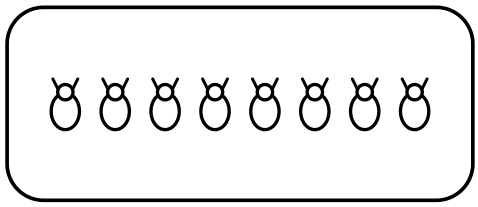
This idea fits animals and plants that breed by sexual reproduction. Scientists use other tests for bacteria, which do not breed in this way.

How can one species become two? It begins with **isolation**. This means that two groups of one species are kept apart, so they cannot breed together. A barrier can do it, such as the sea round an island, a range of mountains, a desert or a new river. We call it geographic isolation.

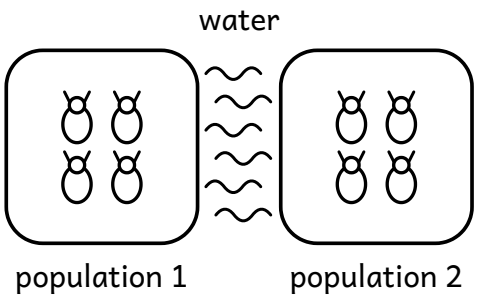
Each side of the barrier has its own conditions. The food, the weather or the enemies may differ. So natural selection favours different features on each side. Each side also gets its own mutations, by chance.

DRAW IT FIRST

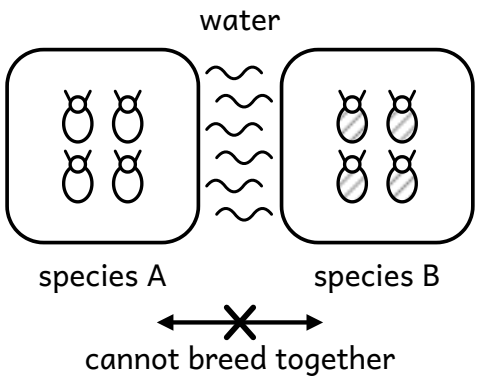
One species becomes two



1 One population lives on one piece of land and breeds together.



2 Water cuts the land in two. The two groups can no longer meet. They are still alike.



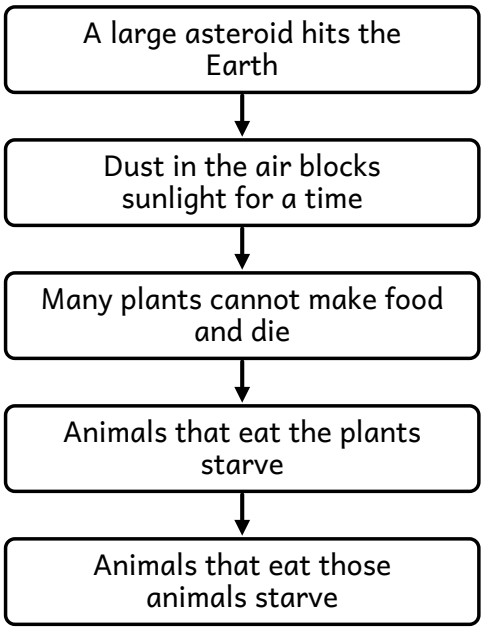
3 After many generations the two groups have changed in different ways. If they met, they could not breed to give fertile young. They are now two species.

This takes a long time, usually many thousands of generations. The hatched animals in the last picture show that one group has changed. The changes may be in colour, in shape or in the sex cells. When the groups can no longer breed together to give fertile young, they are two species.

Notice what does not happen. The animals do not choose to change. Each group is only selected by its own conditions, over many generations.

Now think about the opposite: **extinction**. A species is extinct when the last living member has died. Extinction is normal. Most species that ever lived are now extinct. But sometimes many species die out in a short time. This is a **mass extinction**.

About 66 million years ago a large asteroid hit the Earth. Dust and soot filled the air and blocked sunlight. Plants could not make food. Plant eaters starved, and then the animals that ate them starved. Many species died out, including the dinosaurs that were not birds. Birds are descended from dinosaurs, and they survived.



One account of the extinction about 66 million years ago. A food chain broke from the bottom.

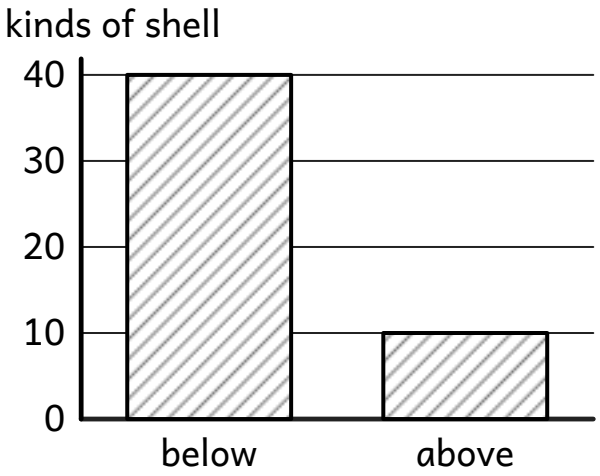
Other past causes include huge volcanic eruptions, which put ash and gases into the air and changed the climate. Climate change from natural causes, such as an ice age, also made some species die out.

Today there are new causes, and many come from people. The first is habitat loss: a forest is cleared or a wetland is drained. The second is hunting that takes more animals than can be replaced. The third is an **invasive species**, a living thing that people carry to a new place, where it harms the local species. Rats and cats carried on ships eat the eggs and young of birds that nest on the ground on islands.

The fourth cause is pollution, such as oil or chemicals in the sea. The fifth is climate change caused by people, for example warmer seas that kill corals. Often several causes act together on the same species.

Causes today
habitat loss
hunting
invasive species
pollution
climate change

Causes of extinction today. Several of them often act together on the same species.



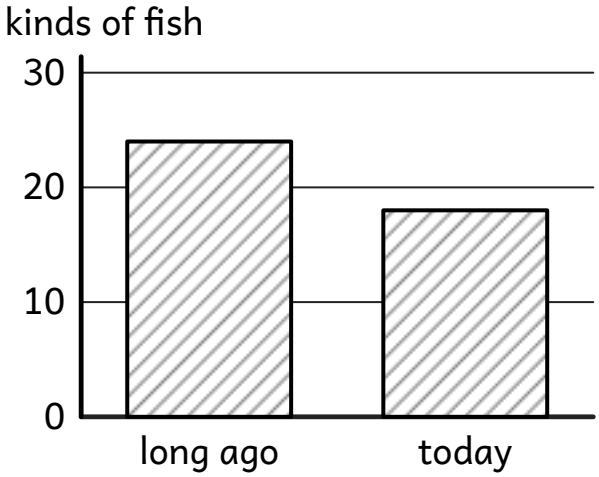
Example numbers: the kinds of shell found in the rock below a layer, and the same kinds found above it.

WORKED EXAMPLE

A scientist finds 40 kinds of fossil shell in the rock below a layer. Only 10 of those kinds are in the rock above it. What percentage of the kinds are missing above the layer?

1. The number of kinds that are missing is 40 − 10 = 30.
2. 30 out of 40 is 30 ÷ 40 = 0.75.
3. As a percentage, 0.75 × 100 = 75%.

Answer: 75%



Example numbers for one river.

WORKED EXAMPLE

A river held 24 kinds of fish long ago. Today it holds 18 kinds. What percentage of the kinds have been lost?

1. The number of kinds lost is 24 − 18 = 6.
2. 6 out of 24 is 6 ÷ 24 = 0.25.
3. As a percentage, 0.25 × 100 = 25%.

Answer: 25%

TRY IT

Find a barrier near you

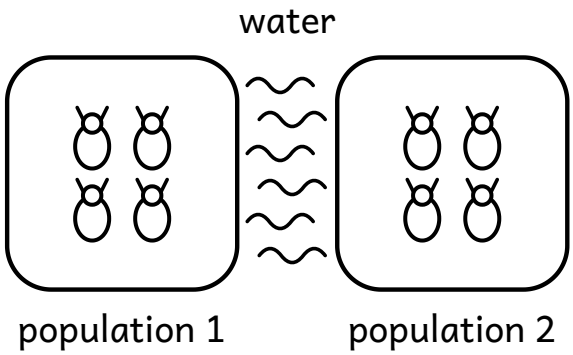
You need: a pencil and paper, a safe place with a clear barrier, such as a hill, a fence or a stream, with an adult.

Be safe: Take an adult with you. Stay away from roads and deep water. Do not touch wild animals or plants you do not know.

1. Draw a plan of the place, with the barrier as a thick line.
2. On each side, write the names of three living things you can see, such as plants, insects or snails.
3. For each one, write whether it could cross the barrier. A bird could. A snail could only rarely cross a wide stream or a busy road.
4. Write which living things the barrier keeps apart.

What you will see: A barrier only isolates the things that cannot cross it. A road or a wide stream keeps most snails apart, but not birds. Different living things are isolated by different barriers.

If you cannot try it, this is what happens.



A WRONG IDEA MANY PEOPLE HAVE

~~Two groups that look different must be two species.~~

Why it feels right: We often sort living things by how they look.

The test that breaks it: A small dog and a large dog look very different. Yet the young of different breeds of dog are fertile, so all dogs are one species.

What is true: Looks are not the test. Two groups are separate species when they can no longer breed together to give fertile young.

KEY WORDS

species
a group of living things that can breed together to give fertile young.

isolation
keeping two groups of one species apart, so that they cannot breed together.

extinction
the death of every living member of a species.

mass extinction
many species dying out in a short time.

invasive species
a living thing carried to a new place, where it harms the local living things.

BACK TO YOUR GUESS

The answer is A: A barrier splits a group. The two sides have different conditions, and after many generations the two groups can no longer breed together.

A barrier is only the start. Each side is selected by its own conditions, and the groups change over many generations. When they can no longer breed to give fertile young, they are two species.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. Which is the best definition of a species?

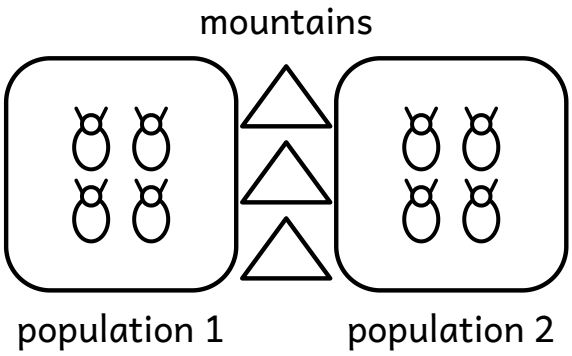
   A A group of living things that can breed together to give fertile young

   B A group of living things that all look the same

   C Any two living things that can mate

   Answer at the back of the book.

2. Look at the picture. Two groups of beetles live on the two sides of a range of mountains. Why might they become two species?



   A The mountains make the beetles on one side change colour.

   B The beetles on each side learn new habits and pass them on to their young.

   C The two sides have different conditions, so selection acts differently on each. They change in different ways over many generations.

   Answer at the back of the book.

3. Two groups of beetles live on opposite sides of a wide river and cannot cross it. What must happen before they count as two species?

   A After many generations they must have changed so that they can no longer breed together to give fertile young.

   B Nothing more. Being kept apart already makes them two species.

   C They must look different from each other.

   Answer at the back of the book.

4. About 66 million years ago a large asteroid hit the Earth. Which account is best?

   A The hit killed every living thing at once.

   B Dust blocked the sunlight for a time. Plants died, and the animals that depended on them died too.

   C Only the dinosaurs died out, and every other kind lived on.

   Answer at the back of the book.

5. A forest is cleared to make farmland, and the monkeys that lived in it disappear. Which cause of extinction is this?

   A Hunting

   B An invasive species

   C Habitat loss

   Answer at the back of the book.

6. Which statement about extinction is true?

   A Extinction began only when people appeared.

   B Extinction has happened many times in the past, and people now add new causes.

   C A species dies out only when the last animal is shot by a hunter.

   Answer at the back of the book.

7. **From an earlier chapter**

   Resistant bacteria were rare before an antibiotic was used. A few days later, almost all the bacteria are resistant. Why?

   A The antibiotic made the other bacteria resistant.

   B The resistant survivors divided, and their descendants are resistant.

   C The person taking it became resistant to the antibiotic.

   Answer at the back of the book.

8. A lake held 40 kinds of fish long ago. Today 30 kinds are left. What percentage of the kinds have been lost?

   Answer at the back of the book.

9. A forest had 200 kinds of bird. Over time 15% of the kinds were lost. How many kinds are left?

   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

A species breeds to give fertile young. A barrier plus different conditions can make two species. Past causes of extinction: an asteroid, volcanoes, climate. Today: habitat loss, hunting, invasive species, pollution, climate change.

Draw: A piece of land split by water, with two groups of animals and a crossed arrow between them.

S4.3.4 CHAPTER 4

Classification

Why does every species get a two part name, such as Homo sapiens?

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** The two words are the first name and the family name of the scientist who found it.
- ☐ **B** Every scientist, in any language, can then use the same name for the same species.
- ☐ **C** The first word says what it eats and the second says where it lives.

IF THIS FEELS HARD, READ THIS FIRST

- Level 3, Ecosystems, S3.2.1. It shows how to sort living things into plants, animals, fungi and microbes.
- Level 3, Ecosystems, S3.2.2. It teaches how to sort living things with yes or no questions.
- Level 4, Genes and inheritance, S4.2.2. It explains what DNA is and why it can be compared.

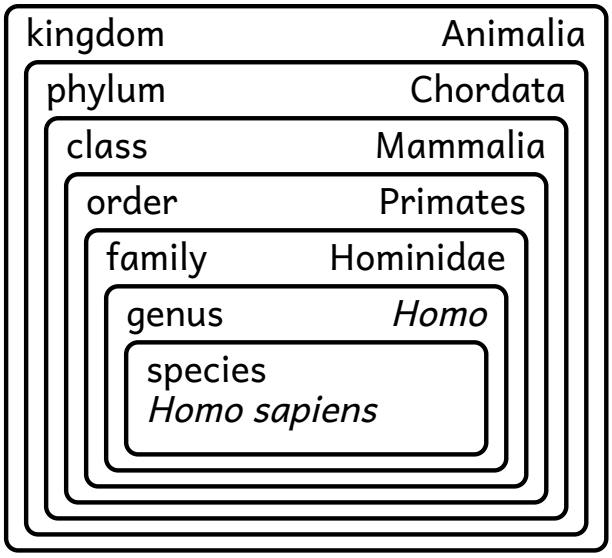
BY THE END YOU CAN

- Explain the two part naming system, such as Homo sapiens
- Explain how DNA evidence changed the way we group living things

There are millions of kinds of living thing. To study them, scientists sort them into groups. This is **classification**. A good classification shows how closely living things are related.

In the 1700s a scientist called Carl Linnaeus built the system we still build on. Later scientists added more levels. Today it has seven levels, from the biggest group to the smallest. The biggest is the **kingdom**. Below it come the phylum, the class, the order and the family. Next comes the **genus**, and last comes the species. The plural of genus is genera.

Each group sits inside a bigger one, like boxes inside boxes. A genus is a group of very closely related species.



How a human is classified. Each level is a smaller group inside the one before.

Linnaeus also gave every species a two part name. The first word is its genus and starts with a capital letter. The second word is its species name and starts with a small letter. Our own name is Homo sapiens. In print the name is written in italics. By hand, you underline each word. The text of this book prints the names upright, but the pictures show them in italics.

DRAW IT FIRST

Write the name of *a* species

genus

Homo

1 Write the genus first, with *a* capital letter. For us it is Homo.

genus species

Homo ***sapiens***

2 Write the species name after it, with *a* small letter. For us it is sapiens.

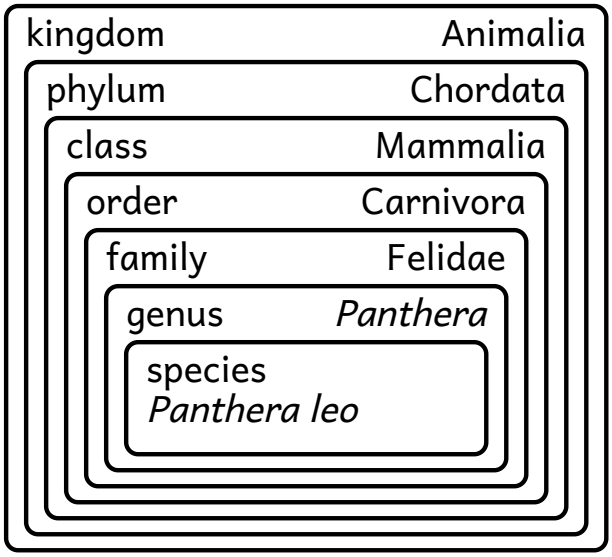
genus species

Homo ***sapiens***

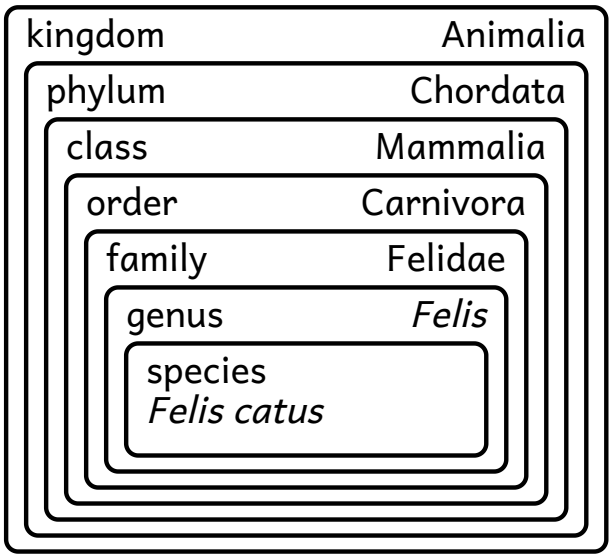
Homo sapiens

3 Together they *are* the name of the species. In print, it is in italics.

Two species in one genus share the first word. A lion is Panthera leo. A tiger is Panthera tigris. They *are* in the same genus, so they *are* close relatives. A domestic cat is Felis catus. It is in the same family *as* the lion, but in *a* different genus.



How a lion is classified.



How a domestic cat is classified. It differs from the lion at the genus.

WORKED EXAMPLE

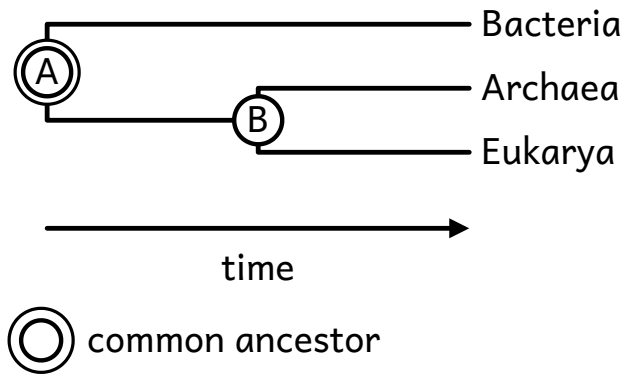
A lion and a domestic cat are classified as in the two pictures. How many levels do they share, counting from the kingdom?

1. Compare the two pictures level by level, from the kingdom down.
2. The kingdom, phylum, class, order and family are the same.
3. The genus is different, so they stop sharing there. They share 5 levels.

Answer: 5 levels

Linnaeus sorted living things by how they look. Later, scientists could compare DNA. DNA shows how closely living things are related, as you saw in the chapter on evidence for evolution. Sometimes it showed that the old groups were wrong.

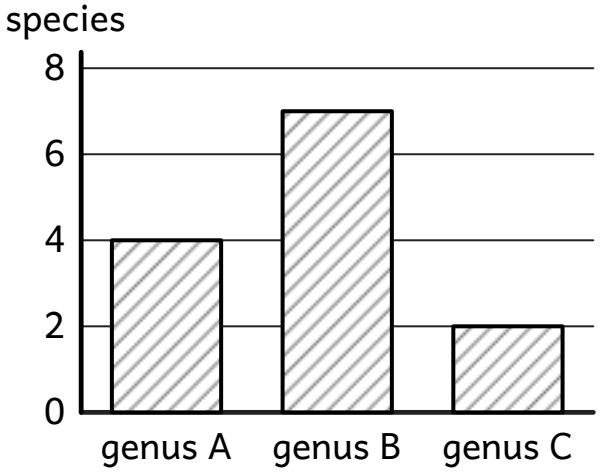
Here are two examples. Fungi look like plants, because they grow from the ground and do not move. But DNA shows that fungi are closer relatives of animals than of plants. And DNA showed that the giant panda belongs with the bears, in the same family as the brown bear.



The three domains. Archaea are more closely related to Eukarya than to Bacteria.

In the 1970s Carl Woese compared one gene that every living thing has, across many single celled living things. He found that one group, now called Archaea, is very different from Bacteria. Both groups have cells with no nucleus. But their genes differ greatly.

So scientists added a level above the kingdom. It is the **domain**. There are three: Bacteria, Archaea and Eukarya. Eukarya have cells with a nucleus. Animals, plants, fungi and many single celled living things are all in Eukarya.



Example numbers for the three genera of one family.

WORKED EXAMPLE

A family has three genera. Genus A has 4 species, genus B has 7 species and genus C has 2 species. How many species are in the family?

1. Each species belongs to one genus, so we add the species of the three genera.
2. 4 + 7 = 11.
3. 11 + 2 = 13 species in the family.

Answer: 13 species

TRY IT

Sort leaves into boxes in boxes

You need: 8 fallen leaves, from at least 3 kinds of plant, a sheet of paper and a pencil.

Be safe: Pick up only fallen leaves, and do not touch plants you do not know, in case they sting or irritate. Wash your hands afterwards.

1. Lay the leaves out. Sort them into two or three big groups by a feature, such as a smooth or a toothed edge.
2. Sort each big group into smaller groups by another feature, such as the shape.
3. Draw a big box for each group, and draw the smaller groups as boxes inside it.
4. Write what each box has in common.

What you will see: Every group sits inside a bigger one, and a smaller group shares more features than a bigger one. This is how kingdoms, families and genera work.

If you cannot try it, this is what happens.

Edge	Shape	Leaves
smooth	long	3
smooth	round	1
toothed	long	2
toothed	round	2

A WRONG IDEA MANY PEOPLE HAVE

~~Living things that look alike must be closely related.~~

Why it feels right: Early scientists grouped living things by their looks, and looks often do show relationships.

The test that breaks it: A dolphin looks a little like a fish. But it breathes air and feeds its young on milk, so it is a mammal. DNA shows that fungi, which look like plants, are closer to animals.

What is true: Looks can mislead, because unrelated living things can come to look alike when they live in the same way. DNA is a more reliable guide to how closely they are related.

KEY WORDS

classification
sorting living things into groups that show how closely they are related.

kingdom
one of the biggest groups of living things, such as animals.

genus
a group of very closely related species. The plural is genera.

domain
the biggest group of all. There are three: Bacteria, Archaea and Eukarya.

BACK TO YOUR GUESS

The answer is B: Every scientist, in any language, can then use the same name for the same species.

Common names change from place to place and from language to language. A two part name is the same everywhere, so scientists always know which species is meant.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. Which is the correct way to write the two part name of the human?

    A homo sapiens

    B Homo Sapiens

    C Homo sapiens

    Answer at the back of the book.

2. Which list gives the levels of classification from the biggest group to the smallest?

    A kingdom, phylum, class, order, family, genus, species

    B species, genus, family, order, class, phylum, kingdom

    C kingdom, class, phylum, order, genus, family, species

    Answer at the back of the book.

3. Two animals have the same first word in their two part names. What does this tell you?

    A They are the same species.

    B They are in the same genus, so they are close relatives.

    C They live in the same place.

    Answer at the back of the book.

4. What led scientists to put Bacteria and Archaea in two different domains?

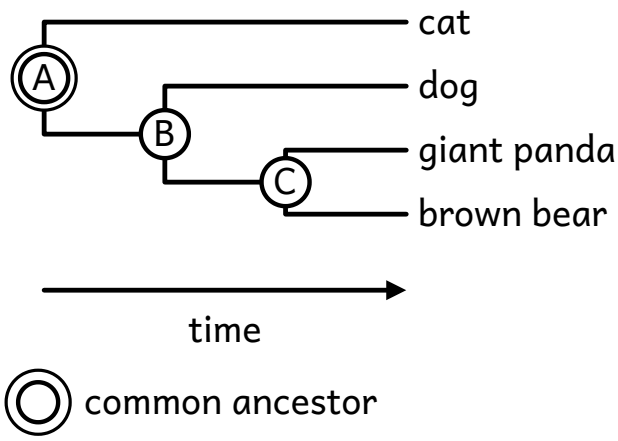
    A Archaea live only in very hot places.

    B They look very different under a microscope.

    C Comparing their genes showed that Archaea are very different from Bacteria.

    Answer at the back of the book.

5. Look at the tree. Which animal is the giant panda most closely related to?



A The brown bear

B The dog

C The cat

Answer at the back of the book.

6. **From an earlier chapter**

Two groups of snails live on opposite sides of a mountain range. Why are they not yet two species?

A Being apart does not make a new species. They are one species until they can no longer breed together to give fertile young.

B Snails cannot form new species.

C They must first be given different two part names.

Answer at the back of the book.

7. Two animals are in the same family, but not in the same genus. How many of the seven levels do they share, counting from the kingdom?

Answer at the back of the book.

8. A family has three genera. Genus A has 3 species, genus B has 5 species and genus C has 6 species. How many species are in the family?

Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Seven levels: kingdom, phylum, class, order, family, genus, species. A species has a two part name, such as Homo sapiens. DNA led to three domains: Bacteria, Archaea and Eukarya.

Draw: Boxes inside boxes from kingdom to species, with Homo sapiens written in the smallest box.

S4.3.5 CHAPTER 5

The carbon and nitrogen cycles

> **The carbon in your body was once in the air. How did it get from there into you, and where will it go next?**

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** You take carbon in when you breathe in air.
- ☐ **B** Carbon is made new inside your body from the food you eat.
- ☐ **C** Plants take carbon dioxide from the air to make food, and you get carbon by eating plants or animals.

IF THIS FEELS HARD, READ THIS FIRST

- Level 4, Cells, photosynthesis and respiration, S4.1.6. It shows how plants take in carbon dioxide and make glucose.
- Level 4, Cells, photosynthesis and respiration, S4.1.8. It shows how living things release carbon dioxide.
- Level 3, Ecosystems, S3.2.5. It explains how fungi and bacteria break down dead things.
- Level 3, Ecosystems, S3.2.3. It shows how food passes from living thing to living thing.

BY THE END YOU CAN

- Draw the carbon cycle with photosynthesis, respiration, decay and burning
- Explain how bacteria in the nitrogen cycle help plants grow

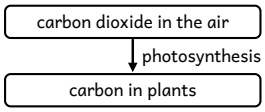
The atoms in a living thing are not made new, and they are not used up. They are used again and again. The path of an element round the living and non living world is a **cycle**. This chapter follows two elements, carbon and nitrogen.

First, carbon. The air holds a very small part of carbon dioxide, about 0.04%. Plants and algae take carbon dioxide in by photosynthesis. They use the carbon to make glucose and, from it, the other substances in their bodies. Carbon moves from the air into living things.

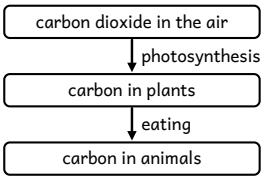
Animals get carbon by eating plants, or by eating animals that ate plants. So carbon passes along a food chain. Every living thing also respires. Plants, animals and **decomposers** all give out carbon dioxide by respiration. Decomposers are the bacteria and fungi that break down dead things and waste.

DRAW IT FIRST

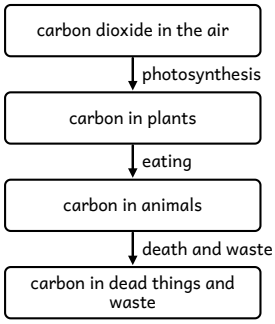
Follow the carbon



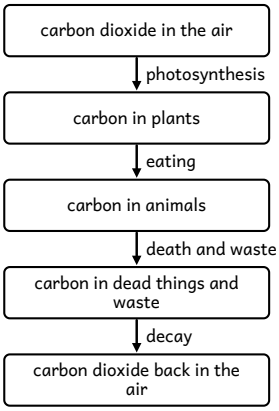
1 Plants take carbon dioxide from the air by photosynthesis. Now the carbon is in the plants.



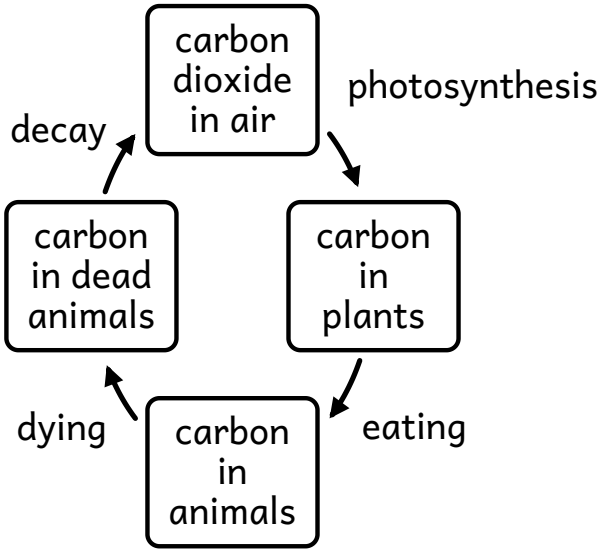
2 An animal eats the plants. Now the carbon is in the animal.



3 The animal dies and leaves waste. Now the carbon is in dead things and waste.

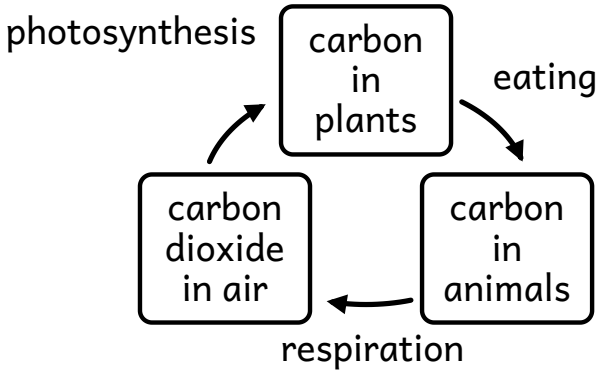


4 Decomposers break them down and respire. They give carbon dioxide back to the air.



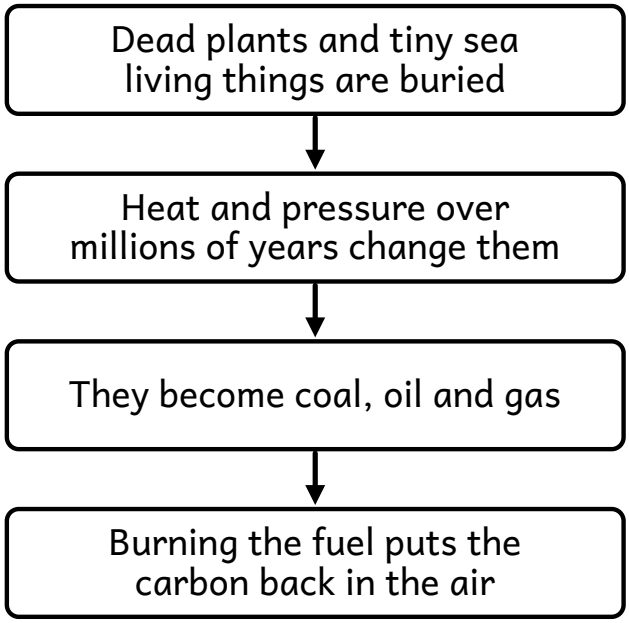
The main path of carbon through living things. Dead plants and animal waste decay in the same way. Respiration is drawn in the next ring.

Respiration is a second way back to the air. An animal gives out carbon dioxide when it respires. Plants and decomposers respire too, in the same way.

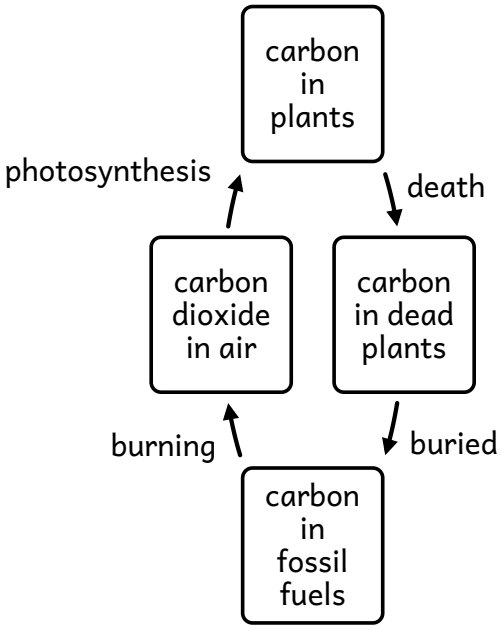


Carbon dioxide goes into plants by photosynthesis. Respiration by animals gives it back to the air.

Carbon dioxide also goes back to the air when things burn. Wood burns, and so do fuels. A fuel such as coal, oil or gas is a **fossil fuel**. Fossil fuels formed from the remains of dead plants and tiny sea living things called plankton. These were buried. Over millions of years, heat and pressure changed them. So fossil fuels are stored carbon.



Fossil fuels took millions of years to form. Burning them returns their carbon to the air much faster.

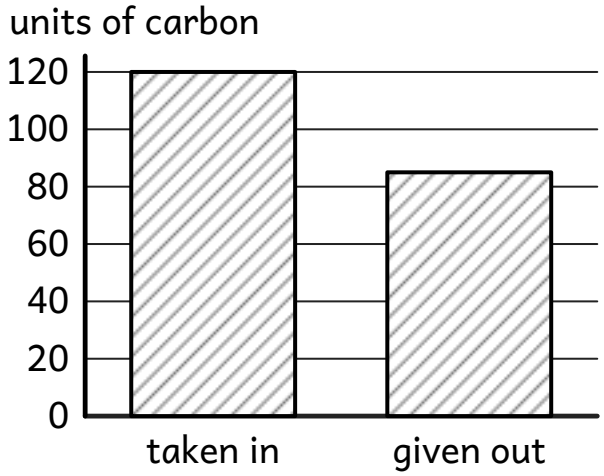


Burning fossil fuels adds carbon dioxide to the air. The carbon had been stored for millions of years.

Process	CO_2
photosynthesis	taken in
respiration	given out
decay	given out
burning	given out

What each process does to the carbon dioxide (CO_2) in the air.

Carbon also moves through the sea and into rocks. This chapter follows the main path, through the air and living things. When the amount taken in equals the amount given out, the amount in the air stays steady.



Example numbers, in made up units, for one year in a small wood.

WORKED EXAMPLE

In one year a small wood takes in 120 units of carbon by photosynthesis. It gives out 85 units by respiration. How many units of carbon are added to the wood?

1. The wood takes in 120 units and gives out 85 units.
2. What stays in the wood is what is taken in, minus what is given out.
3. 120 − 85 = 35 units.

Answer: 35 units

WORKED EXAMPLE

A forest takes in 120 units of carbon in a year. Plant respiration gives out 50 units, decay gives out 40 units and a fire gives out 10 units. How many units of carbon are added to the forest?

1. Add up what is given out: 50 + 40 + 10 = 100 units.
2. The forest takes in 120 units.
3. 120 − 100 = 20 units are added to the forest.

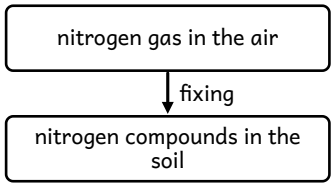
Answer: 20 units

Now nitrogen. Plants need nitrogen to make proteins. About 78% of the air is nitrogen gas. But plants cannot use nitrogen gas. Their roots take in **nitrates**, which are salts that dissolve in soil water. Animals get nitrogen by eating proteins in plants and in other animals.

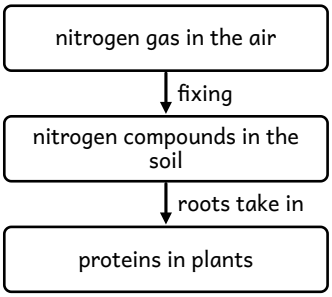
Some bacteria can change nitrogen gas into compounds that plants can use. These are **nitrogen fixing bacteria**. Some live free in the soil. Others live in lumps called root nodules on the roots of plants such as beans and peas. Lightning also fixes a little nitrogen.

DRAW IT FIRST

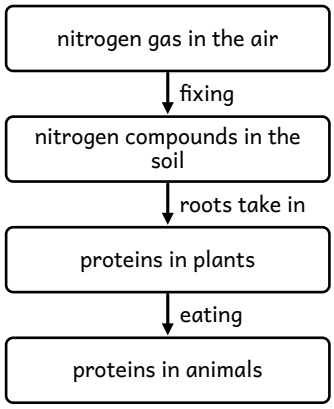
Nitrogen from the air to an animal



1 Fixing bacteria in the soil and in root nodules turn nitrogen gas into nitrogen compounds such as ammonium. Lightning makes a little nitrate.

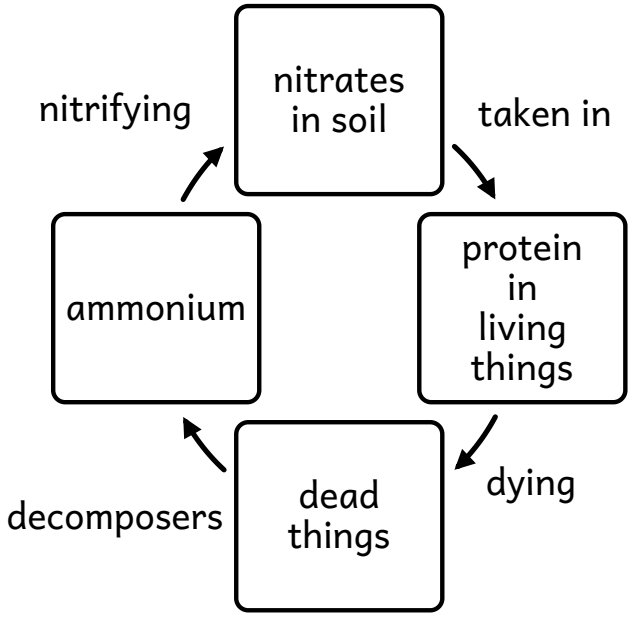


2 The roots of a plant take in nitrogen compounds, mostly nitrates. The plant uses them to make proteins.



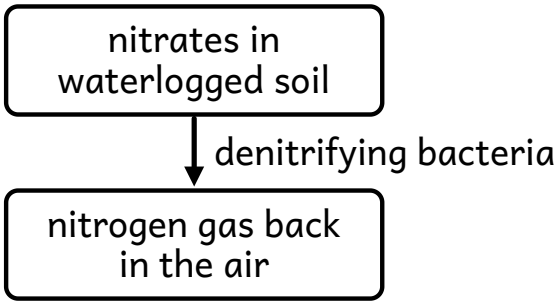
3 An animal eats the plant and takes in the proteins.

When living things die, and when animals pass waste, the nitrogen in their proteins goes back to the soil. Decomposers break down the proteins and make ammonium. Then **nitrifying bacteria** turn the ammonium into nitrates. The nitrates can be taken in by roots again.



The nitrogen cycle through the soil and living things. Roots take in the nitrates. Animals get protein by eating. Animal waste also puts nitrogen back in the soil. The arrow marked nitrifying is the work of nitrifying bacteria.

One more group closes the cycle. In waterlogged soil there is little oxygen. There, **denitrifying bacteria** turn nitrates into nitrogen gas, which goes back to the air. So nitrogen leaves the soil as well as arriving.



Denitrifying bacteria return nitrogen to the air.

Farmers use this knowledge. When a crop is taken away, nitrogen goes with it. A farmer can add fertiliser that holds nitrates. Or the farmer can grow beans or peas in a field. Their root nodules fix nitrogen, so the soil gains nitrogen compounds for the next crop.

TRY IT

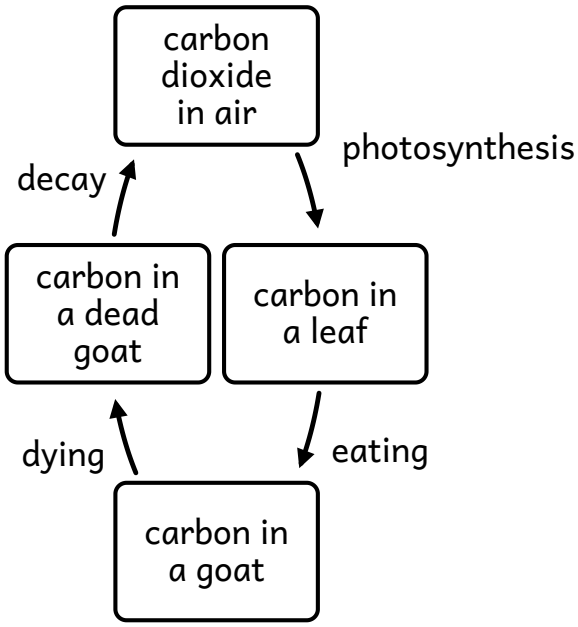
Follow one carbon atom

You need: a sheet of paper, a pencil.

1. Start with one carbon atom in carbon dioxide in the air.
2. Write a short story. The atom is taken in by a leaf, and then the leaf is eaten by a goat.
3. Say what happens when the goat dies, and where the atom goes at the end.
4. Draw your story as a ring of boxes, with an arrow from each box to the next.

What you will see: The atom ends up as carbon dioxide in the air again, ready to start another journey. The ring has no end. Try a different route. The atom could also leave the goat as carbon dioxide each time the goat breathes out.

If you cannot try it, this is what happens.



A WRONG IDEA MANY PEOPLE HAVE

~~Plants take in nitrogen from the air, because the air is 78% nitrogen.~~

Why it feels right: Plants take in carbon dioxide from the air, so it seems that they would take in nitrogen too.

The test that breaks it: Farmers add nitrates to their fields to help crops grow. If plants could use the nitrogen gas in the air, there would be no need.

What is true: Plants cannot use nitrogen gas themselves. Their roots take in nitrates from the soil. Only some bacteria can change nitrogen gas into forms that plants can use.

KEY WORDS

cycle
the path of an element round living things and the non living world, so that it is used again and again.

decomposers
bacteria and fungi that break down dead things and waste.

fossil fuel
coal, oil or gas, formed over millions of years from the buried remains of living things.

nitrates
salts of nitrogen that dissolve in soil water. Plant roots take them in.

nitrogen fixing bacteria
bacteria that change nitrogen gas into compounds that plants can use.

nitrifying bacteria
bacteria that turn ammonium into nitrates.

denitrifying bacteria
bacteria that turn nitrates into nitrogen gas, in waterlogged soil.

BACK TO YOUR GUESS

The answer is C: Plants take carbon dioxide from the air to make food, and you get carbon by eating plants or animals.

Plants take carbon from carbon dioxide in the air and build it into food. You get carbon by eating. When you breathe out, you give carbon dioxide back to the air.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. Which process takes carbon dioxide out of the air?

    A Respiration

    B Burning a fuel

    C Photosynthesis

    Answer at the back of the book.

2. Which list has only processes that put carbon dioxide into the air?

    A Photosynthesis, decay and burning

    B Respiration, decay and burning

    C Respiration, photosynthesis and decay

    Answer at the back of the book.

3. Which statement about plants is true?

    A Plants respire only at night, and photosynthesise only in the day.

    B Plants only take in carbon dioxide and never give any out.

    C Plants respire all the time, and photosynthesise when there is light.

    Answer at the back of the book.

4. Why does burning fossil fuels change the carbon dioxide in the air so quickly?

    A The carbon was stored for millions of years, and burning puts it into the air in a short time.

    B Burning makes new carbon from nothing.

    C Burning only takes oxygen from the air, and nothing else changes.

    Answer at the back of the book.

5. How do most plants get the nitrogen they need to make proteins?

   A Their leaves take in nitrogen gas from the air.

   B Their roots take in nitrates that dissolve in soil water.

   C They make nitrogen from carbon dioxide and water.

   Answer at the back of the book.

6. Which bacteria turn ammonium in the soil into nitrates?

   A Nitrifying bacteria

   B Denitrifying bacteria

   C Nitrogen fixing bacteria

   Answer at the back of the book.

7. **From an earlier chapter**

   Resistant bacteria survive an antibiotic and divide. Which step of natural selection is the survival of the resistant bacteria?

   A Those best suited to the conditions survive and breed more.

   B All the young survive because there is plenty of food.

   C The bacteria change themselves to survive.

   Answer at the back of the book.

8. Air is about 78% nitrogen gas by volume. How many litres of nitrogen gas are in 200 litres of air?

   Answer at the back of the book.

9. In one year a wood takes in 140 units of carbon by photosynthesis and gives out 95 units. How many units of carbon are added to the wood?

   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Photosynthesis takes carbon dioxide in. Respiration, decay and burning give it out. Roots take in nitrates. Fixing bacteria add nitrogen compounds, nitrifying bacteria make nitrates, and denitrifying bacteria return nitrogen gas to the air.

Draw: A ring of boxes for the carbon cycle, with arrows for photosynthesis, respiration, decay and burning.

S4.3.6 CHAPTER 6

Measuring populations

> **How can you find how many daisies are in a field, or snails in a garden, without counting every one?**

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** Count the daisies in several small areas chosen at random, find the average, and scale up to the whole field.
- ☐ **B** Count every single one. Any other way gives an answer that is no use.
- ☐ **C** Count the daisies where there are most, and multiply that number by the size of the field.

IF THIS FEELS HARD, READ THIS FIRST

- Level 3, Ecosystems, S3.2.7. It shows how to estimate the number of plants in a field using a square frame.
- Level 3, Ecosystems, S3.2.6. It explains what plants and animals compete for.

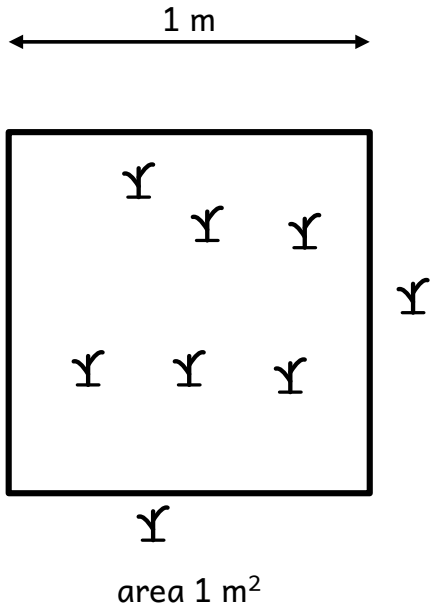
BY THE END YOU CAN

- Estimate a population using quadrats and a transect
- Use capture and recapture to estimate a number of snails or insects

To look after a place, or to study it, we need to know how many living things of each kind are there. Counting every one is usually too slow, and sometimes impossible. So scientists count a **sample**. This is a small part of the whole, and they scale it up.

For plants, and for animals that do not move, we use a **quadrat**. It is a square frame, often 1 m by 1 m, with an area of 1 m^2. You lay it on the ground and count

the plants inside it. A plant that is outside the frame does not count.



A quadrat of 1 m by 1 m. Count only the plants inside the frame.

One quadrat is not enough. It may land on a thick patch or on a bare patch. So we place many quadrats, and we place them at **random**. Random means that every place has an equal chance. For example, you can pick the places with numbers written on slips of paper. Choosing a spot because it looks good would make the sample unfair.

Then we find the mean number of plants in a quadrat. We divide it by the area of one quadrat to get plants for each m^2. Last we multiply by the area of the whole field in m^2. This gives an estimate of the number of plants in the field.

Quadrat	Daisies
1	4
2	7
3	3
4	6
5	5

Example data: daisies in five quadrats of 1 m^2, placed at random in a field.

WORKED EXAMPLE

A field is 10 m by 10 m. Five quadrats of 1 m^2 hold 4, 7, 3, 6 and 5 daisies. Estimate the number of daisies in the field.

1. The total in the quadrats is 4 + 7 + 3 + 6 + 5 = 25.
2. The mean for each quadrat is 25 ÷ 5 = 5 daisies. A quadrat is 1 m^2, so this is 5 daisies for each m^2.
3. The field has an area of 10 × 10 = 100 m^2, so 5 × 100 = 500 daisies.

Answer: About 500 daisies

A quadrat does not have to be 1 m^2. A smaller quadrat, 0.5 m by 0.5 m, has an area of 0.5 × 0.5 = 0.25 m^2. Then we must divide by 0.25, not by 1, to get the plants for each m^2.

Quadrat	Plants
1	2
2	4
3	3
4	1
5	5

Example data: plants in five quadrats, each 0.5 m by 0.5 m.

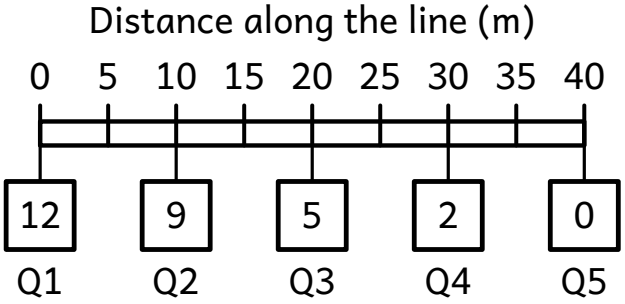
WORKED EXAMPLE

A field has an area of 80 m². Five quadrats, each 0.5 m by 0.5 m, hold 2, 4, 3, 1 and 5 plants. Estimate the number of plants in the field.

1. The total is 2 + 4 + 3 + 1 + 5 = 15, so the mean is 15 ÷ 5 = 3 plants for each quadrat.
2. One quadrat has an area of 0.5 × 0.5 = 0.25 m².
3. 3 plants in 0.25 m² is 3 ÷ 0.25 = 12 plants for each m².
4. The field is 80 m², so 12 × 80 = 960 plants.

Answer: About 960 plants

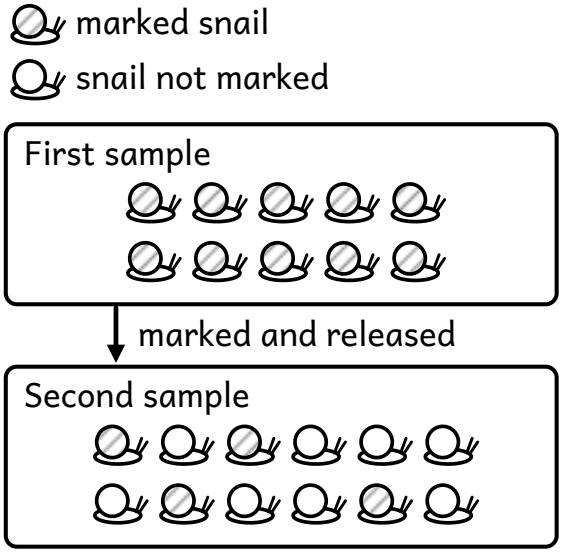
Sometimes a living thing changes in number along a line. For example, grass may thin out from open ground into shade. To study this we use a **transect**. A transect is a line, such as a tape laid on the ground. Quadrats are placed at regular steps along it, and the plants in each are counted.



A transect of 40 m with a quadrat every 10 m. The squares are symbols and are not drawn to scale. The numbers are the plants counted in each quadrat.

Quadrats suit plants, which stay where they are. Animals move, so they leave the square, or hide. For animals such as snails and insects we use **capture and recapture**. It works in four steps. First, catch a sample and mark each animal in a way that does not harm it. Then release them. Wait, so the marked animals mix with the others. Last, catch a second sample, and count how many have a mark.

If only a few of the second sample are marked, the population is large. If many are marked, the population is small. The estimate has three parts. Take the number marked in the first sample. Multiply it by the number in the second sample. Then divide by the number marked in the second sample.



Example numbers. The sum gives the estimate of the number of snails.

WORKED EXAMPLE

Ravi catches 10 snails and marks all of them. He puts them back. Later he catches 12 snails and 4 have a mark. Estimate the number of snails.

1. The marked animals in the first sample are 10. The second sample is 12, and 4 of it are marked.
2. First multiply the marked in the first sample by the second sample: 10 × 12 = 120.
3. Then divide by the marked animals in the second sample: 120 ÷ 4 = 30.
4. The estimate is about 30 snails.

Answer: About 30 snails

The estimate is only fair if three things are true. The marks must not harm the animals or come off. The marked animals must mix back in with the others. And no animals are born, die or move in or out between the two samples.

TRY IT

Capture and recapture with paper slips

You need: a helper, a bag or a cloth sack, about 40 to 80 small slips of torn paper, a pencil.

1. Your helper tears slips of paper and puts them in the bag, without telling you how many.
2. Pick 10 slips from the bag. Put a pencil cross on each one. Put them back and shake the bag.
3. Pick 10 slips again. Count how many have a cross.
4. Work out the estimate: 10 × 10 ÷ the number with a cross. Then ask your helper for the real number.

What you will see: The estimate is close to the real number, but not the same. Try it three times and compare. Never use live animals for this. Use paper slips or beans only.

If you cannot try it, this is what happens.

Step	Slips
first sample marked	10
second sample	10
marked in second	2
estimate	50
real number	46

TRY IT

Count plants with a quadrat

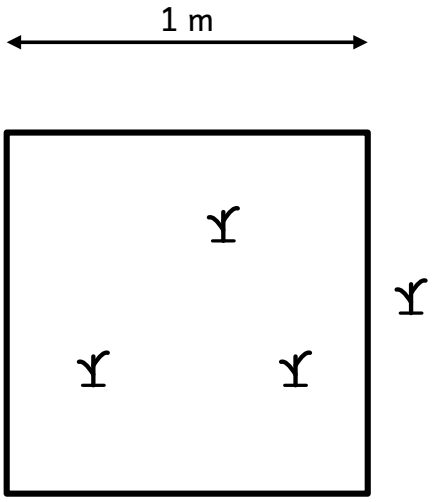
You need: four straight sticks, each 1 m long, string to tie the corners, paper and a pencil, a lawn, a garden or a field, with the owner's leave.

Be safe: Mind the sharp ends of sticks and do not run with them. Wear a hat in the sun, and wash your hands after touching soil. Pick nothing and leave every plant and animal as you found it.

1. Lay the four sticks in a square on the ground, and tie the corners with string. Each side is 1 m, so the area is 1 m^2.
2. Choose 5 places at random. For example, write numbers on slips, draw them, and pace out that number of steps.
3. In each place, count the plants of one kind inside the square, such as clover or daisies. Pick nothing.
4. Work out the mean for each quadrat. Multiply it by the area of the whole patch in m^2.

What you will see: Each quadrat gives a different count, which is why many quadrats give a better estimate than one. Your answer is an estimate, not an exact number.

If you cannot try it, this is what happens.



area 1 m^2

A WRONG IDEA MANY PEOPLE HAVE

~~Put the quadrat where the plants look thickest, so that you get a good count.~~

Why it feels right: A big count feels like a better, fuller count.

The test that breaks it: Place one quadrat on a thick patch and one on a thin patch of the same field. The counts differ a lot. The thick patch is not typical of the field.

What is true: A sample must be fair. Placing quadrats at random, and using many of them, gives a mean that stands for the whole field.

KEY WORDS

sample
a small part of the whole that is counted or measured, and then scaled up.

quadrat
a square frame of known size that is laid on the ground, to count the plants inside it.

random
chosen by chance, so that every place has an equal chance.

transect
a line across a habitat, along which quadrats are placed to show how living things change.

capture and recapture
a way to estimate the number of animals that move. Catch and mark some, release them, then catch again and count the marked ones.

BACK TO YOUR GUESS

The answer is A: Count the daisies in several small areas chosen at random, find the average, and scale up to the whole field.

Counting everything is too slow, and often impossible. A fair sample, taken at random, gives a good estimate. Counting only where there are most would give too high a number.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. Why should quadrats be placed at random?

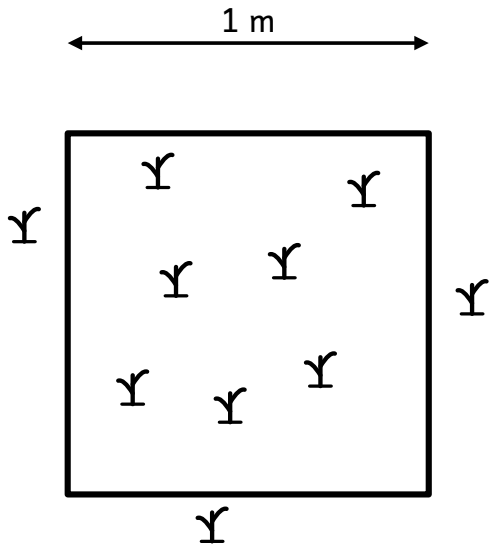
   A So that the sample is fair and does not favour places the person likes.

   B So that every quadrat lands where the plants are thickest.

   C So that all the plants in the field are counted.

   Answer at the back of the book.

2. Look at the picture of a quadrat. How many plants are counted?



area 1 m^2

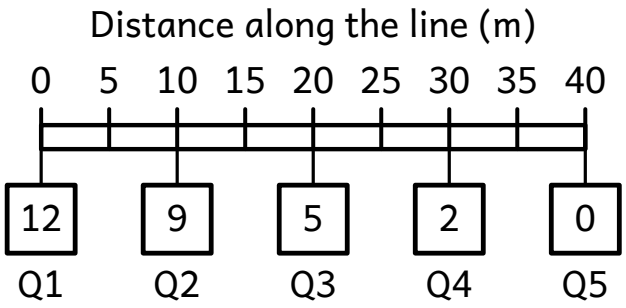
   A 10

   B 3

   C 7

   Answer at the back of the book.

3. Look at the transect. What does it show about the plant along the line?



A The number is the same all along the line.

B The number falls along the line.

C The number rises along the line.

Answer at the back of the book.

4. Which is one of the things that must be true for capture and recapture to give a fair estimate?

A The marks do not harm the animals or come off, and the marked animals mix back in.

B The second sample must be smaller than the first.

C The marked animals must stay in one place so that they can be found.

Answer at the back of the book.

5. Some of the marks on the snails come off between the two samples. What happens to the estimate?

A It is too low.

B It is not changed.

C It is too high.

Answer at the back of the book.

6. Why do we use capture and recapture for snails, but quadrats for daisies?

   A Snails move about, so they cannot be counted in a fixed square. Daisies stay where they are.

   B Snails are too small to see inside a quadrat.

   C Quadrats can only be used for animals.

   Answer at the back of the book.

7. **From an earlier chapter**

   Rats carried on ships eat the eggs of birds that nest on the ground on an island, and the birds die out. Which cause of extinction is this?

   A An invasive species

   B Habitat loss

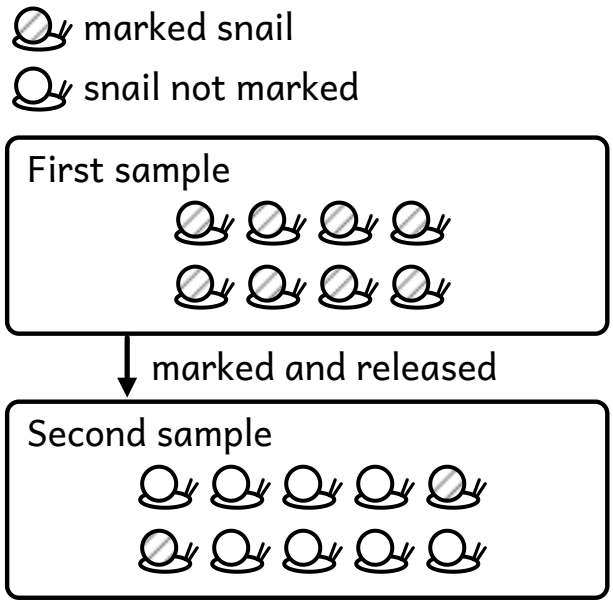
   C A natural volcanic eruption

   Answer at the back of the book.

8. A field has an area of 50 m^2. Five quadrats of 1 m^2 hold 6, 4, 8, 5 and 7 plants. Estimate the number of plants in the field.

   Answer at the back of the book.

9. Look at the picture. Estimate the number of snails.



   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Count a random sample and scale up. Mean per quadrat, divided by its area, times the field area. A transect shows change along a line. Capture and recapture: marked first times second sample, divided by marked in the second.

Draw: A 1 m square frame with a few plants inside it and some outside, and the words area 1 m^2.

S4.3.7 CHAPTER 7

Interdependence

> **Why do the numbers of foxes and rabbits in a wood rise and fall in a pattern, year after year?**

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** Foxes and rabbits rise and fall together, at exactly the same time.
- ☐ **B** When rabbits are many, foxes get more food and increase. Then many rabbits are eaten and fall, and foxes fall after them.
- ☐ **C** Rabbits rise and fall by chance. The foxes have no effect on them.

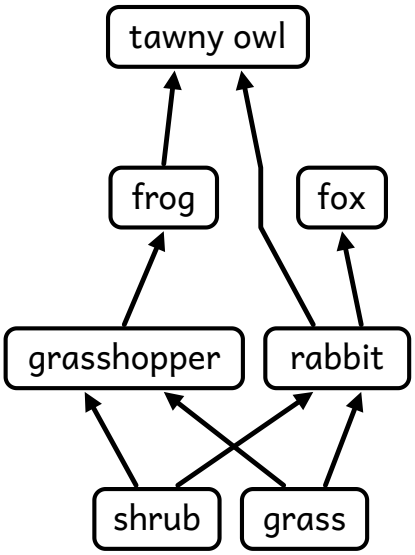
IF THIS FEELS HARD, READ THIS FIRST

- Level 3, Ecosystems, S3.2.3. It shows how food chains join into a food web.
- Level 3, Ecosystems, S3.2.6. It explains what plants and animals compete for.
- Level 2, Food chains and habitats, S2.2.3. It shows how a habitat gives food, water and shelter.

BY THE END YOU CAN

- Explain predator and prey population cycles from a graph
- Explain how living and non-living factors affect a community

All the living things in one habitat make a **community**. The living things in it depend on each other. This is **interdependence**. They depend on each other for food, for shelter, and for jobs such as pollination. Remove one kind and the others change.



energy flows along the arrows

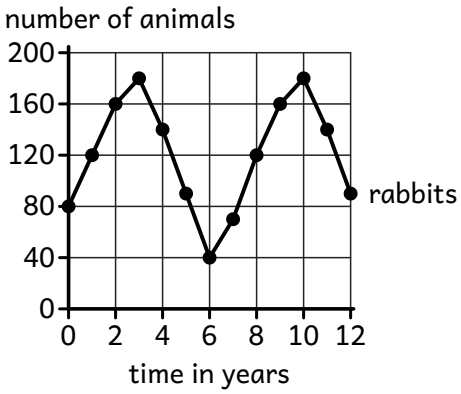
A food web. Energy flows along the arrows, from the food to the feeder. Decomposers feed on every dead thing in it, but they are not drawn.

Look at the web. In this web, the fox eats only rabbits. If the rabbits fell in number, the foxes would soon lack food. The tawny owl eats both frogs and rabbits, so it has another choice. Living things that eat the same food also compete. Rabbits and grasshoppers compete for grass.

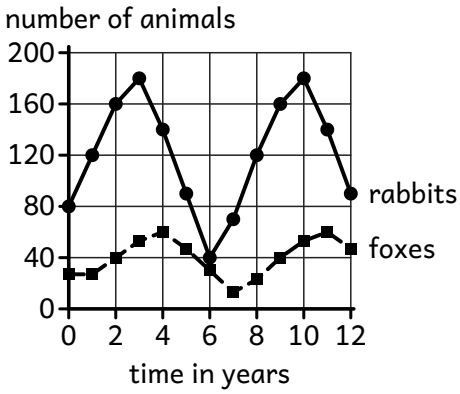
A **predator** is an animal that hunts and eats other animals. The animals it eats are its **prey**. Predator and prey numbers affect each other. Let us follow a wood with rabbits and foxes.

DRAW IT FIRST

Draw the two lines



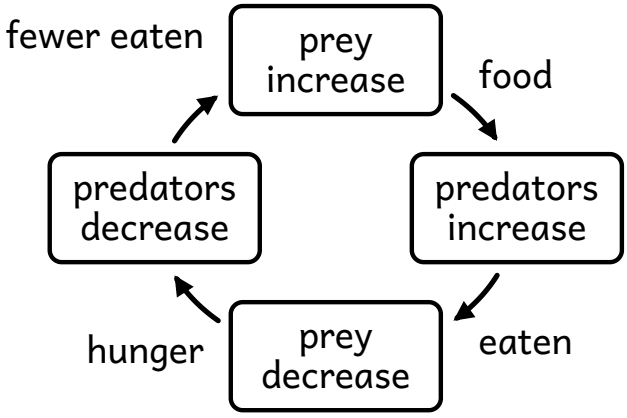
1 The number of rabbits rises, falls and rises again in a regular pattern. These are example numbers.



2 The foxes follow the same pattern, but each peak comes a little later than the rabbits' peak. The fox line is drawn larger than real life so that both lines can be read. Real predators are far fewer than their prey.

Why does this happen? When rabbits are many, the foxes have plenty of food. They survive and breed, and the number of foxes rises. But foxes need time to breed and grow, so the foxes peak a little after the rabbits.

Many foxes eat many rabbits, and the rabbits fall. Now there is less food, so the foxes starve and fall. With fewer foxes, more rabbits survive, and the rabbits rise again. The cycle repeats.



The predator and prey cycle. Real cycles are less regular, because weather, disease and other food also act.

WORKED EXAMPLE

Use the graph of rabbits and foxes. The rabbits peak in year 3 and the foxes peak in year 4. How many years after the rabbit peak is the fox peak?

1. The rabbits peak at 180, in year 3.
2. The foxes peak at 60, in year 4.
3. The foxes peak 4 − 3 = 1 year later.

Answer: 1 year later

WORKED EXAMPLE

Use the same graph. In year 2, how many more rabbits than foxes are there?

1. Read the rabbit line at year 2. It is at 160.
2. Read the fox line at year 2. It is at 40.
3. The difference is 160 − 40 = 120.

Answer: 120 more rabbits

Predators do not only harm prey. They keep prey in check. Suppose all the foxes were removed. The rabbits could rise until they ate all the grass, and then many would starve or die of disease.

The factors that affect a community are of two kinds. **Biotic factors** are living ones: food, predators, disease and competition. **Abiotic factors** are non living ones: temperature, light, water, soil pH and, in water, the amount of oxygen.

Living	Non living
food	temperature
predators	light
disease	water
competition	soil pH
	oxygen in water

Factors that affect a community. The living factors are also called biotic, and the non living ones abiotic.

Here are two examples. Plants that need much light grow well in the open, and plants that cope with shade grow under trees. Light is an abiotic factor. In a pond, warm water holds less dissolved oxygen than cool water. In a hot spell, the fish may lack oxygen.

Factors act together. A hot dry year may lower the number of rabbits by reducing the grass. This gives the foxes less food. A change in one factor can run through the whole community.

TRY IT

Does light change what grows?

You need: a square frame, 0.5 m by 0.5 m, made of sticks and string, paper and a pencil, a sunny patch and a shady patch of ground, with the owner's leave.

Be safe: Mind the sharp ends of sticks and wear a hat in the sun. Pick nothing, and leave every plant and animal as you found it. Wash your hands afterwards.

1. Choose a sunny patch of ground and a shady patch near it. The soil should be much the same.
2. In each patch, lay the frame in 5 places chosen at random. Count the plants inside it each time.
3. Work out the mean count for the sunny patch and for the shady patch.
4. Compare the two means. Then list other things that might differ, such as water.

What you will see: The sunny patch and the shady patch usually hold different numbers of plants, and often different kinds. Light is one abiotic factor. Water and soil may differ too, so be careful when you say that light is the cause.

If you cannot try it, this is what happens.

Place	Mean
sunny	6
shady	2

A WRONG IDEA MANY PEOPLE HAVE

~~If we remove all the predators, there will be more prey, and that will be good for the prey.~~

Why it feels right: Predators kill prey, so it seems that fewer predators must help the prey.

The test that breaks it: Without foxes, rabbits can rise until they eat all the grass. Then many starve or die of disease. Predators keep the number of prey in check.

What is true: Predators and prey keep each other in check. Removing a predator can lead to a boom in prey, and then a crash when the food runs out.

KEY WORDS

community
all the living things of every kind in one habitat.

interdependence
living things depending on each other, for food, shelter and other needs.

predator
an animal that hunts and eats other animals.

prey
an animal that is hunted and eaten by a predator.

biotic factor
a living thing that affects a community, such as food, a predator, disease or competition.

abiotic factor
a non living thing that affects a community, such as temperature, light, water or soil pH.

BACK TO YOUR GUESS

The answer is B: When rabbits are many, foxes get more food and increase. Then many rabbits are eaten and fall, and foxes fall after them.

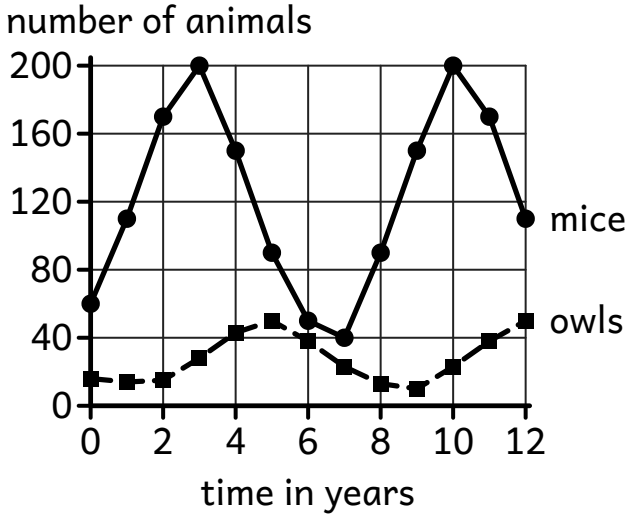
Predators and prey affect each other. The predators rise a little after the prey, because they need time to breed. Then they eat so many prey that the prey

fall, and the predators fall after them.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. Look at the graph of mice and owls. Which statement is true?



   A The owls peak before the mice, so the owls make the mice rise.

   B Each owl peak comes after a mouse peak.

   C The mice and the owls peak in the same year.

   Answer at the back of the book.

2. Why does the predator peak come after the prey peak?

   A Predators move more slowly than prey.

   B The prey rise because the predators have already increased.

   C Plentiful prey give the predators food, but the predators need time to breed and grow.

   Answer at the back of the book.

3. Which of these is a non living (abiotic) factor that affects a community?

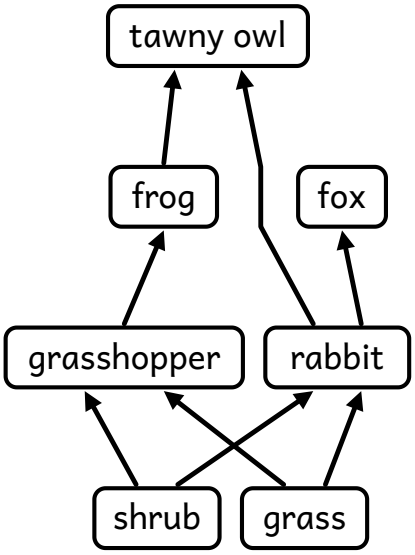
   A The pH of the soil

   B A disease that spreads in rabbits

   C A fox that hunts rabbits

   Answer at the back of the book.

4. Look at the food web. A disease kills all the rabbits. Which animal loses its only food?



energy flows along the arrows

   A The tawny owl

   B The fox

   C The frog

   Answer at the back of the book.

5. Why may fish in a pond have trouble breathing in a hot spell?

   A Warm water has more oxygen, and too much oxygen harms fish.

   B Temperature has no effect on the fish.

   C Warm water holds less dissolved oxygen than cool water.

   Answer at the back of the book.

6. A poison kills most of the bees in a meadow. What is most likely to happen to the flowers that bees pollinate?

   A Fewer flowers are pollinated, so they make fewer seeds.

   B Nothing, because flowers do not depend on animals.

   C The flowers make more seeds, because fewer bees take the pollen.

   Answer at the back of the book.

7. **From an earlier chapter**

   Which method would you use to estimate the number of snails in a garden?

   A Capture and recapture

   B A quadrat laid at random

   C Count only the snails you see at one spot

   Answer at the back of the book.

8. A rabbit population falls from 200 at its peak to 50. By what percentage did it fall?

   Answer at the back of the book.

9. A wood has 240 rabbits and 8 foxes. How many rabbits are there for each fox?

   Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Predator and prey numbers rise and fall in cycles, and the predator peak is a little later. Living factors: food, predators, disease, competition. Non living: temperature, light, water, soil pH, oxygen.

Draw: A graph with two lines that rise and fall, and the second peak a little after the first.

S4.3.8 CHAPTER 8

Biodiversity and people

Why does it matter if a forest is cleared or a river is polluted, and how can people protect living things?

YOUR GUESS

Pick one before you read on. It is fine to be wrong.

- ☐ **A** It matters little, because other species just move in and fill the places of those that are lost.
- ☐ **B** It matters only for the few species that people eat.
- ☐ **C** The variety of living things falls, and species that depend on each other can be lost too. People can protect places, species and seeds.

IF THIS FEELS HARD, READ THIS FIRST

- Level 3, Ecosystems, S3.2.8. It shows how farming, cutting trees and pollution change ecosystems.
- Level 2, Food chains and habitats, S2.2.8. It shows how cutting forests or dirty water harms living things.
- Level 3, Ecosystems, S3.2.5. It explains how decomposers break down dead things.

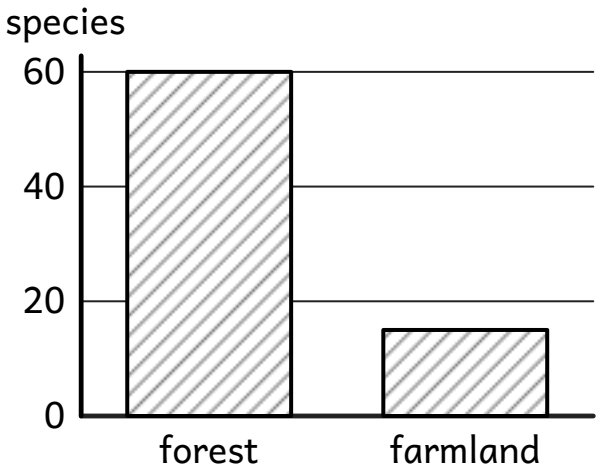
BY THE END YOU CAN

- Explain how habitat loss, pollution and invasive species reduce biodiversity
- Evaluate ways to conserve species, such as reserves and seed banks

Biodiversity is the variety of living things in a place, or in the whole world. It counts how many different species there are. It also counts the variety of alleles within each species.

Why does it matter? Living things depend on each other, as you saw in the last chapter. A varied community is usually better able to cope when something changes. We also depend on biodiversity for food, clean water, pollination of crops, medicines and fertile soil. Many people also value nature for its own sake.

People reduce biodiversity in several ways. The biggest is habitat loss. A forest is cleared for farmland or buildings, a wetland is drained, or a river is dammed. The species that lived there lose their food and shelter. Some move away, and some die out.



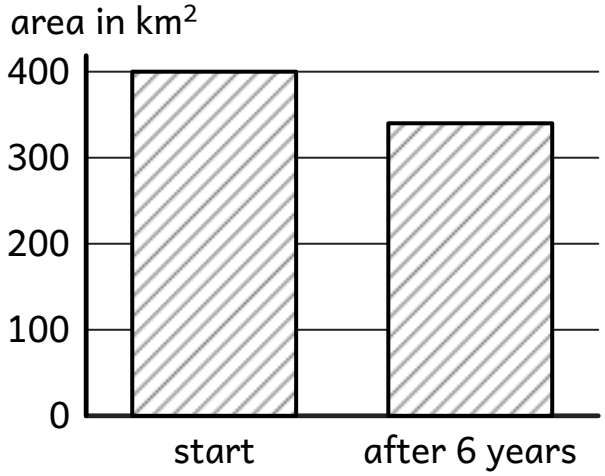
Example numbers. The farmland replaced part of the forest.

WORKED EXAMPLE

A forest site has 60 species. The farmland that replaced it has 15 species. What percentage fewer species does the farmland have?

1. The farmland has 60 − 15 = 45 fewer species.
2. 45 out of 60 is 45 ÷ 60 = 0.75.
3. As a percentage, 0.75 × 100 = 75%.

Answer: 75% fewer



Example numbers. Each year 10 km² of the forest is cleared.

WORKED EXAMPLE

A forest of 400 km² loses 10 km² each year. What percentage of the forest is left after 6 years?

1. The area cleared in 6 years is 10 × 6 = 60 km².
2. The area left is 400 − 60 = 340 km².
3. 340 out of 400 is 340 ÷ 400 = 0.85, which is 85%.

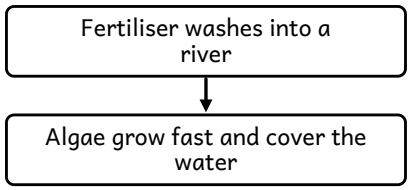
Answer: 85%

Habitat loss also breaks a big habitat into small patches. A small patch holds fewer animals of each kind. The animals cannot reach each other to find mates, so the alleles are not mixed. Each small group has less variety of alleles, and close relatives breed together. So the group copes less well with disease or change.

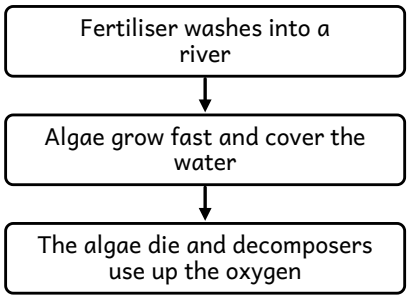
The second cause is pollution. Oil, chemicals and plastic harm living things in water and on land. Fertiliser is another. When rain washes fertiliser from fields into a river, the water becomes rich in nitrates, as you saw in the nitrogen cycle. This causes **eutrophication**.

DRAW IT FIRST

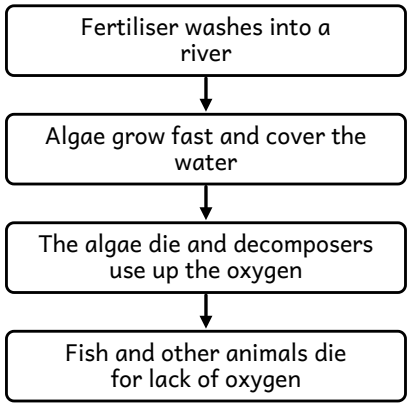
How fertiliser can kill fish



1 Fertiliser washes into a river. Algae use its nitrates and grow fast, so they cover the water.



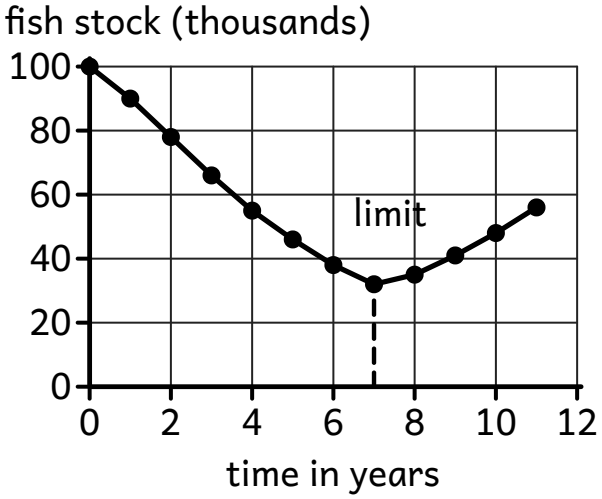
2 The algae shut out the light, and the plants below them die. Then the algae die too. Decomposers feed on the dead algae and use up the oxygen in the water.



3 Fish and other animals that need oxygen die.

The third cause is an invasive species. People carry living things to new places, on ships or as garden plants. In the new place the newcomer may have no predators or diseases to keep it in check. It may eat the local species, or take their food and space. Rats and cats on islands, and a floating water plant that covers a lake, are examples.

The fourth cause is hunting and fishing. If animals are taken faster than they can breed, their number falls. The fifth is climate change caused by people, from the carbon dioxide put in the air by burning fuels. Warmer seas bleach corals, and habitats shift.



Example numbers, in thousands of fish, for a fish stock in a sea. The dashed line marks year 7, when a limit on fishing begins.

The graph shows that overfishing can be reversed. The stock fell until a limit on fishing began, and then it rose. Not every case ends this way. Some species are slow to breed, and some are taken for too long.

Conservation means protecting living things and their habitats. There are several methods. Each has gains and limits.

A **nature reserve** is an area where building, farming and hunting are controlled. It protects a whole habitat and all the species in it. But it costs money to guard. A small reserve can hold only a few animals of each kind. People who live near it may lose land they used.

A **habitat corridor** is a strip of habitat that joins two reserves or patches. Animals can move along it to find food and mates, and alleles are mixed. But it takes land, and a road can cut across it.

A **seed bank** stores seeds of many plants in cold, dry conditions. If a plant dies out in the wild, it can be grown again from the seeds. But the bank saves the seeds, not the animals and the habitat that go with the plant. Some seeds do not keep for long, and some kinds cannot be stored this way.

A **breeding programme** breeds endangered animals in a protected place, and may release some into the wild. Records are kept so that the animals are not bred with

close relatives. But it is costly, and the young can only be released if a safe habitat is left for them.

Laws can also help. A law may forbid hunting a rare species, or limit how much of a fish stock may be taken. But a law works only if it is kept. It is hard to watch wild places, and some people lose the living they made.

Method	Keeps
nature reserve	habitat
corridor	links
seed bank	seeds
breeding programme	animals
law	species

What each method keeps. No method is enough alone, so they are used together.

TRY IT

Make a small seed bank

You need: seeds of 3 kinds, such as a dry bean, a pea and a pumpkin seed, paper envelopes or folded paper, a jar with a lid, a pencil, a cup of soil or wet cloth to test the seeds.

Be safe: Do not eat the seeds you store or test, and keep them away from small children. Use only seeds from food plants. Wash your hands after you touch soil.

1. Dry the seeds in the shade for two days. Fold each kind into its own paper, and write its name and the date on it.
2. Put the papers in the jar and close the lid. Keep it in a cool, dry place for a few weeks.
3. Take 10 seeds of one kind. Sow them in damp soil or on a damp cloth in a cup. Keep it damp and warm.
4. After a week, count how many have sprouted. Work out the percentage.

What you will see: Most of the seeds sprout, but not all. A seed bank must test its seeds from time to time, because some seeds die in storage.

If you cannot try it, this is what happens.

Seed	Sprouted
bean	9
pea	7
pumpkin	5

A WRONG IDEA MANY PEOPLE HAVE

~~It does not matter if a species dies out, because other species will fill its place.~~

Why it feels right: Living things have come and gone throughout the history of the Earth, so it seems natural.

The test that breaks it: Take the fox in the food web. If the rabbits are lost, the fox has nothing to eat. A new species does not appear in a few years to take their place. New species take thousands of generations to form.

What is true: Species that are lost cannot be replaced quickly. Other living things that depend on them may be lost too, so protecting biodiversity matters.

KEY WORDS

biodiversity
the variety of living things in a place or in the world, including how many species there are.

eutrophication
too many nitrates in water, which makes algae grow. When the algae die, the oxygen is used up and animals die.

conservation
protecting living things and their habitats.

nature reserve
an area where building, farming and hunting are controlled, to protect its living things.

habitat corridor
a strip of habitat that joins two patches, so animals can move between them.

seed bank
a store of seeds, kept cold and dry, so that plants can be grown again if they die out.

breeding programme
breeding endangered animals in a protected place, and sometimes releasing them into the wild.

BACK TO YOUR GUESS

The answer is C: The variety of living things falls, and species that depend on each other can be lost too. People can protect places, species and seeds.

When one species is lost, others that depend on it may follow. People cannot always replace what is lost, but they can protect places, animals and seeds.

CHECK YOURSELF

Try each one before you look. A wrong answer tells you where to go next.

1. Which is the best meaning of biodiversity?

   A The variety of living things in a place, including how many species there are

   B The total number of animals in a place

   C The number of trees in a forest

   Answer at the back of the book.

2. Why does clearing a forest for farmland reduce biodiversity?

   A Only the trees are affected, and the other living things stay.

   B Many species lose the food and shelter they need, and they die out or move away.

   C The species that are left breed faster and fill the space with new kinds.

   Answer at the back of the book.

3. Fertiliser washes into a river. Why may fish die?

   A The fertiliser poisons the fish directly.

   B The fertiliser makes the river too warm.

   C Algae grow fast and then die, and decomposers use up the oxygen in the water.

   Answer at the back of the book.

4. Why can an invasive species harm a community?

   A It always grows bigger than the local species.

   B It may have no predators or diseases in the new place, so it spreads and takes food and space from local species.

   C It adds a species, so biodiversity always goes up.

   Answer at the back of the book.

5. What is the main use of a habitat corridor?

   A It lets animals move between reserves, find mates and mix their alleles.

   B It is a road for people to visit the reserve.

   C It stops animals from ever leaving the reserve.

   Answer at the back of the book.

6. A seed bank stores seeds of many plants. Which is a limit of a seed bank?

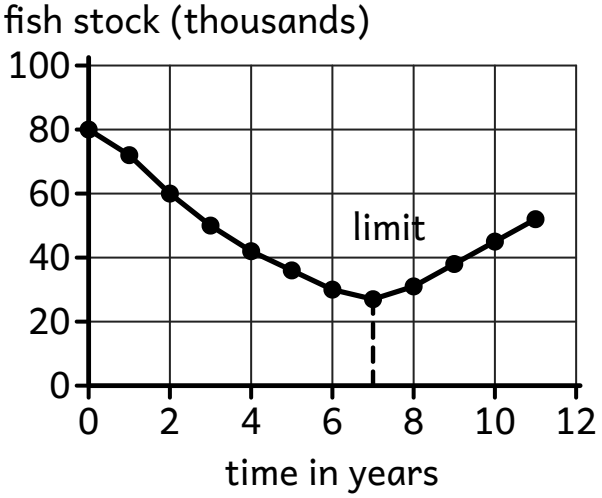
   A Seeds stored in a seed bank can never be grown again.

   B It keeps the whole habitat of each plant, and all the animals that live there.

   C It saves only the seeds, not the animals and the habitat, and some seeds do not keep for long.

   Answer at the back of the book.

7. Look at the graph of a fish stock. A limit on fishing begins in year 7. What does the graph show?



A The stock kept falling after the limit began.

B The stock fell until year 7 and then rose.

C The limit made no difference to the stock.

Answer at the back of the book.

8. **From an earlier chapter**

In a predator and prey graph, where does the predator peak come?

A Before the prey peak, because predators lead.

B At exactly the same time as the prey peak.

C A little after the prey peak.

Answer at the back of the book.

9. A seed bank tests 50 seeds. 42 sprout. What percentage of the seeds sprout?

Answer at the back of the book.

10. A forest of 500 km^2 loses 10 km^2 each year. What percentage of the forest is left after 8 years?

Answer at the back of the book.

KEEP IT

Copy this into your exercise book.

Habitat loss, pollution, invasive species, overhunting and climate change reduce biodiversity. Reserves, corridors, seed banks, breeding programmes and laws help, and each has limits.

Draw: Five boxes, one for each method of conservation, and under each one thing it keeps and one limit.

Key words, A to Z

Every key word in this book, what it means, and the chapter that teaches it.

abiotic factor
a non living thing that affects a community, such as temperature, light, water or soil pH. S4.3.7

antibiotic
a medicine that kills bacteria. It does not work on viruses. S4.3.1

biodiversity
the variety of living things in a place or in the world, including how many species there are. S4.3.8

biotic factor
a living thing that affects a community, such as food, a predator, disease or competition. S4.3.7

breeding programme
breeding endangered animals in a protected place, and sometimes releasing them into the wild. S4.3.8

capture and recapture
a way to estimate the number of animals that move. Catch and mark some, release them, then catch again and count the marked ones. S4.3.6

classification
sorting living things into groups that show how closely they are related. S4.3.4

common ancestor
a living thing from which two or more kinds of living thing came. S4.3.2

community
all the living things of every kind in one habitat. S4.3.7

competition
living things trying to get the same food, space or shelter when there is not enough for all. S4.3.1

conservation
protecting living things and their habitats. S4.3.8

cycle
the path of an element round living things and the non living world, so that it is used again and again. S4.3.5

decomposers
bacteria and fungi that break down dead things and waste. S4.3.5

denitrifying bacteria
bacteria that turn nitrates into nitrogen gas, in waterlogged soil. S4.3.5

domain
the biggest group of all. There are three: Bacteria, Archaea and Eukarya. S4.3.4

eutrophication
too many nitrates in water, which makes algae grow. When the algae die, the oxygen is used up and animals die. S4.3.8

evolution
the change in the inherited features of a population over many generations. S4.3.1

extinction
the death of every living member of a species. S4.3.3

fossil
the remains or trace of a living thing from long ago, found in rock, ice or amber. S4.3.2

fossil fuel
coal, oil or gas, formed over millions of years from the buried remains of living things. S4.3.5

fossil record
all the fossils we know, and what they tell us about life long ago. S4.3.2

genus
a group of very closely related species. The plural is genera. S4.3.4

habitat corridor
a strip of habitat that joins two patches, so animals can move between them. S4.3.8

interdependence
living things depending on each other, for food, shelter and other needs. S4.3.7

invasive species
a living thing carried to a new place, where it harms the local living things. S4.3.3

isolation
keeping two groups of one species apart, so that they cannot breed together. S4.3.3

kingdom
one of the biggest groups of living things, such as animals. S4.3.4

mass extinction
many species dying out in a short time. S4.3.3

natural selection
the process in which the living things best suited to their surroundings survive and breed more, and pass on their alleles. S4.3.1

nature reserve
an area where building, farming and hunting are controlled, to protect its living things. S4.3.8

nitrates
salts of nitrogen that dissolve in soil water. Plant roots take them in. S4.3.5

nitrifying bacteria
bacteria that turn ammonium into nitrates. S4.3.5

nitrogen fixing bacteria
bacteria that change nitrogen gas into compounds that plants can use. S4.3.5

population
all the living things of one kind in one place. S4.3.1

predator
an animal that hunts and eats other animals. S4.3.7

prey
an animal that is hunted and eaten by a predator. S4.3.7

quadrat
a square frame of known size that is laid on the ground, to count the plants inside it. S4.3.6

random
chosen by chance, so that every place has an equal chance. S4.3.6

resistant
not killed by something, such as an antibiotic. S4.3.1

sample
a small part of the whole that is counted or measured, and then scaled up. S4.3.6

sedimentary rock
rock made of layers of mud, sand and other pieces that settled and hardened. S4.3.2

seed bank
a store of seeds, kept cold and dry, so that plants can be grown again if they die out. S4.3.8

species

a group of living things that can breed together to give fertile young. S4.3.3

transect

a line *a*cross *a* habitat, *a*long which quadrats *a*re placed to show how living things change. S4.3.6

Answers

S4.3.1. Natural selection

1. **The living things vary in features that are inherited, and more young are born than can live.**

   There must be inherited variation, and competition because there are too many young. Then the best suited are more likely to live and breed.

   - **If you chose A:** If all had the same alleles, there would be nothing to select. Natural selection needs variation. Go to S4.2.7.
   - **If you chose B:** If every young one lived, there would be no competition and nothing to choose between. Most kinds make more young than can live.

2. **Green beetles were eaten less, so they bred more and passed on their alleles.**

   Green beetles survived more often, so more of them bred. Each generation had a larger share of green beetles.

   - **If you chose A:** A beetle does not change colour because it needs to. The alleles for green were already in the population.
   - **If you chose B:** Birds eat beetles. They do not change alleles. They only decide which beetles live to breed.

3. **They carried an allele for resistance, so the antibiotic did not kill them.**

   A few bacteria already had an allele for resistance. The antibiotic killed the rest and left them to divide.

   - **If you chose A:** The antibiotic did not change them. A mutation made them resistant by chance, before the antibiotic was added.
   - **If you chose C:** The person is not resistant. It is the bacteria that are resistant to the antibiotic.

4. **Feeling better does not mean all the bacteria are dead, so some may be left to divide again.**

   Bacteria that are left have survived the medicine so far. They can divide again, and the ones that are left are the ones the medicine kills least easily.

   - **If you chose B:** It is the bacteria that can become resistant. A person does not become resistant.
   - **If you chose C:** People often feel well before every bacterium is dead. The ones left can divide again. A health worker says how long to take the medicine.

5. **No. The change is in her body, and her alleles are not changed by it.**

   Muscles grow from use. This does not change the alleles in the egg cells, so her children do not inherit it.

   - **If you chose A:** Strong arms from work are a change to the body. The alleles in her sex cells are not changed by lifting jars.
   - **If you chose C:** Daughters and sons get their alleles in the same way. Lifting jars changes no alleles in either case.

6. **The antibiotic kills most of them. The few resistant ones divide, and so most of the next generation is resistant.**

   The resistant bacteria are the survivors, so they are the ones that divide. Their descendants are all resistant.

   - **If you chose A:** A bacterium does not learn. Survival depends on the alleles it already has.
   - **If you chose C:** Bacteria that are killed do not divide. Resistance spreads from the survivors.

7. **80%**

   Generation 2 has 8 green beetles and 2 brown beetles, 10 in all. 8 ÷ 10 = 0.8, which is 80%.

8. **16 bacteria**

   2 hours is 4 lots of 30 minutes. The number doubles 4 times: 2 × 2 × 2 × 2 = 16.

S4.3.2. Evidence for evolution

1. **A footprint made in mud long ago and turned to stone**

   A fossil is a trace or remains of a living thing from long ago. A footprint is a trace fossil.

   - **If you chose B:** A fossil is a trace of something that lived long ago, kept in rock, ice or amber. A new shell is not a fossil.
   - **If you chose C:** A fossil is much older, and has been kept in rock, ice or amber. A bone from last year has not been kept in this way.

2. **Layer D**

   Layer D is at the bottom, so it was laid down first. In layers that have not been moved, the oldest is at the bottom.

   - **If you chose A:** Layer A is at the top. A layer on top settled after the ones under it, so it is the youngest.
   - **If you chose C:** Each layer settled at a different time, one on another. Their ages are different.

3. **Species Y**

   Species Y differs from species X at 1 place. Species Z differs at 4 places. Fewer differences mean a more recent common ancestor.

   - **If you chose A:** Species Z differs from species X in more places than species Y does. More differences mean a more distant relative.
   - **If you chose C:** All DNA uses the same four bases, but the order of the bases differs. The number of differences tells how long ago the species shared an ancestor.

4. **Few dead things become fossils, and many fossils are destroyed or not yet found.**

   Soft bodies rot, fossils form only in rare conditions, rocks wear away or move, and many fossils are not found yet.

   - **If you chose A:** Life existed in those times. Its remains were just not kept, or have not been found.
   - **If you chose B:** It is the other way round. Most dead things rot or are eaten, and few become fossils.

5. **The human and the chimpanzee**

   The human and the chimpanzee branch from point C, which is the latest branch point on the tree.

   - **If you chose A:** Their paths meet only at A, the oldest branch point on the tree, far back to the left.
   - **If you chose B:** Their paths meet at B. The human and the chimpanzee meet later, at C, so they share a more recent ancestor.

6. **A larger share of the moths will be dark.**

   Dark moths are eaten less, so more of them breed and pass on their alleles.

   - **If you chose A:** A moth does not change colour because it needs to. Selection changes the share of each kind. Go to S4.3.1.
   - **If you chose C:** Being there longest does not decide who survives. The ones less likely to be eaten breed more. Go to S4.3.1.

7. **75 million years older**

   The shell is older. 120 − 45 = 75 million years.

8. **98%**

   4 out of 200 differ, which is 2%. So 100 − 2 = 98% are the same.

S4.3.3. New species and extinction

1. **A group of living things that can breed together to give fertile young**

   The test is whether they can breed together and have fertile young. This applies to animals and plants that breed sexually.

   - **If you chose B:** Looks are not the test. Dogs of different breeds look different, but their young are fertile, so they are one species.
   - **If you chose C:** A horse and a donkey can mate, but their young is a mule, which is almost always sterile. So they are two species.

2. **The two sides have different conditions, so selection acts differently on each. They change in different ways over many generations.**

   The barrier keeps the groups apart. Each group is selected by its own conditions, and each gets its own mutations.

   - **If you chose A:** The mountains do not change the beetles. The conditions on each side select different features over many generations. Go to S4.3.1.
   - **If you chose B:** Habits learned in life are not passed on in the alleles. Features change through selection and mutation. Go to S4.3.1.

3. **After many generations they must have changed so that they can no longer breed together to give fertile young.**

   They become separate species only when they can no longer interbreed to give fertile young.

   - **If you chose B:** Being apart is only the start. They are still one species until they cannot breed together to give fertile young.
   - **If you chose C:** Looks are not the test. What counts is whether they can still breed together to give fertile young.

4. **Dust blocked the sunlight for a time. Plants died, and the animals that depended on them died too.**

   Dust and soot cut off the light plants need. This broke food chains from the bottom, and many species died out.

   - **If you chose A:** Many kinds survived, including birds, small mammals and many plants and sea animals.
   - **If you chose C:** Many other kinds died too, such as the ammonites and many sea animals and plants.

5. **Habitat loss**

   The monkeys lost the place that gave them food and shelter. Habitat loss is the biggest cause of extinction today.

   - **If you chose A:** Hunting means taking too many animals by killing them. Here the monkeys lost their home, not their numbers to hunters.
   - **If you chose B:** An invasive species is a living thing that people carry to a new place. Nothing was carried here. The forest was cleared.

6. **Extinction has happened many times in the past, and people now add new causes.**

   Mass extinctions happened before people. Today habitat loss, hunting, invasive species, pollution and climate change caused by people add more.

   - **If you chose A:** Species died out long before people, for example in the asteroid impact 66 million years ago and after huge volcanic eruptions.
   - **If you chose C:** Species die out for many reasons, such as habitat loss, pollution and climate change. Hunters are only one cause.

7. **The resistant survivors divided, and their descendants are resistant.**

   The antibiotic killed the bacteria that were not resistant. The few resistant ones survived and divided.

   - **If you chose A:** The antibiotic does not make bacteria resistant. It kills the others. Go to S4.3.1.
   - **If you chose C:** It is the bacteria that are resistant, not the person. Go to S4.3.1.

8. **25%**

   The number lost is 40 − 30 = 10. 10 ÷ 40 = 0.25, which is 25%.

9. **170 kinds**

   15% of 200 is 0.15 × 200 = 30 kinds lost. 200 − 30 = 170 kinds are left.

S4.3.4. Classification

1. **Homo sapiens**

   The genus starts with a capital letter and the species name with a small one. In print the name is in italics.

   - **If you chose A:** The genus is the first word, and it starts with a capital letter. So it is Homo.
   - **If you chose B:** The species name is the second word, and it starts with a small letter. So it is sapiens.

2. **kingdom, phylum, class, order, family, genus, species**

   Each group sits inside the one before it. A species is in a genus, a genus is in a family, and so on up to the kingdom.

   - **If you chose B:** That list is the wrong way round. The kingdom is the biggest group, and the species is the smallest.
   - **If you chose C:** Two pairs are swapped. A phylum is a bigger group than a class, and a family is bigger than a genus.

3. **They are in the same genus, so they are close relatives.**

   The first word is the genus. Species in one genus are very closely related.

   - **If you chose A:** Two animals of one species share both words. Here only the first word is the same, so the species differ.
   - **If you chose C:** The first word is the genus. It does not say where a species lives.

4. **Comparing their genes showed that Archaea are very different from Bacteria.**

   Carl Woese compared genes and found that Archaea differ greatly from Bacteria, though both are single celled with no nucleus.

   - **If you chose A:** Some Archaea live in hot or salty places, but many do not. Where a living thing lives does not decide its group.
   - **If you chose B:** Both are tiny cells with no nucleus, and they look alike. The difference is in their genes.

5. **The brown bear**

   The giant panda and the brown bear branch from point C, which is the latest branch point on the tree. DNA shows that the panda is a bear.

   - **If you chose B:** The dog shares branch point B with the panda, which is further back in time. The panda and the brown bear share the later branch point C.
   - **If you chose C:** The cat splits off first, at the oldest branch point A. It is the most distant relative on this tree.

6. **Being apart does not make a new species. They are one species until they can no longer breed together to give fertile young.**

   The barrier is only the start. Each group is selected by its own conditions, and over many generations they may stop being able to interbreed.

   - **If you chose B:** Any living thing that breeds can form new species. Snails have done this many times.
   - **If you chose C:** A name is only a label that scientists give after they find that the groups differ. It does not make the groups different.

7. **5 levels**

   They share the kingdom, phylum, class, order and family. That is 5 levels.

8. **14 species**

   Each species belongs to one genus. 3 + 5 + 6 = 14 species.

S4.3.5. The carbon and nitrogen cycles

1. **Photosynthesis**

   Plants and algae take in carbon dioxide by photosynthesis and use its carbon to make glucose.

   - **If you chose A:** Respiration gives out carbon dioxide. It is the opposite of photosynthesis.
   - **If you chose B:** Burning gives out carbon dioxide. It does not take it in.

2. **Respiration, decay and burning**

   Living things respire and give out carbon dioxide. Decomposers give it out as they break down dead things. Burning gives it out too.

   - **If you chose A:** Photosynthesis takes carbon dioxide in. Decay and burning give it out.
   - **If you chose C:** Photosynthesis takes carbon dioxide in. Respiration and decay give it out.

3. **Plants respire all the time, and photosynthesise when there is light.**

   Every living cell respires. A plant photosynthesises only when there is enough light.

   - **If you chose A:** Plants respire all the time, day and night. Photosynthesis needs light, so it stops in the dark.
   - **If you chose B:** Plants take in carbon dioxide by photosynthesis. But they also respire, and respiration gives out carbon dioxide.

4. **The carbon was stored for millions of years, and burning puts it into the air in a short time.**

   Fossil fuels hold carbon from living things of long ago. Burning them returns that carbon to the air as carbon dioxide.

   - **If you chose B:** Atoms are not made when something burns. The carbon was already in the fuel, and burning joins it to oxygen.
   - **If you chose C:** Burning a fuel also gives out carbon dioxide. It takes in oxygen and gives out carbon dioxide.

5. **Their roots take in nitrates that dissolve in soil water.**

   Nitrates dissolve in water in the soil. Roots take them in, and the plant builds the nitrogen into proteins.

   - **If you chose A:** Plants cannot use nitrogen gas themselves. Only some bacteria can change it into a form that plants use.
   - **If you chose C:** An element cannot be made from other elements in this way. Plants must take in nitrogen compounds.

6. **Nitrifying bacteria**

   Decomposers make ammonium from dead things and waste. Nitrifying bacteria then turn it into nitrates, which roots can take in.

   - **If you chose B:** Denitrifying bacteria do the opposite kind of job. They turn nitrates into nitrogen gas.
   - **If you chose C:** Fixing bacteria change nitrogen gas into compounds. They do not make nitrates from ammonium.

7. **Those best suited to the conditions survive and breed more.**

   The antibiotic is the pressure. The resistant bacteria survive and divide, so they pass on their alleles.

   - **If you chose B:** If every one survived, nothing would be selected. The antibiotic kills most of the bacteria. Go to S4.3.1.
   - **If you chose C:** Bacteria do not change on purpose. The resistant ones already had the allele. Go to S4.3.1.

8. **156 litres**

   78% of 200 is 0.78 × 200 = 156 litres.

9. **45 units**

   What stays is what is taken in minus what is given out. 140 − 95 = 45 units.

S4.3.6. Measuring populations

1. **So that the sample is fair and does not favour places the person likes.**

   If a person chooses the places, the choice can favour thick or thin patches. Random placement gives a fair sample.

   - **If you chose B:** Placing quadrats only where plants are thick would give a count that is too high. Random placement gives every place an equal chance.
   - **If you chose C:** Random quadrats still count only a sample. We scale the sample up to estimate the whole field.

2. **7**

   Seven plants stand inside the frame. The three plants outside it do not count.

   - **If you chose A:** That counts the plants outside the frame too. Only the plants inside the frame count.
   - **If you chose B:** That is the number of plants outside the frame. The plants inside the frame are counted.

3. **The number falls along the line.**

   The counts get smaller from Q1 to Q5, and the last quadrat holds none.

   - **If you chose A:** The counts are 12, 9, 5, 2 and 0, so they are not the same.
   - **If you chose C:** Read the counts from Q1 to Q5. They get smaller, not bigger.

4. **The marks do not harm the animals or come off, and the marked animals mix back in.**

   If marks harmed animals or came off, the count would be wrong. So it would if the marked animals did not mix back in.

   - **If you chose B:** The two samples can be any size. What matters is that the animals are marked, mixed back in, and counted fairly.
   - **If you chose C:** The marked animals must mix back in with the others. If they stayed in one place, the second sample would not be fair.

5. **It is too high.**

   We divide by the marked animals in the second sample. If marks come off, that number is too small, so the estimate is too big.

   - **If you chose A:** Fewer marks are seen in the second sample. A smaller number marked makes the estimate larger, not smaller.
   - **If you chose B:** It is changed. The estimate divides by the number of marked animals found in the second sample, and that number is now too small.

6. **Snails move about, so they cannot be counted in a fixed square. Daisies stay where they are.**

   A fixed frame suits things that stay still. Animals that move are counted by marking and recapturing.

   - **If you chose B:** Size is not the reason. Snails move, so they leave the frame or hide.
   - **If you chose C:** Quadrats are mostly used for plants and for animals that hardly move. They suit things that stay in place.

7. **An invasive species**

   The rats are living things that people carried to a new place, where they harm the local species.

   - **If you chose B:** Habitat loss means that the place the animals need is destroyed. Here the place is still there. The rats were carried in. Go to S4.3.3.
   - **If you chose C:** Eruptions are a natural cause. Here people carried the rats to the island, so it is an invasive species. Go to S4.3.3.

8. **About 300 plants**

   The total is 6 + 4 + 8 + 5 + 7 = 30, so the mean is 30 ÷ 5 = 6 plants for each m^2. The field is 50 m^2, so 6 × 50 = 300.

9. **About 40 snails**

   The estimate is the marked in the first sample times the second sample, divided by the marked in the second sample. 8 × 10 ÷ 2 = 80 ÷ 2 = 40 snails.

S4.3.7. Interdependence

1. **Each owl peak comes after a mouse peak.**

   The mice peak in year 3 and the owls peak in year 5. The predator needs time to breed after the prey rise.

   - **If you chose A:** Read the years of the peaks. The mice peak first. Many mice give the owls more food, and then the owls rise.
   - **If you chose C:** Compare the peaks. The owl line peaks later than the mouse line.

2. **Plentiful prey give the predators food, but the predators need time to breed and grow.**

   More prey means more food, but young predators take time to be born and to grow up. So the predators peak a little later.

   - **If you chose A:** Speed is not the reason. The delay is about breeding. Predators need time to breed and grow when food becomes plentiful.
   - **If you chose B:** It is the other way round. Many prey give the predators plenty of food, and then the predators increase.

3. **The pH of the soil**

   Soil pH is not alive. Temperature, light, water and soil pH are non living factors.

   - **If you chose B:** A disease is caused by a living thing, such as a virus or a bacterium. So it is a living (biotic) factor.
   - **If you chose C:** A predator is a living thing, so it is a living (biotic) factor.

4. **The fox**

   The fox eats only rabbits in this web. The tawny owl has the frog as another food, and the frog eats grasshoppers.

   - **If you chose A:** The tawny owl also eats frogs, so it still has food.
   - **If you chose C:** The frog eats grasshoppers. The rabbits are not its food.

5. **Warm water holds less dissolved oxygen than cool water.**

   Fish take oxygen from the water. In warm water, less oxygen is dissolved, so the fish may have too little.

   - **If you chose A:** It is the other way round. Warm water holds less dissolved oxygen than cool water.
   - **If you chose B:** Temperature is an abiotic factor with a big effect. It changes how much oxygen the water can hold.

6. **Fewer flowers are pollinated, so they make fewer seeds.**

   The flowers and the bees depend on each other. Bees get nectar, and the flowers get their pollen carried.

   - **If you chose B:** Many flowers depend on animals such as bees to carry pollen from flower to flower. Without it, they make fewer seeds.
   - **If you chose C:** Bees carry pollen to the next flower. This is how the flowers are pollinated, so fewer bees means less pollination.

7. **Capture and recapture**

   Snails move, so we mark a sample, release it, catch a second sample and count the marked ones.

   - **If you chose B:** Quadrats suit plants and animals that stay still. Snails move about, so they would leave the frame. Go to S4.3.6.
   - **If you chose C:** That is not a fair sample. A few snails in one spot do not stand for the whole garden. Go to S4.3.6.

8. **75%**

   It fell by 200 − 50 = 150. 150 ÷ 200 = 0.75, which is 75%.

9. **30 rabbits for each fox**

   240 ÷ 8 = 30 rabbits for each fox.

S4.3.8. Biodiversity and people

1. **The variety of living things in a place, including how many species there are**

   Biodiversity is variety: how many different species live in a place, and how varied they are.

   - **If you chose B:** A place with a million animals of one species has little variety. Biodiversity counts the different species, not only the number of animals.
   - **If you chose C:** Trees are only one part of the living things in a forest. Biodiversity includes animals, plants, fungi and microbes.

2. **Many species lose the food and shelter they need, and they die out or move away.**

   The forest gave food and shelter to many species. When it is cleared, they lose their habitat.

   - **If you chose A:** Animals, fungi and plants that live among the trees depend on them for food and shelter. They are lost too.
   - **If you chose C:** New species take thousands of generations to form. In the short run, the variety falls. Go to S4.3.3.

3. **Algae grow fast and then die, and decomposers use up the oxygen in the water.**

   The nitrates make algae grow fast. When the algae die, decomposers feed on them and use up the oxygen the fish need.

   - **If you chose A:** The harm usually comes later, from the oxygen that decomposers use up.
   - **If you chose B:** Fertiliser does not warm the water. The harm comes from the oxygen that is used up later.

4. **It may have no predators or diseases in the new place, so it spreads and takes food and space from local species.**

   Without its enemies, an invasive species can spread fast. It eats or outcompetes the local species.

   - **If you chose A:** Size does not decide it. The problem is that nothing keeps it in check, so it spreads and takes food and space.
   - **If you chose C:** It may push out several local species, so the variety can fall.

5. **It lets animals move between reserves, find mates and mix their alleles.**

   A corridor joins small patches, so animals can reach food and mates, and alleles are mixed.

   - **If you chose B:** A corridor is for animals. A road can even cut across a corridor and make it less useful.
   - **If you chose C:** It does the opposite. It joins patches of habitat so that animals can move between them.

6. **It saves only the seeds, not the animals and the habitat, and some seeds do not keep for long.**

   A seed bank is a safe store of seeds. It cannot save habitats or animals, and the seeds must be tested because some die in storage.

   - **If you chose A:** They can. If a plant dies out in the wild, it can be grown again from the stored seeds.
   - **If you chose B:** A seed bank does not keep a habitat. A nature reserve protects a whole habitat.

7. **The stock fell until year 7 and then rose.**

   The line falls to its lowest point at year 7. After the limit begins, it rises.

   - **If you chose A:** Read the line after year 7. It goes up, not down.
   - **If you chose C:** The line changes direction at year 7. The stock rose after the limit began, so the limit seems to have helped.

8. **A little after the prey peak.**

   More prey give the predators food. Predators need time to breed, so their peak comes a little later.

   - **If you chose A:** Predators rise only after there are many prey to eat. Go to S4.3.7.
   - **If you chose B:** Predators need time to breed after food becomes plentiful, so their peak is a little later. Go to S4.3.7.

9. **84%**

   42 out of 50 is 42 ÷ 50 = 0.84, which is 84%.

10. **84%**

    The area cleared is 10 × 8 = 80 km^2. The area left is 500 − 80 = 420 km^2. 420 ÷ 500 = 0.84, which is 84%.

About this book

For learners who can follow a written argument and have met food chains, habitats and genes. In many schools this fits learners of about 14 to 16, and older learners can use it as a reference. Each chapter takes two or three short sessions. A learner can work alone: every exercise has its answer and the reason for it. The Try it activities use paper, beans, string and sticks. Nothing is heated and nothing is tasted. Animals are counted with beans or paper slips, never live ones. For the outdoor counting, choose a safe place with the owner's leave, pick nothing and harm nothing, and mind sharp sticks and the sun. The chapter on antibiotics gives no doses: medicine is taken as a health worker says.

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