

OXFORD

# BIOLOGY

FOR QUEENSLAND

AN AUSTRALIAN PERSPECTIVE

UNITS

**3 & 4**

LORRAINE HUXLEY

MARGARET WALTER

SERIES CONSULTANT  
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*Biology for Queensland An Australian Perspective Units 3 & 4* has been purpose-written to meet the requirements of the QCAA Biology General Senior Syllabus. The second of a two-volume series, *Biology for Queensland An Australian Perspective Units 3 & 4* offers complete support for teachers and students of Units 3 & 4 Biology, providing unparalleled depth and comprehensive syllabus coverage.

**CHAPTER 12**

### Biotechnology

Biotechnology, the application of biological knowledge to the production of organisms, or their products useful to humankind, has been used for thousands of years. Many of the foods that are taken for granted have been produced using artificial selection and breeding of organisms with desirable characteristics. Genetic principles and techniques have been applied to commercial enterprises, such as genetic engineering of drug-discovery and cloning.

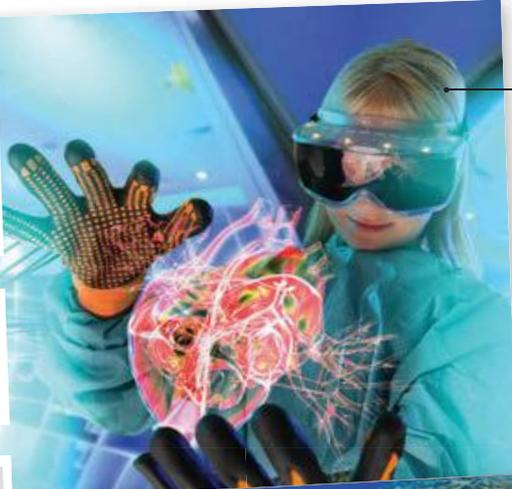
In the twenty-first century the field of DNA technology is one of the fastest growing areas of science. Recombinant DNA technology and DNA fingerprinting and profiling are major branches of this area. Recombinant DNA (genetic engineering) involves the introduction of new genes by cutting them out of the chromosomes of one species and inserting them into the chromosomes of another species. By doing this, organisms are modified to possess new, desirable characteristics.

**OBJECTIVES**

- Describe the process of making recombinant DNA:
  - isolation of DNA, cutting of DNA (restriction enzymes)
  - insertion of DNA fragment (plasmid vector)
  - joining of DNA (DNA ligase)
  - amplification of recombinant DNA (bacterial transformation).
- Recognise the applications of DNA sequencing to map species' genomes and DNA profiling to identify unique genetic information.
- Explain the purpose of polymerase chain reaction (PCR) and electrophoresis.
- Appraise data from an outcome of a current genetic biotechnology technique to determine its success rate.

**PRACTICALS**

- SUGGESTED PRACTICAL:** 12.2 Bacterial transformations
- SUGGESTED PRACTICAL:** 12.4 Gel electrophoresis



**Chapter openers**  
Each chapter begins with a chapter opener that includes:

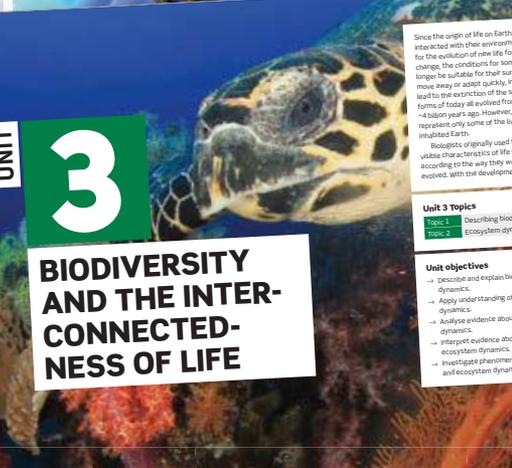
- subject matter from the **syllabus**
- a list of the **mandatory and suggested practicals** from the syllabus

**UNIT 3**

### BIODIVERSITY AND THE INTERCONNECTEDNESS OF LIFE

**Unit openers**  
Each unit begins with a unit opener that includes:

- an overview of topics in the unit
- unit objectives from the syllabus.



Since the origin of life on Earth, organisms have branched with their environment and paved the way for the evolution of new life forms. As environments change, the conditions for some organisms may no longer be suitable for their survival. If they cannot move away or adapt quickly, individuals die, which can lead to the extinction of the species. The diverse life forms of today all evolved from the most primitive life forms of about 3.8 billion years ago. However, present-day life forms represent only some of the living things that have inhabited Earth.

Biologists originally used their knowledge of the visible characteristics of life forms to classify them according to the way they were thought to have evolved, with the development of new research and technology in the field of biology, classification of life forms has dramatically improved.

Biodiversity refers to the range of living things that exists either globally or within a particular ecosystem. The composition of a community of organisms found within an ecosystem is dependent upon a number of factors. Abiotic and biotic components of an environment shape the densities of the populations comprising the community and drive adaptations of organisms to specific conditions. The recycling of matter and energy flow in a system plays a large role in maintaining diversity within a community.

Gross changes to an ecosystem can occur through natural events or human activity. These can bring about either increased or decreased biodiversity.

**Unit 3 Topics**

Topic 1	Describing biodiversity	Chapters 3-3
Topic 2	Ecosystem dynamics	Chapters 4-6

**Unit objectives**

- Describe and explain biodiversity and ecosystem dynamics.
- Apply understanding of biodiversity and ecosystem dynamics.
- Analyse evidence about biodiversity and ecosystem dynamics.
- Interpret evidence about biodiversity and ecosystem dynamics.
- Investigate phenomena associated with biodiversity and ecosystem dynamics.
- Evaluate processes, claims and conclusions about biodiversity and ecosystem dynamics.
- Communicate understandings, findings, arguments and conclusions about biodiversity and ecosystem dynamics.

Source: Biology 2019 v1.2 General Senior Syllabus © Queensland Curriculum & Assessment Authority

**4.3**

### Biogeochemical cycles

**KEY IDEAS**

- Elements are transferred and transformed
- The nutrient cycle
- Elements trapped in reservoir pools
- Cycling pools rapidly recycle elements

**General features**

Chemical elements tend to circulate in the biosphere in characteristic paths, from the environment to organisms and back to the environment. These are known as **biogeochemical cycles** (bio = life; geochemical = the study of chemical elements between different parts of the Earth). There are approximately thirty elements that are essential to living organisms. The pathways for a particular element between living and non-living components of an ecosystem is usually referred to as a **nutrient cycle**.

Biogeochemical cycles have two basic components: the **reservoir pool** and one or more **fluxes** or a **composited** that has relatively little turnover. For example, a significant amount of carbon is pooled as fossils or in deep-sea sediments below the Earth's surface. The cycling environment and organisms. Cycles in which the element is returned to the environment as rapidly as it is removed are said to be more perfect cycles.

Biogeochemical cycles are important because:

- They help retain necessary nutrients in usable forms for the living organisms of an ecosystem.
- They help to maintain a steady state (homeostasis) in ecosystems where populations do not undergo significant changes.

Many nutrient elements are washed out to sea and become part of the deep-sea sediments. Floor, much of which becomes incorporated into sedimentary rock. Most of the nutrients are therefore 'lost' to the ecosystem for great periods of time (millions of years), only entering the cycling pool once again when geological uplift or tectonic volcanism takes place. Due to the movement of the ocean currents, some of these deep-sea sediments can be brought to the surface at particular places on Earth, where there are upwellings of deep waters. The surface waters of these areas, therefore, are rich in plant and animal life.

**TABLE 1** Cycling of some major macromolecules

Nutrients	Reservoir pool	Cycling pool
Water	Atmosphere, glacier, polar ice caps	Transpiration - evaporation - precipitation - uptake
Oxygen	Metal oxides	Photosynthesis - respiration
Carbon	Fossils, peat, coal, oil and gas, tar, tar sands	Respiration - photosynthesis
Nitrogen	Deep-sea sediments	Nitrogen fixation - denitrification
Phosphorus	Phosphate rock, deep-sea sediments	Uptake - excretion - decomposition

**CASE STUDY 4.3**  
Galapagos Islands

The marine environment surrounding the Galapagos Islands is very rich with life. This is largely due to their location at an intersection between five major ocean currents. Together with the air temperature at the equator, the ocean currents create the Islands' climate and extensive food webs above and below the water. The largest of these currents is the Humboldt Current, which carries the cold water from the Antarctic, along the coast of South America, to the Galapagos Islands.

When ice periodically melts into the Southern Ocean, the water is cold and dense. As a result, this water sinks to the base of the Southern Ocean, sweeping up the nutrients from dead organisms that have settled to the ocean floor. These sediments (containing many essential nutrients and nutrients) follow the current west. As a result of the upwelling, the many producers in the waters surrounding the islands are provided with a constant source of nutrients. As the seasons change, waters from the Panama Current arrive from the north. This current of warm water is less dense and doesn't carry as many nutrients from the ocean floor, slowing the growth of phytoplankton producers. As a consequence, the rest of the islands' food web is affected.



**FIGURE 1** The diverse life of the Galapagos Islands

**Section-based approach**  
Content is presented in clearly structured sections. Each section is clearly labelled and numbered to help navigation.

**Case studies**  
Real-life examples illustrate theoretical points being explained in the text.

### Margin glossary

Key terms and definitions are highlighted to help students recall important information.

### Study tips

Practical assessment advice helps students improve their performance in assessment tasks.

## 3.7 Biodiversity in ecosystems

- KEY IDEAS**
- The biodiversity and health of the system
  - Species richness
  - Species diversity
  - Simpson's Index (D)
  - Simpson's Diversity Index (SDI)

Ecosystems are found in a great range of abiotic conditions, which in turn is reflected by the types and abundance of organisms making up the community. The biodiversity of an ecosystem is a measure of the number of different types and abundance of populations in a community. Some ecosystems (e.g. desert ecosystems) will have a very low biodiversity while others (e.g. a coral reef ecosystem) will have a very high biodiversity. Some areas that once supported a large number of different species have been cleared for growing crops. These other plants are actively eliminated. This then impacts on the types of fauna that will be present in this agricultural ecosystem.

A variety of measures can be used to assess the biodiversity of natural ecosystems. Two significant parameters are species richness and species diversity. Since most ecosystems are too large to measure all aspects of the entire area, random samples of the area are taken. Example plots of trees or field later organisms rather than for the entire community.

### Species richness

Species richness is a measure of the number of species compared to the number of individuals found in a sample. The larger the sample, the more species are likely to be found. To account for this, the Margalef Index, the number of species is divided by the square root of the number of individuals in the sample. See the equation below:

$$S = \frac{S}{\sqrt{N}}$$

where  $S$  is species richness,  $s$  is the total number of different species in the sample and  $N$  is the total number of individual organisms in the sample.

The data in Table 1 from samples of organisms obtained from two different communities, A and B.

FIGURE 1 The Simpson's Index (D) is calculated from the number of individuals of each species.

### WORKED EXAMPLE 3.7.1

1 Calculate the species richness for each community in Table 1. The same six species are represented in each community.

### SOLUTION

$$1 \quad S = \frac{S}{\sqrt{N}}$$

$$= \frac{6}{\sqrt{100}}$$

$$= 0.6$$

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### Worked examples

Detailed worked examples take students through how to solve different problems.

### Species diversity

Species diversity differs from species richness in that it takes into account both the number of species present and the evenness of species in relation to one another, i.e. the relative abundance of each species.

Simpson's Index (D) measures the probability that two individuals randomly selected from a sample will belong to the same species (or genus or family, etc.). If the two individuals are the same species, then it may indicate that this species is dominating the ecosystem. See the equation below:

$$D = \frac{1}{\sum \left( \frac{n_i}{N} \right)^2}$$

where  $n$  = total number of individuals of a particular species,  $N$  = total number of organisms of all species and  $\sum(n_i/N)$  is the sum of all species calculations of  $(n_i/N)$ . The value of  $D$  ranges between 1 and 1. The bigger the value of  $D$ , the lower the diversity of the ecosystem. A healthy ecosystem, with a large community of different species, will have a low  $D$  value.

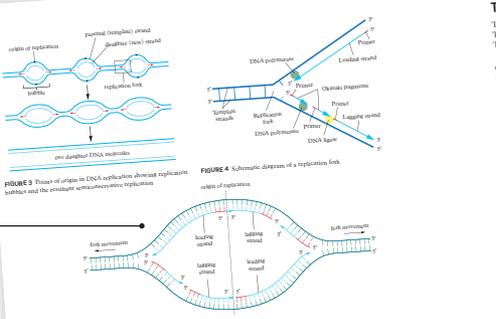
Simpson's Diversity Index (SDI) represents the probability that two individuals randomly selected from a sample will belong to different species (or genus). That is, it gives the reverse probability to that of Simpson's Index. It can be calculated using the following equation:

$$SDI = 1 - D$$

This value also ranges between 0 and 1, but in this case the higher the value, the greater the diversity.

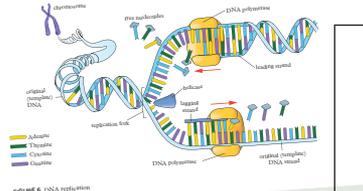
Simpson's Index (D) is the probability that two individuals randomly selected from a sample will belong to the same species (or genus or family, etc.).

Simpson's Diversity Index (SDI) is the probability that two individuals randomly selected from a sample will belong to different species (or genus).



### Termination

The termination of DNA replication occurs when the replication fork is stopped or blocked. This occurs when a special protein binds to the termination sequence in the DNA. The result of replication is two DNA molecules that are exactly like the original. In most cases, the two identical double-stranded DNA molecules remain joined by a centromere, a special kinetochore protein. This produces the X-shaped bivalent chromosome (with two chromatids) that is seen during mitosis and meiosis (Chapter 8).



### CHECK YOUR LEARNING 7.4

- Describe and explain**
- Sketch a segment of a molecule of DNA that is sixteen base pairs long.
  - Describe how this segment of a DNA molecule replicates.
  - Explain why this process is necessary.
  - Describe what would happen during mitosis if this process did not occur.
- 2 Describe a replication bubble.**

**Check your book assess for these additional resources and more:**

- Student book questions
- Weblink
- Termination

### Full-colour diagrams and photos

Rich visual material illustrates concepts and engages students.

### Check your learning

Each section ends with Check your learning questions that revise the content covered in the section and allow students to practise using cognitive verbs.

### Science as a human endeavour

Real-world contexts promote curiosity and can be used as a starting point for research investigations.

## 4.4 Keystone species

- KEY IDEAS**
- Keystone species
  - Keystone species
  - Keystone species

In some ecosystems, a particular species may be responsible for maintaining the balance of organisms. If this species is lost, it affects a number of other species in the community. Because this species holds a unique and crucial role in the way an ecosystem functions, it is called a **keystone species**.

Keystone species are often only identified after an ecosystem has been impacted. Some indicating features of a keystone species include:

- The ability to eat a variety of organisms in the ecosystem. This allows them to keep all populations under control.
- Its influence on other organisms is out of proportion to its biomass or abundance.
- The negative effects of removal of such a species (intentionally or unintentionally) from an ecosystem.

On the Great Barrier Reef, for example, the corals themselves are significant in maintaining the ecosystem as they not only form part of the food chain, but provide myriad microhabitats for other organisms through construction of their hard, skeletal structures. Parrotfish are the only fish, of thousands of reef fish, that scrape and clean off algal deposits from inshore coral reefs. If the parrot fish were removed, the coral would become overgrown with algae, affecting many of the other organisms living there. Therefore, both the coral and parrot fish could be considered keystone species for the reef ecosystem.

Some keystone species are mutualists, for example flying foxes, which are migratory, nectarivorous mammals that are significant in tree pollination and seed dispersal. Many forest plants are dependent on the flying fox for reproduction and spread of the species. With a more abundant supply of these fruiting trees, many other animals benefit. Flying foxes therefore drive biodiversity.

Other keystone species are carnivores. The northern quoll (*Dasyurus hallucatus*) is found across the northern part of Australia. It is an opportunistic feeder, consuming a wide range of organisms – insects, frogs, mammals, birds, reptiles and a variety of plants – and its doing so helps to maintain a balance within its habitat range. Threats to this species include cats (the poison of which has killed 30–40% of the population in road-adjacent areas), feral cats and foxes.

One group of keystone species can be defined as engineers because their behaviour ensures the continuance of a particular ecosystem. Earthworms are important engineers – their tunnelling activities in the soil improve soil aeration while simultaneously improving soil fertility.

In wildlife management, umbrella species are defined as those species that, through their conservation, protect many other species in that community, for example the billy (Macropus lagotis). Its presence requirements are similar to those of a wide range of other species in that habitat.



FIGURE 1 Keystone species come in many forms: (a) the parrot fish eats algae on coral, (b) the flying fox pollinates flowers as pollen attaches to its facial fat, and (c) the carabean northern quoll controls populations.

Conservation groups often use a particularly charismatic animal as a **flagship species** to drive the protection of particular habitats or for a particular environmental cause. The koala (*Phascolarctos cinereus*) and wombat (*Vombatus ursinus*) are such flagship species. Use of these species has the effect of gaining more community interest, enabling the generation of funds that can then be used in habitat conservation.

Flagship species are deliberately selected based on their human appeal. The grey nurse shark is a highly endangered species, but it is not used as a flagship species since many people fear sharks.

While a useful tool in wildlife management, there are some dangers in singling out a particular keystone, umbrella or flagship species in any ecosystem. Full knowledge of their significance is not always known. The difficulty in determining a possible keystone species can lead to minimizing the exact influence the species may have. The influence exerted by a species may be seasonal, depending on climatic conditions or migratory behaviour of other species. The distribution and abundance of these species may change with cyclic weather events and migration of other species.

### CHECK YOUR LEARNING 4.4

- Describe and explain**
- Identify an example of a keystone species that is:
    - a mutualist
    - an engineer
    - a carnivore.
  - Explain why most keystone carnivores are generalist feeders.

**Apply, analyse and interpret**

- Distinguish between a keystone and a flagship species.
- Consider difficulties that might arise when attempting to identify a keystone species in a particular ecosystem.

**Check your book assess for these additional resources and more:**

- Student book questions
- Weblink
- Umbrella species
- Flagship species

## Chapter reviews

Each chapter review includes:

- a **summary of key learning** in each chapter
- **revision questions** written to target assessment through multiple-choice and short-answer questions
- **key terms** introduced throughout the chapter
- **key formulas** used in the chapter.

## CHAPTER 6 Review

### Chapter summary

- Ecosystems undergo dynamic change. Ecosystems interact with each other.
- There are a series of community changes (pulses) that occur in an ecosystem undergoing succession.
  - primary succession results in the build-up of nutrients in soil, colonisation by r-strategist pioneer species, and an increase in biomass.
  - climax communities contain K-strategists, and high biodiversity in a relatively stable biotic and abiotic environment.
- Disturbance communities result from degradation of a community due to biotic and/or abiotic factors.
  - Forests provide evidence of past changes in ecosystems.
  - Pollen and spores are strong indicators of ecosystem changes.
  - Humans can decrease biodiversity through over-exploitation, habitat clearing, monocultures and pollution.
  - Eutrophication is caused by large amounts of nutrients washing into a body of water, resulting in dense plant growth and a decrease in oxygen concentrations. This increases the mortality of aquatic animals.
  - Introduced species can affect the equilibrium of a climax community.
    - Land, water and air pollution can affect the biodiversity of an ecosystem.

### Key terms

- aboriginalisation
- biodegradable
- biological magnification
- biological oxygen demand (BOD)
- climax community
- desertification
- diadromal community
- dominant species
- eutrophication
- exotic species
- habitat fragmentation
- half-life
- latitudinal zonation
- mangrove
- microclimate
- microenvironment
- persistence
- pest
- phenoclimatic zing
- pioneer species
- primary forest
- primary pollutant
- primary succession
- secondary forest
- secondary pollutant
- secondary succession
- seed
- temperature inversion

### Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: \* = low, \*\* = medium, \*\*\* = high.

#### Multiple choice

The paragraph below is used for questions 1–3. In 1883 a volcanic explosion removed all life from the island of Krakatau, near Java in East Indonesia. After only three months 11 species of ferns and 15 species of flowering plants had returned. Ten years later there were 263 species of animals on the island, which were mainly insects. Less than 50 years after the explosion, the whole island was covered with a dense forest.



FIGURE 1.14 An artist's impression of Krakatau erupting in 1883.

1 The above paragraph is a description of:

- A succession
- B an ecosystem
- C a community
- D evolution

- 2 Which of the following factors would **least** influence the rate at which organisms recolonised on the island?
- A temperature
  - B ocean tides
  - C spontaneous generation
  - D the distance from another island

3 The first organisms to recolonise on the island were plants. Identify which of the statements below helps to explain this.

- A Plants are able to make their own food.
- B Seeds and spores are easier to disperse than animals.
- C If animals reached the island first they would die from lack of food.
- D All of the above.

4 Select the statement that best completes this sentence: 'The climax stage of a biotic succession...'

- A persists until the environment changes significantly
- B changes rapidly from time to time, seldom equalling at any stage for more than a decade or so
- C is the first stage in the reclamation of land from a life bottom
- D is the stage in which trees are always dominant

5 Which of the following is **not** a requirement for a colonising species?

- A an available niche in the new area
- B a favourable climate
- C physiological potential to survive in the new area
- D an effective means of locomotion for dispersal

6 The effects of an algal bloom in waterways are collectively called:

- A biological magnification
- B nutrient recycling
- C eutrophication
- D decomposition

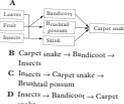
## UNIT 3 Practice examination questions (in preparation for external assessment)

These questions are exam style questions.

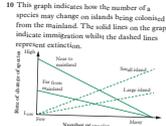
### Multiple choice

Select the alternative (A, B, C or D) that best answers the question or completes the statement.

- 1 Biodiversity:
  - A only refers to the ecosystems in which particular organisms are found
  - B results from the loss of some genes and gain of other genes in a range of different organisms
  - C refers to the types of organisms found on Earth
  - D refers to the variety of organisms, their genetic makeup and the ecosystems in which they are found
- 2 With reference to dogs, the possible and the sausage dog are:
  - A subspecies
  - B races
  - C varieties
  - D hybrids
- 3 An abiotic factor related to the climate of an area would be:
  - A water currents
  - B pH
  - C temperature
  - D topography
- 4 Which of the following best illustrates a food chain?
  - A
  - B
  - C
  - D
- 5 Which of the following statements is correct?
  - A There is greater stability in a complex food web than a simple food chain.
  - B Food webs exist because most animals are specialist feeders.
  - C Since matter is an infinite resource it is recycled between the abiotic and biotic environment.
  - D The ultimate release of mineral nutrients back into the environment is achieved by detritivores.
- 6 An ecological pyramid:
  - A, as the name suggests, the shape is always a pyramid, with primary producers forming the base and higher order consumers the top
  - B the base trophic level is always the largest
  - C the pyramid of numbers is always the same shape as the pyramid of biomass
  - D the pyramid of biomass is the same size pyramid shape as the pyramid of energy in all ecosystems
- 7 Which of the following is correct?
  - A Water → Aquatic photosynthesising organisms → Phytoplankton
  - B Carbon → Insects → Carnivorous insects
  - C Nitrogen → Fungi, pest → Decomposers
  - D Phosphorus → Rock, clay → Insects → Aquatic photosynthesising organisms



- 8 Population growth rate refers to:
  - A the change in population size
  - B the spread of population changes
  - C an increase in population size due to births and immigration
  - D the number of deaths and emigrations that occur in the population
- 9 Character displacement always results:
  - A when two species occupy the same niche in the same locality
  - B due to resource partitioning
  - C when the behaviour of two competing species is identical
  - D from divergence of overlapping characteristics in two species with the same niche
- 10 This graph indicates how the number of a species may change on islands being colonised from the mainland. The solid lines on the graph indicate immigration while the dashed lines represent extinction.
  - A Many species on a small island
  - B A small island far from the mainland
  - C An island near the mainland with few species
  - D A large island far from the mainland with many species



What conditions is the rate of immigration highest?

- A many species on a small island
- B a small island far from the mainland
- C an island near the mainland with few species
- D a large island far from the mainland with many species

### Short answer

- 1 The Red miter, *Mastomys natalensis*, is a bird (grass finch) in the order *Falconiformes* and family *Alcedinidae*. Classify the Red miter from kingdom to species. 3 marks
- 2 Describe how you could measure the height of a tree using an anemometer triangle. Explain why the same method cannot be used to measure the height of a hill. 4 marks

- 3 Consider three countries required prior to using a transect to compare an ecological survey. 3 marks
- 4 Compare the composition of a plant community in a tall open forest ecosystem with frequent annual fires and one in which there have been no fires for several centuries. 4 marks
- 5 The kākapo is a flightless bird from New Zealand. It is in danger of extinction because introduced predators such as cats, weasels and stoats. Fifteen pairs of kākapos were placed on an island that was free of predators in 2012. The number of birds were counted every December over the next six years. The results are shown below.
  - a Predict two reasons for the low breeding population in 2015. 2 marks
  - b Propose two reasons for the low breeding population in 2015. 2 marks
- 6 Differentiate between a primary and a secondary forest. 1 mark
- 7 Describe the process of desertification. 2 marks
- 8 Interpret the process of determining past climate change using core samples of polar ice. Compare this with the use of core samples of deep-sea sediments. 3 marks
- 9 Analyse the claim that 'success of ecosystem management is based on the classification of organisms'. 6 marks

Year	2012	2013	2014	2015	2016	2017	2018
Breeding population	20	14	8	25	27	34	34
Population	9	10	13	14	19	22	22
Deaths	6	12	5	4	4	15	15
Total birds	23	22	29	37	62	58	58

## Practice exam questions

Each unit includes a set of practice questions to prepare students for their end-of-year external examination. Questions include:

- **multiple-choice questions** to consolidate learning
- **short-answer questions** with additional guidance on how long students should spend on each question.

## Practical manual

Each mandatory practical from the syllabus has **proposed methodologies and materials** included in the practical manual. Suggested practicals are included via **obook assess**. Each practical is flagged in the relevant section of the Student book.

## CHAPTER 16 Practical manual

The QCAA Biology General Senior Syllabus outlines a number of mandatory and suggested practicals for completion in Units 3 & 4. All practicals are included in this chapter.

Suggestion for methodology and materials have been supplied in this chapter. However, the following is not prescriptive; schools may complete mandatory or suggested practicals in any other form suited to their resources.

The experiments in this chapter have been trialled and cautious of obvious hazards given; however, it is the legal obligation of the individual teacher to carry out their own risk assessment prior to undertaking any practical activity.

If you are unsure of any procedures in the lab or need any clarification for a practical, consult your teacher and/or lab technician.

### SAFETY IN THE LABORATORY

This chapter will highlight the safety concerns within each practical, but there are some general safety concerns to be considered before completing all practicals.

- Hair should be tied back.
- Do not eat or drink in the lab.
- Always be aware of your peers and act sensibly.
- Wear a lab coat, safety glasses, closed-toed shoes and gloves.
- Review the school's safety procedures and the location of eye wash, shower, spill kits and first aid kits.
- Handle all chemicals with care and consult your teacher and risk assessments for the hazards involved with each chemical.
- Keep open flames away from flammable materials.
- Handle hot materials with the appropriate equipment (i.e. heat-resistant gloves or tongs).
- Fieldwork should be completed in groups with a full risk assessment completed prior to the trip.

## 3.8A Analyzing vegetation patterns using a transect line

- Part A – Measure abiotic factors in the classroom using field samples (e.g. pH, nitrogen nutrients, salinity, carbonates, turbidity) – Suggested practical. Source: Biology 2019 V.1.2 General Senior Syllabus © Queensland Curriculum & Assessment Authority
- Part B – Measure abiotic factors in the field (e.g. dissolved oxygen, light, temperature, wind speed, infiltration rate) – Suggested practical. Source: Biology 2019 V.1.2 General Senior Syllabus © Queensland Curriculum & Assessment Authority
- Part A and B – Use appropriate technology, such as data loggers, chemical tests, turbidity tubes and other equipment to measure factors – Manipulative skill. Source: Biology 2019 V.1.2 General Senior Syllabus © Queensland Curriculum & Assessment Authority
- Part C – Determine species diversity of a group of organisms based on a given index – Mandatory practical. Source: Biology 2019 V.1.2 General Senior Syllabus © Queensland Curriculum & Assessment Authority

### Aims

- 1 To use data collected from a transect profile to:
  - a measure a variety of abiotic factors along a transect
  - b determine the relative abundance of a species and families of plants
  - c calculate and compare densities of plant species and families across an ecosystem
  - d calculate and compare species diversity across an ecosystem
  - e determine possible relationships between chosen plant species and abiotic conditions

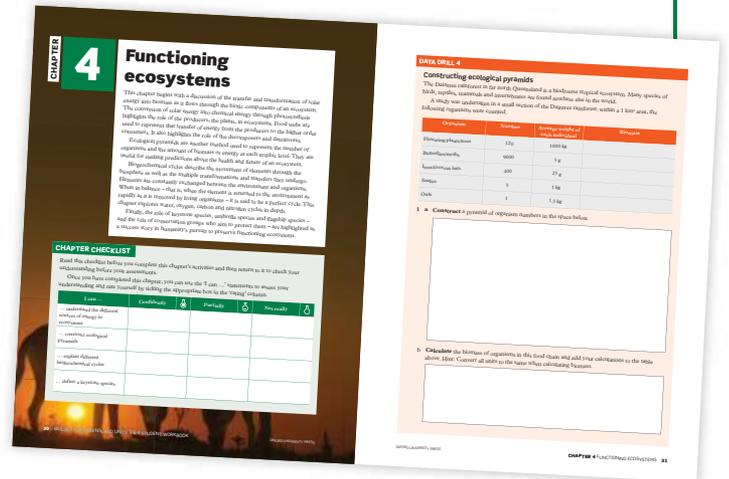
### Materials

- Class requirement:**
- 100 metre length of rope marked at 5 metre intervals (transect line)
- For each group:**
- Laboratory thermometer
  - Wet-and-dry bulb thermometer
  - Light meter (LUX)
  - Anemometer
  - Compass
  - Ribbon or cloth on a stick (wind direction)
  - Trowel
  - Sample bottles for soil (4)
  - 500 mL deionised/distilled water
  - Spirit level
  - Metre ruler and plastic 30 cm ruler
  - Zip lock plastic bags with labels
  - Pencil and marker pen
  - Clipboard
  - Paper to record data

## Student workbooks

*Biology for Queensland An Australian Perspective Units 3 & 4* and *Units 1 & 2* are supported by two Student workbooks that follow the same structure as the Student books, ensuring that students are consolidating relevant topic knowledge and developing key assessment skills. The workbooks include:

- a **toolkit** chapter that explains each key internal assessment
- **Data drill** activities that allow students to practise analysis and interpretation skills for the Data test
- **Experiment explorer** features to support the modification of a practical as required in the Student experiment
- **Research review** activities to help students develop skills in evaluating a claim and conducting research
- **Exam excellence** questions that include multiple-choice and short-answer questions to prepare students for the external assessment
- **practice internal assessments** (Data test, Student experiment and Research investigation)
- write-in worksheets for all **mandatory** and **suggested practicals**
- **answers** to all activities and assessments.



## obook assess

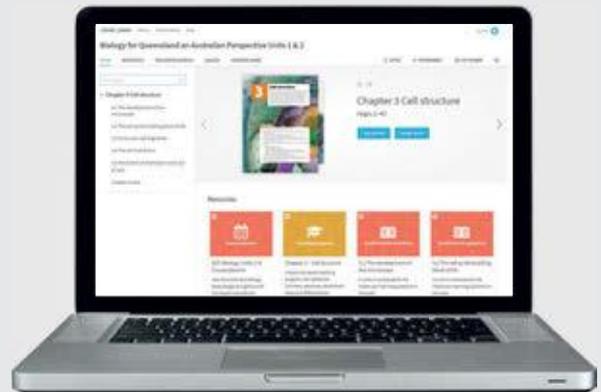
*Biology for Queensland An Australian Perspective Units 3 & 4* is supported by a range of engaging and relevant digital resources via obook assess.

Students receive:

- a complete digital version of the Student book with notetaking and bookmarking functionality
- video tutorials demonstrating key skills
- write-in worksheets to accompany all mandatory and suggested practicals
- interactive auto-correcting multiple-choice quizzes
- a range of engaging weblinks to support understanding
- access to work assigned by their teacher: reading, homework, tests, assignments.

In addition to the student resources, teachers also receive:

- detailed planning resources
- Student book answers
- printable (and editable) sample assessments, including data tests and exams with answers
- the ability to set up classes, set assignments, monitor progress and graph results, and to view all available content and resources in one place.



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# BIOLOGY TOOLKIT

Biology is the study of how all life forms interact with the living and non-living components that make up their environment. An environment is shaped by the interaction of chemical and biological processes. The earliest life forms on Earth were thought to live in simple ecosystems, but with evolution and diversification of species, modern-day life forms thrive in the wide variety of complex ecosystems that exist today. Biologists investigate ecosystems through observations, measurements and experiments. They formulate hypotheses that are modified over time. This process is known as the scientific method.

This chapter is a toolkit of concepts, and it can be referred to throughout the year when preparing for the various assessment tasks.

A variety of assessment tasks are included in Year 12, all of which count towards the final result. In order to maximise understanding and learning, it is important to use appropriate learning and revision strategies throughout the year to be best prepared for assessments.

**FIGURE 1** Biology experiments often involve field work to collect samples and run ongoing observations.



# 1.1

## Year 12 assessment

### KEY IDEAS

- + Data test (10%), Student experiment (20%) and Research investigation (20%)
- + The external examination (50%)

The Queensland Curriculum and Assessment Authority (QCAA) sets the number and types of summative assessment instruments that are used to determine the student's overall results. It is important to be familiar with the expectations of each form of assessment to allow adequate time to complete tasks.

Half of the overall assessment result will be set by each school and administered by the school at an appropriate time. These tasks will be monitored and the results verified by trained assessors to ensure comparability of tasks, level of student responses, and marking.

The other half of the overall result is gained from an external examination: two papers that are developed and marked by QCAA. These papers are administered to all students in the state taking the subject, under the same conditions, at the same time of the same day.

## Summative internal assessment

Three pieces of summative internal assessment are to be performed – two covering Unit 3 (Biodiversity and the interconnectedness of life) and one addressing Unit 4 (Heredity and continuity of life).

It is required that Unit 3 be assessed using a Data test and Student experiment while the assessment for Unit 4 is a Research investigation. The skills you will require to complete your internal assessments and practice internal assessments can be found in the *Biology for Queensland An Australian Perspective Units 1 & 2 Student Workbook* and *Biology for Queensland An Australian Perspective Units 3 & 4 Student Workbook*.

### Data test

The overall weight of the Data test is **10%**. The test is completed individually and under supervised conditions. The time allowed is 60 minutes plus 10 minutes of perusal time.

The types of questions may include:

- short response
- extended response
- calculations
- interpreting graphs, tables or diagrams
- responding to quantitative and qualitative data and/or content from practicals and case studies.

The QCAA objectives include:

- apply understanding of biodiversity or ecosystem dynamics to given algebraic, visual or graphical representations of scientific relationships and data to determine unknown scientific quantities
- analyse evidence about biodiversity or ecosystem dynamics to identify trends, patterns, relationships, limitations or uncertainty in datasets
- interpret evidence about biodiversity or ecosystem dynamics to draw conclusions based on analyses of datasets.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

### Study tip

Practice Data tests can also be found for Units 1–3 in *Biology for Queensland An Australian Perspective Units 1 & 2 Student Workbook* and *Biology for Queensland An Australian Perspective Units 3 & 4 Student Workbook*.

## Student experiment

The overall weight of this task is **20%**.

This assessment task evaluates the student's ability to use the **scientific method** by modifying (e.g. refining, extending or redirecting) an experiment in order to address their own related hypothesis or research question.

**scientific method**  
the testing of a hypothesis by controlled experimentation

Ten hours are to be provided in class time for this task, but completion may require some extra out-of-class time. During class time the student is expected to:

- perform background research and develop the methodology
- conduct the experiment
- process and analyse evidence and evaluate the methodology
- prepare and present the results.

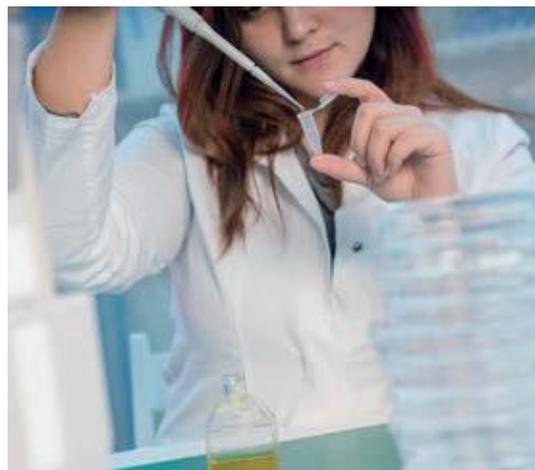
Although it is acceptable that students work in groups to determine a research question, develop a methodology and perform an experiment; the processing of data, analysis of evidence and evaluation of an experimental design must be carried out individually.

The QCAA objectives include:

- apply understanding of biodiversity or ecosystem dynamics to modify experimental methodologies and process primary data
- analyse and interpret experimental evidence about biodiversity or ecosystem dynamics
- investigate phenomena associated with biodiversity or ecosystem dynamics through an experiment
- evaluate experimental processes and conclusions about biodiversity or ecosystem dynamics
- communicate understandings and experimental findings, arguments and conclusions about biodiversity or ecosystem dynamics.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

The response will either be a written report (1500–2000 words) or a multi-modal presentation (e.g. a poster or PowerPoint presentation) of 9–11 minutes.



**FIGURE 1** Student filling a microcentrifuge tube for a polymerase chain reaction (PCR)

## Research investigation

The overall weight for this task is **20%**.

In this assessment the students are to individually evaluate a **claim** by researching, analysing and interpreting **secondary evidence** from scientifically credible sources. Ten hours of class time is to be provided to carry out the major component of this task.

The QCAA objectives include:

- apply understanding of DNA, genes and the continuity of life or the continuity of life on Earth to develop research questions
- analyse research evidence about DNA, genes and the continuity of life or the continuity of life on Earth
- interpret research evidence about DNA, genes and the continuity of life or the continuity of life on Earth
- investigate phenomena associated with DNA, genes and the continuity of life or the continuity of life on Earth through research
- evaluate research processes, claims and conclusions about DNA, genes and the continuity of life or the continuity of life on Earth

**claim**  
a statement without evidence to support it

**secondary evidence**  
evidence from a secondary source (e.g. a peer-reviewed scientific article)

- communicate understandings and research findings, arguments and conclusions about DNA, genes and the continuity of life or the continuity of life on Earth.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

The response will either be a written report (1500–2000 words) or a multi-modal presentation (e.g. a poster or PowerPoint presentation) of 9–11 minutes.

## Summative external assessment

### Study tip

Practice external examination questions can be found in the *Biology for Queensland An Australian Perspective Units 1 & 2 Student Workbook* and *Biology for Queensland An Australian Perspective Units 3 & 4 Student Workbook*.

The external assessment comprises **50%** of the overall student result. This examination is made up of two papers, each of which assesses learning from both Units 3 and 4.

Using questions, scenarios and problems the student is given the opportunity to demonstrate their knowledge and understanding of terminology, key ideas and concepts by:

- describing and explaining
- applying understanding
- analysing evidence to identify trends, patterns, relationships, limitations or measures of uncertainty in datasets
- interpreting evidence and drawing conclusions based on analysis of datasets.

## Specifications

Each paper consists of a number of types of possible items:

- multiple-choice questions
- short-response questions
- extended response questions (300–350 words or equivalent)
- calculations
- interpreting graphs, tables or diagrams
- responding to unseen data and/or content.

## Conditions

Paper 1

- Time: 90 minutes plus 10 minutes of perusal time
- Other: QCAA-approved graphic calculator permitted

Paper 2

- Time: 90 minutes plus 10 minutes of perusal time
- Other: QCAA-approved graphic calculator permitted



**FIGURE 2** The external examination will be 50% of your overall result.

## CHECK YOUR LEARNING 1.1

### Describe and explain

- 1 **Describe** the difference between a Research investigation and a Student experiment.

- 2 **Explain** the objectives of the Data test.

- 3 **Summarise** the specifications of the summative internal assessment.



Check your obook assess for these additional resources and more:

» **Student book questions**

Check your learning 1.1

» **Video**

The Data test

» **Video**

The Student experiment

» **Video**

The Research investigation

# 1.2

## Student experiments

### KEY IDEAS

- ✦ Experiments and bioethics
- ✦ Research methods must be valid and reliable
- ✦ Qualitative and quantitative data
- ✦ Experimental investigations in a formatted report

### Experimental ethics

Experimental ethics is the series of principles that guide the way an experiment is carried out. These principles govern who or what may participate in the experiment and how they should be treated. In Australia, experiments may not be conducted on vertebrate animals (including humans) without submitting a full experimental report to the relevant bioethics committee for approval. The guidelines for animal experimentation are extremely strict to ensure the animals are treated with respect, and that their well-being is considered.

When humans participate in experiments, each participant needs to be provided with a form outlining exact procedures, a confidentiality agreement (e.g. no names recorded) and safety procedures. Each participant (or their guardian if they are under 18 years old) needs to sign a consent form. School students should not undertake experimental investigations using human subjects.



**FIGURE 1** Plants are the most commonly used specimens in classroom experiments.

### The use of a logbook

The use of a logbook is very important when conducting an experiment. It should include the following:

- a list of experimental ideas or questions (with advantages and disadvantages)
- a summary of library and internet research (including full references)
- notes on experimental procedures
- possible means of collecting data
- raw data or results
- possible interpretations of data.

All information is then in one place when it comes time to write the report. Experimental logbooks can also be used as evidence of intellectual property.



**FIGURE 2** Logbooks are a tool for recording information that will later be crucial to writing the report.

### Developing a research question and hypothesis

The Student experiment will be carried out over a limited time. Thus, the research question must be succinct and provide results that can be easily analysed.

**valid**

describes an experiment which provides data relating directly to the hypothesis

**reliable**

the degree to which an investigation produces stable and consistent results

**hypothesis**

a statement that attempts to answer questions raised by observations and can be tested by experimentation

**table**

a display of information in named rows and/or columns

**Study tip**

Measures of central tendency and variance, and different types of graphical representations can be reviewed in *Biology for Queensland An Australian Perspective Units 1 & 2* and found in your qbook assess.

Once the research question has been determined, a check on whether other people have already conducted research in that area is required. The methodology they used should be compared with the proposed method. A research method is **valid** if the data provided in the results directly answers the scientific question that was asked. The validity of an experiment can be improved if the variables are controlled, the data is carefully measured, and randomised samples are used.

The experimental method must also be **reliable** (a measure of how similar the results will be if the experiment was repeated by another group of scientists). Reliability can be improved by repeating the experiment or increasing the sample size and determining the central tendency of the data.

Careful planning will increase both the validity and reliability of an experiment. Do different abiotic conditions occur on the school oval and do these determine specific growth of (name the species under consideration)? The following points should be considered:

- What abiotic conditions exist on the school oval? Consider sunlight, slope of the immediate and surrounding land, soil type(s), soil pH, soil water-holding capacity and drainage at different parts of the oval.
- How can the abiotic conditions be determined? Careful observation of the oval at different times of the day could eliminate some factors from the investigation and may narrow down the investigation to soil features.
- How many quadrats will be tested?
- What equipment is available to perform the experiment?
- What is to be measured and how?
- How will the raw data be recorded?
- How can the raw data be manipulated to provide meaningful results (e.g. using graphs, tables and statistical tests)?
- What are the independent and dependent variables for this investigation?

Having decided on these points, the hypothesis can be developed. A **hypothesis** is a tentative explanation for an observed phenomenon, expressed as a precise and unambiguous statement that can be tested. It must clearly state the procedure for testing, controls (i.e. factors that remain constant throughout the experiment), independent and dependent variables, and how measurement and recording of data will occur. Once the method has been established, from the hypothesis it is important to consider any safety measures needed and an audit of all the required chemicals and equipment needs to be undertaken.

## Presentation and analysis of data

Raw data needs to be presented clearly so that it is easy to analyse.

**Tables** can be used to present quantitative (nominal or numerical) and qualitative (descriptive) data. All tables should be given a title at the top and each column should have its own heading. Quantitative data may show trends, changes or variation, and so graphs are often a good way to present this data.

## The experimental report

Experimental reports need to be both concise and precise. The standard format of the report includes the following:

Title	A clear statement outlining the problem to be investigated. This is followed by the student's name and date of submission.
Abstract	A short summary of the findings.
Introduction	The introduction has several sections: <ul style="list-style-type: none"> <li>• a short explanation of the reasons for and development of the research question</li> <li>• findings of previous studies (e.g. library research)</li> <li>• reasons for the method used</li> <li>• a hypothesis predicting the outcomes of the investigation (e.g. change in the dependent variable(s) associated with change in the independent variable(s)) the sample used, the conditions of the experiment and the time frame.</li> </ul>
Equipment list	A list of equipment used, including the brands and concentrations.
Safety audit	A list of all possible hazards and the measures taken to ensure safety. Ask your teacher for chemical Material Safety Data Sheets (MSDSs).
Method	An account of the activities that have been done in the investigation. It should be succinct, precise and with a logical order for apparatus set-up and activities performed in the experiment. Where appropriate, a diagram or photograph of the equipment set-up is included. The method is usually written as a concise list of instructions. It must be written in such a manner that another scientist could easily and exactly repeat the experiment.
Results	Qualitative (subjective or objective) or quantitative and presented clearly in a form or forms best suited to the results. The forms may be a verbal description, tables of data, graphs, photographs or any other suitable form. Any mathematical analyses of data should be included.
Discussion	A brief account that may answer the question posed by the hypothesis. It should not be a repeat of the results, but instead a genuine attempt to state and relate the theoretical aspects of knowledge to the experimentally obtained results. It should include: <ul style="list-style-type: none"> <li>• analysis of the data to support or reject the hypothesis, or show that it is inconclusive</li> <li>• a paragraph critiquing the methodology (e.g. the validity and reliability of the data, any possible variables that could not be controlled, and other relevant observations)</li> <li>• possible improvements, along with suggestions for future hypotheses or experimental ideas.</li> </ul>
Conclusion	A short statement of the findings of the investigation that are related to the hypothesis.
Bibliography	An alphabetical list of all references used in the report.

## CHECK YOUR LEARNING 1.2

### Describe and explain

- 1 Describe** why ethics is an important part of many biological experiments.

### Investigate, evaluate and communicate

- 2 Investigate** the best types of datasets to use with pie graphs, column graphs and line graphs.

Check your obook assess for these additional resources and more:

» **Student book questions**

Check your learning 1.2

» **Video**

The Student experiment

» **Increase your knowledge**

Measures of central tendency

» **Increase your knowledge**

Graphing data



# 1.3

## Research investigations

### KEY IDEAS

- ✦ Time management during a Research investigation
- ✦ Key words and concepts in Research investigations
- ✦ Peer reviewed and credible source resources

### scientifically credible sources

resources from government and institute sites, peer-reviewed scientific articles and reports, textbooks, etc.

A Research investigation requires students to evaluate a claim. This is achieved by researching, analysing and interpreting secondary evidence from **scientifically credible sources**. This will provide the basis for a justified conclusion about the claim.

### Time management

It is important to note the due dates for the task, which may include those for progress reports and draft reports, and a final date. The time allowed may appear generous, but if assignments in several subjects are all due at around the same time, it is human nature to focus on the one due first.

### Clarifying the task

The Research investigation contains a number of different things that must be considered. To make sure you do not miss an important criterion, it is important to have a checklist of all aspects of the task. Things to consider before starting the Research investigation include:

- How will the task be presented – as a scientific report, a poster presentation, or a PowerPoint presentation?
- How long should the response be (words/minutes)?
- What course objectives are being assessed?
- The task is assessed from the marking criteria sheet. Consider the:
  - relative importance of each section (criterion)
  - allocation of research time to be spent on each section to complete the total task
  - number of words for each section so that you comply with the total number of words for the whole task.
- How many resources are needed to provide enough information?
- What determines whether a resource is relevant and reliable?

Most of these questions or points can be answered by careful reading of the assignment sheet, but your teacher will be able to assist with further information.

### Beginning the task

Before starting the task, it is important to identify the key words and concepts.

For example, the following claim has been selected for the Research investigation:

In view of a greater understanding of epigenetics, it is highly probable that the Lamarckian theory of evolution could explain many instances of rapid evolution.

The key concepts are epigenetic inheritance, Lamarck's theory of evolution and rapid evolution.

Make notes on what is already known about these three areas.

Write down any further questions that are needed to find out about these three areas.

- How can environmental conditions influence regulatory genes (and therefore the structural genes)?
- How can changes in the expression of regulatory genes be inherited?
- What links exist between epigenetics and changes in an organism's characteristics?
- How many generations have been shown to respond to epigenetic programming?
- In what way could this explain the rapid evolution of a new species?

Breaking the large claim into a series of smaller questions will help you to organise your thoughts and develop a considered, specific and relevant response to the claim.

## Research techniques

It is very important that the research question be approached with an open mind. Preforming an opinion (bias) may mean that only data that supports this bias is examined. Consider what evidence is needed to disprove preconceived ideas. The research should examine evidence that both supports and rejects the claim.

It is also important to look for information from a range of sources. While it can be easy to use a search engine to find information online, valuable information is also available at the library in books and scientific journals. A good Research investigation should refer to a range of sources from a number of different authors.

## Identifying credible sources

A Research investigation requires evidence to be obtained from scientifically credible sources. A topic search on a search engine such as Google Scholar will find many articles. Some of these will be simplified explanations of the topic that appear to be clear and that make strong assertions. However, anyone can submit an article and have it published on the internet; many of these are anecdotal and without scientific evidence.



**FIGURE 1** Seeking information for a research question can involve textbooks and online resources.

Questions to ask when deciding if the source is scientifically credible could include:

- Is the article published in a recognised scientific journal?
- Was it from a website set up by a government department (.gov) (e.g. DPI or CSIRO), a university (.edu), an independent research organisation (.org) (e.g. The Cancer Foundation) or a manufacturer of scientific and technological equipment?
- Was the information in a book written by a scientist working in the field under investigation?

Checking that the information is consistent across more than one source gives a strong indication of the validity and reliability of the source.



**FIGURE 2** Google is a great starting place for your research.

## Analysing sources

A good way to start analysing the information obtained is to summarise the article (making sure that all relevant details, such as title, author, date and publication are recorded). This should include notes on:

- how it answers the question posed
- evidence provided to support its claims
- how the evidence was collected
- further sub-questions raised by the article.

As more information is gathered, comments on the links between ideas and evidence can be made that can help form the final argument.

In this way the data can be examined to determine if:

- enough information has been collected (e.g. several further sources do not provide extra information)
- the evidence is of high quality and relevant to the research question
- there are limitations in the evidence (e.g. small studies with limited sample size).

### Study tip

Use a different colour to highlight information for each sub-question. This allows you to check that you have enough evidence to answer each section.

# Interpreting the data and evaluating the claim

Using the summaries of the research articles, several questions can be posed, such as:

- Do different articles contradict each other?
- How were the data collected in each source – observation, questionnaire, experiment?
- How valid is each set of data?
- Do the data show a clear cause and effect relationship?
- Are any trends obvious?
- What further analysis is required to determine a trend?

The information from the research can often be put into tables that compare (similarities and differences) and contrast (deliberate comparison of opposing arguments – for and against), or show evidence to support or refute, the claim. Both quantitative and qualitative data can be presented as graphs. Concept or mind maps could be drawn to show links between ideas and data. All of these methods assist in interpretation (clarifying a position and recognising trends). This interpretation needs to show the extrapolation of the research question to the claim.

An evaluation can then be made concerning the validity of the claim – supporting evidence is provided.

## Preparing the response

The response required can be varied. Most written reports (e.g. literature review or argumentative essay) are about 2000 words long whereas a poster presentation, for example, should take 9–11 minutes. Regardless of the style of response, it should contain the following:

- the claim
- the research question posed
- the rationale for the investigation
- evidence-based, justified scientific arguments
- the conclusion to the research question based on the interpretation of the evidence
- evaluation of the claim and suggestions of improvements and extensions to the investigation
- a **reference list**.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

**reference list**  
a list of resources used in a study

The emphasis placed on each of these areas will be indicated by the marking scheme.

### CHECK YOUR LEARNING 1.3

#### Describe and explain

**1 Describe** why some websites are not credible sources for your Research investigation.

**2 Explain** how you can determine the main points of a research question.

**3 Clarify** different ways to present your Research investigation.

#### Check your obook assess for these additional resources and more:

» **Student book questions**

Check your learning 1.3

» **Video**

The Research investigation

» **Weblink**

Google Scholar



# 1.4

## Exam preparation

### KEY IDEAS

- + Preparing for an end of year examination
- + Key cognitive verbs used in the examination

Success in exams requires a deep understanding that is embedded in long-term memory. Since knowledge of facts and concepts learnt in Unit 1, for example, may be presumed when studying Unit 4, the development of strategies to ensure long-term memory is very important. The best way to prepare for exams is to start a study program from the first day of the academic year.

### Preparing a study timetable

The combination of assessments spread throughout the year, and the end-of-year examinations, means that you will need to develop a good study routine and maintain it throughout the year. The best way of doing this is to spend at least 3 hours per week outside of class time on each of your subjects. This time needs to be divided between completing the tasks set by your teacher, learning the content covered in class and revision of previous content.

One way to ensure that all requirements are met is to set up a weekly study timetable. When setting up the timetable, make sure you consider the following points:

- Eight hours sleep per night is essential for overall good health.
- Space the study of one subject over several days (this may change during assignments).
- Review each lesson on or near the day it was covered in class.
- Determine the most effective times of the day for your learning.
- Switch off your phone.
- Allocate a 15-minute break after every hour.
- Allow for extra contingencies, such as illness.
- Allow time for social activities.
- If study classes are part of the class timetable, allocate each one to a specific subject.

A weekly timetable might look like something in Table 1.

**FIGURE 1** A typical student's study space



**TABLE 1** A weekly study timetable

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
6–7 am	Check all set homework completed	Athletics training					
Breakfast Travel Classes Travel	Study class 50 mins Biology	Study class 50 mins History		Study class 50 mins Maths	Study class 50 mins Chemistry	8–11 am Athletics meet 3–4 pm English	9:30–10:30 am Physics 11–12 pm Chemistry
4–4:30 pm	Relax	Relax	Relax	Athletics training	Work		
4.30–5:30 pm	Chemistry	Biology	English				
5.30–6:30 pm							
7–8 pm	Maths	Physics	History	Physics			
8:15–9:15 pm	English	Maths	Biology	History			

## Setting weekly goals

Setting weekly goals for each subject focuses attention on what needs to be achieved in a 3-hour time frame. The goals need to be SMART (specific, measurable, agreed upon, realistic and time-based). For example, for Biology week 1 they might include:

- Revise information in 2.1.
- Complete Check your learning 2.1 and 2.2.
- Summarise 2.2.
- Write the meaning of glossary terms in own words.
- Revise any points that were not clear from answering the Check your learning questions.

Summarising and learning the course content each week makes it easier to understand the new subject matter. This means that before the exam, you only need to revise the content, not learn it for the first time.

## Work space

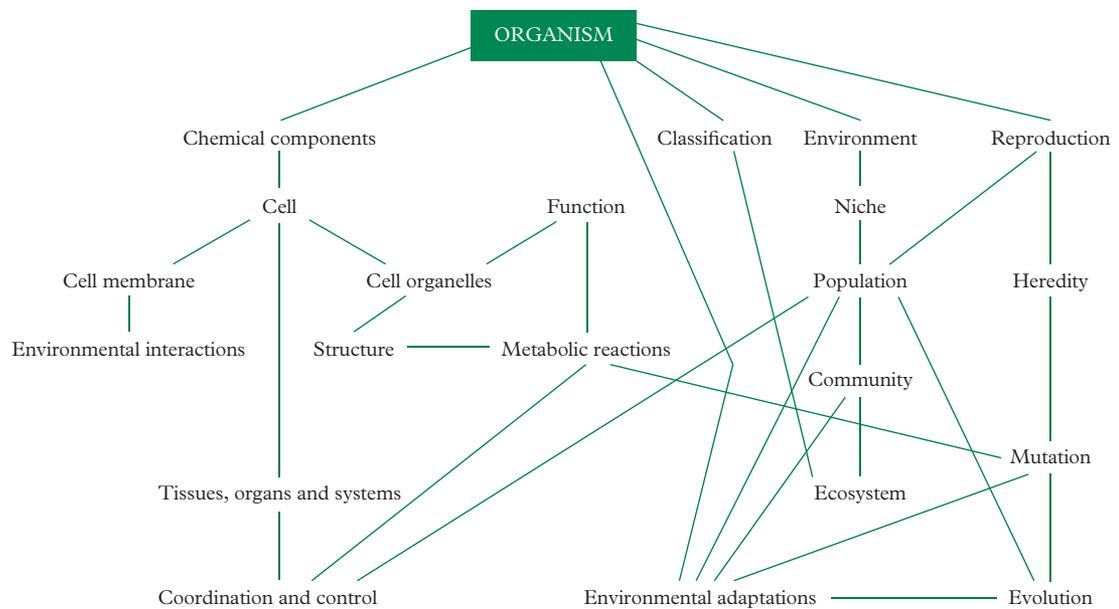
Everyone's home circumstances are different and few have an ideal study area. Where possible it is best to study in a quiet space with suitable light and ventilation. Your desk or table should be large enough to accommodate textbooks, your computer and any other equipment that is needed. The chair should be upright to support your back.

## Learning strategies

Although you have studied for exams in the past, the biology exam will test all the work you learn throughout the year. This means a single technique may not lead to the best results. Using a variety of techniques will help you remember the content, and prevent you getting bored with studying.

Strategies to assist learning could include the following:

- Ask questions in class and participate in class discussions.
- Define key words and summarise the text in your own words to gain a deeper understanding of the topic.



**FIGURE 2** A possible mind map showing the interconnection between an organism and major aspects of biology

- Write and rewrite summaries until they are reduced to a simple statement or key words.
- Make lists of new points in a logical sequence.
- Classify and group ideas.
- Translate text into diagrams or a concept map to show the relationship between important ideas.
- Watch videos or listen to podcasts on the topic.
- Learn new material while being active (e.g. walking on a treadmill or bouncing a ball).

## Exam revision

The lead-up to an exam does not need to be stressful. If work has been summarised and learnt in increments throughout the course, exam preparation only requires revision of the summaries and making sure you can apply the knowledge. The first requirement then is organisation and planning – **it is important to make sure all learning is completed well before the exam.** Dividing work into manageable chunks makes learning easier.

Review small sections of the material ahead of time and in different ways. For example, develop flash cards one day and check your recall the next, explain the material to a peer, or revisit the questions in the text to ensure you can do the following in relation to the topic:

- describe and explain
- apply understanding
- analyse and interpret evidence
- evaluate evidence and draw conclusions.

Clarify any difficulties in the understanding of a section of the work with the teacher well before examination time.

Be honest about time spent studying; for example, be aware of time spent on social media rather than checking a detail of the topic on the internet.

Focus on achievements (even if it means progressing from a D grade or a C– on the last test) and make goals realistic (a C+ in this test).



**FIGURE 3** Having a comfortable place to study will make your revision time more effective.

Be persistent – some sections of the course may be tough, but extra effort makes the rewards in conquering them all the sweeter.

Remember that sharp focus and retrieval of memory depend on good eating and sleeping habits as well as a level of physical exercise.

## Exam techniques

Before entering the examination room, it is important that you have all of the allowed equipment with you. Ensure that you have a highlighter and replacement pen or pencil.

Some people like to talk when they are nervous, while others need a quiet space to help them think clearly. Take time to make sure you know which environment you prefer, and that you do not add to others' anxiety.

In the examination room, make yourself as comfortable as possible.

In Units 3 and 4, the external examinations will consist of two papers (a short-response paper and a combination paper), each of 90 minutes, plus 10 minutes for perusal.

### During perusal time

Use the perusal time effectively.

- First scan the paper to check the type of questions in the paper, and the approximate allocation of time you need to apply to each.
  - Multiple-choice questions are normally designed to take about a minute each, so if there are 10 of these questions, no more than 10 minutes should be spent on them.
  - The mark value of short-response questions gives a good indication of the time that should be allocated, approximately a mark a minute. Ensure that the requirements of the question are understood – it is a waste of time to respond with a sentence when a single word will suffice, or a paragraph when a short statement is needed.

- Extended answers usually take more time and some time should be allocated for planning so that the response is succinct, includes scientific evidence and answers all parts of the question. Extended-answer questions need a short introduction, the main body with justified evidence, and a short conclusion.
- Read each question carefully to ensure you understand the requirements – often a question or statement in one part of the paper jogs the memory to complete another question.
- Make a mental note of the questions with which you feel confident and those that will need further reflection.

## During the exam

During the exam, highlight the important points of each question and keep track of the time spent on each section. Complete the questions you feel confident in answering first. In this way you will have time to go back to the tricky questions. Remember that, although the question may be worded in a different way, the underlying concept and facts pertaining to the concept have been covered in the course. In problem-solving questions:

- highlight the required response
- note any given information
- identify the basic concept being tested
- apply background knowledge and given information to answer the question.

This system often clarifies thoughts and leads to the successful completion of the task.

## Multiple-choice questions

Most students prefer multiple-choice questions to written-response questions – perhaps because one of the options will be correct (and they hope to recognise it) or that there is a chance that they will guess the correct answer. However, the response given will be either correct or incorrect, and no part marks are given.

Many multiple-choice questions emphasise basic definitions, but others may require analysing and interpreting data. They also tend to cover a broader range of material than short-answer items. For a student to succeed in such items, they are forced to be familiar with the details of all aspects of the subject matter being examined. Thorough knowledge of the material is the best predictor of success.

Multiple-choice questions start with a stem (the body of the question), and the student is asked to select one of four given answers. It is recommended that the type of response is highlighted. These may be:

- complete a statement (as with true/false short-answer questions, all aspects of the answer must be correct)
- select the **best** or **most correct** answer
- select the incorrect answer (e.g. select what does **not** apply).

Only one option will be completely correct. The other options are distractors, and good distractors are designed to appear to be correct on the surface. Such an answer may in fact be correct, but is still not as good a response as one of the other options. Although no particular strategy is infallible, some tips that could help with this type of question include:

- Cover the possible alternatives when reading the stem and deciding the answer.
- Look for the anticipated answer among the options and highlight this.
- Check all options so as not to miss the best response.

- If unsure of the answer, cross out the options that you know are incorrect; this improves the chances of selecting the correct response.
- Do not look for trick questions – reading too much into a question not only wastes time but also generally leads to an incorrect answer.
- Never leave a multiple-choice question unanswered (unless marks are deducted for an incorrect response) – you have one in four chances of being correct if you select an option but no chance if you leave the question blank.

## Responding to cognitive verbs

In assessment tasks and examinations, students will encounter ‘**cognitive verbs**’. These verbs are ‘task words’ that will provide information on what is expected in the assessment task to answer a question. A list of common cognitive verbs is included on your [obook assess](#).

It is important to understand the difference between task words. For example, a question that asks a student to ‘compare’ is different to a command asking a student to ‘contrast’. One requires a student to show similarities and differences, while the other is only asking the student to list the differences.

Understanding exactly what a cognitive verb is asking for means that a student can provide exactly what the examiner is looking for. Examiners want to give students marks, but can only do so if the student provides the correct information. For example, if a student describes data in their answer, but does not analyse the data, they will not receive full marks.

The following table contains a list of cognitive verbs that might come up on your assessments. All ‘Check your learning’ questions in your textbook have cognitive verbs bolded so you become familiar with them.

**cognitive verbs**  
QCAA-assigned verbs to help students answer questions correctly

**TABLE 2** List of cognitive verbs

Cognitive verb	Definition	Sample question
Analyse	dissect to ascertain and examine constituent parts and/or their relationships; break down or examine in order to identify the essential elements, features, components or structure; determine the logic and reasonableness of information;  examine or consider something in order to explain and interpret it, for the purpose of finding meaning or relationships and identifying patterns, similarities and differences	<b>Analyse</b> the graph provided below to identify the relationship between the independent and dependent variables.
Apply	use knowledge and understanding in response to a given situation or circumstance; carry out or use a procedure in a given or particular situation	<b>Apply</b> your knowledge of photosynthesis to explain how algae receive their energy.
Calculate	determine or find (e.g. a number, answer) by using mathematical processes; obtain a numerical answer showing the relevant stages in the working; ascertain/determine from given facts, figures or information	<b>Calculate</b> the mean for the following dataset.

Cognitive verb	Definition	Sample question
Classify	arrange, distribute or order in classes or categories according to shared qualities or characteristics	<b>Classify</b> the different stages of mitosis into the correct order.
Compare	display recognition of similarities and differences and recognise the significance of these similarities and differences	<b>Compare</b> archaea to bacteria.
Consider	think deliberately or carefully about something, typically before making a decision; take something into account when making a judgment; view attentively or scrutinise; reflect on	<b>Consider</b> why it is essential that foetal haemoglobin has a higher affinity for oxygen than adult haemoglobin.
Contrast	display recognition of differences by deliberate juxtaposition of contrary elements; show how things are different or opposite; give an account of the differences between two or more items or situations, referring to both or all of them throughout	<b>Contrast</b> an action spectrum and an absorption spectrum.
Deduce	reach a conclusion that is necessarily true, provided a given set of assumptions is true; arrive at, reach or draw a logical conclusion from reasoning and the information given	<b>Deduce</b> why the stomach contents are acidic.
Define	give the meaning of a word, phrase, concept or physical quantity; state meaning and identify or describe qualities	<b>Define</b> qualitative data.
Describe	give an account (written or spoken) of a situation, event, pattern or process, or of the characteristics or features of something	<b>Describe</b> how a protein differs from a polypeptide.
Determine	establish, conclude or ascertain after consideration, observation, investigation or calculation; decide or come to a resolution	<b>Determine</b> reasons why the ability to detect sugars is more sensitive than detection of other organic chemicals in many animals.
Discuss	examine by argument; sift the considerations for and against; debate; talk or write about a topic, including a range of arguments, factors or hypotheses; consider, taking into account different issues and ideas, points for and/ or against, and supporting opinions or conclusions with evidence	<b>Discuss</b> how this mechanism may help quadrupeds travel large distances at speed.
Evaluate	make an appraisal by weighing up or assessing strengths, implications and limitations; make judgments about ideas, works, solutions or methods in relation to selected criteria; examine and determine the merit, value or significance of something, based on criteria	<b>Evaluate</b> these two species and discuss which you would expect to be more successful in an arid region.
Explain	make an idea or situation plain or clear by describing it in more detail or revealing relevant facts; give an account; provide additional information	<b>Explain</b> the functions of DNA and RNA.

Cognitive verb	Definition	Sample question
Identify	distinguish; locate, recognise and name; establish or indicate who or what someone or something is; provide an answer from a number of possibilities; recognise and state a distinguishing factor or feature	<b>Identify</b> the three components of a nucleotide.
Interpret	use knowledge and understanding to recognise trends and draw conclusions from given information; make clear or explicit; elucidate or understand in a particular way; identify or draw meaning from, or give meaning to, information presented in various forms, such as words, symbols, pictures or graphs	<b>Interpret</b> the graph to comment on the biological significance of the relationship between the action spectrum and the absorption spectrum.
Justify	give reasons or evidence to support an answer, response or conclusion; show how an argument, statement or conclusion is right or reasonable	<b>Justify</b> why the current cell theory is more detailed than that proposed by Schleiden and Schwann.
Predict	give an expected result of an upcoming action or event; suggest what may happen based on available information	<b>Predict</b> whether the 5% glucose solution will be hypertonic, hypotonic or approximately isotonic.
Propose	put forward (e.g. a point of view, idea, argument, suggestion) for consideration or action	Digestion of chunks of food is either within a food vacuole or extracellular. <b>Propose</b> possible reasons for this phenomenon.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

As shown in Table 2, some cognitive verbs have multiple definitions. It is therefore important to read the whole question to determine specifically what the question requires.

### CHECK YOUR LEARNING 1.4

#### Describe and explain

1 **Explain** why cognitive verbs help you to understand how to approach answering a question.

2 **Describe** what perusal time is.

3 **Describe** methods to help you while you are in an examination.

Check your obook assess for these additional resources and more:

» **Student book questions**

Check your learning 1.4

» **Video**

How to prepare for your exam

» **Increase your knowledge**

Cognitive verbs



# Review

## Chapter summary

- 1.1** • The summative internal assessment consists of two assessments in Unit 3, a Data test (10%) and Student experiment (20%), and one assessment in Unit 4, a Research investigation (20%).
- The external examination consists of two papers worth a total of 50%.
- 1.2** • Experiments on vertebrate animals requires preapproval by bioethics committees.
- Research methods must be valid and reliable.
- Experimental investigations are presented in a formatted report.
- A logbook will help organise the data and analysis required in a Student experiment and Research investigation.
- 1.3** • Research investigations need all the key words and concepts to be defined before being analysed and evaluated.
- All resources should be peer reviewed or from a credible source such as a university or government website or a peer-reviewed scientific article.
- 1.4** • Preparing for an end of year examination requires planning.
- Establishing a study timetable will help memory retention and allow you to structure your workload.
- Setting weekly goals will ensure that work is not left until the last minute.
- Using different learning strategies prevents boredom when studying.
- It is important to know the key cognitive verbs that will be used in the examination. This will allow you to answer all questions confidently and to completion.

## Key terms

- claim
- reference list
- scientifically
- table
- cognitive verbs
- reliable
- credible sources
- valid
- hypothesis
- scientific method
- secondary evidence

## Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number:

\* = low; \*\* = medium; \*\*\* = high.

### Multiple choice

- 1 Which of the following is **not** an internal assessment?
  - A Summative examination
  - B Research investigation
  - C Data test
  - D Student experiment
- 2 Which of the following is **not** important for a good study station?
  - A An upright ergonomic chair
  - B A strong desk
  - C A working phone
  - D A quiet space
- 3 Which one of the following is **not** a good learning strategy?
  - A Creating a concept map
  - B Cramming last minute
  - C Participating in class discussions
  - D Listening to a podcast on the topic
- 4 Which of the following does **not** need ethics approval to work with?
  - A Rat
  - B Human
  - C Earthworm
  - D Shark

### Short answer

#### Describe and explain

- ★ 5 **Explain**, with reasons, why some experiments require bioethics approval.
- ★ 6 **Describe** the criteria for your Research investigation.
- ★ 7 **Describe** a good study environment.
- ★ 8 **Explain** what is needed for a good study timetable.
- ★ 9 **Determine** which study methods are best for you.
- ★★ 10 **Construct** a concept map to plan your study.

#### Apply, analyse and interpret

- ★ 11 **Consider** which topics you find interesting as these will be the best areas to research for your Research investigation.
- ★ 12 **Reflect on** which topics you find difficult prior to your examination so you can **derive** additional notes and a stronger understanding of these.
- ★ 13 **Consider** how managing your Biology workload affects your other subjects. **Construct** a study timetable that takes into account all your subjects for the year.

#### Investigate, evaluate and communicate

- ★★ 14 **Investigate** different methods for retaining knowledge.
- ★★★ 15 **Investigate** the 'dos and don'ts' for displaying data in a poster format.

Check your [ebook assess](#) for these additional resources and more:

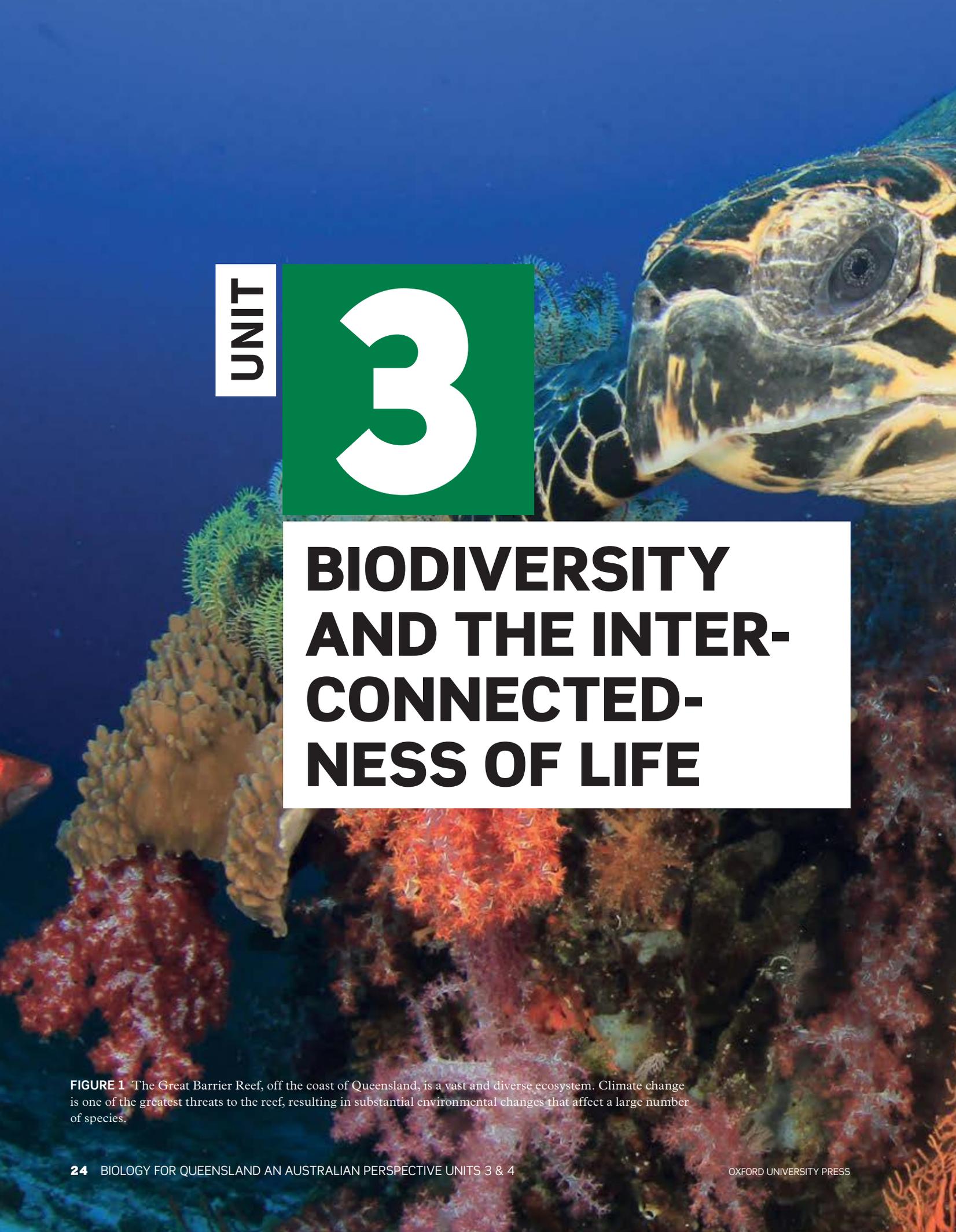
» **Student book questions**  
Chapter 1 review

» **Revision notes**  
Chapter 1

» **assess quiz**  
Chapter 1 auto-correcting multiple-choice quiz

» **Flashcard glossary**  
Chapter 1 glossary





**UNIT**

# 3

## **BIODIVERSITY AND THE INTER- CONNECTED- NESS OF LIFE**

**FIGURE 1** The Great Barrier Reef, off the coast of Queensland, is a vast and diverse ecosystem. Climate change is one of the greatest threats to the reef, resulting in substantial environmental changes that affect a large number of species.



Since the origin of life on Earth, organisms have interacted with their environment and paved the way for the evolution of new life forms. As environments change, the conditions for some organisms may no longer be suitable for their survival. If they cannot move away or adapt quickly, individuals die, which can lead to the extinction of the species. The diverse life forms of today all evolved from the most primitive life ~4 billion years ago. However, present day life forms represent only some of the living things that have inhabited Earth.

Biologists originally used their knowledge of the visible characteristics of life forms to classify them according to the way they were thought to have evolved. With the development of new research and

technology in the field of biology, classification of life forms has dramatically improved.

Biodiversity refers to the range of living things that exists either globally or within a particular ecosystem. The composition of a community of organisms found within an ecosystem is dependent upon a number of factors. Abiotic and biotic components of an environment shape the densities of the populations comprising the community and drive adaptations of organisms to specific conditions. The recycling of matter and energy flow in a system plays a large role in maintaining diversity within a community.

Gross changes to an ecosystem can occur through natural events or human activity. These can bring about either increased or decreased biodiversity.

### Unit 3 Topics

Topic 1	Describing biodiversity	Chapters 2–3
Topic 2	Ecosystem dynamics	Chapters 4–6

### Unit objectives

- Describe and explain biodiversity and ecosystem dynamics.
- Apply understanding of biodiversity and ecosystem dynamics.
- Analyse evidence about biodiversity and ecosystem dynamics.
- Interpret evidence about biodiversity and ecosystem dynamics.
- Investigate phenomena associated with biodiversity and ecosystem dynamics.

- Evaluate processes, claims and conclusions about biodiversity and ecosystem dynamics.
- Communicate understandings, findings, arguments and conclusions about biodiversity and ecosystem dynamics.

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# BIODIVERSITY

In order to make sense of the huge array of living organisms, people have tended to group organisms with similar characteristics together. These characteristics vary according to the purpose of the grouping. Most biological systems of classification are hierarchical and attempt to take into account the organism's evolutionary history. With advanced technologies, biologists have more detailed information on which to base classification. Cladistics is a method of classification based purely on evolutionary lines.

## OBJECTIVES

- Recognise that biodiversity includes the diversity of species and ecosystems.
- Recognise that biological classification can be hierarchical and based on different levels of similarity of physical features, methods of reproduction and molecular sequences.
- Describe the classification systems for:
  - similarity of physical features (Linnaean system)
  - methods of reproduction (asexual, sexual)
  - molecular sequences (molecular phylogeny – also called cladistics).
- Analyse data from molecular sequences to infer species evolutionary relatedness.
- Define the term *clade*.
- Recall that common assumptions of cladistics include a common ancestry, bifurcation and physical change.
- Interpret cladograms to infer the evolutionary relatedness between groups of organisms.
- Recognise the need for multiple definitions of species.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

**FIGURE 1** Rainforests, such as this one in Dinden National Park in Queensland, Australia, have a large number of different plant and animal species.



# 2.1

## Living things and their environments

### KEY IDEAS

- ✦ Biodiversity of ecosystems
- ✦ Biotic and abiotic factors in ecosystems
- ✦ Adaptation in a species and survival in an environment

### adaptation

a feature of an organism that enhances its ability to survive and reproduce in a particular environment

### biodiversity

the range of living organisms and their environments

### ecosystem

a biological community of interacting organisms and their physical environment

### biotic

the living components in the environment

### abiotic

the non-living physical factors that affect an organism's ability to survive

Organisms exist in a variety of shapes and sizes. They can be found in the water, inside or attached to other organisms, in the soil, on land and in the air. Each type of organism has special structures and behaviours (**adaptations**) that allow it to survive in its environment. Different adaptations are required for each type of environment.

The term **biodiversity** refers to the variety of life, from the smallest microbe to the largest animals and plants, the genetic material that gives them their specific characteristics, and the **ecosystems** in which they survive. In order to maintain a balanced, healthy ecosystem it is important to know the types of organisms that make up the community, their needs for survival and how they interact with both the living (**biotic**) and non-living (**abiotic**) world.



**FIGURE 1** The limbs of the platypus are adaptations to its swimming and burrowing mode of life, while its 'duckbill' is a highly sensitive adaptation to detecting and collecting food.

## Living in water

The cells that make up all living things are composed of combinations of chemicals either suspended or dissolved in water. Water is an ideal environment for organisms as it is a stable living place that doesn't change its temperature or composition easily. Since water is very buoyant, organisms can grow to a large size; some can do this without needing any support structure, such as bones.



**FIGURE 2** This large jellyfish does not have a skeleton but maintains its shape due to the hydrostatic pressure of the water in its cells and the buoyancy of the surrounding sea water.

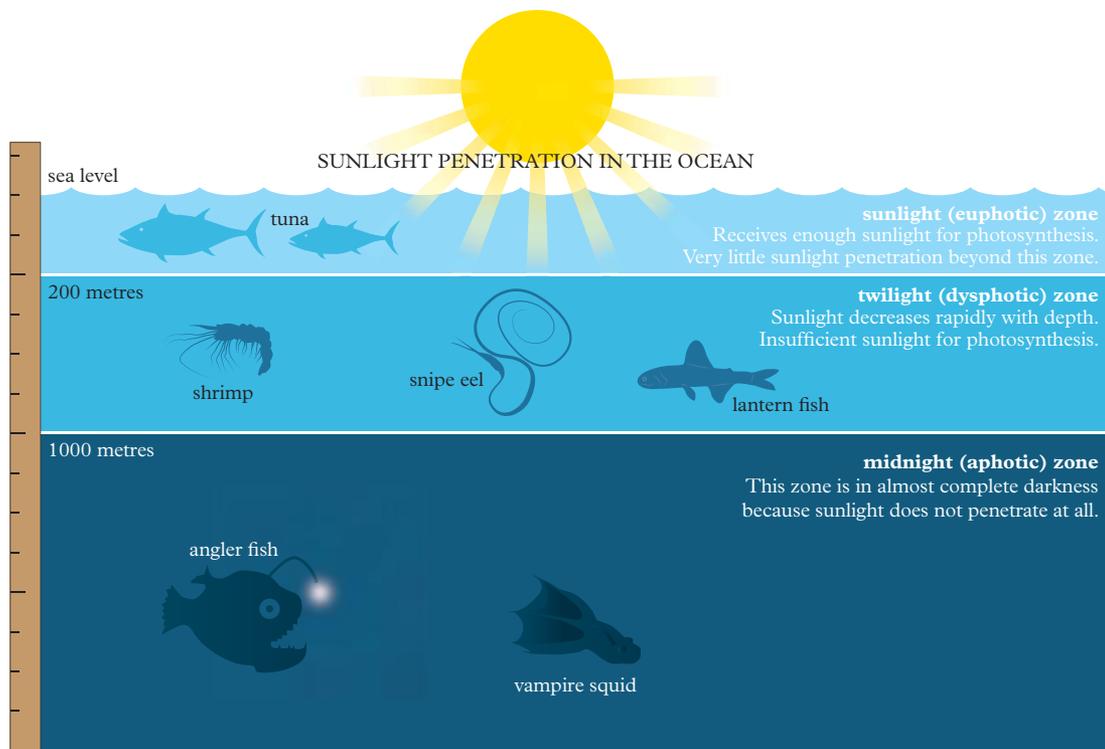
Minerals such as salt need to be in solution (mixed with water) to pass in and out of cells. Sometimes the amount of salts or other minerals in the water are too high or too low. When this happens, the organisms will have adaptations that enable them to control the flow of minerals in and out of their cells. For example, fish in fresh water have adaptations to store salt and remove excess water, while fish in the salty ocean need adaptations to remove excess salt and prevent water loss.

Sexual reproduction occurs more easily in water. Fertilisation and development are often external. Sperm cells (the male gametes) will not dry out as they transfer to the ova (female gametes). Special protective structures for their developing young are not needed since they can grow and develop in the water, obtaining their needs from the environment.

Representatives of prokaryotes, protists, plants, fungi and animals can live in water while many organisms (most prokaryotes, the protists and simple animals) can live only in this habitat. Some parasites, such as the bacteria *Escherichia coli*, have solved their water requirement problems by living within tissue fluids or organs of other organisms.

Living in water can, however, provide some limitations on organisms. For instance, oxygen does not dissolve well in water. This means many organisms are restricted to the upper, more turbulent water surfaces, where wave action can mix oxygen from the air. Water also absorbs light, limiting photosynthetic organisms to the surface regions. The turbulence that is important for dissolving oxygen, however, restricts light penetration. This means there is a competition for resources (light and oxygen) between organisms living in the sunlight zone of the aquatic environment.

Millions of years ago, any species with adaptations that enabled them to move from the aquatic environment and live in a terrestrial environment had an advantage because they did not need to compete against other water-based organisms for light and oxygen.



**FIGURE 3** The absorption of light with increasing depth of water

## Living on land

On land, light is abundant and is not blocked by turbulent water. Carbon dioxide, which makes up 0.03% of the total gases in the atmosphere, is readily available in air where it circulates more freely than in water. Carbon dioxide is also essential for photosynthesis. At the time of their evolution some 400 million years ago, the emerging land plants did not have to compete with any other life forms. Once a food supply was available, however, evolution of land-based (terrestrial) animals soon followed.

The terrestrial environment is hostile in many ways, and many adaptations were needed for organisms to survive in this environment. Among the many problems they faced were:

- preventing excessive loss of water by evaporation
- maintaining a moist surface for gas exchange when the surrounding medium is air instead of water; materials can only pass across cell membranes in solution
- transporting water and dissolved substances around the body
- supporting the body against the pull of gravity when the buoyancy of water is no longer available
- reproducing when there is little water through which the sperm may swim to the egg, and where the zygote and young embryo may suffer from dehydration
- surviving the changes in temperature, humidity, wind, light and other environmental conditions that occur on land.

Fungi, plants, insects and vertebrates have been the most successful organisms in colonising the terrestrial environment. Some terrestrial animals, for example the dolphins and whales, have permanently returned to the sea, showing a variety of adaptations for this mode of life.

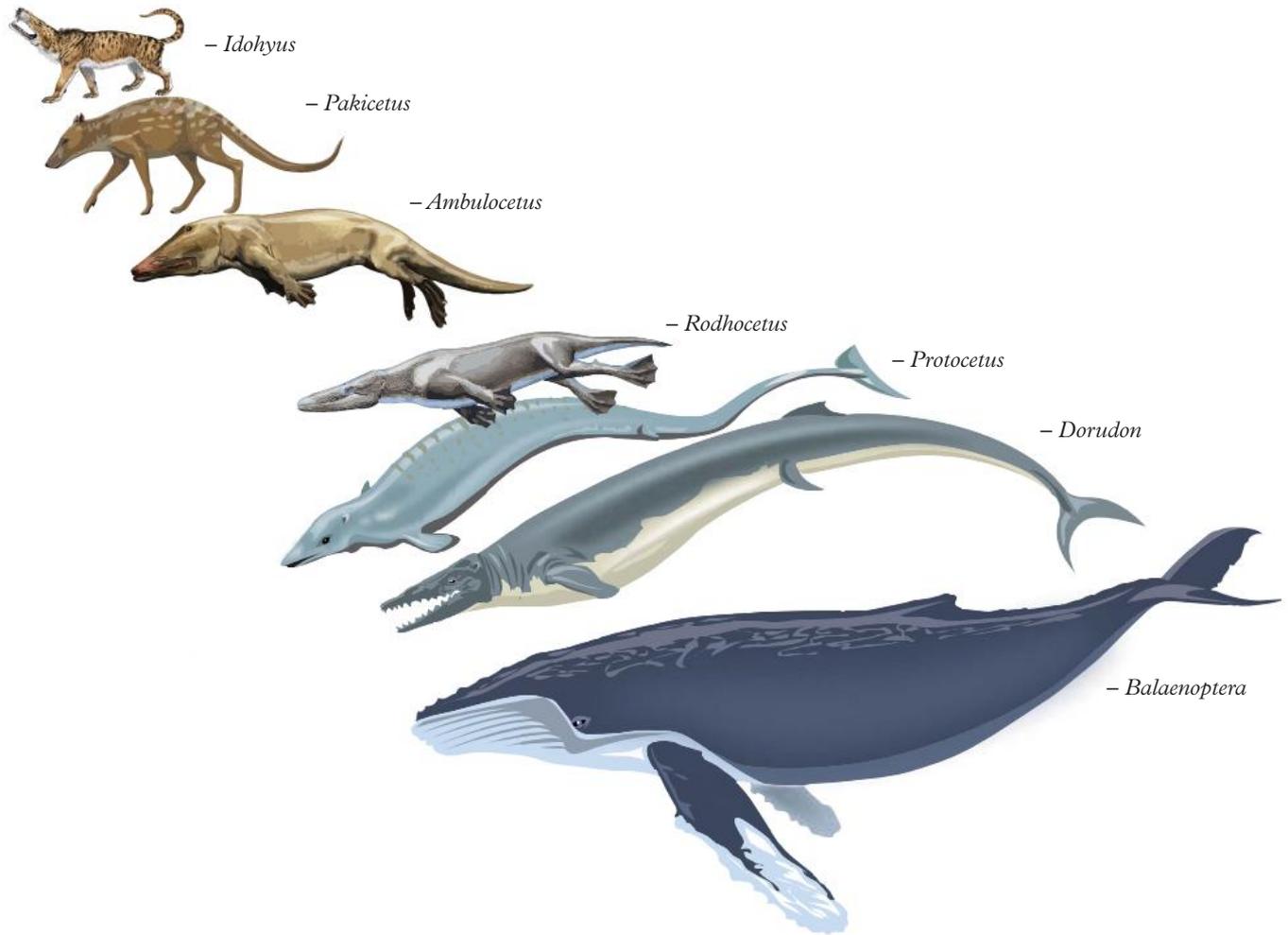


FIGURE 4 The evolution of whales from terrestrial animals to marine animals

## CHECK YOUR LEARNING 2.1

### Describe and explain

- 1 **Describe** the environmental conditions that are advantageous to living in water.
- 2 **Explain** the factors that can limit life in an aquatic environment.
- 3 **Describe** some of the problems associated with a transition from living in water to living on land.

### Apply, analyse and interpret

- 4 **Consider** why whales evolved to live back in the ocean.
- 5 **Determine** whether insects are more suited to aquatic or terrestrial environments and why.
- 6 **Determine** whether sexual reproduction occurs more easily in aquatic or terrestrial environments and why.

Check your **obook assess** for these additional resources and more:

» **Student book questions**

Check your learning 2.1

» **Weblink**

Marine life

» **Weblink**

Terrestrial life

# 2.2

## Making sense of the diversity of life forms

### KEY IDEAS

- ✦ Classification of objects or organisms
- ✦ Biological classification and hierarchical systems
- ✦ Data use depends on classification

### Hierarchical classification

Humans characteristically name and group objects together to make sense of the world and communicate effectively with others. The more specific the object, the greater the detail in which it is described. For example, consider non-identical twins, a brother and sister that both go to Billabong High School. They are in Year 12 and study Biology. Specifically, they are Mirabelle (who has blue eyes) and Joshua Marconi (who has green eyes). This description or grouping started as general (they both go to Billabong High School, are in Year 12, and study Biology), before becoming specific (their eye colour). This method of grouping from larger general groups to specific detailed groups is termed **hierarchical**, with groups within groups. Arranging things into groups according to their observed similarities is known as **classification**.

**hierarchical**  
relating to the graded organisation of grouping from general to very specific subgroups

**classification**  
grouping of organisms based on similarities in morphology, anatomy and biochemistry

### Kinds of classification

The kind of classification of organisms used depends on the needs of the organiser of the system. According to the beliefs of Aboriginal and Torres Strait Islander peoples, all plants and animals are related to them through the spirit world of the Dreamtime and so their naming is associated with religion, various taboos and food usage. Most early humans grouped plants and animals into edible, non-edible and dangerous. Animals can be grouped according to their main food source (herbivores, omnivores and carnivores) or the manner in which they obtain their food (chunk feeders, particle feeders or fluid feeders). Plants can

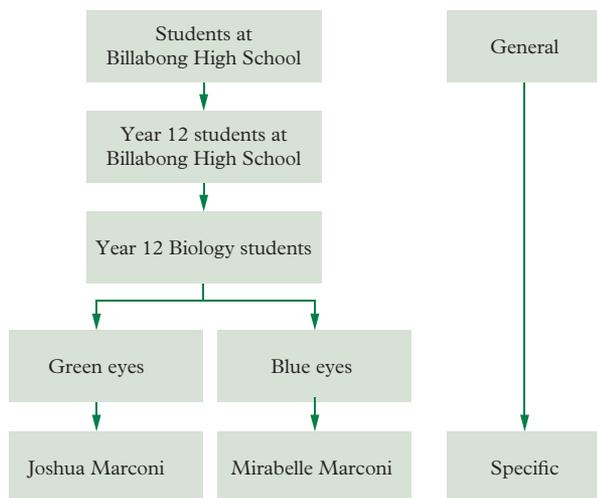
be grouped according to their environmental conditions (mesophyte, xerophyte, hydrophyte, halophyte).

Biologists face the task of identifying, studying and exchanging information about this vast diversity of life forms. They therefore need an orderly and logical system for naming and grouping organisms that shows their past and present relationships.

In 300 BCE Aristotle developed the first biological system of classification.

He distinguished two major groups: plants (herbs, shrubs and trees) and animals (according to where they lived, i.e. land, water or air).

Since this time there has been a massive expansion in knowledge of the different types of organisms and the means by which biologists can study them. This has led to the development of different classification systems.



**FIGURE 1** A hierarchical classification of students at Billabong High School

## Physical features

The early biological systems of classification used the observable structural features of organisms to separate them into individual groups. Aristotle (384–322 BCE) separated living things into plants (with leaves and roots) and animals (able to move from place to place). The invention of the microscope allowed smaller differences in cellular structure to be observed, allowing the classification of even smaller groups within the overall hierarchy. The physical features of organisms still play a role in modern day Linnaean classification systems.

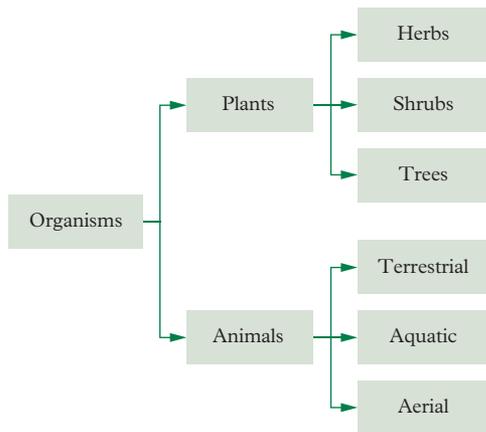


FIGURE 3 Aristotle's classification of organisms

## Methods of reproduction

Another system is based on reproductive strategies. Some organisms can produce offspring that are genetically identical clones of themselves. This is called **asexual reproduction**. Other organisms need genetic material from two parents to produce offspring (**sexual reproduction**). This system also classifies organisms according to the number of offspring and the level of care the parent(s) play in their upbringing. This latter system is linked to growth of a population of a species in a particular ecosystem and will be discussed in Chapter 5.

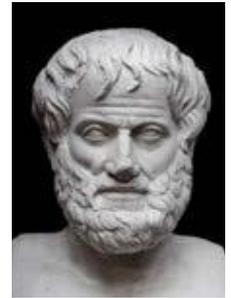


FIGURE 2 The Greek philosopher and scientist Aristotle

**asexual reproduction**  
the production of genetically identical offspring from a single parent

**sexual reproduction**  
the production of offspring that has genetic material from two parents

## Molecular sequences

The identification of genetic material and the ability to sequence DNA has led to scientists comparing the molecular sequences of different organisms. This has led to previous classification systems being reviewed.

Any system of classification is only an aid to understanding and communication and will continue to change as new information is discovered.

### CHECK YOUR LEARNING 2.2

#### Describe and explain

- Define** the term 'classification'.
- Classification systems tend to be hierarchical.  
**Explain** the meaning of the term 'hierarchical'.

#### Apply, analyse and interpret

- Classify**, from general to specific, an example for each of the following:

- music
  - food in a supermarket
- Explain** why the classification system for organisms needed to be modified following the ability to sequence DNA.

#### Check your obook assess for these additional resources and more:

##### » Student book questions

Check your learning 2.2

##### » Weblink

Hierarchical classification

##### » Weblink

Historical classification

# 2.3

## The basis of the Linnaean biological classification

### KEY IDEAS

- ✦ Taxonomy based on physical and biochemical characteristics
- ✦ The Linnaean classification system
- ✦ The binomial naming system

### taxonomy

the science of naming and classifying living things

### taxon

(plural taxa)  
any group in a biological classification into which related organisms are classified, for example phylum, class etc.

### mutation

small permanent change in the DNA of an organism

### species

taxonomic group, allocated two (genus and specific) names; only members of the same species can produce fertile offspring when mating under natural conditions

### genus

classification category between family and species; first part of the scientific name of an organism

### family

subdivision of an order in the classification of living things

### order

subdivision of a class in the classification of living things

The science of naming and classifying living things based on physical and biochemical characteristics is called **taxonomy**. This system was devised in the eighteenth century by a Swedish naturalist, Carolus Linnaeus, and many of the methods he devised are still used today. He based the classification of plants on reproductive structures and those of animals on similar physical features – features he could readily see. Each category in the Linnaean system represents a level of grouping from a large general group (or **taxon**) to a smaller group with more specific characteristics. The development of microscopes showed that many organisms could not be easily slotted into two groups: plants and animals. Cellular and sub-cellular differences were found.

At that time, it was considered that the organisms present on Earth had always been present and so few taxonomists of the 18th and 19th centuries questioned the basis for the patterns of similarities and differences between the organisms.

This changed with the publication of Charles Darwin's *On the Origin of Species by Means of Natural Selection* in 1859. The static view of nature was overturned. Instead, groups of organisms were found to change over time. **Mutations** (small permanent changes) in the DNA of a cell cause changes in an organism's physical characteristics that may be transmitted from one generation to the next. This suggests that the characteristics found in a group of organisms, and therefore their classification, may also change. Closely related groups may not just have similar features, they may also share a recent common ancestor.

Taxonomists using the modern Linnaean classification system, therefore, are concerned with how groups evolve, and classification systems attempt to reflect this accurately.

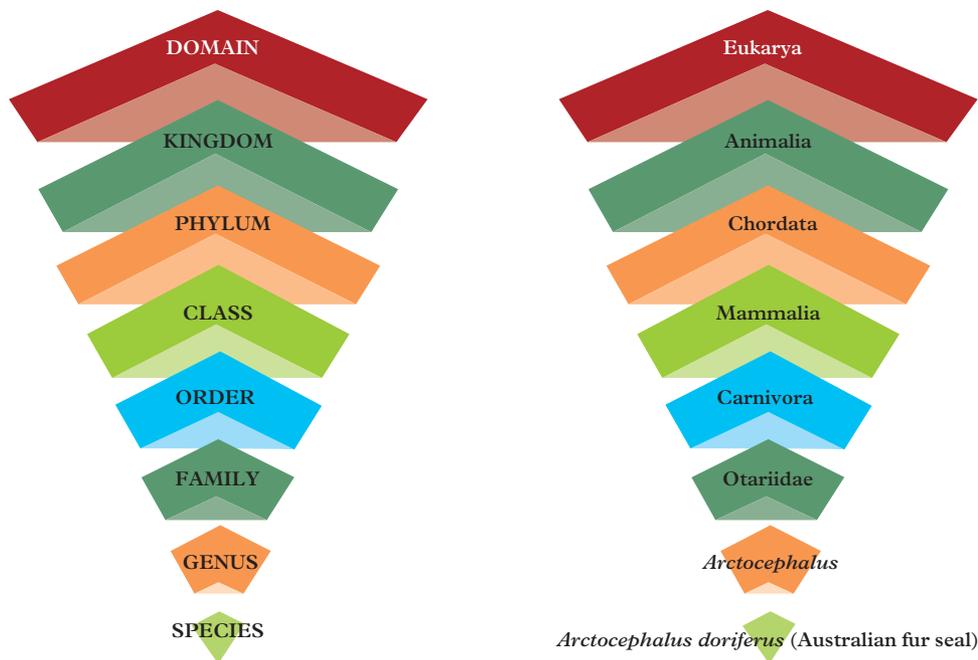
## Grouping organisms

In the hierarchical system of biological classification, related **species** are grouped together into genera (singular, **genus**), related genera into **families**, related families into **orders**, related orders into **classes**, related classes into **phyla** (singular, phylum) or **divisions**. The term 'phylum' is used in the description of animals and the single-celled *Protozoa*, whereas 'division' is used in describing all other types of organisms (bacteria, plants, etc.).

Related phyla or divisions are grouped together into **kingdoms**, and kingdoms are placed into **domains**. Each of these groups is referred to as a taxon. Within each of these **taxa** there may be subdivisions. Thus, a phylum may include several subphyla.

With the advance of technology, a greater understanding of the living world was gained, resulting in ongoing changes to classification. These have included the following:

- Until 1866 all organisms were classified into the plant or animal kingdom.
- In 1866 all single-celled organisms moved to the kingdom Protista. Many of these single-celled organisms cannot be classified as either a plant or animal.



**FIGURE 1** The hierarchical arrangement used in Linnaean taxonomy. Members of each species share characteristics at each taxa from broad (domain) through to very specific (species).

**class**  
one of the groups used in the classification of organisms consisting of a number of orders, for example animals in class Mammalia all share specific characteristics

**phylum**  
major classification group of the animal kingdom

**division**  
major classification group of the plants, fungi and plant-like protists

**kingdom**  
a subdivision of a domain; group of organisms with very general common features

**domain**  
broadest taxonomic group

**taxa**  
plural of taxon

- In 1938 prokaryotes were moved from the kingdom Protista to the kingdom Monera based on their cell structure.
- In 1959 it was found that there were significant differences (e.g. cell wall composition) between plants and fungi and so the kingdom Fungi was created.
- In 1977 the kingdom Monera was split into two new kingdoms – Archaeobacteria and Eubacteria – based on ribosomal RNA studies and cell wall structure.
- In 1990 the three domain system (Archaea, Bacteria and Eukarya) was introduced.

**TABLE 1** Classification showing separation of Bacteria, Archaea and Eukarya

Domain	Archaea	Bacteria	Eukarya			
Kingdom	Archaeobacteria	Eubacteria	Protista	Fungi	Plantae	Animalia
Characteristics	Distinguished on the basis of rRNA and cell wall composition					
Cell type	Prokaryote	Prokaryote	Eukaryote	Eukaryote	Eukaryote	Eukaryote
Chloroplasts	Absent	Absent	Present in some forms	Absent	Present	Absent
Mode of nutrition	Heterotrophs or chemosynthetic autotrophs	Heterotrophs that require oxygen or autotrophs (photosynthesis)	Photosynthesis or heterotrophic or combination of both	Heterotrophic by absorption	Photosynthesis	Heterotrophic by ingestion
Multi-cellularity	Absent	Absent	Absent	Present except in yeasts	Present	Present
Locomotion	Absent	Absent in most	Present in some	Absent	Absent	Present
Nervous system	Absent	Absent	Absent	Absent	Absent	Present except in sponges

**binomial nomenclature**

method of naming species of organisms with two parts: the generic and specific names, e.g. *Eucalyptus crebra*

**specific name**

the descriptive name of a species

**Study tip**

The scientific name is typeset in *italics*, but is underlined when handwritten.

The many levels, each with their own name, generated by this hierarchical Linnaean system of classification could result in very long scientific names for every organism. Instead, Linnaeus developed the two-word naming system called **binomial nomenclature** (*bi* = ‘two’; *nomen* = ‘name’; *calator* = ‘caller’).

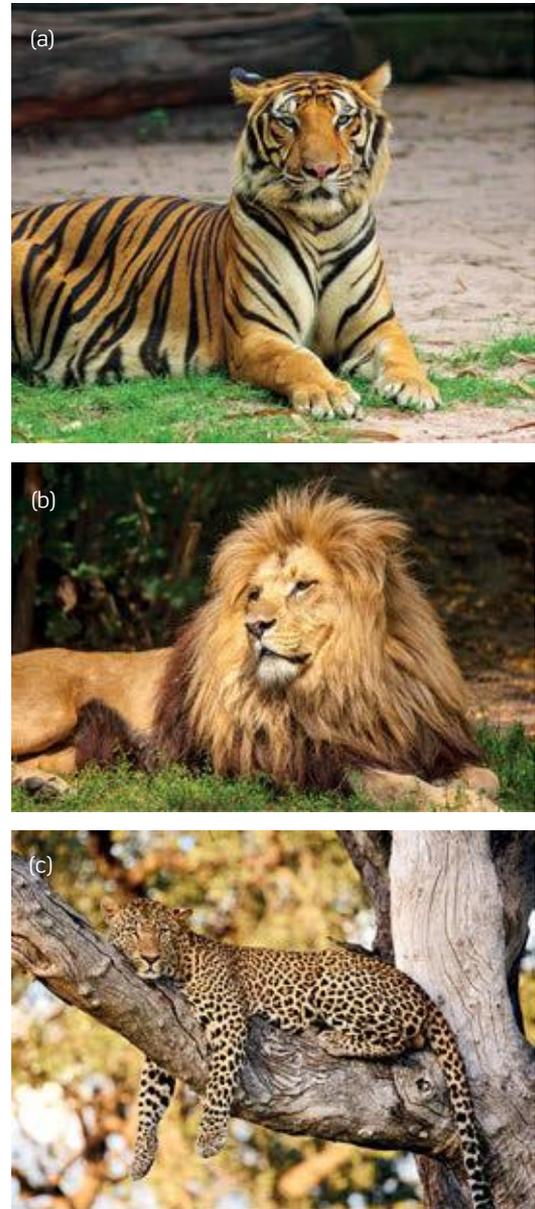
### Scientific nomenclature

Different species are given scientific names. The scientific name was originally written in Latin because that was the common language of scientists of Linnaeus’s time. Better known organisms also have common names. Although these may be easier to learn, they can be confusing since different common names can be used for the same species in different localities or may refer to many different unrelated species. The scientific name always refers to one specific type of organism and is used worldwide.

### Genus and species

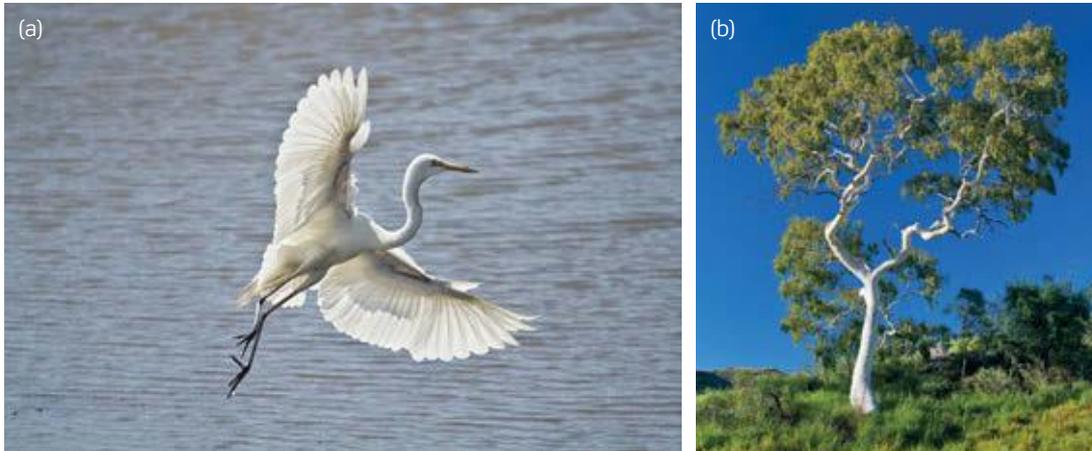
The scientific name consists of the genus name and a **specific name**. A group of closely related species, most probably arising from a common ancestor, belong to the same genus (plural, genera). The specific name indicates the particular species within that genus. The lion, tiger and leopard have so many common characteristics that they are placed in the same genus, *Panthera*. The specific names distinguish the different types of cats: tiger *Panthera tigris*, lion *Panthera leo* and leopard *Panthera pardus*.

The genus name begins with a capital letter and the specific name in lower case. The genus is always placed first in the scientific name. When referring to a particular group of organisms, it is common to use the genus name. The word *Panthera* automatically refers to common features of one of the groups of large wild cats. A specific name, on the other hand, is meaningless when written alone since it can be used as a descriptor for many unrelated genera. For example, two organisms are given the specific name *alba*: *Ardea alba* and *Eucalyptus alba*. *Ardea alba* is a large white bird found feeding in shallow waters and swamps in tropical and temperate regions of the world. *Eucalyptus alba*, with its smooth, white bark, is known as the poplar gum or white gum tree, and is found in the tropical regions of northern Australia.



**FIGURE 2** These three species all have strong features in common and are grouped together in the same genus, *Panthera*, but their specific names distinguish them from each other: (a) tiger (*Panthera tigris*); (b) lion (*Panthera leo*); (c) leopard (*Panthera pardus*).

In a context where there is no possible confusion, the genus name may be abbreviated to its initial letter. An author discussing a particular group of fruit fly, for example, might write *Drosophila melanogaster* as *D. melanogaster* after the scientific name has already been mentioned in full.



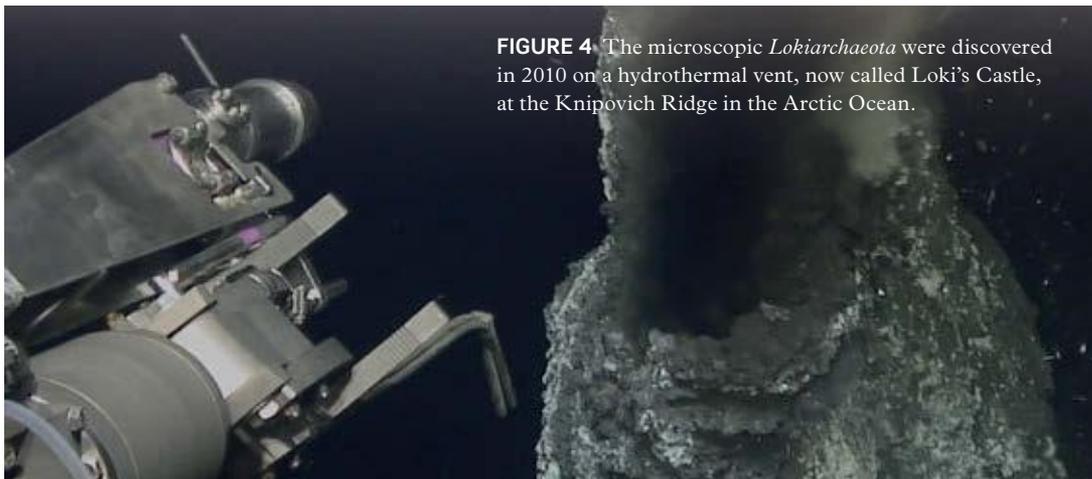
**FIGURE 3** Both of these organisms have the specific name *alba* (referring to their predominantly white colour) but are not related: (a) *Ardea alba*; (b) *Eucalyptus alba*.

## Naming organisms

The person who first discovers a species has the right to name it. There are various sources of scientific names. The scientist may name it after a person (but never themselves), or the locality in which it was first observed. Many Australian biologists have utilised words from Aboriginal and Torres Strait Islander languages. For example, the burramys, the mountain pygmy possum found in the high country on the New South Wales–Victorian border, belongs to the genus *Burramys* from the place name *Burra* (near Taralgo, NSW, where fossils of the animal were discovered) and the Greek *mys* (= ‘mouse’).

Some biologists have a great sense of humour and have used this in naming new species. For example, members of mosquito genera have been given the specific names of *tormentor* and *horrida*. The Asgard archaea have been given genera names after Norse gods, such as *Thoarchaeota*, *Lokiarchaeota* and *Odinarchaeota*. These archaea are newly discovered ancient **extremophiles** from hydrothermal vents on the ocean floor.

**extremophiles**  
organisms that  
live in extreme  
environments



**FIGURE 4** The microscopic *Lokiarchaeota* were discovered in 2010 on a hydrothermal vent, now called Loki's Castle, at the Knipovich Ridge in the Arctic Ocean.

It is more common for a name to be descriptive. The scientific name for the red kangaroo is *Macropus rufus*, which gives a physical description: *Macropus* means 'large-footed' (*macro* = 'large'; *pous* = 'foot') and *rufus* means 'red'.



**FIGURE 5** The scientific name of the red kangaroo, *Macropus rufus*, indicates that it has a large foot and is red in colouration.

### CHECK YOUR LEARNING 2.3

#### Describe and explain

- 1 **Describe** how scientists name a species.
- 2 **Explain** why biologists use scientific names instead of common names.
- 3 *Bactrocera tryoni* is the Queensland fruit fly, which lays its eggs in soft-skinned fruit. When the larvae hatch, they use the ripening flesh for nourishment to complete their development. **Identify** which one of the following organisms it is most closely related to. **Explain** your choice.

- A *Rosana tryoni*
  - B *Pinuta dacus*
  - C *Bactrocera cucumis*
  - D *Tryoni rosana*
- 4 **Identify** the taxon level where two different species have the most features in common.
    - A Kingdom
    - B Class
    - C Family
    - D Genus

### Apply, analyse and interpret

- 5 Based on your own knowledge of their characteristics, **organise** the animals listed below into groups and subgroups. Scientific terms are not required.  
baboon, bear, lion, clam, fly, frog, earthworm, horse, jellyfish, lobster, mosquito, prawn, emu, panther, oyster, sparrow, turtle, tuna, whale, snake, snail
- 6 The smallest hummingbird is called *Mellisuga helenae* and the largest is called *Patagona gigas*. The hummingbird with the longest beak is called *Ensifera ensifera*, while the one with the smallest beak is called *Ramphomicron microrhynchum*. For the hummingbirds described above, **deduce** which of the following they all belong to:  
**A** same genus but different species  
**B** same family but different classes  
**C** same genus but different classes  
**D** same class but different genera



**FIGURE 6** The hummingbird is the only bird that can fly backwards.

- 7 Listed below are some common Latin and Greek root words used in naming animals.

Root word	English meaning	Derived from Latin or Greek
a-	without	Greek
-cephalus	head	Latin
giga-, gigan-	giant	Greek
leuco-	white	Greek
macro-	large	Latin
natus	birth	Latin
ornitho-	bird	Greek
ptero-	wing, feather	Greek
-pus	foot	Latin
rhynchus	snout, beak	Greek

- a Identify** as many physical characteristics as possible of the following species:  
**i** *Macropus giganteus*  
**ii** *Pteropus giganteus*  
**iii** *Rattus leucopus*  
**iv** *Ornithorhynchus anatinus*
- b Determine** a common name for each species based on the descriptions you gave in part a.
- 8 An organism has been found that has eukaryotic cells, is multicellular and heterotrophic. **Determine** which domain and kingdom you would place it in. **Consider** what further information you would require to be sure of your answer.

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An overview of all living things using Linnaean classification



# 2.4

## Defining a species

### KEY IDEAS

- ✦ Interbreeding in natural conditions to produce viable fertile offspring
- ✦ Hybrid offspring have parents from two different species
- ✦ Certain organisms are not defined by their ability to reproduce
- ✦ Varieties and subspecies classifications of organisms with slightly different physical characteristics

The basic unit of biological classification is the species. This word means ‘kind’ in Latin. It is written in the same way in both singular and plural. A species is generally defined as a group of similar organisms whose members can interbreed with each other in their *natural environments* to produce living (i.e. viable), fertile (i.e. can breed) offspring. This implies that two different species cannot interbreed to produce offspring. This is referred to as being reproductively isolated. **Reproductive isolation** may result from:

- different types of behaviour
- different requirements from the same environment, use of different parts of the same environment (some rainforest birds forage for insects on tree trunks whilst other species forage for insects in the canopy of the same tree) or from a physical barrier (for example a deep canyon or river) running through the environment
- different arrangements of the genetic material (nucleic acid) within the cells.

Closely related organisms have been known to interbreed in artificial situations (e.g. lions and tigers in zoos), but the **hybrid** offspring are usually sterile.

### reproductive isolation

inability of different populations or species to successfully interbreed due to behavioural, structural or physiological features of the organisms

### hybrid

offspring resulting from a cross between parents that are genetically unlike, for example two closely related species or varieties within a species



**FIGURE 1** A liger is a cross between a male lion and a female tiger under artificial conditions.

## Species limitations

Although this species concept works well with sexually reproducing animals, it presents some problems in classifying many other organisms.

## Asexual reproduction

There are many bacteria and unicellular eukaryotes that do not form gametes such as eggs or sperm. Nor do they exchange genetic material when they reproduce. Instead, these cells produce genetically identical clones. Because of this, their ability to reproduce in natural conditions cannot be tested. As a result, the definition of species cannot be used for these organisms.

## Fossils

Fossils are the remains and/or impression of dead organisms that are embedded in the rock record. As fossils are no longer alive, they cannot be classified on the basis of their ability to reproduce. Many fossils are found separately (such as leaves and flowers), so each is given a different species name even though they are the same species. As more fossils are discovered, species identifications evolve. For example, a large number of dinosaurs are now known to have had feathers, except the feather impressions do not preserve as well in the fossil record as bones do.



FIGURE 2 The *Microraptor* shows feather impressions in this well-preserved fossil.

## Apomixis

**Apomixis** refers to the ability of an embryo to develop without fertilisation. In animals, this process is called **parthenogenesis**. Although parthenogenesis can also occur in plants, they can undergo another form of apomixis where the embryo develops from the cells of the ovule instead of the egg cell.

**apomixis**  
asexual reproduction

**parthenogenesis**  
reproduction from an ovum without fertilisation in animals

## Ring species

Some populations of organisms (such as birds) can live close to each other. These connected series of neighbours (ring species) are capable of sexually reproducing with the neighbours on either side of each other. However, as the different populations get further away from each other, they become more different, until the populations at each end of the ring cannot reproduce to produce viable fertile offspring.

For example, there are seven linked populations of seagulls that interbreed in a ring around the Arctic. At the two ends of the ring are the herring gull (*Larus argentatus*) and the lesser black-backed gull (*Larus fuscus*). Although they look similar, with some slight colouration differences, they do not interbreed.

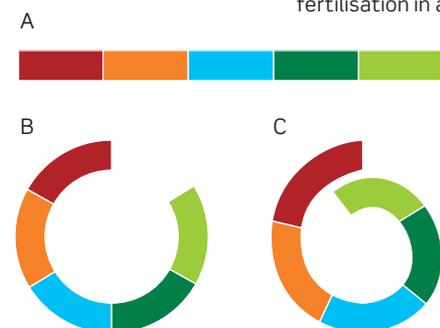


FIGURE 3 The neighbouring species in this ring can reproduce with each other; however, species at the extreme ends of the ring, the red and light-green ends, cannot interbreed.

## Infertile organisms

Many social insects (such as bees, ants, termites) have different castes of males, fertile females and infertile females. For example, many of the ants in a colony are worker ants that are unable to reproduce. It is thought that the role of the ants is determined by quantity and composition of food given to the larvae. If they are unable to reproduce, their species cannot be classified.

## Varieties and subspecies

There have been many attempts to establish an all-embracing definition of species, some of which refer only to fixed characteristics, mate recognition, genetic similarity or environmental requirements. In each, some organisms do not fulfil all requirements of the definition. Like the environment in which they live, species are subject to change. This change may come about by evolving into new species, exchanging genes with other species or by becoming extinct.

Members of a species may differ, but not enough to be considered separate species. They are placed into categories called **varieties** – the poodle is a variety of dog (*Canis lupus familiaris*). In other situations, members of a particular species may be reproductively isolated because they live in different places with limited overlap between their ranges. Those members at the far ends of the range are **geographically isolated**. These groups have adaptations (e.g. different colour patterns) that better suit them to their particular habitats, but they still belong to the same species because they are still *potentially* capable of interbreeding. Biologists term these groups **subspecies** or **races**. They are distinguished from varieties in that they have a greater possibility of forming new species in the future.

Ring species are now considered to be subspecies of a single species. The crimson, yellow and Adelaide rosellas, for example, were once considered separate species but are now classified as one species of rosella, *Platycercus elegans*. The crimson rosella in Queensland is *Platycercus elegans nigrescens*, but in eastern NSW and Victoria it is *Platycercus elegans elegans*. The yellow rosella is *Platycercus elegans flaveolus* and is found along the Murray River whilst the Adelaide rosella, *Platycercus elegans fleurieuensis*, is found in the Adelaide region as shown in Figure 5.



**FIGURE 4** The fertile queen ant surrounded by infertile females (worker caste).

### variety

a group that distinctly differs from other varieties within the species, for example a poodle and a Great Dane

### geographic isolation

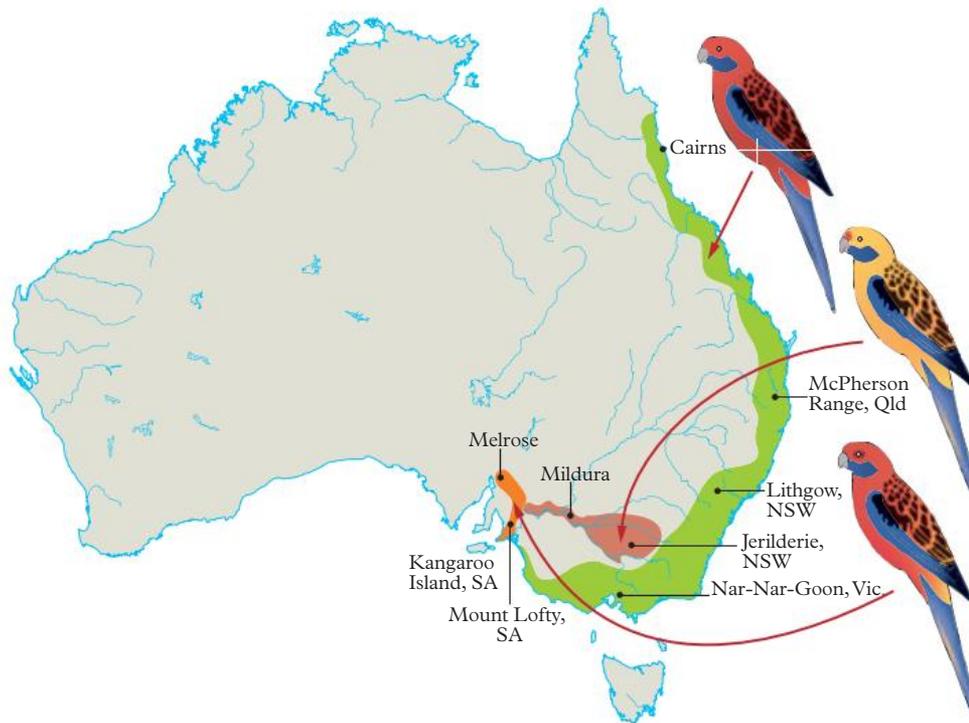
a physical barrier that prevents interbreeding between members of different populations of a species

### subspecies

a rank immediately below a species; a population that is genetically distinguishable from other populations of the same species in a particular geographic region, capable of interbreeding successfully where ranges overlap

### race

one group of a population that is genetically different from other groups as a result of having a different range



**FIGURE 5** The subspecies of the crimson rosella include: the crimson rosella along the eastern side of the Great Dividing Range, the yellow rosella along the Murray River and the Adelaide rosella in the Adelaide region.

## CHECK YOUR LEARNING 2.4

### Describe and explain

- 1 Define** the term 'species' in terms of reproductive isolation. **Explain** difficulties with this definition.
- 2 Identify** a species that does not produce fertile offspring.

### Apply, analyse and interpret

- 3 Deduce** why determining whether the following two groups of organisms are the same species may be difficult.
  - a** African genus *Acacia* and Australian genus *Acacia* plants.
  - b** The variety of bacteria found in the human intestine.

**c** Fossilised remains of a pine tree, and the modern-day Woolamai pine found in Australia.

- 4** A farmer bought two mules (a hybrid between a horse and a donkey) with the intention of breeding them. **Determine** why the farmer may not succeed.

### Investigate, evaluate and communicate

- 5** Biology classification is a dynamic and evolving process that keeps changing as our understanding of living organisms change. **Justify** this statement with two examples.

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Infertile organisms

# 2.5

## Features used in classification

### KEY IDEAS

- ✦ Diagnostic features to distinguish organisms
- ✦ The modern Linnaean system of classification
- ✦ Homologous diagnostic features
- ✦ Analogous diagnostic features
- ✦ Geographic distribution and the classification of fossils

Biologists group species to reflect the relationships between them, both in the present and in the past. The groups are, in effect, hypotheses about evolutionary history. As a result, they can be tested, by detailed study of the fossil record and comparing them with the anatomical features of other living organisms. As new information becomes available, the relationship hypothesis is revised.

**Diagnostic features** are those characteristics that distinguish one group from all others, most generally at the kingdom level.

### diagnostic feature

any feature used to separate groups in the classification of organisms

## Divergent and convergent evolution

The general appearance of organisms gives important clues to their classification. Structure alone can be very misleading. Insects, birds and bats all have wings, but they are in very different classification groups. Sharks and dolphins are both streamlined in water and have fins; however, the tail on a shark moves from side to side, while the tail on a dolphin moves up and down. Therefore, do not rely on the physical features to determine the classification group. Instead they examine how the organisms evolved, and how recently they shared a common ancestor.

## Homologous structures and adaptive radiation

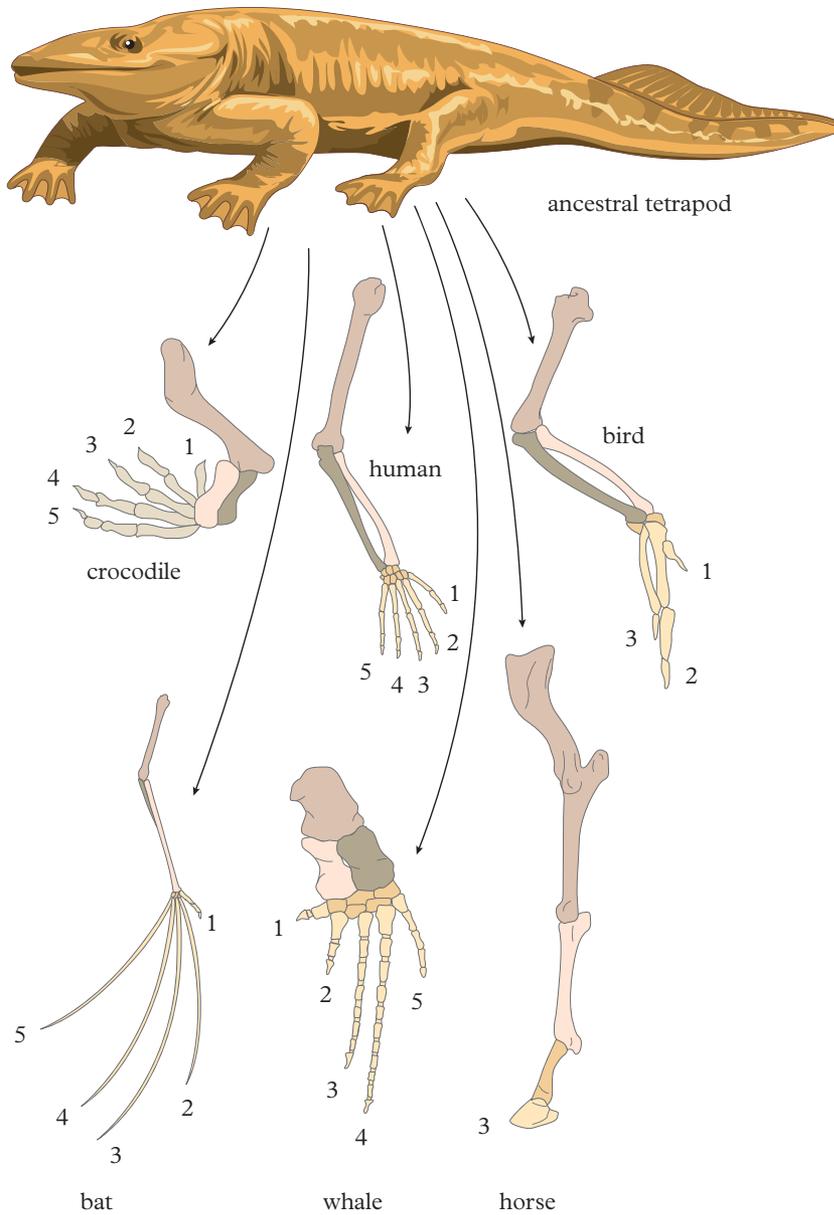
Taxonomists use the internal as well as external structure of an organism to classify it into a group. The wing of a bird, the flipper of a whale, the forelimb of a horse and the human arm all serve different functions and look different on the surface. A detailed study of the bone structure of each, however, reveals that they have the same basic internal structure. Structures that share a similar internal structure, despite have a slightly different function, are termed **homologous structures**. This suggests that they all shared a recent (only a few hundred million years) common ancestor. The greater the number of homologous organs different species have, the closer is the relationship between them.

### homologous structures

similar structures with slightly different functions, indicating shared ancestry

Similarly, although they may differ in detail, all flowering plants share the following features:

- roots
- stems and branches
- leaves and chlorophyll
- flowers, usually composed of sepals, petals, pistils and stamen.



**FIGURE 1** Homologous structures: the forelimb of terrestrial vertebrates. (Colour shows matching bones; numbers show matching fingers.) All originate from a common ancestor, the tetrapod.

These similar organisms begin to diversify when two groups are exposed to different selection pressures. If one group of plants is exposed to strong winds and cold temperatures, the smaller plants that are lower to the ground will survive and produce seeds. Plants that are exposed to hot dry environments will survive if their leaves are narrow to prevent water loss. Over millions of years, the two plants will become more diverse from each other due to the environmental pressures driving different characteristics in the surviving organisms. Their distinguishing characteristics diverge from their shared common ancestor, resulting in **divergent evolution**.

**divergent evolution**  
 evolution that leads to descendants becoming different in form from their common ancestor

## Analogous structures

### analogous structure

structures with a similar function but no structural relationship

### convergent evolution

the independent development of similarities between species as a result of their having similar ecological roles and selection pressures

### vestigial structure

a structure with no apparent function, but which may have had a function in an ancestral species

### embryology

growth and development of zygote until birth

Other organisms have similar looking characteristics, with similar functions; however, their shared common ancestor is much further back in time than it initially appears.

The wings of birds and insects are an example of this phenomenon. The bird's wing develops as part of a bony skeleton, while insects do not have bones. Although both sets of wings serve the same function and have a similar superficial appearance, they show no evidence of relatedness. The wings are said to be **analogous structures** (similar structures with similar functions due to similar environmental selection pressures). This process of selecting common distinguishing characteristics from different ancestral forms due to similar selection pressures is called **convergent evolution**. It is sometimes very difficult to determine whether a structure is homologous or analogous, and other characteristics are needed to classify organisms.

## Vestigial structures

The possession of **vestigial structures** is also taken as evidence of a common ancestral origin. These structures are smaller and simpler than those in related species and have lost, or almost lost, their original function. Examples include:

- the reduced bones in the limb of a horse
- stomata on the petals of flowering plants
- the coccyx of humans
- the hind limb bones of snakes and whales.

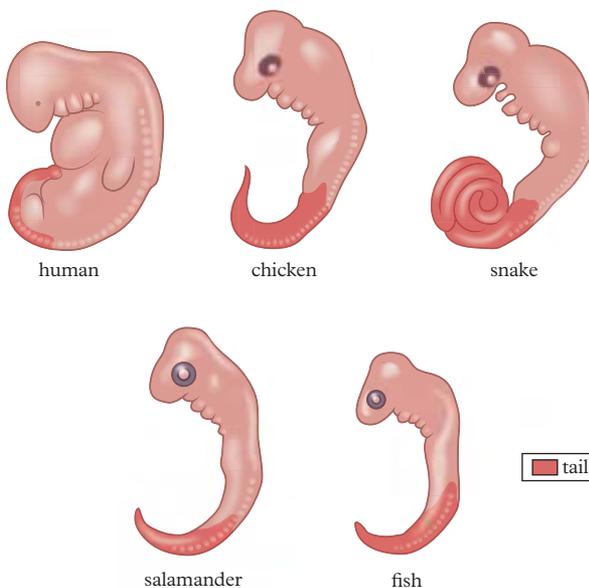
Anatomical structures of fossils are compared with those of living organisms in order to determine any relationship between them.

## Comparative embryology

The study of the fertilised cell that results from two gametes (egg and sperm or pollen and ova) is called **embryology**. Examination of how the embryos of different organisms develop over time has shown that embryos of many animals closely resemble each other, even though the adults show wide divergence. All vertebrate embryos (including humans) go through a stage with gill slits (visceral clefts) and a tail. This means they all have genetic material that carries the code for such structures.

Embryological evidence has also been used to show the relationships between different groups of plants. The life cycles of the thallophytes (mosses) through to the spermatophytes (seed-producing plants) demonstrate a common origin.

Similarities in different embryological structures, therefore, indicate inheritance from a common ancestor.



**FIGURE 2** Early embryonic developments of some vertebrates, which all possess the tail.

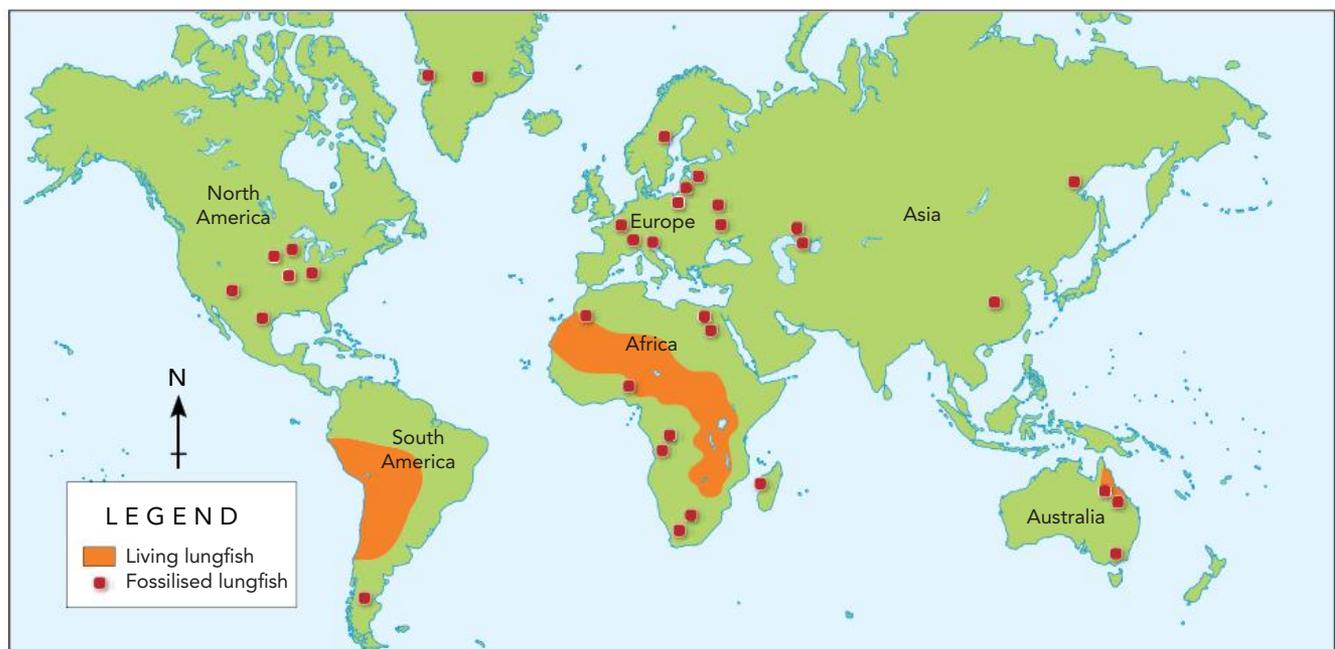
# Geographic distribution

**Geographic distribution** of both fossils and current species with similar diagnostic features can be found on different continents across the Earth. Remnants of an ancient Antarctic beech forest (*Nothofagus moorei*) exist in the temperate and subtropical rainforests of eastern Australia, and the mountains of New Guinea, New Zealand and South America. Fossil records indicate that in past times these forests also existed in New Caledonia and Antarctica. There are three existing genera of lungfish found separately in tropical regions of South America (*Lepidosiren*), Africa (*Protopterus*) and Australia (*Neoceratodus*). Fossils also show this discontinuous distribution.

**geographic distribution**  
the natural range of the various forms of animals and plants in the different regions and localities of the Earth

This unusual distribution of similar species is due to the slow movement of Earth's tectonic plates over millions of years. Measurements of continental movement suggest that 200 to 250 million years ago there was one supercontinent, Pangaea. About 180 million years ago this single land mass separated into Laurasia in the north and Gondwana in the south. Thus, fossils found on all continents must have originated from Pangaea earlier than 180 million years ago. This distribution can be seen in Figure 3, which shows the location of lungfish fossils across all continents.

Not all fossils with similar distinguishing features are found on all continents. Fossils are commonly found in coal beds in India, Australia, South Africa, South America and Antarctica, but not in many countries in the present Northern Hemisphere. For example, fossils of *Mesosaurus*, a reptile that existed 200 million years ago, are found only in what is now western South America and south-eastern Africa. A sheep-sized reptile of the same age, *Lystrosaurus*, flourished in South America, India and Antarctica. This supports the notion that the African, Indo-Australian and Antarctic tectonic plates were once joined in a single land mass.



**FIGURE 3** Distribution of living and fossil lungfish

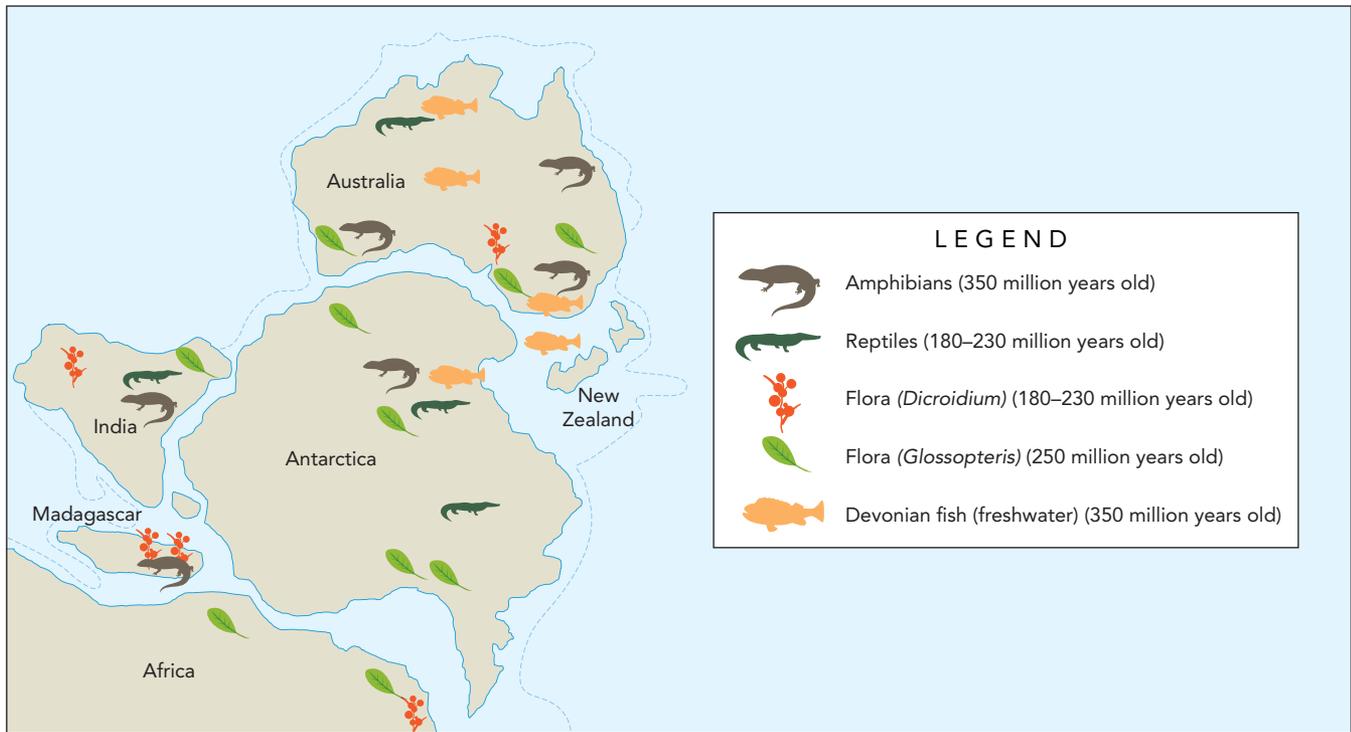


FIGURE 4 Fossil evidence of continental drift

## CHECK YOUR LEARNING 2.5

### Describe and explain

- 1 Explain** what the term ‘diagnostic feature’ means.
- 2 Define** the terms ‘homologous’ and ‘analogous’ as used by biologists to describe structures. **Identify** an example of each type of structure.
- 3 Describe** which features are used by biologists to determine the relatedness of organisms.

### Apply, analyse and interpret

- 4 Distinguish** between convergent and divergent evolution.

### Investigate, evaluate and communicate

- 5** Bifurcation is the division of something into two branches. **Determine** whether this is an example of divergent or convergent evolution. Provide evidence to **justify** your answer.



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Divergent and convergent evolution

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Continental drift

# 2.6

## Cladistics – an alternative system of classification

### KEY IDEAS

- + Clades from a common ancestor
- + Cladistics
- + Cladograms
- + Nuclear DNA, mitochondrial DNA and proteins in cladograms
- + A molecular clock and mutations
- + Mitochondrial DNA from the maternal line

### phylogeny

the evolutionary history of a kind of organism

### cladistics

a method of grouping organisms that uses evolutionary lines of descent rather than structural similarities

### shared characteristic

a feature that all members of a group have in common

### derived characteristic

a feature that sets members of that clade apart from other individuals

### cladogram

a branching diagram showing the evolutionary relationships between a number of species

### cladogenesis

the making of a clade by means of an ancestor species evolving into two or several new species

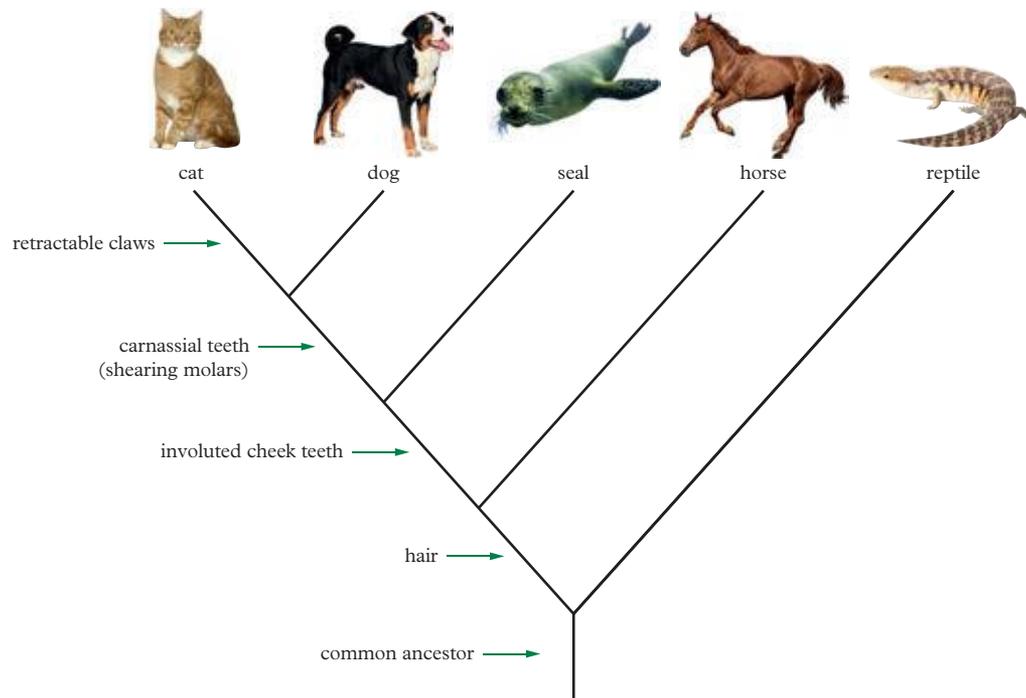
The evolutionary history of a species is called **phylogeny**. A phylogenetic classification system shows the evolutionary history of a species or group. It shows the points where different groups separated from a recent common ancestor. Although Linnaean classification acknowledges the evolutionary history of organisms, its focus is on homologous structures.

In 1966 Willi Hennig developed **cladistics**, a system of phylogenetic analysis that uses **shared** or **derived characteristics** as the only criteria for grouping taxa. In this system, it is assumed that as groups of organisms diverge and evolve from a common ancestral group, they retain some unique common characteristics. For example, all mammals have hair and carnivorous mammals are meat eaters with common tooth and intestinal structures. The domestic cat and leopard are more closely related to each other than to the wolf because they can both purr. A derived characteristic is a feature that evolved only within the group under consideration (e.g. the ability to purr). The basic idea behind cladistics is that members of a group share a common evolutionary history and are more closely related than members of another group.

In this system, organisms are classified according to the order in time that groups arise along a phylogenetic tree. The tree (or **cladogram**) is composed of a series of branches where each separation is defined by a new feature. For example, the reptile, horse, seal, dog and cat are all vertebrates that have a mixture of characteristics that existed in the common ancestor of all vertebrates (pentadactyl limbs). At one point in the evolutionary history, the ancestor of the mammals (horse, seal, dog and cat) evolved hair and mammary glands, while the ancestor of the reptiles did not. In the more recent evolutionary history, the ancestor of the seal, dog and cat evolved skeletal changes that the horse ancestor did not. This continued until the early ancestors of each organism diverged from each other.

Three basic assumptions are made in cladistics:

- Any group of organisms are related by descent from a common ancestor. This is based on evidence that life arose on Earth only once and that biodiversity has been produced through the reproduction of existing organisms.
- There is a bifurcating pattern in **cladogenesis**. This means that new kinds of organisms may arise when existing populations divide into exactly two groups. Although some biologists suggest that many new species can diverge from a common ancestor within a short time, there are only a limited number of cases of this occurring. This assumption also does not consider the possibility of interbreeding between distinct groups.



**FIGURE 1** A cladogram, which is a sequence of branches based on derived characteristics from a common ancestor. The features shown are illustrative only and are not the only ones that would be used in determining the branching points. The beginning of the tree, called the root of the tree, is the last common ancestor.

**plesiomorphy**

an ancestral characteristic or trait that is shared by two or more taxa

**apomorphy**

a specialised trait or characteristic unique to a group or species

**clade**

a group of organisms that is believed to comprise a common ancestor and all of its evolutionary descendants

**karyotype**

the number and appearance of chromosomes in the cell nuclei of an organism or species

- Change in characteristics occurs in lineages over time. Cladists use the term **plesiomorphic** for the ‘original’ characteristic and **apomorphic** for the characteristic derived from it. This assumption is central to cladistics.

There are two main types of cladograms. Most cladistic analysis focuses on identifying groups showing a given species and all of its direct descendants – **clades** – that do not include any other lineages. Other cladograms show a group of species with its most recent common ancestor but do not show all the descendants of the ancestor.

## Chromosome and DNA analyses

The **karyotype** of an organism is a description of the number and arrangement of DNA into chromosomes present in the cell. Each species has a set number of chromosomes found in each cell of its body.

Differences between the types of chromosomes in any species can be determined by the:

- position of the centromere
- banding on the chromosomes.

When specific stains are used on the chromosomes, banding similar to bar codes can be seen. The patterns made by these bands are unique to the particular chromosome.

Similarities and differences between species can therefore be determined by comparing their karyotypes. Differences in karyotype between species can sometimes be explained by chromosomal mutations (permanent changes in the number or arrangement of chromosomes).

Each chromosome (made of a DNA molecule wound around histones) contains the genetic code that can be translated into proteins (the building blocks of all organisms). Any variation in the genetic code can result in a different (and possibly non-functioning) protein being made.

The unravelling of the code contained in each chromosome and its role in controlling how an organism develops and survives has led to a greater understanding of relationships between organisms and their evolutionary pathways. Protein comparisons between different organisms are, in effect, a comparison of that part of the chromosome. The greater the number of similar proteins, the closer the relationship between the organisms. If two organisms have very similar proteins, they will have similar nucleic acids and therefore may have a common origin. Therefore, the analysis of molecules such as DNA or proteins can be used to determine the evolutionary relationship between organisms.

## Molecular analysis

**Molecular analysis** techniques have become easier and more accessible for scientists. This means the construction of cladograms using molecular data has become more detailed.

## Molecular clock

Comparisons between the molecules of particular organisms can be used to provide more information of possible evolutionary pathways. One of the significant features of these studies has shown that particular molecules (e.g. DNA) mutate (have a permanent change) at a constant rate, and that the rate differs from one part of the DNA to another. This means the sections of DNA are acting like a clock (**'molecular clock'**) that starts when the two groups of organisms diverge.

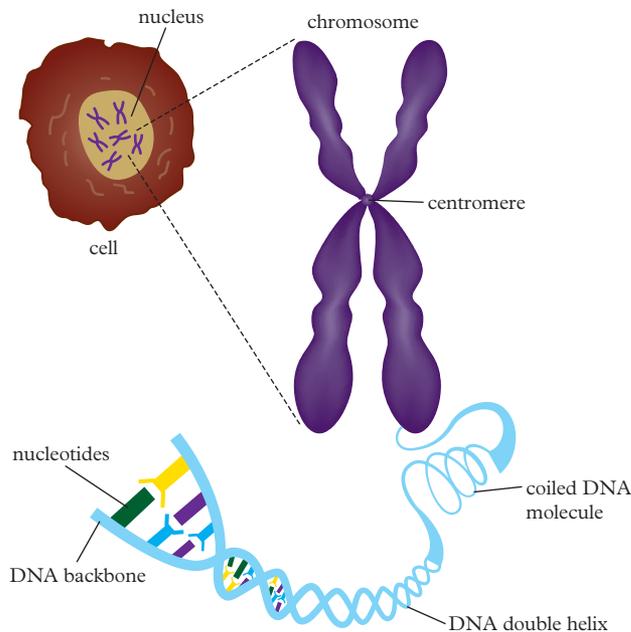
As time passes, more and more mutations accumulate in the DNA. Many of these sections of DNA contain the code for a protein, so increasing changes in the DNA results in changes in the proteins. The greater the number of changes in DNA or proteins, the more time has passed for these mutations to accumulate. By calibrating the DNA and protein clock with fossil dating, an estimate of 'real' time differences can be determined.

### molecular analysis

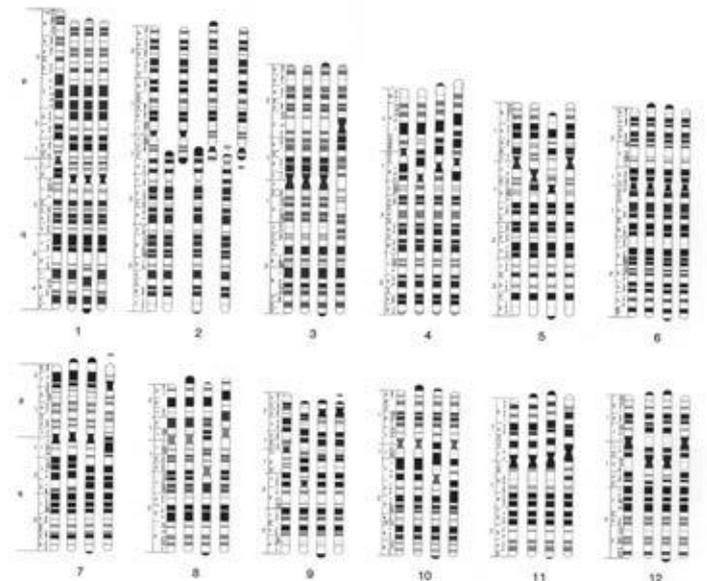
a branch of biochemistry in which the molecular basis of biological activity of molecules such as DNA, RNA and proteins is studied

### molecular clock

a technique that uses the mutation rate to deduce when two or more life forms diverged



**FIGURE 2** Every somatic cell in an organism contains a set of paired chromosomes (DNA molecules). Each chromosome replicates prior to cell division to form sister chromatids joined by the centromere.



Source: 'The Origin of Man: A Chromosomal Pictorial Legacy' by J.J. Yunis and O. Prakash, in *Science*, 19 March 1982, vol. 215: 1525-1530.

**FIGURE 3** Comparisons of the banding patterns between the chromosomes of humans, chimpanzees, gorillas and orangutan (left to right) shows many similarities. This indicates they shared a relatively recent common ancestor.

## Serological tests

There are many similarities in the structure and function of cells in different organisms. When organisms share a common ancestor, they often have the same proteins on the surface of their cells. This suggests that the more diverse the cell surface proteins are, the further back in time they shared a common ancestor.

The similarities in surface cell proteins can be compared using the blood serum from rabbits. The antibodies in the rabbit serum will only bind to proteins of a specific shape. The more similar the cell surface proteins in different organisms, the more the antibodies in the serum will bind and form a precipitate. Similar proteins suggest similar genetic material and recent common ancestors.

The high level of precipitation in chimpanzees shown in Table 1 suggests that the cell surface proteins in chimpanzees are very close to those found in humans. Although this technique has been used for a long time, it was initially a fairly crude technique involving the entire blood serum. It is now possible to use purified samples of particular proteins. The degree of difference between two proteins is termed the **immunological difference**.



**FIGURE 4** Humans share over 95% of their DNA with chimpanzees.

**TABLE 1** Amounts of precipitate produced by adding rabbit serum containing anti-human antibodies.

Source of serum	Precipitation (%)
Man	100
Chimpanzee	97
Gorilla	92
Gibbon	79
Baboon	75
Spider monkey	58
Lemur	37

### immunological difference

the degree of difference between two proteins

## Amino acid sequences

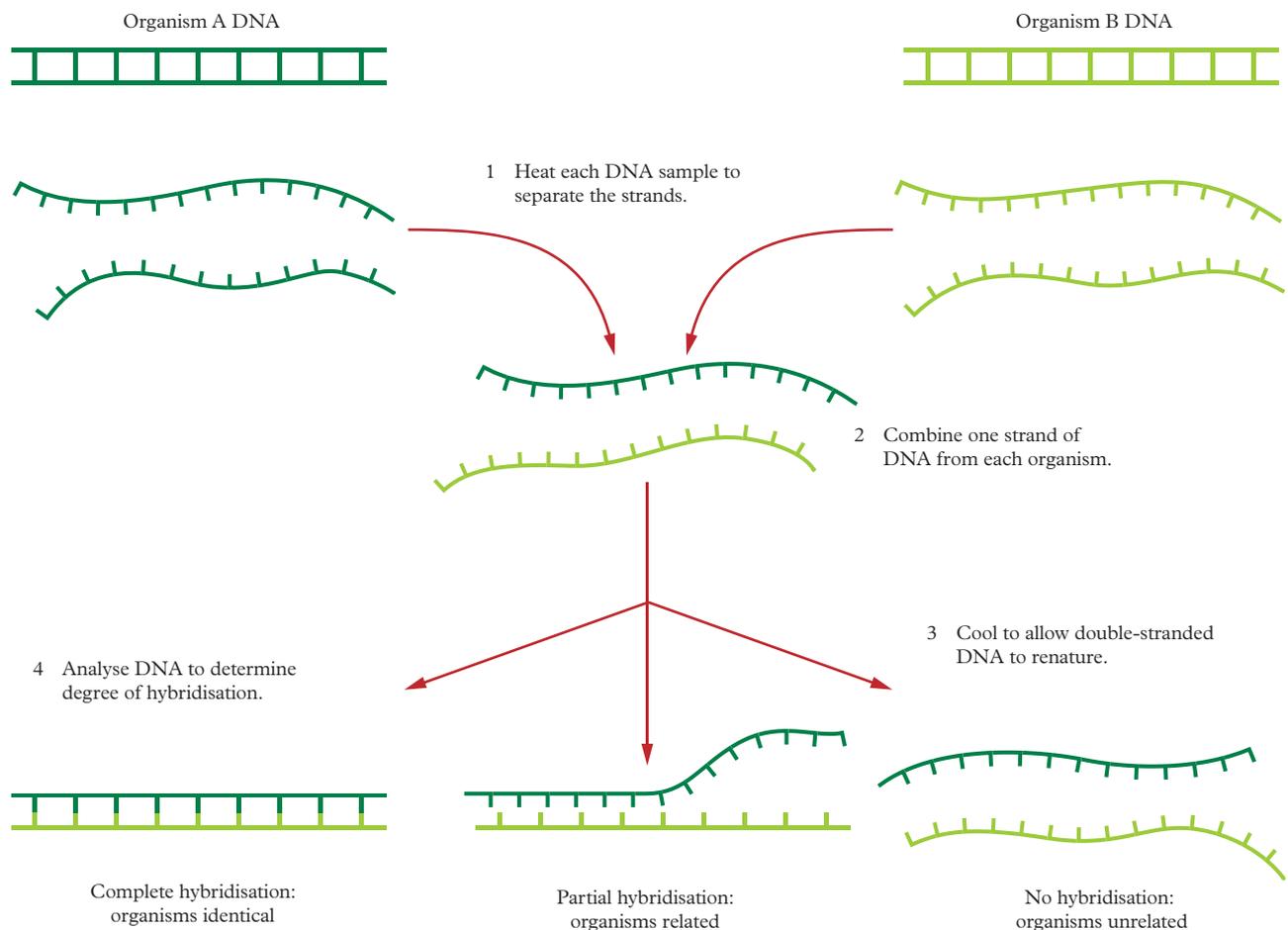
Serological data gives information about differences in proteins, but it does not show what the exact difference is. Each protein is made up of a chain of amino acids (called a polypeptide chain). A change in one amino acid along this chain results in changes to the shape of the final protein. New technologies have resulted in relatively rapid analyses of the sequence of amino acids in the proteins. When the sequences of amino acids for the same protein are compared, the number of differences in the amino acids can be determined. The greater the number of differences in amino acids between two organisms, the more time has passed for changes to accumulate since their common ancestor.

## DNA sequencing

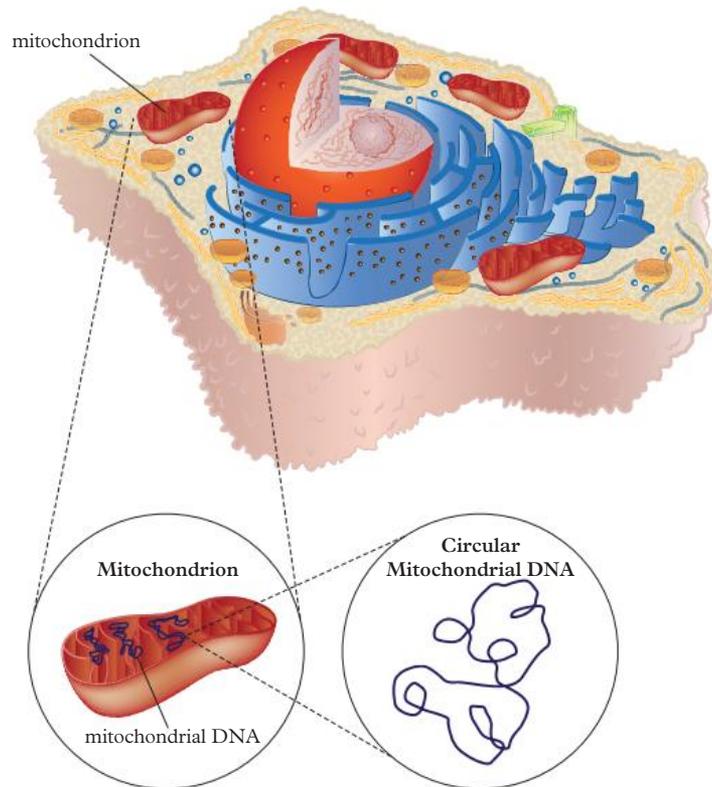
Not every mutation in the DNA results in a change in an amino acid. Therefore, two species may have exactly the same amino acid sequence for a protein but have different DNA sequences. Comparison of these DNA sequences in determining relatedness between species is therefore more powerful than comparison of proteins.

A technique used to compare DNA of different species is called **DNA-hybridisation**. Because the two chains of the DNA molecules are bound by weak hydrogen bonds between complementary bases, they are easily broken by heating to  $\geq 85^{\circ}\text{C}$ . If the sample of separated chains is allowed to cool slowly, the bonds re-form the normal double-stranded DNA. When a mixture of DNA from two species is heated and then allowed to cool, one strand of DNA can form partial bonds with that of another species. The strength of the bonding between the two chains is determined by how many bonds are formed between them. The more bonds that are formed between the two chains, the greater the similarity between the two types of DNA. The strength of bonding is tested by the temperature needed to separate the hybrid strand. If the chains separate at a low temperature, few bonds are formed between the DNA of the two species, suggesting there are few commonalities between the two species. This indicates that the species are not closely related. If a higher temperature is required to separate the two strands of DNA, then more bonds are formed between them, suggesting the species are closely related and shared a recent common ancestor.

**DNA-hybridisation** a technique that measures the degree of genetic similarity between the DNA sequences of different individuals



**FIGURE 5** The process of DNA hybridisation



**FIGURE 6** Circular strands of DNA (mtDNA) are found in the mitochondria. These are passed on from the maternal line only.

## Mitochondrial DNA

Each pair of chromosomes (DNA) found in the nucleus of any sexually reproducing individual is composed of one chromosome inherited from the individual's mother and a chromosome inherited from its father.

In mammals, the Y chromosome must be inherited from the father's paternal line. Any mutations in the Y chromosome should be able to be traced through the father's lineage.

In all sexually reproducing species, all of the mitochondria found in the cells of an organism are inherited from the mother only. The mitochondria (like the chloroplasts in plants and algae) are able to replicate themselves. Like the bacteria from which they are thought to have originated, mitochondria contain a circular molecule of DNA that contains the code for the enzymes essential for cellular respiration.

In the human, the mitochondrial genome consists of about 16 500 base pairs which are known to code for thirteen proteins, twenty-two tRNAs and two rRNAs. During fertilisation, only the nucleus of the sperm (containing no mitochondria) enters the ovum. Even when sperm cells are injected directly into the cytoplasm of the ovum (during IVF), no paternal **mitochondrial DNA** will be found in the zygote.

Using the DNA found in the mitochondria (mtDNA) to determine the relationship between two groups of organisms has many advantages over the DNA found in the nucleus. For example:

- Direct genetic lines can be traced, since only maternal mtDNA is passed on to offspring.
- mtDNA does not exhibit recombination (swapping bits of chromosome in a pair, one of which is maternal and the other paternal) creating a garbled genetic history.

### mitochondrial DNA

a double-stranded DNA found only in mitochondria; in most eukaryotes is circular and is maternally inherited

- Mitochondria are present in large numbers in each cell, so fewer cell samples are required to obtain large amounts of mtDNA.
- mtDNA has a higher rate of mutations than nuclear DNA, making it easier to compare differences between closely related individuals. By determining the rate at which this mutation occurs, a molecular clock can be calculated that can give the point in time at which different groups diverged.

Although the human mitochondrial genome was one of the first human chromosomes to be analysed and sequenced in its entirety, it is only very recently that technology has allowed the comparison of the whole sequence.

## CHECK YOUR LEARNING 2.6

### Describe and explain

- 1 **Explain** how the cladistic system of classification differs from the Linnaean system.
- 2 **Describe** a cladogram.
- 3 **Explain** the assumptions that underpin cladistics.
- 4 **Describe** the main features of organisms that are used to develop a cladogram.
- 5 **Define** a clade.
- 6 Modern methods of molecular analysis are significant in cladistic analysis. **Describe** two of these methods and explain how each assist in the development of a cladogram.

7 **Define** a 'molecular clock'.

8 **Explain** how the molecular clock is used to date when a species diverged from its ancestor.

### Apply, analyse and interpret

- 9 Both hypothetical phylogenetic trees below show that the human is more closely related to the chimpanzee than it is to the gorilla and orangutan. Tree a is based on overall similarities resulting from plesiomorphic characteristics. Tree (b) is based on apomorphic characteristics. **Deduce** which of these trees is a cladogram. Give reasons for your answer.

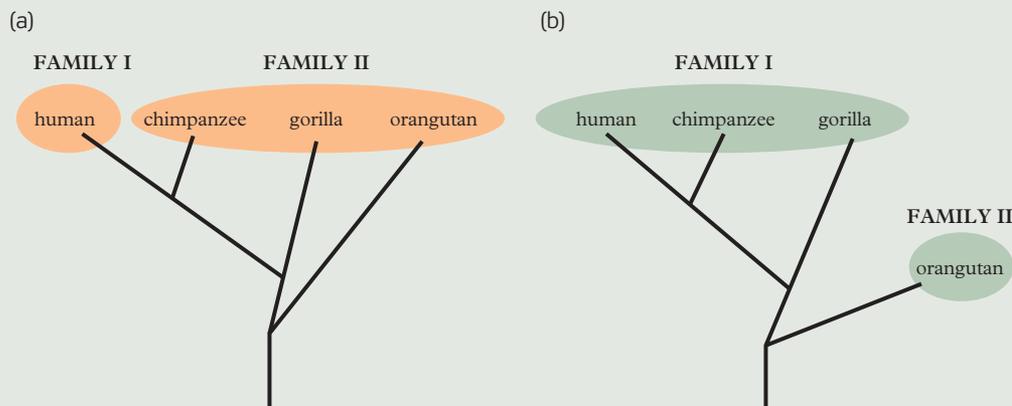


FIGURE 7 Two hypothetical phylogenetic trees of humans in relation to other primates

Check your **obook assess** for these additional resources and more:

» **Student book questions**

Check your learning 2.6

» **Weblink**

DNA sequencing

» **Weblink**

Mitochondrial DNA

# 2.7

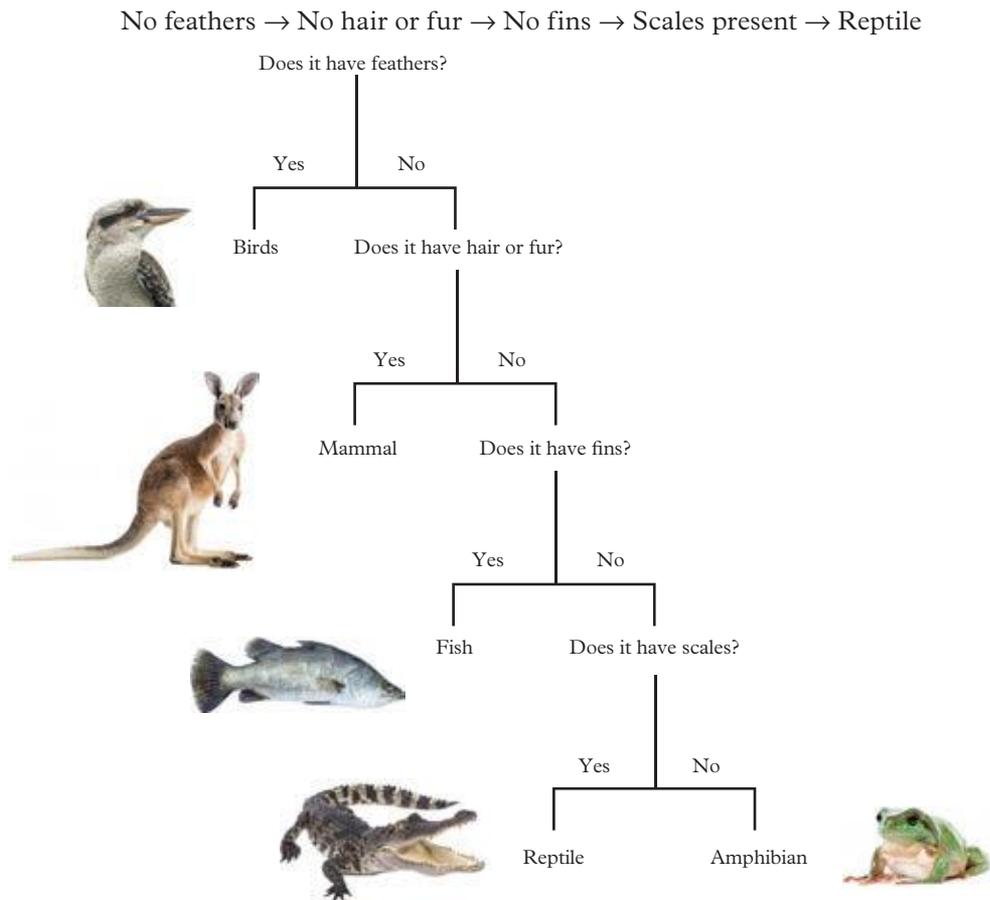
## Identification keys

### KEY IDEAS

- + Biological keys are a tool to identify an organism's classification group
- + Dichotomous keys
- + Keys are limited to a small number of organisms

Biologists often use keys or flow diagrams to help them identify different organisms. Observable features are used to separate organisms into smaller and smaller groups until the organism can be identified using its unique features. Alternatives in such keys should be comparative (e.g. legs or no legs). These keys may be very general.

In using such a key, a start is made at the top and the alternatives are worked through until the organism is identified. A decision is made about the characteristic at each branch point. Depending on the feature displayed, one of two pathways is followed to the next branch. For example, identifying a vertebrate with scales but no fins would involve the following steps:



**FIGURE 1** An example of a dichotomous key

**dichotomous key**  
identification key  
with only two  
alternatives at each  
stage

Keys with only two alternatives at each stage are said to be **dichotomous keys**. Rather than being shown diagrammatically, keys may be in tabular form. In the example below, the key is specific for a group of species known to exist in a particular locality and therefore would not be useful in other localities.



FIGURE 2 Young Koala eating Eucalyptus leaves

Some keys have many choices at each step and thus are not dichotomous.

TABLE 1 Key to ironbark species of eucalypts in Brisbane as identified by H.T. Clifford in 1972

1	Mature buds greater than 2 cm long Mature buds less than 2 cm long	<i>E. sideroxylon</i> – go to: 2.
2	Leaves opposite Leaves alternate	<i>E. melanophloia</i> – go to: 3.
3	Coppice leaves twice as long as broad Coppice leaves several times longer than broad	<i>E. siderophloia</i> – go to: 4.
4	Mature buds about 1 cm long Mature buds less than 1 cm long	<i>E. drepanophylla</i> <i>E. crebra</i>

## CHECK YOUR LEARNING 2.7

### Describe and explain

- Describe** dichotomous keys and how they are used.
- Construct** dichotomous keys to distinguish the koala, dingo, snake, lizard, turtle, emu and green tree frog:
  - in the form of a table
  - as a flow chart.

### Apply, analyse and interpret

- A dichotomous key was produced that identified each bird found in a particular environment. **Deduce** why it would be difficult to use the same key in another environment.

Check your obook assess for these additional resources and more:

» **Student book questions**

Check your learning 2.7

» **Weblink**

Dichotomous keys

» **Weblink**

How to make dichotomous keys

# Review

## Chapter summary

- 2.1**
- Biodiversity refers to the variability between living organisms or their ecosystems.
  - Ecosystems consist of an interacting community of organisms (biotic factors) and their physical environment (abiotic factors).
  - An adaptation is a structure or function in the population that increases the chances of survival of a species in an environment.
- 2.2**
- The arrangement of objects or organisms into groups according to their observed similarities is called classification.
  - Biological classification arranges organisms in a hierarchical system.
  - Different types of classification will depend upon how the data is used.
- 2.3**
- Taxonomy is the study of classifying living things based on physical and biochemical characteristics.
  - The taxa (groups) in the Linnaean classification system are domain, kingdom, phylum, class, order, genus and species. It also includes subdivisions at some levels.
  - The binomial naming system uses the genus and species written in italics and/or underlined. The genus is always written with a capital, and the species with a lower-case letter.
  - The Linnaean classification system continues to be modified as new information is discovered.
- 2.4**
- Species can be defined by organisms that can interbreed in natural conditions to produce viable fertile offspring. This means different species are reproductively isolated.
  - Hybrid offspring have parents from two different species. They are usually infertile.
  - Asexual organisms, fossils, species reproducing by parthogenesis, ring species and infertile organisms cannot have their species defined by their ability to reproduce.
  - Varieties and subspecies classifications are used to identify groups of organisms that have slightly different physical characteristics and may not be able to reproduce in natural conditions due to geographic isolation.
- 2.5**
- Diagnostic features are the characteristics that distinguish one group of organisms from all others.
  - The modern Linnaean system of classification does not rely solely on diagnostic features.
  - Homologous diagnostic features result from divergent evolution from a recent common ancestor.
  - Analogous diagnostic features result from convergent evolution from different recent common ancestors.
  - Geographic distribution can be used to support the evolutionary relationship in the classification of fossils.

- 2.6**
- A clade is a group of organisms that consists of a common ancestor and all its lineal descendants.
  - Cladistics is the study of how organisms have evolved from a common ancestor and diverged due to different selection pressures, causing physical changes.
  - Cladograms can be used to classify the evolutionary relationship between groups of organisms.
  - Cladistics is based on a number of assumptions.
  - Molecules such as nuclear DNA, mitochondrial DNA and proteins can be compared to determine a cladogram.
  - A molecular clock assumes that sections of DNA will mutate at a constant rate. The greater the number of mutations, the more time has passed for the mutations to accumulate.
  - Mitochondrial DNA is inherited through the maternal line.
- 2.7**
- Biological keys are tools used to identify an organism's classification group.
  - Dichotomous keys have two choices or branches at each junction that lead to the scientific name of the organism.

## Key terms

- abiotic
- adaptation
- analogous structure
- apomixis
- apomorphic
- asexual reproduction
- binomial nomenclature
- biodiversity
- biotic
- clade
- cladistics
- cladogenesis
- cladogram
- class
- classification
- convergent evolution
- derived characteristics
- diagnostic feature
- dichotomous key
- divergent evolution
- division
- DNA-hybridisation
- domain
- ecosystem
- embryology
- extremophiles
- family
- genus
- geographic distribution
- geographic isolation
- hierarchical
- homologous structure
- hybrid
- immunological difference
- karyotype
- kingdom
- mitochondrial DNA
- molecular analysis
- molecular clock
- mutation
- order
- parthenogenesis
- phylogeny
- phylum
- plesiomorphic
- race
- reproductive
- isolation
- sexual reproduction
- shared characteristic
- species
- specific name
- subspecies
- taxa
- taxon
- taxonomy
- variety
- vestigial structure

## Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number:

\* = low; \*\* = medium; \*\*\* = high.

### Multiple choice

- Linnaeus based his system of classification on:
  - structures
  - size
  - habitat
  - genetics
- Which one of the following categories includes the greatest number of different types of organisms?
  - genus
  - family
  - phylum
  - class
- Because classification systems are developed by scientists they are:
  - acceptable to taxonomists
  - unchanging and reliable
  - a permanent part of biology
  - subject to modification
- Scientists of all nations use scientific names because these names are:
  - different in all languages
  - the same languages
  - accurate descriptions of organisms
  - written in Latin
- An amateur bird watcher sighted two robins that were both black, red and white in colour, but one had red head feathers and the other had black head feathers. One robin was male and the other was female. The bird watcher was unsure whether or not they belonged to the same species. In order to be certain, he would need to:
  - determine whether the two robins would mate under natural conditions
  - refer to a catalogue of type specimens of robins
  - determine whether the offspring produced by mating these two robins were fertile
  - refer to preserved specimens of robins that had been collected and labelled by experts
- Cladistics is based on:
  - evolved and inherited characteristics
  - common physical characteristics
  - similar and dissimilar physical characteristics
  - inherited and common characteristics
- The advantage in using mitochondrial DNA (mtDNA) in tracing ancestry is that:
  - direct genetic lines can be traced as only maternal mtDNA is passed onto offspring
  - direct genetic lines can be traced as only paternal mtDNA is passed onto offspring
  - mtDNA has a lower rate of mutation than nuclear DNA
  - there is less mtDNA in a cell and so contamination of material is low
- In the cladogram shown in Section 2.6 Figure 1, which feature separates a dog from a cat?
  - carnassial teeth
  - presence of curved cheek teeth
  - hair
  - retractable claws
- Cladograms are based on:
  - observable features only
  - hierarchical groupings of organisms
  - both observable features and molecular analyses
  - immunological differences between organisms only

### Short answer

#### Describe and explain

- ★ **10 Explain** the difference between taxa and clades.
- ★★ **11** Most biologists use either the Linnaean or cladistic system when classifying organisms. **Summarise** the advantages and disadvantages of each system.

★★★ 12 Two groups of frogs resemble each other very closely. One group lives on the lower eastern slopes of the Eastern Highlands. The other group lives on the top of these mountains. A biologist discovers that the frogs on the lower slopes breed in September–November, whereas those on the higher slopes breed in January–March.

- a **Propose** possible reasons for the different breeding times of these two groups.
- b **Explain** whether you would classify the frogs as the same species.
- c **Describe** any additional information you may require to validate your classification.

**Apply, analyse and interpret**

★ 13 Using the word key to eucalypts in Section 2.7 Figure 2, **deduce** the scientific name of the specimen in Figure 1.



FIGURE 1 Narrow-leaved ironbark

★ 14 Using the Latin or Greek roots or names provided in Table 1, **suggest** a scientific name for the animal shown in Figure 2. **Describe** how you derived the name.



FIGURE 2 Striped possum

TABLE 1 Latin words and their meanings

Latin word	Meaning
ancylo	crooked
albo	White
-acis	Pointed/barb
amphi	on both sides
australis	belonging to the south
bi	two, double
brachy	short
capit -o, -a	head
caud - a, -ata	tail
dactylo	finger, toe
gracil	slender
macro	large
meta	between
nocti	night
-onch	barb, hook
-phaga	eat
psita	tapping
philo	loving
pus	foot
tri	three
trisho	hair
virgate	striped

★★★ 15 Residents of the outer Brisbane suburbs can sometimes be confronted with small mouse-sized mammals inside their homes. It is important for residents to be able to recognise which is a house/field mouse and which is a native mouse, marsupial mouse or feathertail glider, because many of these native species are rare and should be released back into the bush.

Here are some descriptions of mouse-like mammals found around Brisbane.

- A House mouse (‘field mouse’) Introduced pest species *Mus musculus*  
Body length 75 mm; tail length 85 mm; weight 15 g. Typical mouse, usually olive-brown back and slightly paler belly. Very strong musky-mouldy scent. Small notch on inner side of upper incisors is characteristic.

**B** Common planigale (marsupial mouse)  
*Planigale maculata*  
Body length 80 mm; tail length 77 mm; weight 11 g. Mouse-sized, mouse-coloured. Flat head; pointed snout; cat-like teeth; inner 'big' toe on hind foot has no nail. Female has 'kangaroo-like' pouch and male has a pendulous scrotum; both these features are lacking in the house mouse.

**C** Common dunnart (marsupial mouse)  
*Sminthopsis murina*  
Body length 90 mm; tail length 80 mm; weight 22 g. Large mouse-size. Sharply pointed snout; large bulging black eyes; delicate white hind feet; grey-brown head and body; belly pure white; cat-like teeth; inner 'big' toe on hind feet has no nail. Female has 'kangaroo-like' pouch.

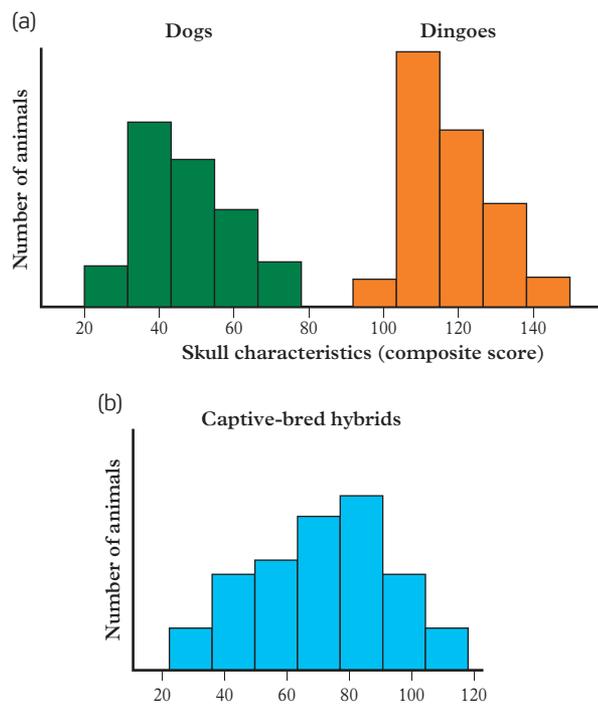
**D** Feather-tail glider (marsupial) *Acrobates pygmaeus*  
Body length 80 mm; tail length 80 mm; weight 13 g. Mouse-sized; grey-brown back; white belly; tail like a small feather (feature found in no other Australian mammal).

**E** Water mouse (false water rat) *Xeromys myoides*  
Body length 115 mm; tail length 95 mm; weight 40 g. Large mouse-sized; silky, slate grey back sharply defined by pure white belly; tail short, sparsely haired, without white tip.

Your aunt rings you saying that her cat has chased a 'mouse' into her house. She has caught it in a clear plastic container. She wants to release it if it is not a house mouse.

**Consider** what TWO questions you could ask her to establish whether her trapped species is a house mouse.

★★★ **16** CSIRO scientists studied a number of skull characteristics of the dingo, the dog, and captive-bred hybrids between the dingo and the dog. On the basis of these characteristics each skull was allocated a composite score



**FIGURE 3** Skull sizes of (a) dogs and dingoes; (b) captive-bred hybrids

that ranged between 20 and 140. The results were plotted on the bar graphs above.

**a Deduce** whether the measurements from the dog and dingo samples (Graph a) form two distinct groups. **Explain** your answer.

**b Determine** whether you can be certain that a skull with a score of 40 is that of a dog. **Explain** your answer.

**c Consider** how the skull scores of the hybrid group compare with those of the 'pure' dog and the 'pure' dingo groups.

### Investigate, evaluate and communicate

★★★ **17** Konrad Lorenz stated that:

*Beneath the varying behaviours which animals learn, lie the unvarying motor patterns which they inherit. These behaviour traits are as much a characteristic of a species as bodily structure and form. Just as the skeletal structure of the whale's flipper, bat's wing and human arm are essentially similar (despite diverging functions), indicating a common ancestor, so too certain behaviour patterns also point out common ancestries.*

As an example, he describes scratching in dogs, birds and reptiles, a behaviour he maintains is inherited.

Is this similarity of behaviour conclusive evidence of a common ancestry of these animals? **Justify** your response.

★★★ 18 Dogs, bears (and related racoons, weasels and otters) and pinnipeds (sea lions, walruses and seals) are all classified in the order Carnivora based on shared characteristics such as canine teeth and inability to move the lower jaw from side to side. Fossil and other evidence suggests that the suborders Feliformia ('cat-like') and Caniformia ('dog-like') diverged from a common ancestor about 50 million years ago. Based on features of skull bones it was thought that sea lions and walruses descended from bear-like ancestors and seals from otter-like ancestors. Other features shared by the pinnipeds, such as fore and hind limbs modified as flippers, streamlined body and reduction of hair, were considered as convergent, i.e. adaptations to an aquatic life style. Other biologists thought the pinnipeds were a single group, all descended from a common aquatic ancestor.

The sense of smell is reduced in pinnipeds compared with the dog and bear lines.

Although they have canine teeth, the pointed molars (carnassial teeth) of the other carnivores are absent to allow the pinnipeds to swallow whole prey. In bears the carnassial molars are reduced. Like dogs and the bear line, sea lions have external ear flaps (pinnae), a feature not shared with walruses and seals. Sea lions are agile on land. Although all four limbs have been modified as flippers, they are able to draw the hind limbs underneath

them on land and move quadrupedally. The seals on the other hand are very graceful in water but move in a caterpillar-like motion on land, since they are unable to bring their hindlimbs forward under their body. Walruses are between sea lions and seals in this respect – they use their front limbs to prop the front of the body whilst the hind limbs propel them. Dogs retain the long tail of their ancestors, but the bear has a very reduced tail as do the pinnipeds. The dog walks on its toes whereas the bear walks on the flat of the foot in a similar way to the flipper of the sea lion. New evidence has been forthcoming regarding the relationships of the pinnipeds.

- The eye lens protein ( $\beta$ -lens crystallin A) shows two amino acid substitutions (at positions 51 and 52) shared by sea lions and seals that are unique among vertebrates.
- Seals, walruses and sea lions also share another amino acid substitution that occurs in a few other animals (whales and chickens) outside the carnivores.
- Pinnipeds have a unique bile acid as yet found in no other animal.
- DNA hybridisation shows that the pinnipeds are more similar to each other than they are to other dog-like carnivores.
- The karyotypes of the pinnipeds are similar and chromosome banding patterns appear to be homologous.
- The pinnipeds share closely related ectoparasites (a particular group of lice).

From this data, **construct** a possible cladogram that includes dogs, the bear line, sea lions, walruses and seals. **Justify** each step in your cladogram.

Check your **obook** **assess** for these additional resources and more:

» **Student book questions**  
Chapter 2 review

» **Revision notes**  
Chapter 2

» **assess quiz**  
Chapter 2 auto-correcting multiple-choice quiz

» **Flashcard glossary**  
Chapter 2 glossary



# BIOLOGICAL INTERACTIONS

An ecosystem is the interaction of the species living in the area with their physical surroundings. The physical (abiotic) conditions of any ecosystem are varied and related to climate, soil and geography. Similarly, the relationships between the organisms (biotic factors) are also varied. The wide variety of ecosystems can be classified according to the dominant vegetation, the local climate, the types of organisms living in that environment or their evolutionary history. The diversity of living organisms found in an ecosystem is often a sign of the health of the environment. This means data on the number and types of organisms and the physical factors that affect them need to be measured in the field, and the population mathematically determined.

FIGURE 1 Biologically diverse freshwater aquatic ecosystem

## OBJECTIVES

- Explain how environmental factors limit the distribution and abundance of a species in an ecosystem.
- Use species diversity indices, species interactions (predation, competition, symbiosis, disease) and abiotic factors (climate, substrate, size/depth of an area) to compare ecosystems across spatial and temporal scales.
- Understand that ecosystems are composed of varied habitats (microhabitat to ecoregion).
- Interpret data to classify and name an ecosystem.
- Explain how the process of classifying ecosystems is an important step towards effective ecosystem management (consider old growth forests, productive soils and coral reefs).
- Determine diversity of species using measures such as species richness, evenness (relative species abundance), percentage cover, percentage frequency and Simpson's diversity index.
- Use the Lincoln Index to estimate the population size from secondary or primary data.
- Describe the process of stratified sampling in terms of:
  - purpose (estimating population, density, distribution, environmental gradients and profiles, zonation, stratification)
  - site selection
  - choice of ecological surveying technique (quadrats, transects)
  - minimising bias (size and number of samples, random-number generators, counting criteria, calibrating equipment and noting associated precision)
  - methods of data presentation and analysis.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

## PRACTICALS

	MANDATORY/ SUGGESTED/ MANIPULATIVE SKILL	<b>3.8A</b> Analysing vegetation patterns using a transect line
	MANDATORY PRACTICAL	<b>3.8B</b> Stratified sampling of vegetation patterns

# 3.1

## Defining an ecosystem

### KEY IDEAS

- + Ecosystems are a community of organisms and their physical surroundings
- + All organisms are affected by other organisms
- + Abiotic factors affect an organism's survival
- + Producers are able to convert light or chemicals into energy
- + Consumers eat other organisms
- + Decomposers consume organic matter
- + Detritivores break down organic matter

### ecology

the study of relationships between organisms and their environment

### environment

the conditions (biotic and abiotic) in which an organism lives

### biosphere

the part of the Earth that supports life

### habitat

a specific location, with a particular set of biotic and abiotic conditions; where an organism normally lives

### population

number of individuals of a species living in a particular place at a particular time

### community

all the species that occupy a particular place at a given time

### ecosystem

a biological community of interacting organisms and their physical environment

### niche

a species' role and position in its environment; a species' interactions with the biotic and abiotic factors of its environment

### abiotic

the non-living physical factors that affect an organism's ability to survive

**Ecology** is the study of relationships between living things and their **environment**. The word 'ecology' is derived from the Greek word 'oikos' (home), and thus in its broadest sense, ecology is the study of the area of the world that provides homes for living things. This is known as the **biosphere**.

Each organism shares its living place or **habitat** with other organisms of the same species. When a number of the same species is living in the same habitat at the same time, they are called a **population**. The different species living in the same habitat form a **community**. When the members of a community interact with each other and their physical surroundings, they form an **ecosystem**.

ECOSYSTEM = COMMUNITY + PHYSICAL SURROUNDINGS

Ecosystems vary in size. They may be as small as a decaying log on the forest floor or as large as the Great Barrier Reef. All ecosystems interact, where the output of one ecosystem may become the input of the next ecosystem. For example, the temperature of the water will affect organisms on the shore line, and the chemical composition of the shore line will eventually affect the organisms in the water.

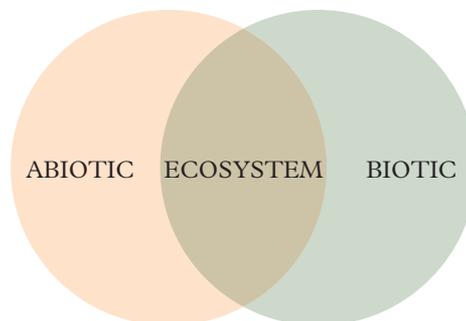
Each type of organism has a particular **niche** or role in the ecosystem. The niche includes the species' requirements, the physical conditions and resources it needs.

## Components of the ecosystem

Each ecosystem, therefore, has a population of a particular species that interact with each other, a community of different populations that interact with each other, and a series of **abiotic** factors that affect the survival of all organisms in the environment.

Since abiotic environmental conditions are extremely variable in different parts of the world, the numbers and types of species varies considerably. All organisms in an ecosystem can be divided into four broad categories.

- **Producers** are autotrophic (self-feeding) organisms that form complex organic compounds (that contain carbon and



**FIGURE 1** An ecosystem is the interaction between the abiotic and biotic components found in an area.

hydrogen atoms) from simple inorganic molecules including carbon dioxide or sulphur dioxide. Chemosynthetic organisms (some prokaryotes) break down inorganic molecules to obtain energy, while photosynthetic organisms such as plants and algae use the energy from sunlight. These organisms are the primary energy source for all the other organisms in the ecosystem.

- **Consumers** are **heterotrophs** feed on other living organisms. They cannot produce their own food but must consume already formed organic molecules. They are grouped according to what they consume:
  - First order consumers (**herbivores**) eat producers, e.g. a kangaroo eats grass.
  - Second and higher order consumers are **carnivores**. They eat living animals, e.g. a wedge-tailed eagle that preys on rabbits, which eat grass, and native quolls that eat insects, birds and small mammals.
  - **Omnivores** have a plant and animal diet so are a first and higher order consumer, e.g. most possums eat leaves, fruit and insects.
- **Detritivores** are a special group of consumers that eat decomposing organic matter such as rotting leaves and decaying animal remains, e.g. earthworms and prawns.
- **Decomposers** such as bacteria and fungi that release enzymes onto dead plant and animal remains to absorb digested matter. In doing so, many complex organic chemicals are broken down into simple inorganic molecules that are recycled back into the environment for further use by producers.

**producer**  
(autotrophic) organism forming the base of all food chains; converts simple inorganic chemicals into complex organic molecules (food)

**consumer**  
organism that eats another living organism (or part of an organism) for nutrition

**heterotroph**  
an organism that eats other living organisms

**herbivore**  
plant-eating organism

**carnivore**  
meat-eating organism

**omnivore**  
an organism that can utilise a range of nutrients; both herbivorous and carnivorous

**detritivore**  
an organism that feeds on detritus

**decomposer**  
an organism (e.g. bacteria and fungi) that utilises dead organisms or waste matter for its nutrients, releasing simple inorganic molecules



FIGURE 2 Ring-tail possum



FIGURE 3 The giant freshwater river prawn

### CHECK YOUR LEARNING 3.1

#### Describe and explain

- 1 **Distinguish** between:
  - a abiotic and biotic
  - b habitat and environment.
- 2 **Define** an ecosystem.

- 3 **Describe** why ecosystems are considered to be self-sustaining.

#### Apply, analyse and interpret

- 4 **Distinguish** common features that could be found in all ecosystems.

Check your **obook assess** for these additional resources and more:

» **Student book questions**

Check your learning 3.1

» **Weblink**

Producers and consumers

» **Weblink**

Decomposers within the seafloor

# 3.2

## Abiotic environmental factors

### KEY IDEAS

- + Abiotic features include climate, soil and geography
- + The optimum range for an organism
- + The tolerance range for an organism

### optimal range

the level of an abiotic factor at which an organism will best survive

### physiological stress

the inability of an organism to function at maximum efficiency as a result of some factor

### tolerance range

the range of a particular abiotic factor within which organism can survive

The physical conditions of habitats (such as temperature range, humidity, wind and air currents, water currents, pH, availability of light, water and nutrients) vary dramatically. These conditions are known as abiotic conditions, from the Greek 'a' (without) and 'bios' (life). In order to survive, grow and reproduce, each organism in a particular habitat must be able to survive in the physical and chemical conditions that surround it.

## Optimal and tolerance range

Each species has an **optimal range** for *each* abiotic factor in the environment. This is the level at which it can best survive. For example, a certain plant will grow very well in a pH range of 6.5 (slightly acidic) to 8.0 (slightly basic). This is its preferred niche for that particular plant. Although it can grow in soils of pH 6 or pH 8.5, it does not function as efficiently and suffers **physiological stress**. This means the plant can tolerate these conditions but will struggle to grow or reproduce. The plant is said to have a **tolerance range** for soil with a pH of 6 to 8.5. An organism will only be found in an area where it encounters the tolerance range for *all* of its abiotic requirements.

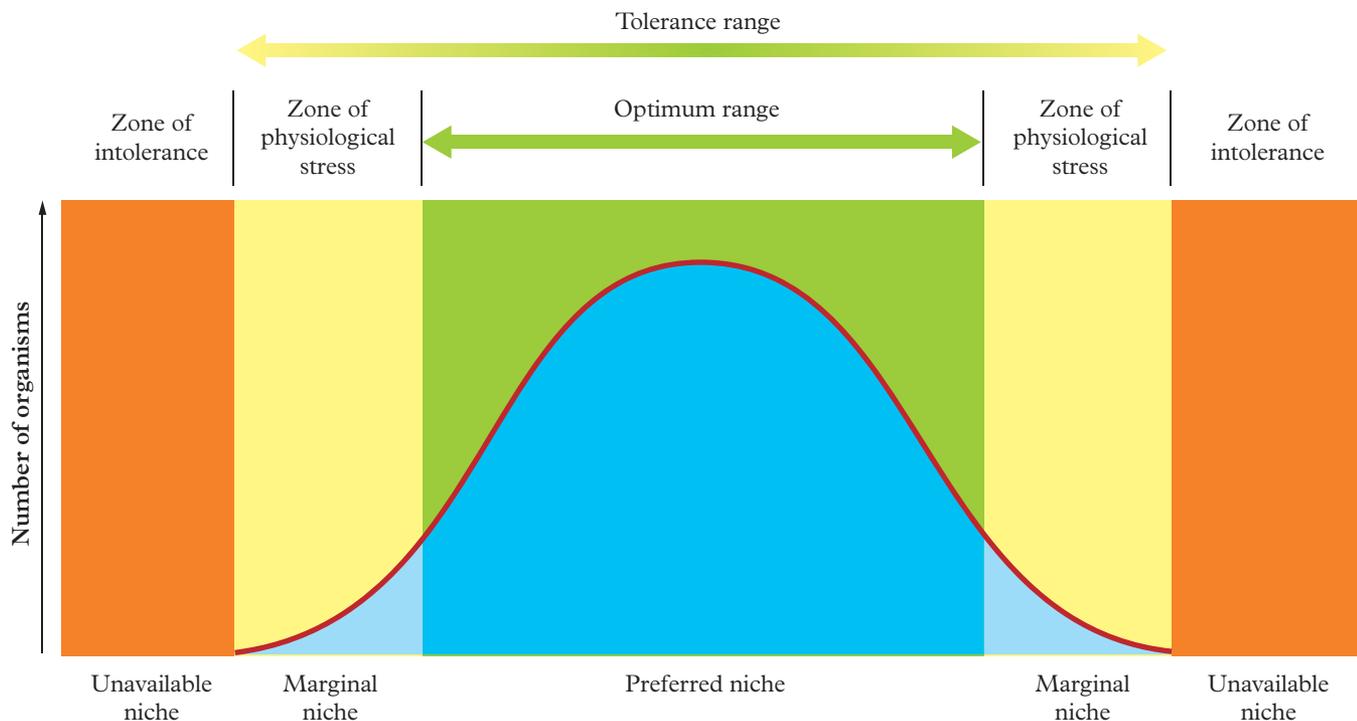


FIGURE 1 The relationship between tolerance range and optimum range of any particular abiotic requirement for an organism

# Abiotic factors directly associated with climate

## Temperature

The temperature range over which biochemical processes can function is narrow. Organisms must therefore have physiological or behavioural adaptations to combat or avoid environmental temperature extremes. The highest temperature at which an organism is currently known to survive is 121°C. This is a bacterium that lives on hydrothermal vents.

## Water

Water is essential for life. The extent to which an organism can tolerate dry environmental conditions is tied to its ability to conserve water. As with temperature extremes, this involves behavioural and/or physiological adaptations of the organism.

## Radiant energy

Light is essential for all green plants and photosynthetic prokaryotes, and for all animals that are directly or indirectly dependent on the plants. Plants have numerous adaptations for obtaining optimum illumination.

## Humidity

Humidity affects the rate of water evaporation from the surface of an organism. High humidity can affect the ability of an organism to cool itself by evaporative water loss, and low humidity can affect its ability to withstand drought.

## Wind and air currents

Only plants with a strong root system and tough stem can live in exposed areas with persistent strong winds. On the other hand, wind and air currents provide an important means of dispersing insects, spores and seeds, and are important factors in animal flight or gliding modes of locomotion.



**FIGURE 2** The shape of this tree has been dramatically distorted by persistent prevailing winds.

## Abiotic factors connected with soil

### pH

pH (a measure of acidity) influences the distribution of plants in soil and freshwater ponds. Some plants thrive in acid conditions; others in neutral or alkaline conditions. Most plants are highly sensitive to changes in pH.

### Mineral salts and trace elements

The chemical composition of the soil especially affects the distribution of plants. Plants living in soil that is deficient in a particular element must have special methods for obtaining it. For example, some plants that grow in nitrogen-deficient soil harbour nitrogen-fixing bacteria, while some others are carnivorous.

### Water retention

Some soils (e.g. sands) do not retain water well, whereas others (e.g. clay) can hold water so well that air spaces in the soil are obliterated in wet conditions. Many soils are between these extremes. Plants need adaptations if they are to survive in either extreme.

## Abiotic factors related to geography

### Water currents

Water currents and waves are particularly important in oceans, rivers and streams. Only organisms capable of swimming or avoiding strong currents can survive where this is a persistent feature of the environment. Waves have a substantial effect on organisms living in the intertidal zone. To survive periodic buffeting by waves and exposure to air, special adaptations are required.

### Salinity

There is a sharp distinction between marine and freshwater species. Estuarine organisms must have special physiological or behavioural adaptations for withstanding the daily fluctuations in salinity that accompany tidal rhythm and freshwater flow from the land.

### Topography

Topographic features (geographical surface features) influence illumination, temperature, moisture and so on. Within a relatively small area (e.g. the slopes and base of a gully), the general texture and pattern of the habitat may affect survival. Some species (**cryptic organisms**) have adapted to their environment to change shape or colouration to camouflage them when viewed against a particular background.

### Shelter

The availability of shelter is a critical factor for many organisms. For instance, insectivorous bats need caves or hollows, and the spinifex hopping mouse must have an underground system of tunnels. Soil or rock strongly influence the presence or absence of such organisms, even if all other conditions are favourable.

#### cryptic organism

an organism that has the ability to avoid observation or detection by using camouflage, nocturnality, underground habitat, mimicry or any other method of concealment



**FIGURE 3** Bats often use caves as their dwellings.

## CASE STUDY 3.2

### Intertidal zone

The intertidal zone can be found between the low tide and high tide marks on a beach or rocky shore line. The organisms that live in this zone must be able to tolerate a wide range of abiotic conditions. When the tide is high, the organisms are covered in salt water. Although the temperature is relatively stable and there may be a supply of nutrients and food in the water, there are also strong waves and currents exerting forces on the organism. There is also the difficulty of the high salt levels in the surrounding water causing the organism's body to lose internal moisture.

When the tide is low, the organism faces new abiotic challenges. It is now exposed to bright sunlight and possible high temperatures. Any water that was left by the tide has now evaporated, leaving behind traces of salt on the rocks or sand. There is also no access to nutrients or oxygen dissolved in water.

Animals such as the common limpet (*Cellana tramoserica*) have a large tolerance range. The limpet has the ability to excavate a small hollow in which to hide during low tide. When not covered by water it clamps down tightly to the rock to limit any water loss from temperature or sunlight. It also encourages sea lettuce to grow on its shell to aid with camouflage and maintain a moist microenvironment when exposed.



**FIGURE 4** A common limpet clamping down on a rocky surface in the intertidal zone

## CHECK YOUR LEARNING 3.2

### Describe and explain

- 1 Cryptic colouration may be an adaptation to an abiotic factor. **Identify** another example where an abiotic factor contributed to the evolution of an adaptation.
- 2 The vast majority of Australian plants are sclerophylls – woody plants with evergreen leaves that are narrow and thick to reduce water loss. **Identify** what primary environmental factor these plants are adapted for.

### Apply, analyse and interpret

- 3 Abiotic factors in an environment can be classified in different ways. **Classify** the factors listed in this section (e.g. temperature, water, etc.) under the headings 'Energy', 'Physical' and 'Chemical'.
- 4 **Compare** the abiotic differences between the habitat of an east-facing slope and that of a west-facing one on the eastern Australian coast. **Consider** how these differences would influence plants growing on them.

Check your **obook assess** for these additional resources and more:

» **Student book questions**

Check your learning 3.2

» **Weblink**

Mineral salts and trace elements

» **Weblink**

Salinity



# 3.3

## Biotic environmental factors

### KEY IDEAS

- + Intraspecific competition
- + Interspecific competition
- + Symbiosis between two members of different species
- + Mimicry

#### biotic

the living components in the environment

#### intraspecific

within a species; between individuals of the same species

#### interspecific

between different species

#### predator

an organism that captures, kills and feeds on another animal

#### competition

rivalry between individuals, of the same or different species, for a specific resource(s)

#### symbiosis

a relationship in which two organisms live in close association over a long period of time

Organisms are influenced by all the other organisms they come in contact with. These influences are the **biotic** (living) factors that can affect the survival of an organism in a particular habitat. These relationships can be broken into two key groups, **intraspecific** (between members of the same species) and **interspecific** (between members of different species).

### Intraspecific relationships

There are many benefits of organisms living with other members of their species. By cooperating, organisms such as ants and bees can share the workload of collecting food and caring for young. Living together in a group also increases an individual's chances of surviving an attack by a **predator**. In an attack, an individual organism does not need to be faster than the predator, they just need to be faster than their group members.

Living in a group does have its disadvantages. Members of the group may need to compete against each other for food, space, water, air, light, shelter and mates. If a resource is scarce, **competition** can be fierce and lead to fighting. The aggressive interaction of magpies competing for nesting sites is an example of intraspecific competition.

### Interspecific relationships

Organisms from different species form a variety of relationships. Predation occurs when one organism (the predator) attacks and kills another living organism (the prey) to obtain food (for example, the noisy pitta feeding on rainforest snails; insectivorous plants trapping and digesting insects). This short-term interspecific relationship is beneficial for the predator, but harmful for the prey.

Some organisms from different species compete against each other. Competition is rivalry between individuals for a specific resource(s). Kangaroos and sheep, for example, compete for grass. This interspecific competition can ultimately be harmful for both if the resources are limited.

When two species of organisms interact with each other in a close relationship over a long period of time, the relationship is called **symbiosis**. At least one of the organisms in the symbiotic relationship benefits from the arrangement. There are five key types of symbiosis.



FIGURE 1 Magpies fighting for the best nesting site

- 1 **Mutualism:** Both species benefit from the obligatory interaction (e.g. lichen, which is a mixture of fungal and algal cells; bacteria living in the intestines of termites; algae living within coral polyps).
- 2 **Cooperation:** Each species benefits from the association, but the presence of one is not essential to the survival of the other (e.g. sea anemones living on the shells of crabs).
- 3 **Commensalism:** One organism benefits and the other is not affected (e.g. epiphytic ferns and orchids on rainforest trees). True examples of animal commensalism are hard to find because it is unlikely that one animal will be totally unaffected by the presence of another. Examples include egrets and cattle, in which the egrets feed on insects disturbed by the grazing cattle, or the suckerfish attached to the surface of a shark.
- 4 **Amensalism:** One species inhibits the other (e.g. antibiotics produced by moulds inhibit the growth of some bacteria; the tannins in fallen eucalyptus leaves inhibit the growth of both their own and other species of plants).
- 5 **Parasitism:** Parasites obtain food by living in (endoparasites, for example a tape worm) or on (ectoparasites, for example a flea) a host organism. In these cases, the parasite benefits while the host is harmed. When the normal functioning of the host is disrupted by the parasite, it is said to cause a disease.

**mutualism**  
necessary and positive association between two organisms

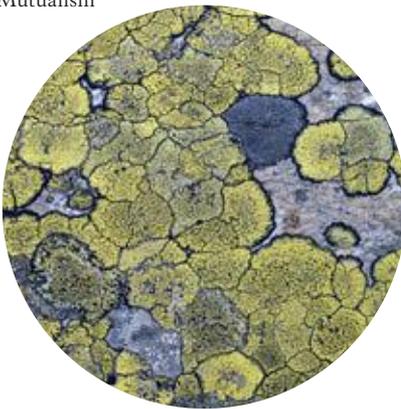
**cooperation**  
association between (or within) species that benefits both but is not essential for survival of either

**commensalism**  
relationship between two organisms in which one organism benefits and the other is not affected

**amensalism**  
a relationship in which one species is inhibited by another

**parasitism**  
association between organisms in which one species (the parasite) is completely dependent upon the other (the host), which is usually harmed

(a) Mutualism



(b) Commensalism



(c) Amensalism



(d) Parasitism



**FIGURE 2** Examples of symbiosis: (a) lichen is a mix of algae and fungus (mutualism); (b) a suckerfish living on a shark (commensalism); (c) a chemical produced by mould inhibits the growth of some bacteria (amensalism); (d) a flea is a parasite on other animals.

**TABLE 1** Comparison of the different types of interspecific relationships

Relationship	Species A	Species B
Mutualism	+	+
Cooperation	+	+
Commensalism	+	0
Amensalism	0	-
Parasitism	+	-
Predation	+	-
Competition	+ or -	-

Key: + = advantaged; 0 = not affected; - = disadvantaged

Other relationships between members of different species are subtler.

In the course of evolution some animals have come to bear a striking resemblance to parts of a plant, thereby making themselves virtually invisible to predators. Stick insects are a striking example of this **camouflage** relationship.

**camouflage**

adaptations which 'hide' the organism in its environment; any means of blending with the environment



**FIGURE 3** Camouflage of (a) a stick insect, (b) a lizard, (c) a moth and (d) ghost mantis

Some animals closely resemble another species of plant or animal that their predators have learnt to avoid. An example of this **mimicry** relationship occurs when organisms of one species look very similar to another species that is toxic to the predator. The toxic species generally has distinctive colours, odours or markings, which the predators learn to recognise and avoid. The stingless hoverfly, for example, mimics the honey bee, which has a protective sting.

**mimicry**

protective adaptation in which one organism (the mimic) resembles another organism (the model)



**FIGURE 4** The (a) hoverfly (*Melangyna viridiceps*) mimics the (b) honey bee (*Apis mellifera*).

### CASE STUDY 3.3

#### The peppered moth

The peppered moth (*Biston betularia*) has been observed in Manchester, in the north of England, for more than a century. Although a rare black form was occasionally observed, the moths collected in the first part of the nineteenth century were light coloured with darker speckles. Active at night, they rested during the day on lichen-covered tree trunks and rocks where they were well camouflaged from insect-eating birds such as robins and sparrows.

Manchester became industrialised at the beginning of the nineteenth century, so that by the 1850s soot covered buildings and trees, darkening them, and chemicals in the smoke from factory chimneys killed the lichen. At this time, the black form of the moth started to increase in numbers, and by 1895 it was estimated that they comprised 98% of all the moths.

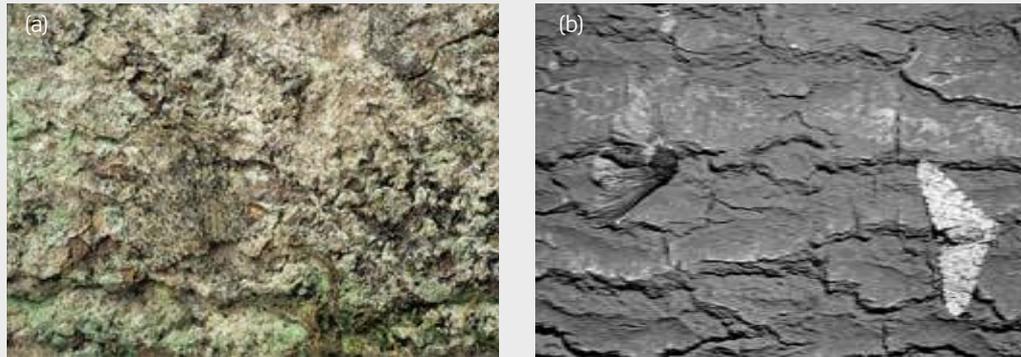
A group of scientists investigated this change in colour predominance over many years. They selected two woodland areas (one polluted and one unpolluted) where robins and sparrows were found, and released a large and equal number of each coloured moth into the trees of each. The predation by birds was observed by the scientists. In the unpolluted woodland, they found that the birds mainly captured the dark moths (164 to 26 light) whereas in the polluted areas it was mainly the light moths that were eaten.



**FIGURE 5** Manchester, United Kingdom

Other experiments, such as releasing marked moths of both colours into polluted and unpolluted woodlands and recapturing the survivors at a later date, confirmed the scientists' findings. They concluded that both colours of the moth existed in nature and that colour was genetically determined. In unpolluted environments where light-coloured lichen existed on the bark and rocks, the light form was predominant because they were better camouflaged from insect-eating birds. In polluted environments, where lichen could not survive, and soot covered the tree trunks and rocks, the dark form was better adapted to survive predation.

In this case both biotic (predation by birds) and abiotic factors (level of industrial pollution) influence the particular colour form of the peppered moth in a specific location.



**FIGURE 6** The influence of background colour on the survival of different coloured peppered moths. Can you see the mottled moth on the lichen-covered bark in (a)? Which moth is more difficult to see in (b)?

### CHECK YOUR LEARNING 3.3

#### Describe and explain

- 1 **Identify** an example of camouflage as an adaptation that may have evolved as a result of a biotic factor.

#### Apply, analyse and interpret

- 2 Resources are everything that a particular organism needs to survive. **Classify** general resources required by the human species under the headings 'Biotic' and 'Abiotic'.
- 3 **Determine** which abiotic and biotic factors contribute to the predominant colour of the peppered moth.
- 4 **Analyse** why the researchers in Case study 3.3 released the same number of light and dark moths into both a polluted and an unpolluted locality.



Check your obook assess for these additional resources and more:

» **Student book questions**

Check your learning 3.3

» **Weblink**

Commensalism

» **Weblink**

Parasitism

# 3.4

## Classifying ecosystems

### KEY IDEAS

- + Different hierarchical classification systems
- + The Holdridge life zone system
- + Specht's classification of Australian vegetation
- + The Australian National Aquatic Ecosystem (ANAE) classification framework
- + The European Nature Information System (EUNIS)

**distribution**  
regions in which a species is found

**abundance**  
number (of a species) in a specific area at any time

**Distribution** (where a particular species is found) and **abundance** (number of the species in that locality) are directly influenced by all of the biotic and abiotic conditions of that species' environment. A community of co-existing organisms in a particular location is very dependent upon the abiotic components of the environment.

One of the most important groups of organisms in any ecosystem are the producers. Any change in the abiotic factors, such as the amount of light or water, can directly impact the size or growth of a photosynthesising producer population. This in turn affects how much organic matter is formed. A lack of organic matter will result in a decrease in the types of animals (each of which has its own set of tolerance levels) that can be supported by these plants. This example not only emphasises the importance of producers in any ecosystem, it also illustrates the importance of the abiotic factors in maintaining the biodiversity of any ecosystem.

### Naming ecosystems

As the human population continues to grow, there is a pressure to increase areas available for agriculture, mining, industry and housing. This can result in further land clearing and so decrease the natural ecosystems. It is important, therefore, that ecosystems are identified, and fragile areas protected. Species diversity must be maintained while achieving use of natural resources in a sustainable manner. Identifying and classifying ecosystems is an important step towards effective ecosystem management.

Several different systems are used to classify ecosystems – some are used globally and others for particular countries.

### Holdridge life zone system

The **Holdridge life zone system** is a global system predominantly based on climate.

This system takes into account:

- annual precipitation (as rain or snow)
- mean annual bio-temperature (based on the growing season length and temperature)
- potential evapotranspiration (the amount of water that would be evaporated or transpired if there were sufficient water present)
- humidity levels in particular areas (provinces)
- latitudinal regions
- altitudinal belts.

This system assumes that the soil and vegetation communities can be mapped if these climatic factors are known. One difficulty with this form of classification are the subpolar and polar regions, which have low temperatures and almost all available water is locked up in ice.

**Holdridge life zone system**  
a system of classifying areas of land, encompassing climate and ecological types

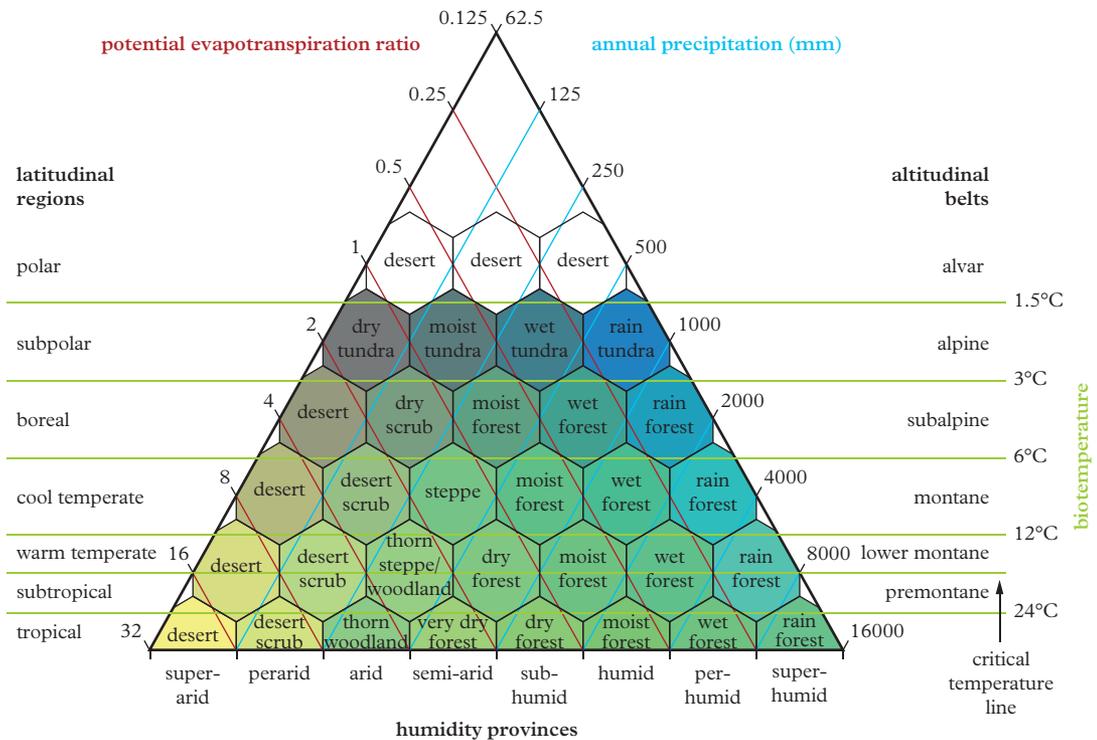


FIGURE 1 Holdridge life zones

This means the polar and subpolar regions have a very low potential evapotranspiration ratio and is equivalent to a desert for organisms living in that environment. Moisture availability is the determining factor for producers in any ecosystem. It is, however, a useful tool in determining possible changes in natural vegetation patterns due to climate change.

## Specht's classification system

Another method in classifying ecosystems is to use the structural features of the plants in an area. Specht's classification of Australian vegetation uses the foliage cover by the tallest plants in an area and the height of those plants. Foliage cover is determined by taking a number of vertical sightings (using a specific device) through the canopy of the tallest plant and calculating the percentage of those sightings in which foliage is observed.

TABLE 1 Specht's structural classification of Australian vegetation

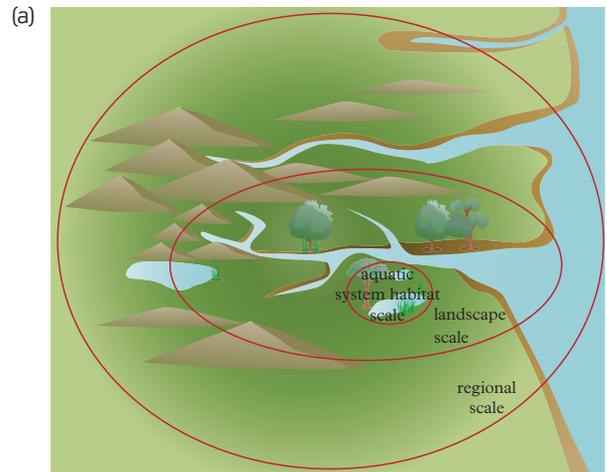
Growth form of tallest stratum	Foliage cover by the tallest stratum			
	>70%	30–70%	10–30%	<10%
Tall trees (>30 m)	tall closed forest	tall open forest	tall woodland	
Medium trees (10–30 m)	closed forest	open forest	woodland	open woodland
Low trees (<10 m)	low closed forest	low open forest	low woodland	low open woodland
Tall shrubs (>2 m)	closed scrub	open scrub	tall scrubland	tall open scrubland
Low shrubs (<2 m)	closed heath	open heath	low shrubland	low open shrubland
Hummock grasses			hummock grassland	
Tufted/tussock grasses	closed tussock grassland	tussock grassland	open tussock grassland	dense open grassland
Graminoids	closed sedgeland	sedgeland	open sedgeland	
Other herbaceous species	dense sown pasture	sown pasture	open herb field	sparse open herb field

## Australian National Aquatic Ecosystem classification framework

The Australian National Aquatic Ecosystem (ANAE) classification framework is a semi-hierarchical system designed to classify different aquatic (water-based) ecosystems firstly according to their region, before describing their landscape, climate, hydrology and topography. This is designed to provide context for the final classification of the different classes of water-based systems such as surface water, subterranean, estuarine, riverine and floodplain. It is intended to be flexible, while also identifying and describing important aquatic ecosystems across Australia.

## European Nature Information System habitat classification

The European Nature Information System (EUNIS) is a way of classifying all types of natural and artificial habitats. This system identifies the topography of the land, the characteristics of the soil, climate or water quality, and the general appearance of plants or animals that live there (physiognomy). Like the previous classification systems, the EUNIS system is hierarchical, with Level 1 containing very broad general groups (i.e. marine), while lower levels contain the smaller, more specific groups (i.e. rockpools found on shore lines).



(b)

ANAE structure									
LEVEL 1	Regional scale (Attributes: hydrological, climate, landform)								
LEVEL 2	Landscape scale (Attributes: water influence, landform, topography, climate)								
LEVEL 3	Surface water						Subterranean		
	Marine	Estuarine	Lacustrine	Palustrine	Riverine	Floodplain	Fractured	Porous sedimentary rock	Unconsolidated
Habitat	Pool to attributes to determine aquatic habitats (e.g. water type, vegetation, substrate, porosity, water source)								

**FIGURE 2** (a) When classifying an ecosystem, size and location of the region are provided before details of the local systems or habitats. (b) The ANAE classification is designed for this purpose.

### CHECK YOUR LEARNING 3.4

#### Describe and explain

- Identify** the similarities between the different classification systems described in this section.
- Identify** the major feature(s) each of the described classification systems is based on.
- A particular, humid locality has a potential evapotranspiration ratio of 1, an annual precipitation of 9000 mm and biotemperature of 20°C. Using Holdridge's classification:

- identify** what type of plant community should be present
- describe** what latitudinal region this would be found in.

#### Apply, analyse and interpret

- Determine** how better management and conservation measures can be achieved by naming ecosystems.

#### Check your obook assess for these additional resources and more:

» **Student book questions**

Check your learning 3.4

» **Weblink**

ANAE classification framework

» **Weblink**

European Nature Information System

# 3.5

## Identifying features in aquatic ecosystems

### KEY IDEAS

- ✦ Aquatic environments: marine or fresh water
- ✦ Marine ecosystems: littoral, neritic or abyssal
- ✦ Freshwater ecosystems vary

An aquatic ecosystem is one that is found in a body of water. There are two main types of aquatic systems: marine ecosystems and freshwater ecosystems.

### The marine ecosystem

Approximately 71% of the surface of the earth is covered by the sea. The oceans, by evaporation and condensation, provide the water that falls on land, indirectly sustaining the existence of all terrestrial life. Oceans absorb solar radiation and store it as thermal energy before exchanging it with the atmosphere. This then regulates the world's weather and determines the climates of the continents. The oceans around the globe are constantly in motion, driven by winds, tugged by the tidal attraction of the sun and moon, and swirled in their basins by the rotation of the earth.

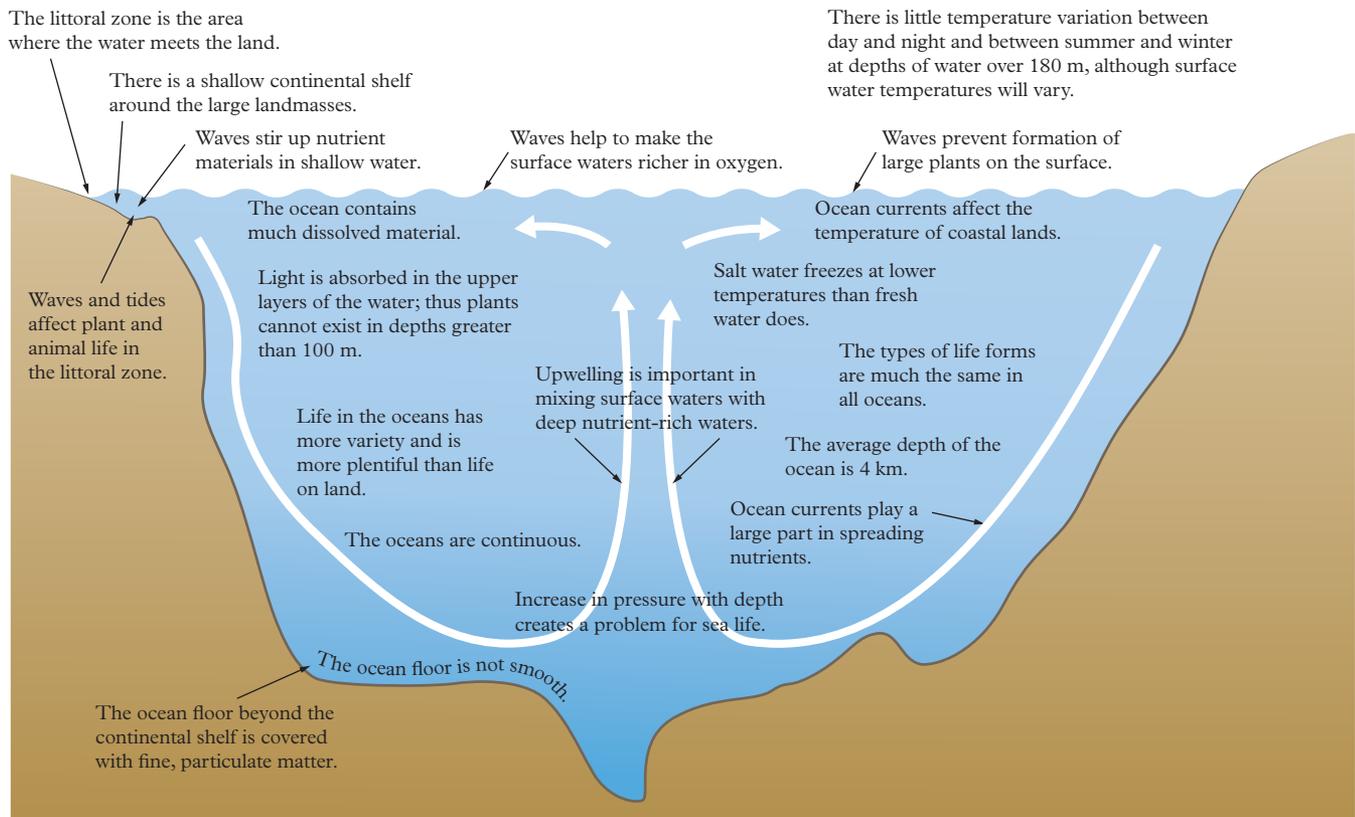


FIGURE 1 Cross-section through an ocean, showing major features

The warm surface currents overlies a series of very deep ‘rivers’ of cold, dense waters flowing from the poles towards the equator. This bottom water is rich in nutrients and low in dissolved oxygen. In equatorial regions, the warmer surface water is moved by the prevailing winds, causing the deep water to be ‘pulled’ to the surface. These upwellings bring rich nutrients to the surface, providing a food source for phytoplankton (the primary producers of the ocean). The large population of phytoplankton that can survive in this environment is able to support a large biodiverse community in this marine ecosystem.

Features of oceans that contribute to the great biodiversity of this environment are illustrated in Figure 1.

The majority of marine organisms have no problems controlling their water balance because the salt concentrations of their cells and body fluids are similar to that of sea water. Marine vertebrates, however, have an internal salt concentration that is lower than that of sea water and so water tends to be lost from their tissues. The marine vertebrates swallow sea water and pass it into the bloodstream. The excess salts taken in are actively (uses energy) pumped out of the body through the gills of fish, whilst turtles and marine birds secrete salt either from lacrimal glands (the ‘tears’ of turtles) or nasal glands (of sea birds).

The buoyancy provided by sea water allows marine organisms to grow larger than would be possible in a terrestrial environment, particularly in those organisms without a skeletal system. Floating organisms such as jellyfish and many larvae of larger animals are abundant. Rapid locomotion, however, is difficult in water and many vertebrates have evolved a very streamlined body shape, which reduces resistance to movement in water.

Sea water absorbs a large percentage of the visible spectrum in the upper layers. This means organisms that require light for photosynthesis can only live in the upper zones of the ocean. The organisms that live below this level tend to have poor vision and rely more on touch, chemical and sound stimuli.

The ocean can be divided broadly into two ecosystems: those of the surface and of the ocean floor.

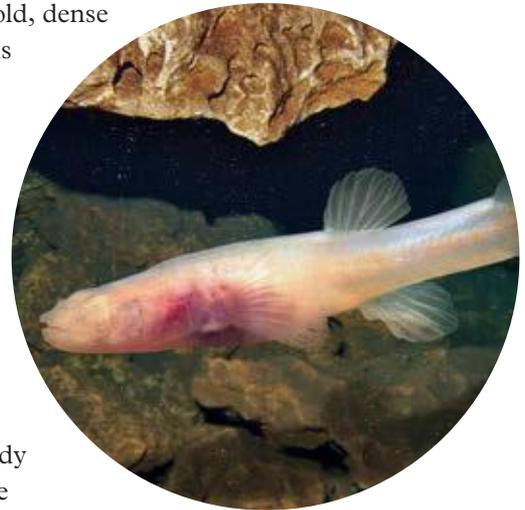
The **plankton–nekton ecosystem** is the ecosystem of the ocean surface. **Nekton** consists of free swimmers including fish, turtles and seals. Plankton consists of microscopic organisms. Phytoplankton refers to photosynthetic plankton; zooplankton to planktonic animals.

The **benthic** (noun ‘*benthos*’) **ecosystem** is the ecosystem of the ocean floor. The benthic ecosystem may be **littoral** (where the water meets land), neritic (shallow coastal water to 200 metres), bathyal (200 to 4000 metres), **abyssal** (4000 to 6000 metres) and hadal (>6000 metres).

## Littoral

The **littoral zone** is wide along shore lines because of tidal action. This means that the littoral zone is covered with water for only part of the daily tidal cycle. Therefore, organisms living in this zone must:

- be restricted to rock pools, where temperature variations may be great; or
- be capable of existing both in water and on land, and therefore overcome the problems of desiccation (drying out), breathing in both water and air, locomotion and reproduction; or
- move in and out of the area with the tide.



**FIGURE 2** In deep dark environments, fish have no use for their eyes and so have evolved to have none.

### **plankton–nekton ecosystem**

the ecosystem of the ocean surface consisting of nekton (free swimmers) and plankton (microscopic organisms)

### **nekton**

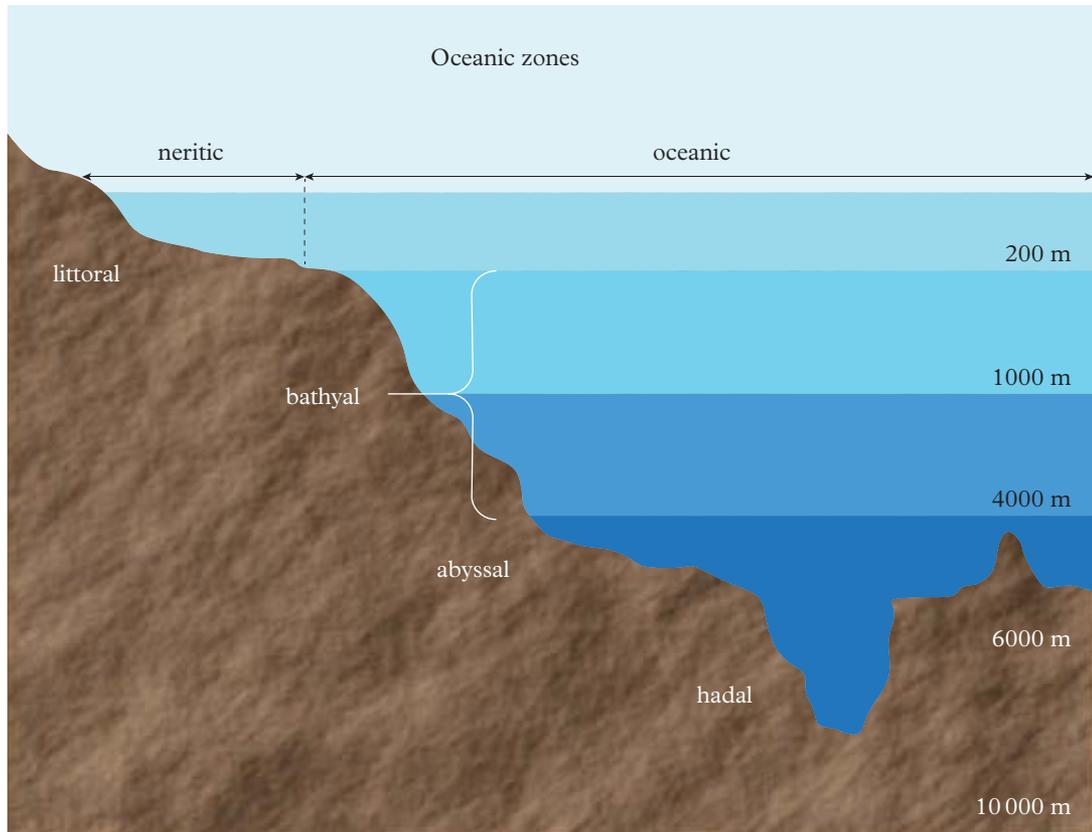
free-swimming organisms of surface waters

### **benthic ecosystem**

the ecosystem at the lowest level of a body of water; includes the sediment surface and some subsurface layers

### **littoral zone**

the zone between water and land, which may be affected by tidal action



**FIGURE 3** Oceanic zones according to depth of water

There are many different environments in the littoral zone, such as rocky shore, muddy flat, sandy beach or estuary. Each has their own distinctive community. Life in this area can be very difficult because of the sun, wind, waves and variable water level. On the other hand, it is a very fertile area because:

- many nutrients are swept down from the land and in from the sea
- tides and waves circulate these nutrients
- tides and waves dissolve oxygen in the water
- light can penetrate all depths
- ideal conditions for photosynthesis means abundant algal and plant life is present and is readily available to consumers
- high water temperatures cause rapid decomposition of dead organisms.

## Neritic

The **neritic zone** consists of shallow coastal water (to a depth of approximately 200 m), which is associated with the continental shelf. Phytoplankton and zooplankton are able to exist in large numbers due to a relatively consistent temperature range. This is due to the relatively shallow depth of the water and the action of waves and currents. The salt levels in this ecosystem can vary due to evaporation in shallow waters and freshwater runoff (particularly floods) from land and rain. Tides and currents can have a large effect on organisms. Life is plentiful in the first 50–100 m of the ocean because this region contains some light (this reduces rapidly with depth) and oxygen; it is also subject to wave action, which circulates both oxygen and nutrients.

**neritic zone**  
shallow region of the ocean overlying the continental shelves

## Abyssal

The **abyssal zone** can be found in the deep ocean water (depths of between 4000–6000 m). There is no light penetration and therefore no photosynthetic organisms are able to survive. Consequently, the oxygen content of the water is low. Most animals tend to be small, sluggish organisms that rely on odour to detect food. Some of these are detritus feeders, obtaining their food from dead organisms and organic matter drifting down from the upper surfaces. Others are carnivores which, like the angler fish, have light-producing (bioluminescent) organs on their body surface to attract prey. The water pressure at these depths of the ocean is very great, so a hard, outer surface protects the inner organs of most animals.

Deep trenches and rifts in the ocean floor support some communities at a water depth of >3000 m. In some of these regions, lava seeps through the surface of the ocean floor and produces geological structures such as hydrothermal vents. Geothermal energy from the radioactive material in the Earth's mantle raises the temperature of the water. This hot water reacts with minerals in rocks, producing hydrogen sulphide, which is metabolised by chemosynthetic prokaryotes. This allows the prokaryotic producers of this community to survive, providing energy for the variety of mussels and clams. These then become the food for crabs, starfish, octopuses, fish and giant tube worms.

**abyssal zone**  
deep-water zone  
(depth 4000–6000)



**FIGURE 4** Angler fish can live in waters over 2000 metres deep.



**FIGURE 5** Giant tube worms living near hydrothermal vents are supported by chemosynthetic bacteria.

# The freshwater ecosystem

Freshwater environments can be isolated by vast tracts of land. Due to the non-permanence of many freshwater ecosystems, the variety of organisms living in them is much less than in marine ecosystems. One of the major differences between the two environments is the depth and volume of water. The relative shallowness of freshwater ecosystems has both positive and negative effects.

A vital problem facing freshwater organisms arises from the fact that the salt concentration of the water is less than that of the cells and body fluids of the organisms. This means water is more likely to move into the organism and that salts will move out. For the organism to survive, the salt and water levels must be controlled. Various mechanisms are used:

- In some organisms (insects, freshwater crayfish and shrimp) the outer cuticle is impermeable to water.
- The outer surfaces of fish are protected by scales and a thin layer of mucus, which reduces permeability.
- The shells of molluscs help conserve body salts.
- The thin-walled gills of animals in fresh water actively absorb salts from the surrounding water.



**FIGURE 6** A freshwater creek located in the Gold Coast hinterland, Queensland

- Many freshwater aquatic animals have complex excretory systems, which retain considerable amounts of salts and produce a large volume of very dilute urine.

Freshwater environments may be classified as either standing water (lakes, ponds, dams and swamps) or running water (streams, creeks and rivers). Isolated permanent ponds approach a closed community where inputs and outputs are fairly balanced.

**TABLE 1** The effects of shallowness of water in freshwater environments

Positive effects	Negative effects
<ul style="list-style-type: none"> <li>• Surface nutrients readily available</li> <li>• No problems with the high water pressure found in deep water</li> <li>• Buoyancy, although less than in marine environments</li> </ul>	<ul style="list-style-type: none"> <li>• Seasonal variations in depth, which may be very dramatic</li> <li>• Salt and ion concentrations can vary with location</li> <li>• Temperature variations between day and night and between seasons can be great in shallow areas or in surface waters of deep lakes or dams</li> <li>• Oxygen levels decrease as the water temperature increases</li> <li>• Waters tend to be turbid and thus reduce light penetration at the bottom</li> <li>• Deep water is low in oxygen due to an inability to absorb it from the atmosphere</li> </ul>

**TABLE 2** Characteristics of freshwater ecosystems

Environment	Characteristics of environment	Typical organisms
Rapid streams	<ul style="list-style-type: none"> <li>• Rapid flow of water producing a firm bottom</li> <li>• Rocks with crevices for protection of organism</li> <li>• Often shallow with good light penetration and high oxygen concentration</li> </ul>	<ul style="list-style-type: none"> <li>• Larvae of insects with high oxygen requirement (e.g. mayflies, stoneflies, caddisflies, bloodworms, snails, bivalves and fishes)</li> <li>• Minimal vegetation and plankton</li> </ul>
Pools (quiet parts of streams)	<ul style="list-style-type: none"> <li>• Slow movement of water</li> <li>• Bottom usually soft mud or sand, suitable for burrowing organisms</li> </ul>	<ul style="list-style-type: none"> <li>• Larvae of insects, e.g. dragonflies and damselflies, beetles, bugs, bloodworms; mussels, fish, water snakes, turtles, frogs</li> <li>• Vegetation more plentiful</li> </ul>
Ponds	<ul style="list-style-type: none"> <li>• Slow movement of water due to wind or convection</li> <li>• Soft, muddy bottom</li> </ul>	<ul style="list-style-type: none"> <li>• Larvae of insects, e.g. dragonflies and caddis flies; mussels, snails, shrimp, amphipods, copepods, fish, water snakes, turtles, frogs</li> <li>• Vegetation and plankton plentiful</li> </ul>
Lakes	<ul style="list-style-type: none"> <li>• Wave action depending on size, depth and wind strength</li> <li>• Bottom mud or sand and gravel, or rocks</li> <li>• Lakes larger and deeper than ponds</li> </ul>	<ul style="list-style-type: none"> <li>• Animals vary greatly according to the nature of the bottom</li> <li>• Vegetation limited to region of light penetration</li> </ul>

### CHECK YOUR LEARNING 3.5

#### Describe and explain

- 1 Identify** the advantages and disadvantages for organisms living in a:
  - a marine ecosystem
  - b freshwater ecosystem.
- 2 Identify** the abiotic factors that affect the biodiversity in each of the following ecosystems.
  - a plankton–nekton ecosystem
  - b freshwater ecosystem

#### Apply, analyse and interpret

- 3 Determine** the zone in a marine environment that would have the lowest biodiversity.  
**Describe** the biotic and abiotic factors that would contribute to the limited survival rate of organisms in this zone.

Check your **obook assess** for these additional resources and more:

» **Student book questions**

Check your learning 3.5

» **Weblink**

Littoral zone

» **Weblink**

Abyssal zone



# 3.6

## Identifying features in terrestrial ecosystems

### KEY IDEAS

- ✦ Terrestrial ecosystems; soil, geography, abiotic conditions and the dominant species
- ✦ Biomes
- ✦ Vertical stratification of a habitat
- ✦ Ecozones
- ✦ Ecoregions

Land environments are controlled by a wide range of factors that make conditions more variable than in water environments. These can be grouped into four main categories:

- chemical (e.g. nature of the soil)
- geographical (e.g. topography and altitude)
- physical and climatic (e.g. transparency of air, lack of buoyancy)
- biological.

Some of these factors and their effects are listed in Table 1.

**TABLE 1** Factors affecting terrestrial communities

Unfavourable factor	Effect	Favourable factor	Effect
Very variable temperatures	Adaptation to specific temperature ranges	Plentiful oxygen supply	Animals can have high metabolic rate and thus be very active
Air not buoyant	Few floating forms; plants and animals need supporting structures; animals need structures for locomotion	Air transparent	Sunlight readily penetrates air, therefore high rate of photosynthesis; visual perception
Scarcity of water	Paucity of life in areas; concentrated excretory products; respiratory surfaces internal; internal fertilisation; seeds hard and dry; external surfaces prevent water loss	Air has low viscosity	Greater variation of animal shapes; sound production by a great variety of animals
		Greater variety of habitats	Diversity of form and requirements

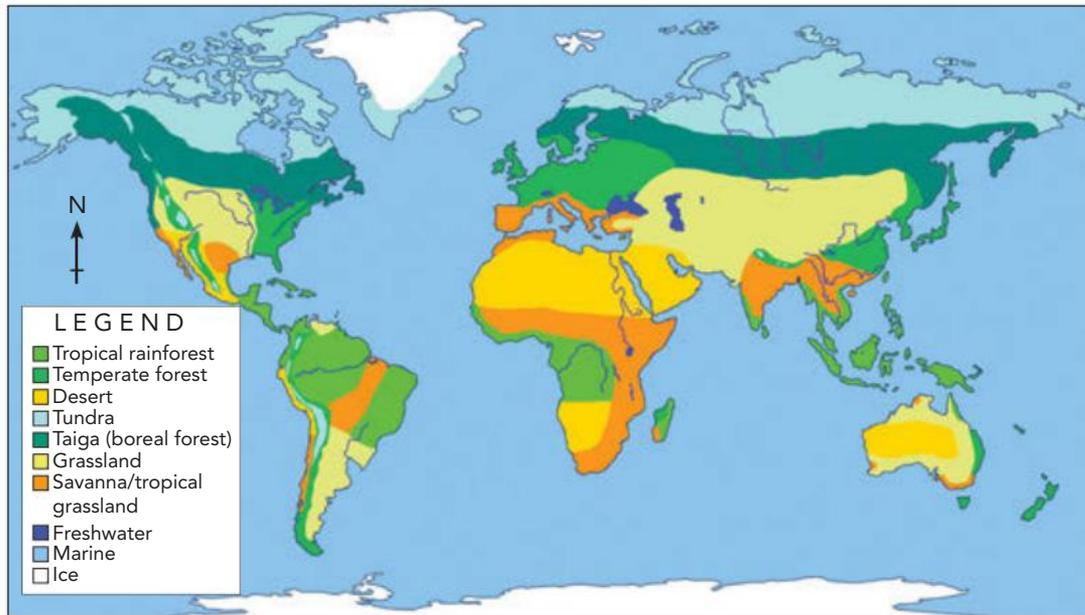
All terrestrial communities ultimately depend on the vegetation that is the producer of the ecosystem. This may be trees, bushes or grasses, or a combination of all three forms. Since plants are immobile, they are completely controlled by their environment and therefore strongly reflect it. As environmental conditions (landform, soils, animal life, human activities and climate) change from region to region, so does biodiversity.

## Biomes

One of the ways that scientists have classified terrestrial environments is by dividing them into areas called **biomes**. Biomes are classified according to the community units, particularly the vegetation types, that are found in the specific climate regions. The nature of the biome is based on the abiotic factors, including the amount of light, water and the temperature.

### biome

the living organisms of a large area defined by its climate and dominant plant species (e.g. a desert community)



**FIGURE 1** The major world terrestrial biomes. Areas with similar climates belong to the same biome.

Some biomes display a series of different vertical layers on top of each other. This arrangement is called **vertical stratification**. The leafy branches, or **canopy**, of the trees shade the ground below and provide food and shelter for a variety of animals. The small trees and shrubs grown beneath are limited by the amount of sunlight that can penetrate the canopy. If the trees are widely spaced, these are relatively abundant.

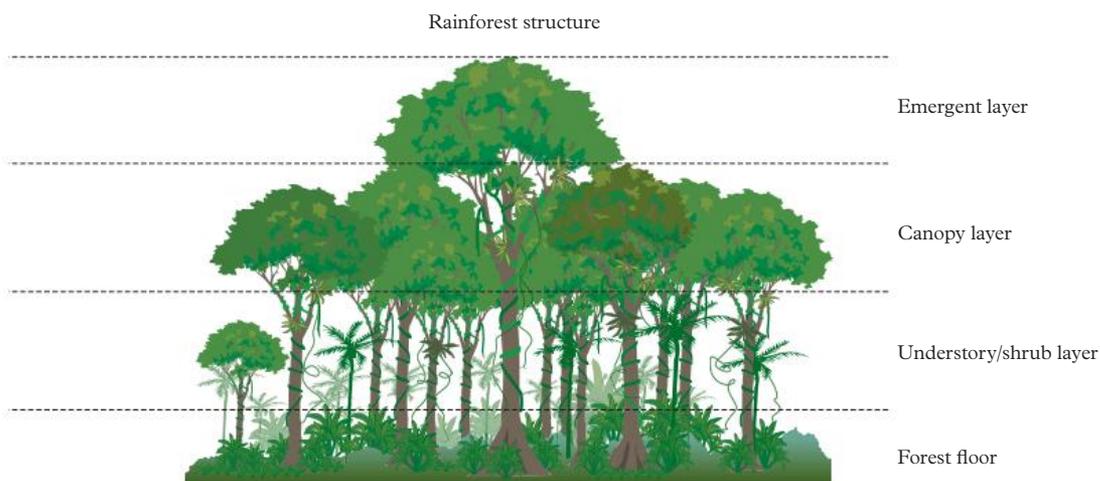
The forest floor is even more limited by available sunlight. It has a layer of leaf litter where arthropods, snakes, rodents and decomposers live.

Fallen logs provide **microhabitats** (a small habitat different from the surrounding larger habitat) for other organisms. Sub-communities may form within these microhabitats. The canopy also influences the humidity and effect of wind at various strata. Humidity in a closed forest increases from the top of the canopy to ground level, while the effects of wind decrease. Each stratum, or layer, of the forest has its own set of environmental conditions and so will support different life forms.

**vertical stratification**  
the vertical arrangement of vegetation into layers (or strata), providing a variety of niches

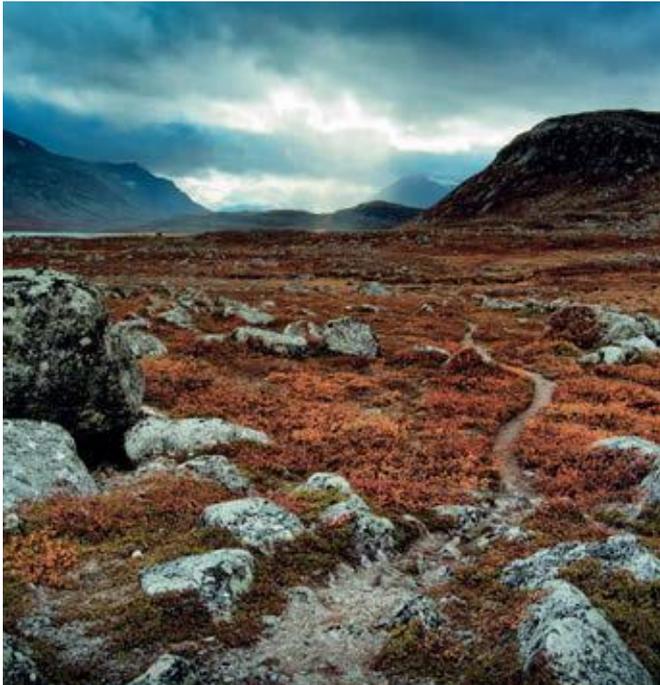
**canopy**  
the upper layer or habitat zone, formed by mature tree crowns

**microhabitat**  
a small habitat that may be different from the surrounding larger habitat



**FIGURE 2** The different vertical layers in the forest have their own environmental conditions.

## Latitudinal zones of the terrestrial biome



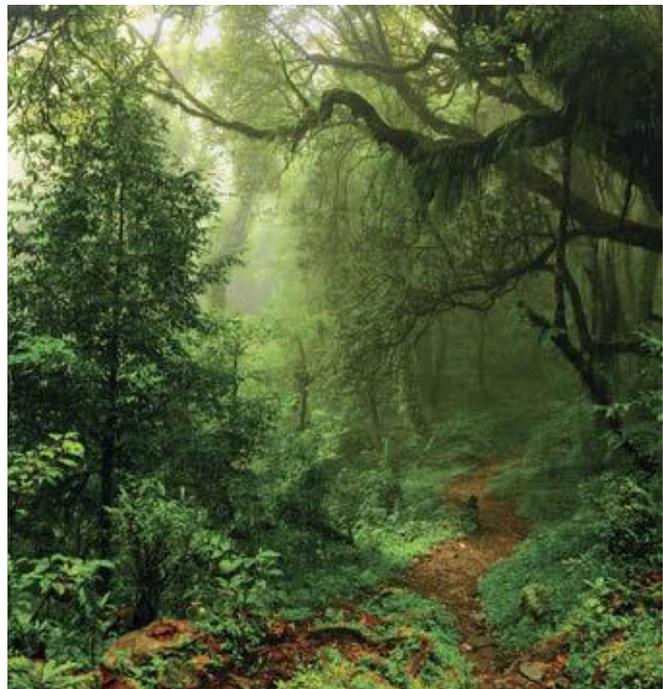
**FIGURE 3 Tundra biomes** have low temperatures, little precipitation (only in the form of snow) and high soil moisture that can remain frozen as permafrost. These biomes have only low-lying vegetation, therefore no trees.



**FIGURE 4 Taiga coniferous forest biomes** are found south of the tundra. Although the rainfall is not high (35–40 cm per year), the low temperatures inhibit evaporation and the soils are therefore very wet and acidic. The tall trees provide shelter for organisms, allowing greater biodiversity.



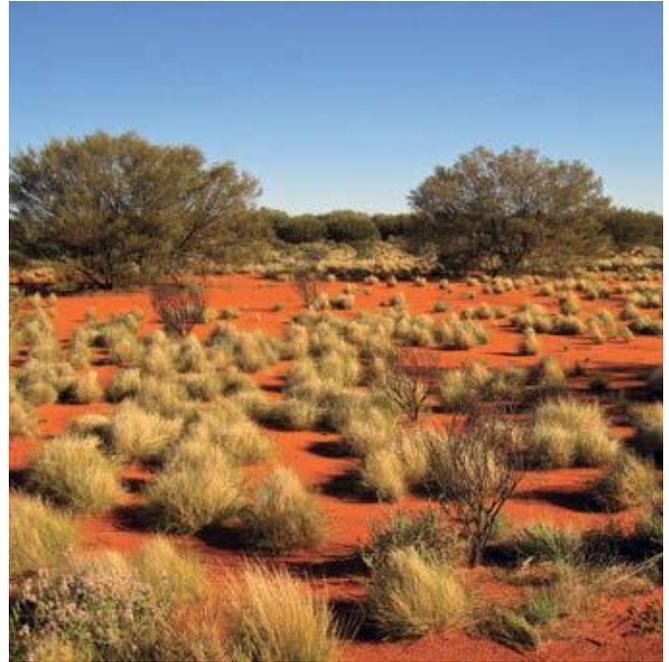
**FIGURE 5 Temperate deciduous forest biomes** display vertical stratification. The trees of this biome characteristically lose their leaves during winter. These forests are found in warmer regions that encounter distinct seasons and have an annual rainfall of about 100 cm.



**FIGURE 6 Rainforest biomes** have a high annual rainfall. The temperatures usually remain within a narrow range. They are dense forest communities with tall moisture-loving trees growing very close together. The canopy is closed and layered, limiting sunlight on the forest floor, which is usually covered with leaf litter.



**FIGURE 7 Grassland biomes** occur in both temperate and tropical regions where there is unevenly distributed rainfall of between 25 and 75 cm per year. Depending on the region, this biome may be termed steppe, prairie, plain, pampa or veldt. A savannah biome is very similar to the grassland biome except there are also scattered trees.

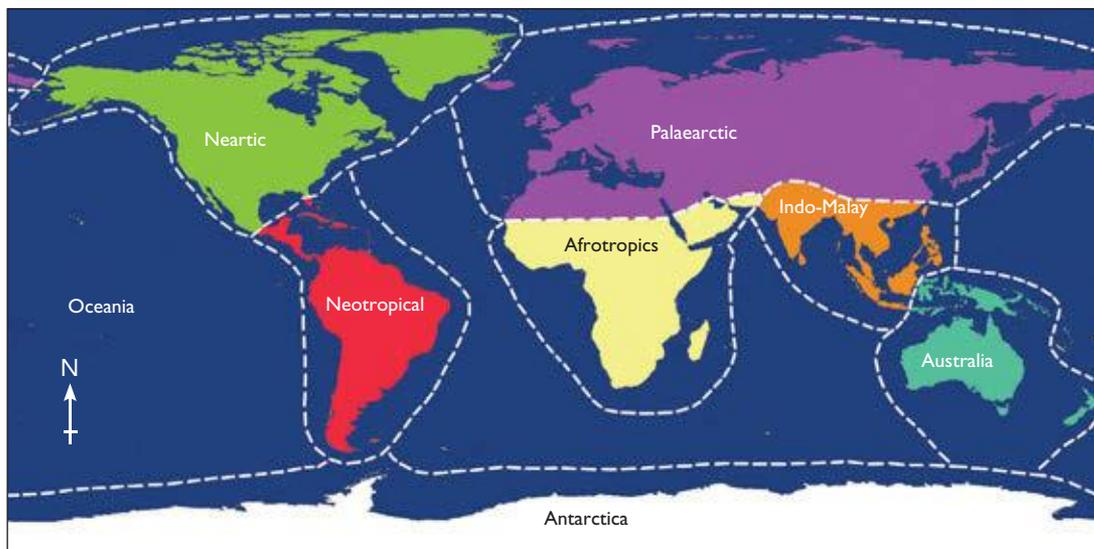


**FIGURE 8 Desert biomes** have less than 25 cm of rainfall per year. Rainfall is irregular and there is a high evaporation rate. Plants and animals find survival difficult in these areas and most adaptations are centred around maximising water uptake while reducing water loss.

## Ecozones and ecoregions

Another way to classify the terrestrial biosphere is **ecozones**. Ecozones are large areas where organisms have been evolving in relative isolation over long periods of time. They are characterised by the evolutionary history of the organisms they contain. As a result, an ecozone may contain more than one biome. Each ecozone is separated by a geographic barrier, for example an ocean, broad desert or high mountain range, that prevents migration between other ecozones. Australia, therefore, constitutes an ecozone.

**ecozone**  
a large area in which organisms have been evolving in relative isolation over long periods of time

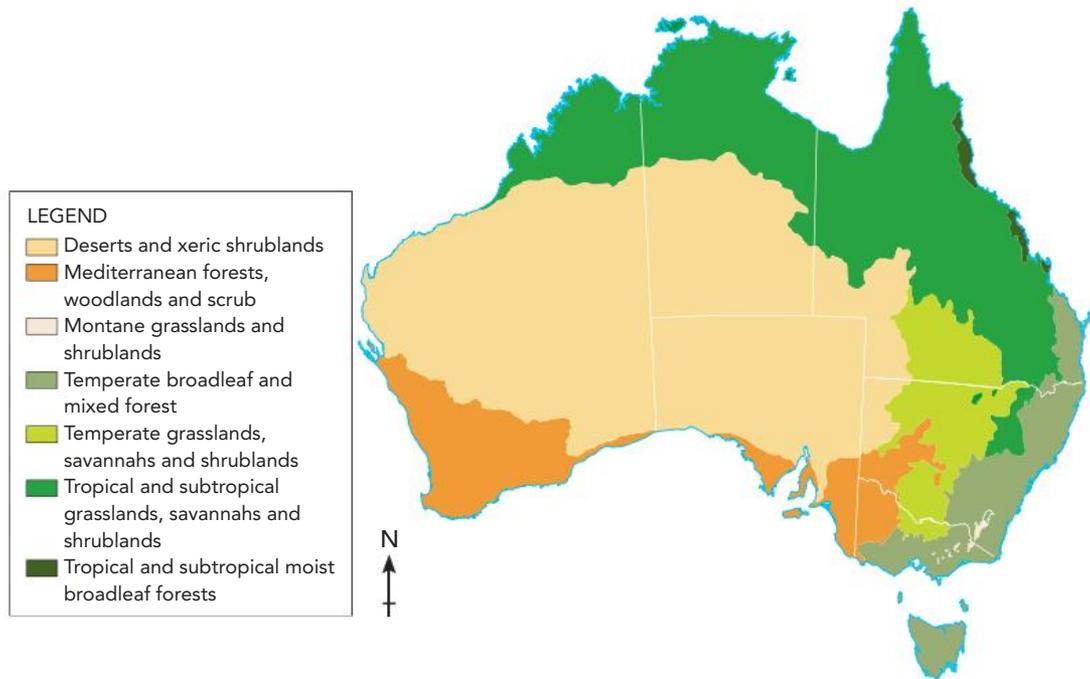


**FIGURE 9** The different ecozones of the world

**ecoregion**

a subdivision of an ecozone; a geographically distinct community based on geology, soils, climate and predominant vegetation

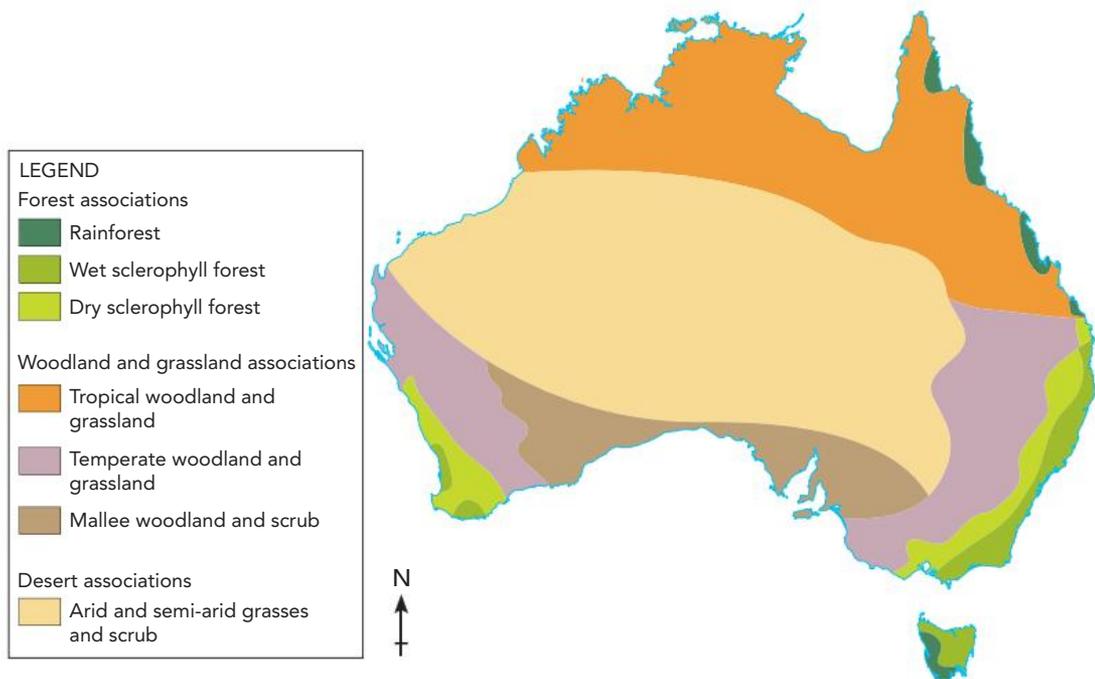
Ecozones are further divided into **ecoregions**. These are geographically distinct communities based on geology, soils, climate and predominant vegetation.



**FIGURE 10** Ecoregions of Australia

## Vegetation zones

Another method of categorising Australian vegetation zones is shown in Figure 11 and Table 2. This method is based on zones of decreasing moisture from the coast to the dry interior.



**FIGURE 11** Australian vegetation zones. Although different terminology is used to describe them, the zones are very similar to ecoregions.

**TABLE 2** Characterisation of Australian vegetation zones based on rainfall

Zone	Characteristics
Rainforest	<ul style="list-style-type: none"> <li>• Found in high-rainfall regions near the coast.</li> <li>• Require fertile soils, or soils in which there is a rapid rate of decomposition and recycling of nutrients.</li> <li>• Trees grow close together and display species diversity.</li> <li>• The canopy forms a cover that excludes light from the forest floor.</li> <li>• Grasses and herbs tend to be absent from the forest floor.</li> <li>• Epiphytes (plants that use other plants for support) are present.</li> <li>• Mosses and ferns survive well in the limited light and high humidity of the forest floor.</li> </ul>
Wet sclerophyll (= hard leaf) forests	<ul style="list-style-type: none"> <li>• Found in high-rainfall coastal regions.</li> <li>• Large number of eucalypts present.</li> <li>• Shrubs and ferns present on the forest floor due to the less dense canopy.</li> <li>• Broadleaved creepers present.</li> </ul>
Dry sclerophyll forests	<ul style="list-style-type: none"> <li>• Found on drier soils than wet sclerophyll forests.</li> <li>• Eucalypts are the main trees.</li> <li>• Trees are not as tall as those of the wet sclerophyll and the canopy is more open.</li> <li>• Trees are widely spaced.</li> <li>• Fewer shrubs and ferns than in wet sclerophyll.</li> </ul>
Woodland	<ul style="list-style-type: none"> <li>• Trees are more scattered than in forests and thus the canopy is very open.</li> <li>• Grasses and shrubs cover the ground.</li> <li>• In savannah woodland, grasses more numerous than shrubs.</li> <li>• In shrub woodland, shrubs more numerous than grasses.</li> </ul>
Scrub	<ul style="list-style-type: none"> <li>• Trees not present.</li> <li>• Main plants are tall shrubs.</li> <li>• Perennial grasses (those in which growth continues for many years) are usually found.</li> </ul>
Saltbush	<ul style="list-style-type: none"> <li>• Short, widely spaced shrubs only.</li> <li>• Grasses occupy the areas between the shrubs.</li> <li>• Leaves of the shrubs are semi-succulent.</li> </ul>
Desert	<ul style="list-style-type: none"> <li>• Very little moisture available.</li> <li>• Sparse covering of bunch grasses such as spinifex.</li> <li>• Flowering ephemerals (able to go through their life cycle extremely quickly) grow after rain.</li> </ul>

An ecosystem may be as large as the ecoregion, or a small portion of one, depending on the particular community's composition.

## CASE STUDY 3.6

### Wallum heathland ecosystem

Wallum is the name given in Queensland to a type of country and a type of vegetation found close to the sea. These areas have poorly drained sandy flats interspersed with low sandy ridges, and sometimes slightly higher gravelly rises. The sandy flats may be rich in humus. Layers impervious to water often form and the area becomes swampy. Wallum grows in areas of high rainfall where soil is naturally low in mineral nutrients, particularly nitrates and phosphates. The term 'wallum' refers to the most obvious tree of the area, the wallum banksia (*Banksia aemula*).

The plants of the flats are typical of any heathland, including stunted trees (particularly banksias) that are rarely more than 2 m in height, boronias, heath, small-leaved tea trees, bush peas, Christmas bells and vanilla lily. The low sandy ridges carry banksias and other low trees including she-oaks, wedding bush and bush peas. The higher ridges can support eucalypts, particularly scribbly gum, bloodwoods and ironbarks. Where conditions are swampy, melaleucas (tea trees) dominate, and patches of rainforest may occur along moist gullies.

Several factors control the vegetation of the wallum.

#### Low-nutrient soils

The plants show various adaptations to lack of nutrients:

- Wattles harbour nitrogen-fixing bacteria in root nodules.
- Mycorrhizal fungi grow in association with the roots of many species.
- Extensive, shallow root systems maximise absorption of minerals and moisture.
- Lignotubers (swollen roots) store excess nutrients and/or water.
- Some plants, such as the sundew, are insectivorous.

#### Water stress

Plants experience water stress when there is too little or too much groundwater present for their normal life functions. There can be water stress in wallum areas for the following reasons:

- The predominant rainfall is in the summer months and there can be prolonged periods of drought at other times.
- Soils tend to be sandy and thus do not retain moisture.
- Highly leached sandy soils tend to have an underlying hardpan of clay, which severely restricts water penetration and results in large surface run-off. In some flat areas, absorption of water by the hardpan can result in waterlogging.
- Seasonal flooding of flats decreases the oxygen content of the soil. The root cells need oxygen to survive and transport materials to the rest of the plant. Low levels of soil oxygen, therefore, reduce the uptake of water and mineral nutrients by the root hairs.
- Summer is characterised by long hot days, with persistent prevailing winds that increase evaporation of water from both the soil and the plants themselves.

#### Fire

Fire is a common phenomenon of heathlands and has played a significant role in eliminating potential colonisers. Plants must be either fire tolerant or produce fire-resistant seeds.



**FIGURE 12** Heathland bushfires in Queensland play a large role in eliminating colonising plants.

### CHECK YOUR LEARNING 3.6

#### Describe and explain

- 1 **Identify** the two major factors responsible for the distribution of the world biomes.
- 2 In which terrestrial biome would you expect to find the greatest species diversity and species abundance? **Explain** your answer.
- 3 **Explain** how vertical stratification influences species diversity in a community.
- 4 **Describe** the structural features of the plants in an open scrub ecosystem. In which ecoregion would you expect to find this community?

#### Apply, analyse and interpret

- 5 **Compare** the environments of the taiga and temperate deciduous forest.

- 6 **Distinguish** between a biome and an ecozone.
- 7 Based on the information in the Case study 3.6, **consider** the types of animals you would expect to find in a Wallum heathland ecosystem. Give reasons for your choice.

#### Investigate, evaluate and communicate

- 8 The dominant trees in a large area of bushland are brush box (*Lophostemon confertus*) and smooth-barked apple (*Angophora leiocarpa*). Both trees grow to over 30 m in height and have a combined foliage cover of 50%. **Decide** how this ecosystem could be named.

Check your **obook assess** for these additional resources and more:

» **Student book questions**

Check your learning 3.6

» **Weblink**

Rainforest biomes

» **Weblink**

Desert biomes



# 3.7

## Biodiversity in ecosystems

### KEY IDEAS

- + The biodiversity and health of the system
- + Species richness
- + Species diversity
- + Simpson's Index (*D*)
- + Simpson's Diversity Index (*SDI*)

Ecosystems are found in a great range of abiotic conditions, which in turn is reflected by the types, and abundance, of organisms making up the community. The biodiversity of an ecosystem is a measure of the number of different types and abundance of populations in a community. Some ecosystems (e.g. desert ecosystems) will have a very low biodiversity whilst others (e.g. a coral reef ecosystem) will have a very high biodiversity. Some areas that once supported a large number of different species have been cleared for growing crops. These crops are usually of a single type, for example wheat, and so a **monoculture** is established. Other plants are actively eliminated. This then impacts on the types of fauna that will be present in this agricultural ecosystem.

A variety of measures can be used to assess the biodiversity of natural ecosystems. Two significant parameters are **species richness** and **species diversity**. Since most ecosystems are too large to measure all aspects of the entire area, random samples of the area are taken. Similarly, these parameters are usually only considered for sub-communities at a time (for example shrubs or trees or leaf litter organisms) rather than for the entire community.

### Species richness

Species richness is a measure of the number of species compared to the number of individuals found in a sample. The larger the sample, the more species are likely to be found. To account for this, in the Menhinick Index, the number of species is divided by the square root of the number of individuals in the sample. See the equation below:

$$S = \frac{s}{\sqrt{N}}$$

where *S* is species richness, *s* is the total number of different species in the sample and *N* is the total number of individual organisms in the sample.

The data in Table 1 is from samples of organisms obtained from two different communities, A and B.

**FIGURE 1** The Simpson Desert, which stretches from the Northern Territory to South Australia and Queensland, has low biodiversity.

#### monoculture

a system that has very low diversity; in agriculture, it describes the practice of growing a single crop type

#### species richness

a measure of the numbers of species present and the evenness of species in relation to one another

#### species diversity

a measure of the number of species found in a community, compared with the number of individuals

#### Study tip

If the *D* value is close to 1, then there is a high probability that the species is dominating the ecosystem.

### WORKED EXAMPLE 3.7A

- 1 Calculate the species richness for each community in Table 1. The same six species are represented in each community.

#### SOLUTION

$$\begin{aligned} 1 \quad S &= \frac{s}{\sqrt{N}} \\ &= \frac{6}{\sqrt{100}} \\ &= 0.6 \end{aligned}$$

- 2 As both communities have the same total number of different species and total number of individual organisms, they have the same species richness.

TABLE 1 Samples of organisms from two different communities

Community A		Community B	
Species	Number of individuals	Species	Number of individuals
A	49	A	21
B	17	B	20
C	11	C	17
D	10	D	16
E	5	E	14
F	8	F	12
<b>Total</b>	<b>100</b>	<b>Total</b>	<b>100</b>

Species richness does not, however, reflect how evenly the species are represented in each community.

## Species diversity

Species diversity differs from species richness in that it takes into account both the numbers of species present and the evenness of species in relation to one another, i.e. the relative abundance of each species.

**Simpson's Index ( $D$ )** measures the probability that two individuals randomly selected from a sample will belong to the same species (or genus or family, etc.). If the two individuals are the same species, then it may indicate that this species is dominating the ecosystem. See the equation below:

$$D = \frac{\sum n(n-1)}{N(N-1)}$$

where  $n$  = total number of individuals of a particular species,  $N$  = total number of organisms of all species and  $\sum n(n-1)$  is the sum of all species calculations of  $n(n-1)$ .

The value of  $D$  ranges between 0 and 1. The larger the value of  $D$ , the lower the diversity of the ecosystem. A healthy ecosystem, with a large community of different species, will have a low  $D$  value.

**Simpson's Diversity Index ( $SDI$ )** represents the probability that two individuals randomly selected from a sample will belong to different species (or groups). That is, it gives the reverse probability to that of Simpson's Index. It can be calculated using the following equation:

$$SDI = 1 - D$$

This value also ranges between 0 and 1, but in this case the higher the value, the greater the diversity.

### Study tip

The QCAA syllabus calculates the Simpson's diversity index using the equation

$$SDI = 1 - \left( \frac{\sum n(n-1)}{N(N-1)} \right)$$

which combines the two equations in this section into one step.

#### Simpson's Index ( $D$ )

the probability that two individuals randomly selected from a sample will belong to the same species (or genus or family, etc.)

#### Simpson's Diversity Index ( $SDI$ )

the probability that two individuals randomly selected from a sample will belong to different species (or groups)

Calculating  $p$ -values is another method used to determine species diversity of a community. This is not required for the external examination, but it is a useful tool for all biologists and an explanation of how to calculate  $p$ -values can be found in on your [obook assess](#).

### WORKED EXAMPLE 3.7B

- Use the Simpson's Diversity Index to compare the diversity of the two communities in Table 1.
- The probability that two individuals (in this survey) randomly selected from a sample belong to:
  - the same species (Simpson's Index,  $D$ )
  - different species (Simpson's Diversity Index,  $SDI$ ).

Community A		Community B	
Species	Number of individuals	Species	Number of individuals
A	49	A	21
B	17	B	20
C	11	C	17
D	10	D	16
E	5	E	14
F	8	F	12

### SOLUTION

Community A			Community B		
Species	Number of individuals ( $n$ )	$n \times (n - 1)$	Species	Number of individuals ( $n$ )	$n \times (n - 1)$
A	49	2352	A	21	520
B	17	272	B	20	380
C	11	110	C	17	272
D	10	90	D	16	240
E	5	20	E	14	182
F	8	56	F	12	132
	$N = \sum n = 100$	$\sum n(n - 1) = 2900$		$N = \sum n = 100$	$\sum n(n - 1) = 1726$

- Simpson's Index ( $D$ ) for Community A = probability two randomly selected organisms in Community A are the same species:

$$\begin{aligned}
 D &= \frac{\sum n(n - 1)}{N(N - 1)} \\
 &= \frac{2900}{100(99)} \\
 &= 0.29
 \end{aligned}$$

Simpson's Diversity Index ( $SDI$ ) for Community A = probability two randomly selected organisms are different species:

$$\begin{aligned}
 SDI &= 1 - D \\
 &= 0.71
 \end{aligned}$$

$$\begin{aligned}
 D \text{ (for Community B)} &= \frac{\sum n(n-1)}{N(N-1)} \\
 &= \frac{1726}{100(99)} \\
 &= 0.17
 \end{aligned}$$

$$\begin{aligned}
 SDI \text{ (for Community B)} &= 1 - D \\
 &= 0.83
 \end{aligned}$$

Because the Simpson's Index for Community A (0.29) is higher than Community B (0.17), it means it is more likely that one species in Community A is dominating the ecosystem. Community B is considered to be more diverse than Community A. Species diversity is generally a more reliable measure of biodiversity than species richness.

**2a**

$$\begin{aligned}
 \text{Community A} &= 0.29 \\
 &= 29\% \\
 \text{Community B} &= 0.17 \\
 &= 17\%
 \end{aligned}$$

**2b**

$$\begin{aligned}
 \text{Community A} &= 0.71 \\
 &= 71\% \\
 \text{Community B} &= 0.83 \\
 &= 83\%
 \end{aligned}$$

### CHECK YOUR LEARNING 3.7

#### Describe and explain

- 1 Define** the term ecosystem biodiversity.
- 2 Explain** the difference between Simpson's Index and Simpson's Diversity Index.

#### Apply, analyse and interpret

- 3 Distinguish** between species richness and species diversity.
- 4** A survey of a wallum heathland ecosystem (approximately 50 hectares in size) showed that there were 15 species of birds. A total of 100 birds were counted.

- a Determine** how likely it is that these numbers were a sample of the community or represented the whole community. **Explain** your answer.
- b Calculate** the species richness of this wallum heathland ecosystem.
- c** From this calculation, can you **determine** the biodiversity of birds in the community? **Explain** your answer.
- d Identify** further information that would be needed to determine diversity of the birds in this ecosystem.

Check your **obook assess** for these additional resources and more:

» **Student book questions**

Check your learning 3.7

» **Increase your knowledge**

Calculating *p*-values

» **Weblink**

Simpson's Diversity Index



# 3.8

## Measuring features of an ecosystem

### KEY IDEAS

- ✦ Stratified sampling of an ecosystem
- ✦ Random, unbiased sampling of an ecosystem
- ✦ Equipment used to determine abiotic factors
- ✦ Sampling methods for the biotic components

Before decisions can be made about the management of an ecosystem, the type of environment and its biodiversity must be determined. This means the ecosystem must be divided into smaller groups, or strata, so that the various components can be sampled. This includes the estimation of the size, density and distribution of a population; the gradient or profile of the land; **zonation**; and any **stratification**.

### Random sampling

There are few situations where it is possible to count all members of a population, let alone those of a community and the abiotic components significant to that community. Biologists therefore sample the particular features and apply statistical tests to the data in order to come to a conclusion about the whole ecosystem.

The first step in any sampling is to define precisely what is to be sampled, for example, the distribution of spotted gums on the western slope of Mt Coot-tha. The second step is to determine how many samples will be taken, and the sampling locations. Normally, samples should be taken at random across the area being examined.

Sampling is biased if:

- some members of any population are more likely to be recorded than others
- the recording of some samples affects the recording of others
- the investigator selects particular sample sites that:
  - are easy to reach
  - are not unpleasant to work in
  - give the results they are expecting, and so on.

**Random sampling** implies that each measurement in the study has an equal chance of being selected as part of the sample. Biologists often use a table of random numbers from which to select map coordinates or numbered sample sites.

The area under investigation might be mapped as a grid pattern, as illustrated in Figure 1. Each square of the grid is allocated a number. An alternative systematic approach would be to sample predetermined squares, where samples are taken at fixed, predetermined intervals.

Random and systematic sampling minimise bias by deliberately ignoring features of the habitat. Legitimate conclusions can be drawn from data obtained from these types of sampling.

1	2	3	4	5
6	7	8	9	10
11	12	13	14	15
16	17	18	19	20
21	22	23	24	25

**FIGURE 1** An area mapped into a grid. Systematic sampling would involve sampling a set sequence of squares: e.g. 1, 4, 7, 10, 13, 16, 19, 22, 25. In random sampling, the grid squares to be sampled would be selected using a table of random numbers.

**zonation**  
the breaking of the biome into habitat zones

**stratification**  
the division of the physical environment into smaller components for sampling

**random sampling**  
a method of selecting a sample from a total array in such a way that every possible sample that could be selected has an equal chance of being selected

A single measurement is generally insufficient for conclusions to be drawn about a characteristic. Repeated measurements may vary greatly. A single value could be far from the average value. Therefore, a series of replicated measurements should be taken to work out the mean of the characteristic.

## Types of assessment

The most common student field study is an environmental analysis that describes the geographical, physical, chemical and biotic characteristics of an area. Examples include assessment of environmental impacts; management of fish, wildlife and vegetation habitats for the benefit of desired species; and habitat reclamation. The principal objective is often one of the following:

- **Basic ecological research:** proposing and testing hypotheses relating to ecological theories and principles
- **Ecological inventories:** collection of data and samples to be used for reference
- **Environmental planning:** use of ecological information for proposing potential sites for preservation, management or other environmentally sound uses
- **Environmental impact assessment:** collection of information for assessing present or potential impacts of human activities
- **Ecological resource management:** collection of information needed for management of populations and for reclamation of disturbed habitats.

The prime objective of the study determines what is to be measured and the sampling techniques to be used.

## Measurement of the abiotic environment

The distribution and abundance of any specific species in a community is linked to both the physical and chemical features of the habitat and to the species present. Physical and chemical factors may be measured using a variety of techniques, as listed in Table 1. It is important that any equipment used in this testing has been calibrated for accuracy before use.

Data loggers can be used to determine many chemical aspects of the abiotic environment, particularly in aquatic environments. Examples include pH, light intensity, oxygen and carbon dioxide levels, and salinity.

**TABLE 1** Measuring some physical and chemical factors in the abiotic environment

Factor	Method of measurement
Light intensity	Light meter
Temperature	Thermometer
Topography and altitude	Measure slope; draw profile and transects to scale
Pressure	Barometer
Depth of soil	Soil profile cut down and measured; or soil corer
Soil moisture	Sample weighed, water evaporated and soil reweighed
Soil or water pH	pH meter or pH indicators
Organic matter (humus)	Sample weighed, burned then reweighed
Soil or water nutrients	Soil-testing kits
Dissolved oxygen	Oxygen meter
Rainfall	Collection and measurement
Humidity	Hygrometer; or measure evaporation rate over time
Wind	Rotating vane anemometer; or wind speed meter and compass

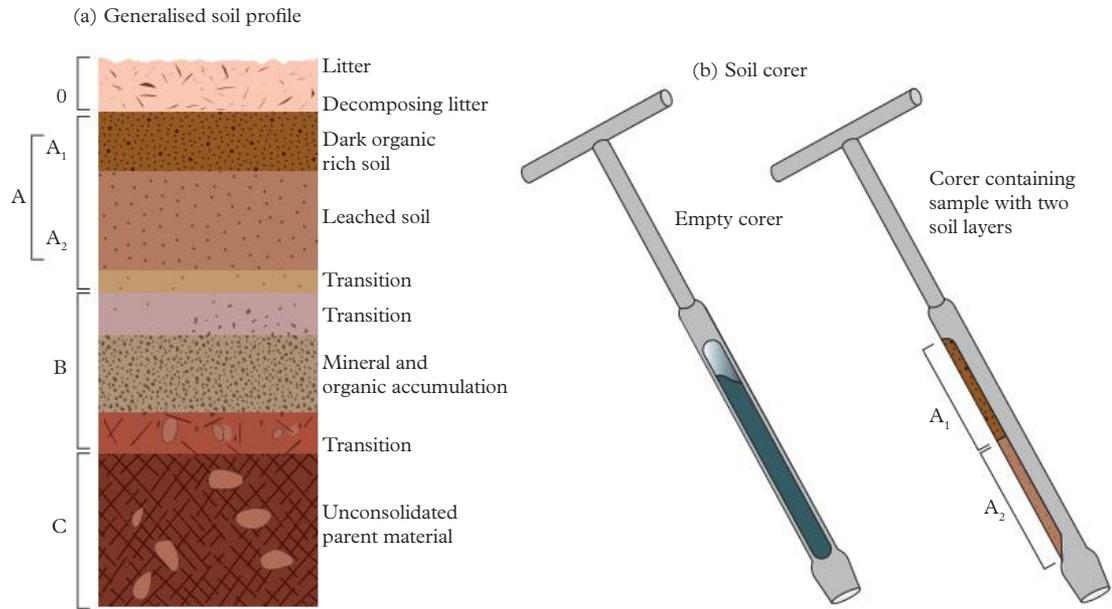


FIGURE 2 Generalised soil profile and a soil corer used to take a core sample

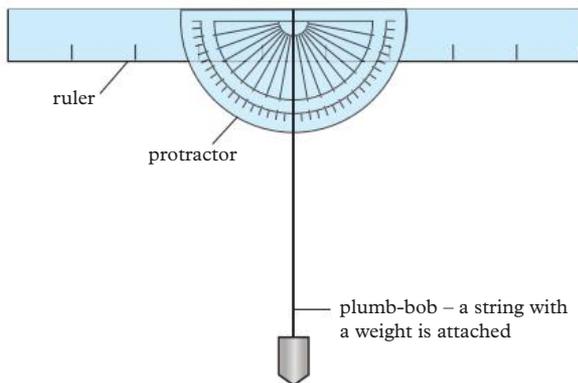


FIGURE 3 Construction of a simple device to measure slope.

The slope and aspect of the study area affect factors such as light, temperature and soil moisture. The difference in elevation between two points may be expressed as the distance relative to the horizontal distance between them (e.g. a slope of 15 m per 100 m) or as an angle.

Measurement of slope may be calculated using simple equipment: a protractor, ruler, plumb-bob, tape measure or string.

Two people hold a known length of string taut, one metre above ground level. The string is therefore parallel to the slope. The ruler, with its protractor and plumb-bob attached, is lined up along the string at the upper end of the slope as shown in Figure 4(a).

The angle inscribed by the plumb-bob is measured as shown in Figure 4. The vertical height between the two measuring points can then be calculated using trigonometry (Figure 4c):

$$\cos \theta = \frac{v}{l}$$

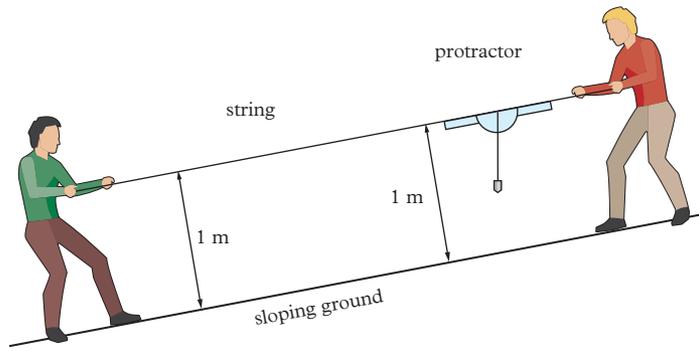
$$v = l \times \cos \theta$$

where  $\theta$  is the angle inscribed by the plumb-bob,  $l$  is the length of the string and  $v$  is the difference in height between the two ends of the string.

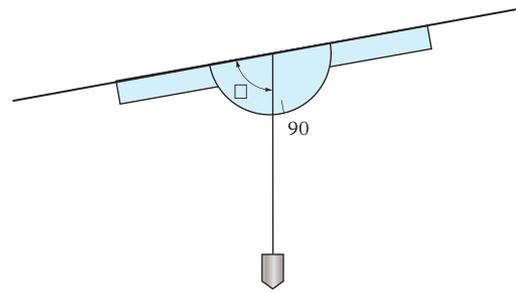
A similar method can be used to estimate the height of objects whose base can be seen: for example, a cliff face or tree. A right-angle isosceles triangle can be constructed out of heavy cardboard or plywood. One  $45^\circ$  corner is held at eye level and the object is viewed 'through' the triangle. The observer walks backwards until the whole object just 'fits' the triangle, as shown in Figure 5. The horizontal distance from the observer to the object will be roughly equivalent to its height, since:

$$\tan 45^\circ = \frac{\text{side opposite (height)}}{\text{side adjacent (horizontal distance)}} + \text{height of observer}$$

(a) Position of recorders and measuring device



(b) Reading the angle



(c) Triangle produced from the measurements

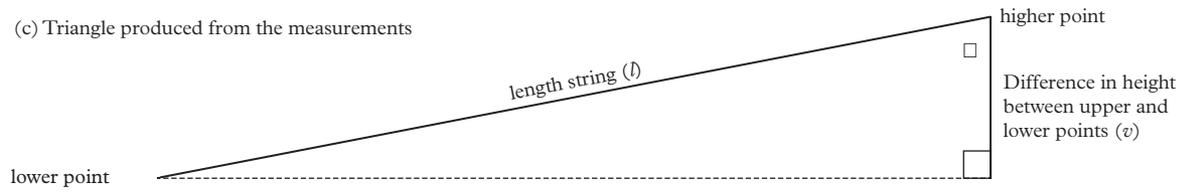


FIGURE 4 Using the protractor to measure slope

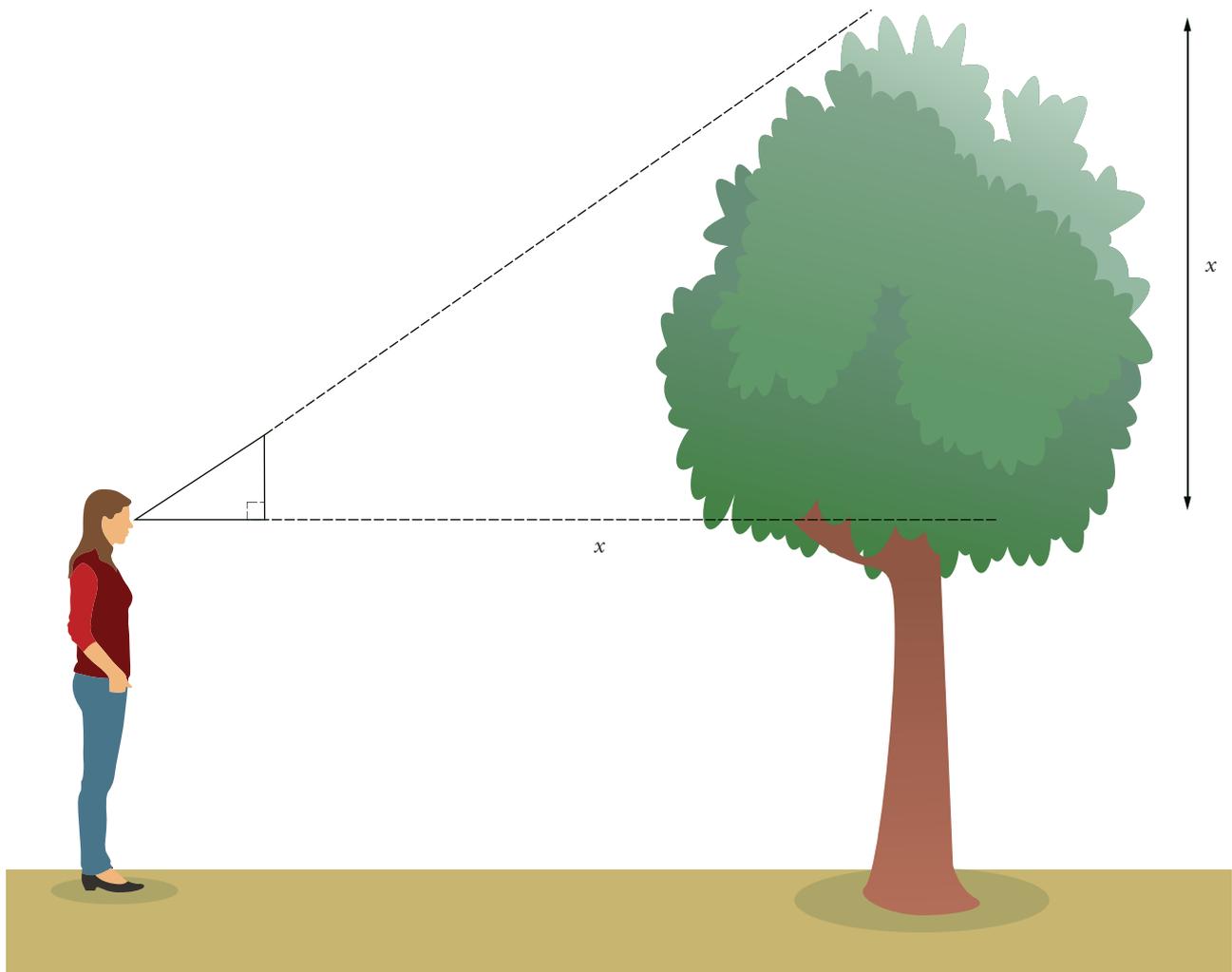


FIGURE 5 Estimating the height of an object using triangulation.

## Measurement of biotic factors

In large and/or remote areas, many biotic factors can be determined using remote sensing, radar imaging and drones. The number of emus, for example, can be assessed using a drone without affecting the emu's behaviour.

The vegetation type of a particular area can be determined in a variety of ways. The dominant species may be identified, or a more generalised description used.

**Foliage cover** can be determined by taking several sightings (either along a predetermined line at set distances apart, or randomly) using crosswire sighting tubes. The tube is held to the eye, looking vertically upwards towards the sky for tree canopies or downwards for herbs and grasses. What is seen exactly where the two wires cross – sky, green foliage, ground, etc. – is recorded and the percentage foliage cover is calculated from the following formula:

$$\% \text{ foliage cover} = \frac{\text{number of foliage sites recorded}}{\text{number of observation sites}} \times 100$$

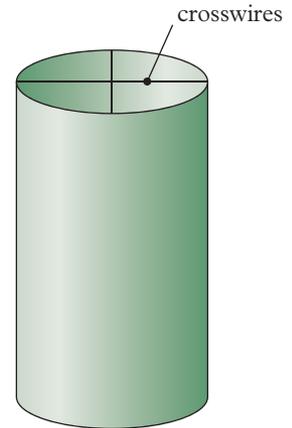


FIGURE 6 A crosswire tube

### foliage cover

an estimate of the area or percentage of a sample site occupied by the natural spread of plant foliage

### plot

an area under investigation – generally a subset of a larger area

### quadrat

a rectangular or square plot of known dimensions

### quadrant

each of four quarters of a circle

### transect

a measured length or strip of terrain in an environment along which individual organisms or environmental parameters are measured and recorded

### belt transect

an elongated area of known length and width through a particular environment in which specific community parameters are measured and recorded

## Plot method

The **plot** method is a basic and commonly used procedure for sampling many types of organisms. A plot is generally a rectangle or a square (**quadrat**), however circles or other shapes can be used. In sampling soil or aquatic organisms, a volume of the habitat is often sampled and analysed. Within this plot or volume, individual organisms can be identified, counted and measured. Random or systematic sampling can give indications of abundance and distribution over a much larger area.

Plot methods of sampling are often very laborious and time-consuming, and results depend on size, shape and number of plots used. Plotless methods are useful for plants or sessile animals and have the advantage of not requiring sampling areas of a certain size or shape to be marked out.

## Quarter-point sampling

The most popular plotless method is quarter-point sampling. This should only be used for populations with highly aggregated or uniformly spaced individuals. Randomly determined points are marked out in the study area. Each point represents the centre of four compass directions that divide the sampling site into four quarters or **quadrants**.

Measurements are made within each quadrant of the distance from the centre point to the centre of the nearest individual, regardless of species. Only one plant (or sessile animal) per quadrant is measured, so a total of four individuals are recorded for each point sampled. Each species encountered is identified. Population density and distributions of the various species can be determined from these recordings.

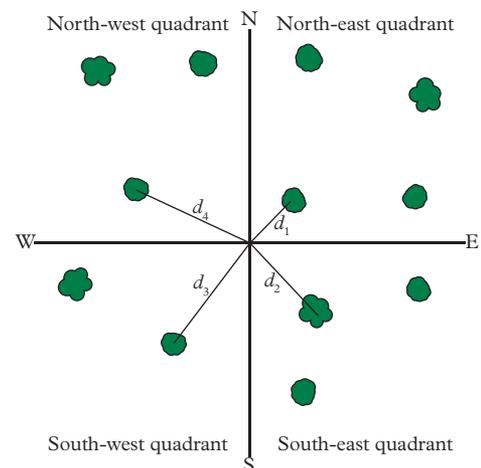


FIGURE 7 In quarter-point sampling, the shortest point-to-point distance is calculated in each of four quadrants.

## Transects

In some types of vegetation, the use of plots may be impractical. **Transects** often give better information over large areas and also show up non-random distributions of some species. There are three main types of transect: belt transect, line intercept, and strip census or line transect.

A **belt transect** is a long strip of terrain in which all organisms are counted and/or measured (Figure 8). Knowing the width and length of the transect makes it possible to estimate species diversity and abundance for the total area. Vegetation transects are often represented by a **profile** or a **plan sketch**.

Profiles can also be constructed for many types of habitat (e.g. rocky shores and freshwater ponds). More information about rocky shore and standing water ecosystems can be found on your [obook](#) [assess](#).

**Line intercepts** are used to estimate relative densities of species and involve counting the numbers of a particular species that lie on a straight line cutting across the community. Line intercepts are often used in grassland community studies where estimates of absolute density either cannot be made or are difficult to interpret because of the difficulty in distinguishing individual plants.

A **strip census** involves walking a line established through an area and recording individuals observed from that line. As for line intercepts, the data recorded are only an index of density. This method can be used in vertebrate population studies such as road kill censuses, bird counts and small mammal trapping. A strip census is very useful in studies of animals that are highly mobile.

**profile**  
slope of the terrain, position and height of vegetation types, and canopy cover

**plan sketch**  
an aerial view showing position and canopy cover of species

**line intercepts**  
a sampling technique used to estimate relative densities of a species by counting the number of individuals that lie on a straight line cutting through the community

**strip census**  
an estimate of the numbers of a wild animals in an area by counting individuals along a typical strip and assuming a uniform population

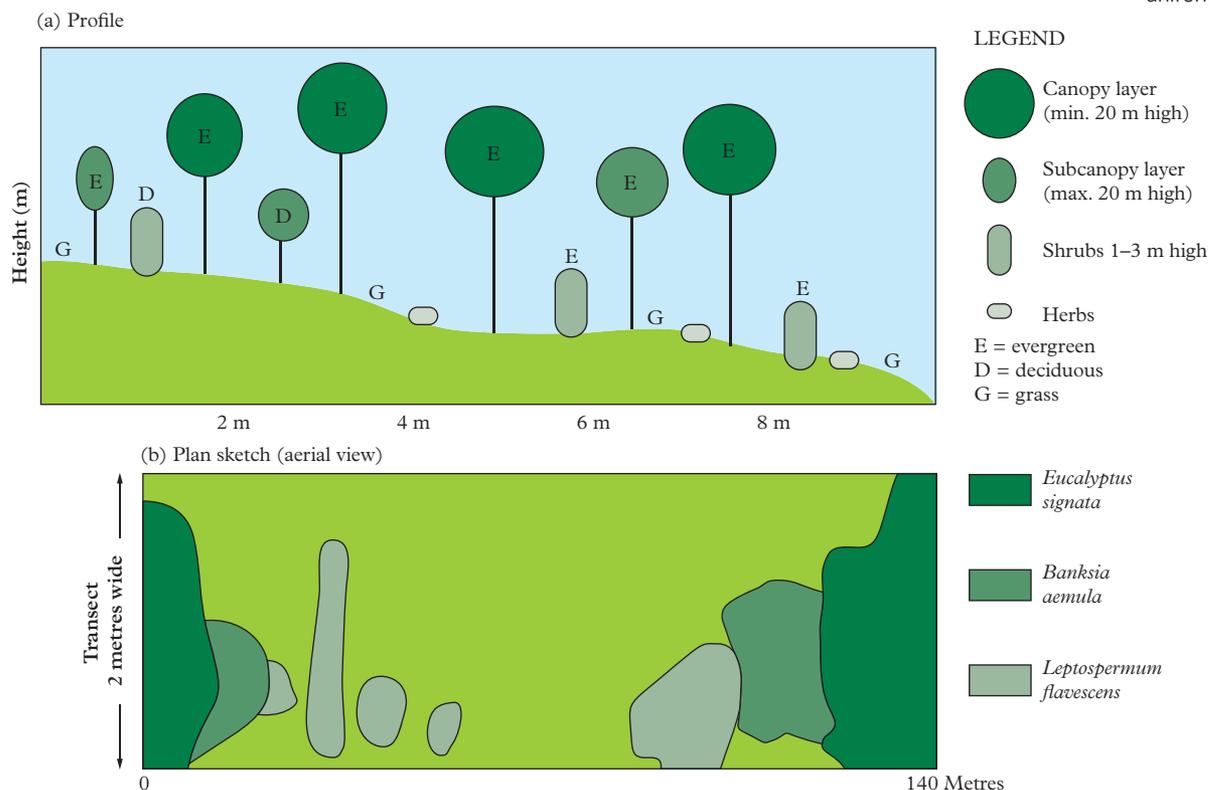


FIGURE 8 Representations of a belt transect

### Berlese–Tullgren funnel

a device used to extract small animals from leaf litter

### pit-fall trap

a device used to trap small animals that are active on the ground surface

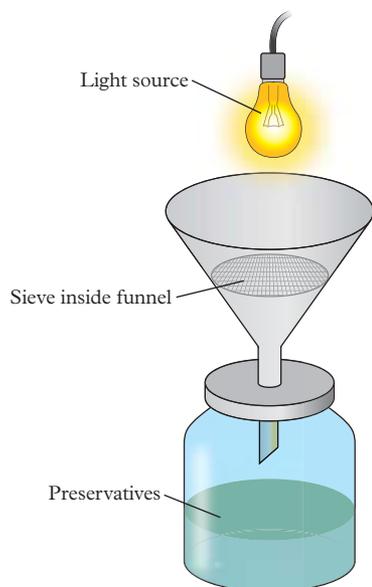


FIGURE 9 A simplified Berlese–Tullgren funnel

## Traps

Soil and litter organisms may be sampled by extracting them from a known volume of material.

The equipment generally used is a **Berlese–Tullgren funnel**. A known volume of soil or litter is placed on the sieve in the funnel. When the light above the funnel is switched on, the organisms move downwards to avoid the light, heat and drying effects. In doing so, they fall into the jar containing preservatives. This method is limited because it favours those species that do not desiccate easily and are mobile.

A **pit-fall trap** is another method used to sample soil and litter organisms. These can be set randomly along a transect or in a grid. An individual trap, consisting of a large can or jar, is set into the ground with its rim at the level of the soil surface, and is either baited or contains a few centimetres of water. Many animals traversing the area fall into the trap and cannot escape up the smooth sides.

### capture–recapture

method of estimating population density of animals where animals are captured, marked and released; their proportion in subsequent trapping allows estimation of population size

### Lincoln Index ( $N$ )

a method used to estimate the size of closed populations in which random samples of the population are captured, marked and released to mingle with the general population for a period of time before subsequent trapping

## Capture–recapture

Population density estimates of larger or more mobile animals can be made using the **capture–recapture** method. A number of individuals from a population are captured, marked by some identifying means, and released within a short period of time. At a later date, a second sample is taken from the population. Some of the individuals in this second sample may already be marked from the first sample. If the population is large, the marked individuals will have become ‘diluted’ within it and only a few would be expected to appear in the second sample. But if the population is relatively small, the proportion of marked animals in the second sample will be larger.

Theoretically the proportion of marked individuals in the second sample is the same as that in the entire population, and the total population can then be estimated using the **Lincoln Index ( $N$ )**:

$$\text{Size of population } (N) = \frac{M \times n}{m}$$

where  $M$  = number originally marked,  $n$  = total number captured in the second sample and  $m$  = number of recaptured (marked) individuals in the second sample.

This method does have some inherent problems:

- Weather conditions may vary at the times of sampling and this may affect the activity of the particular organism under study. Wet or dry conditions, for example, would affect sampling of amphibians.
- Baiting a trap with food may continually attract the same members of a population. These animals are termed ‘trap happy’ as they learn that there is food in the traps. This will make the population estimate lower than reality.
- The process of trapping and handling may make some members of the population become ‘trap shy’. This would result in proportionately fewer marked individuals in subsequent trapping, giving a population estimate higher than reality.

- The method of marking may be unreliable. Tags may be torn off, and colour marking may be lost in feather moulting of birds.
- The length of time between sampling is also significant. If animals are highly mobile, they distribute themselves randomly in a population more quickly than if they were slow moving.



FIGURE 10 Biologists capture birds and tag them for tracking and recapturing.

### CHECK YOUR LEARNING 3.8

#### Describe and explain

- 1 **Describe** what random sampling means.
- 2 **Explain** why observations are replicated.
- 3 **Explain** how you would measure:
  - a depth of soil
  - b pH
  - c humus content of soil
  - d light intensity.
- 4 **Describe** methods that could be used to collect insects from various strata of a forest, for example, from shrubs, flying, in grass or in litter.

#### Apply, analyse and interpret

- 5 **Distinguish** between a belt transect and a line transect.
- 6 One evening 55 mice in an area were captured, marked and released. The following evening 70 mice were captured in the same area, of which 35 were marked. **Infer** a mouse population for that area.

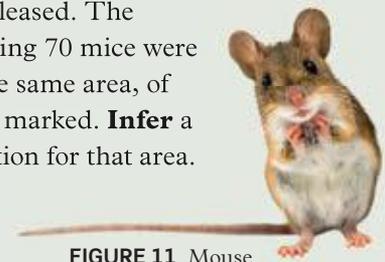


FIGURE 11 Mouse

#### Check your obook assess for these additional resources and more:

##### » Student book questions

Check your learning 3.8

##### » Mandatory practical

3.8A Analysing vegetation patterns using a transect line

##### » Mandatory practical

3.8B Stratified sampling of vegetation patterns

##### » Increase your knowledge

Rocky shore and standing water ecosystems

# 3.9

## Ecosystem management

### KEY IDEAS

- + Coral reefs and soils have high biodiversity levels
- + Crop rotation and maintaining surface covering
- + Negative effects on coral ecosystems

Scientific classification of organisms allows scientists all over the world to communicate with clarity. Similarly, using an accepted system of naming ecosystems achieves the same purpose. The particular name of the ecosystem provides a general understanding of soil type, climate, topography and vegetation. These factors determine the fauna of the area. Classification, and therefore communication, is the key to understanding, managing and protecting important ecosystems.

### Productive soils

The health of a soil is directly linked to its ability to support the growth of plants, which in turn affects the consumers that eat the plants. For example, the continuous growth of a monoculture (such as sugar cane) can detrimentally affect the soil chemistry (pH, nitrogen and other nutrients). Constant grazing of a dry ecosystem by some animals can cause the soil to become compacted, restricting further plant growth. Tillage (breaking the soil with a plough or harrow) can result in water loss, or the soil eroding. The quality of the soil can be improved through careful soil management. This includes:

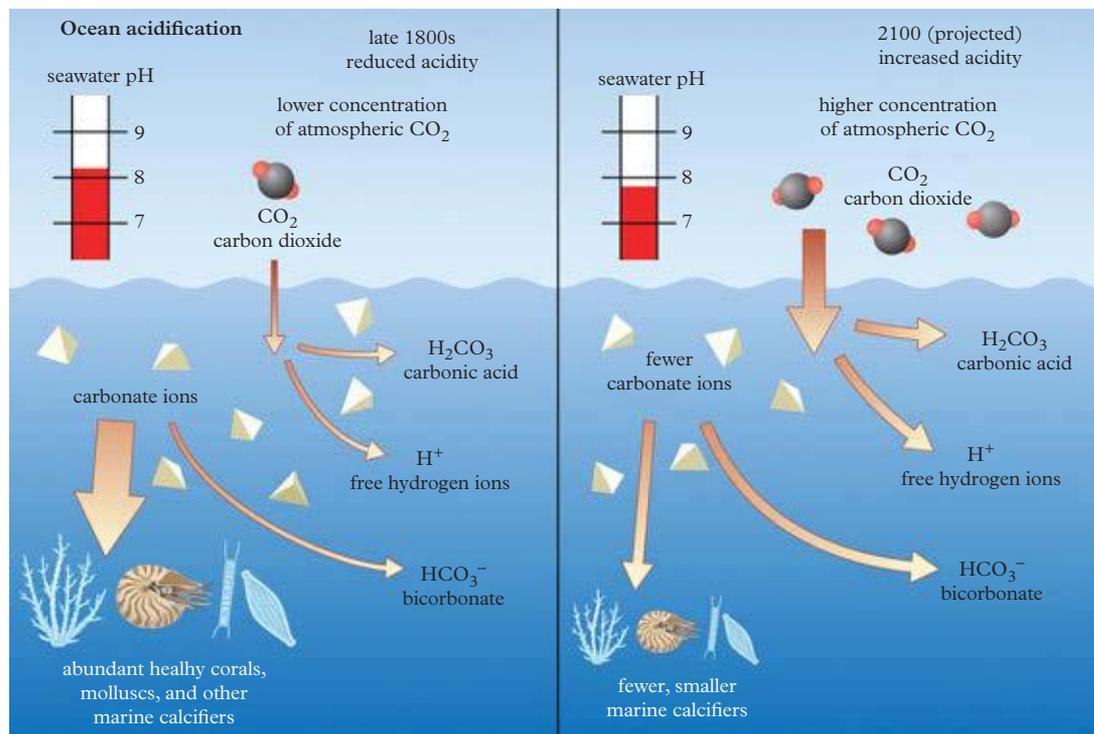
- using plants to cover the soil to keep it anchored and prevent erosion
- rotating monoculture crops with other legume-based crops (legumes containing nitrogen-fixing bacteria that can increase the nitrogen levels in the soil)
- mulching the soil to reduce erosion and water loss.

### Coral reefs

Besides being a beautiful tourist attraction, coral reefs protect coastlines from the damaging effects of waves and storms, while providing essential nutrients, shelter and habitats for marine organisms. For this reason, the coral reef ecosystem must be carefully managed. The recent reports of coral bleaching due to increased water temperatures illustrates the need to measure the abiotic and biotic factors that affect this environment.

The reef is formed from colonies of minute individual organisms called polyps. Each polyp extracts calcium from sea water and deposits it as a calcium carbonate exoskeleton. The individual exoskeletons merge to form a single, solid structure that has a characteristic shape for each species of coral polyp. Reef-building coral polyps form a mutualistic relationship with photosynthetic organisms called Zooxanthellae. The Zooxanthellae live inside the tissues of the coral, providing oxygen to the coral and removing their wastes. In return the coral provides shelter and the nutrients for photosynthesis. Increased water temperatures cause the coral to reject the colourful Zooxanthellae, ejecting it from their cells and causing the coral to become white.

The increase in carbon dioxide in the atmosphere results in increased amounts of carbon dioxide dissolving in sea water. This causes the formation of carbonic acid, which reacts with the calcium carbonate that makes up the coral, the shells of oysters and other shellfish.



**FIGURE 1** Increased carbon dioxide in the atmosphere results in increased ocean acidification. This negatively affects the ability of corals and shellfish to produce the calcium carbonate in their shells.

### CHECK YOUR LEARNING 3.9

#### Describe and explain

- 1 **Explain** why it is important to classify an ecosystem before it can be managed.
- 2 **Identify** three reasons why each of the following ecosystems should be managed.
  - a soils
  - b coral reefs

#### Apply, analyse and interpret

- 3 **Determine** how you may manage the ecosystem in your school grounds.

#### Investigate, evaluate and communicate

- 4 **Research** the ecological and economic effects of coral bleaching.

Check your obook assess for these additional resources and more:

» **Student book questions**

Check your learning 3.9

» **Weblink**

Productive soils

» **Weblink**

Coral bleaching

# Old growth forests

## KEY IDEAS

- ✦ Old growth forests have high biodiversity levels
- ✦ Managing old growth forests

## What are old growth forests?

Old growth forests are significant ecosystems with high biodiversity. The term old growth forest does not imply that all of the trees in the forest are old, but a large percentage of them are. After reaching maturity (for some this may take hundreds of years), trees undergo senescence and then die. In these latter stages, parts of the tree decay and hollows are formed within them. As the loss of the canopy of these trees increases, new trees can germinate and grow, as light reaches the forest floor and nutrients become available. A number of animal species are reliant on these types of forests because of their range of nesting hollows, variety of microclimates and greater structural complexity in comparison with forests in earlier stages of development. Some fauna, such as Leadbeater's possum, depend on the old trees for nesting sites but use the younger trees for feeding.

In Australia, old growth forests are those that have not had recent large-scale disturbances (fire, logging, grazing, etc.) and have the following features:

- an overstorey dominated by relatively large trees, many of which are old with hollows that provide shelter and nesting sites for fauna
- a well-developed understorey of trees, shrubs and herbs
- the ground level littered with large fallen logs and woody debris
- low rates of change in composition and structure.

The trees have:

- low average growth rates, with growth in young trees balanced by death of older trees
- a high level of biomass in live trees, dead trees, logs and on the forest floor
- lower water transpiration, higher water flow to streams and higher soil moisture than younger growth stages.

## Management of old growth forests

These characteristics apply to a variety of vegetation types, such as rainforests and several types of eucalypt forests. An understanding of the significance of these forests to Australian biodiversity has led to all states undertaking measures to protect them. By using a common definition of classification and determining the size of the forest required to ensure long-term survival, authorities can make decisions on which forest areas should be reserved and how they may be used.

In south-east Queensland, for example, all identified old growth forests on public land are reserved for conservation purposes. Including those set aside for reserves on private land, a total of 73% of all old growth forest in the region is protected. In south-west Western Australia, with its extremely diverse ecoregion of Mediterranean forests, woodlands and scrub, 100% is reserved. Logging activities in these reserves are restricted to new growth trees.

Quite apart from the importance of maintaining biodiversity, a recent global study has shown that the tall, old growth mountain ash forests of Victoria's Central Highlands is the world's most carbon-rich forest. Because of the range of environmental conditions in this region, the rate of plant growth is high. Due to cooler temperatures, however, decay rates are slow. The mountain ash grows heavy, dense wood over a period of about 350 years. The density and volume of wood produced results in the storage of massive amounts of carbon. With the world currently experiencing global warming, it is important to maintain such forests to ensure continued uptake and storage of carbon dioxide from the atmosphere.



FIGURE 1 An old growth forest in Mossman Gorge, Queensland

### CHECK YOUR LEARNING 3.10

#### Describe and explain

1 **Identify** three reasons why old growth forest ecosystems should be managed.

2 **Define** the term 'old growth forest'.

Check your obook assess for these additional resources and more:

» **Student book questions**  
Check your learning 3.10

» **Weblink**  
Victoria's Central Highlands mountain ash forest

» **Weblink**  
Mossman Gorge forest



# Review

## Chapter summary

- 3.1**
- An ecosystem consists of a community of organisms and their physical surroundings.
  - All organisms are affected by other living (biotic) factors in the ecosystem.
  - The physical (abiotic) factors in an ecosystem can affect an organism's survival.
  - Producers are able to convert light or chemicals in the environment into energy to survive, grow and reproduce.
  - Consumers eat other organisms to provide the energy to survive, grow and reproduce.
  - Detritivores consume organic matter.
  - Decomposers break down organic matter into inorganic matter.
- 3.2**
- Abiotic features of the environment that influence the ecosystem include those associated with climate, soil and geography.
  - The optimum range consists of the most favourable values for a specific abiotic factor in which an organism survives, grows and reproduces.
  - The tolerance range lies between the maximum and minimum values for an abiotic factor at which an organism struggles to stay alive.
- 3.3**
- Intraspecific competition occurs between members of the same species.
  - Interspecific competition occurs between members of different species.
  - Symbiosis is a close, long-term relationship between two members of different species. It includes mutualism, cooperation, commensalism, amensalism and parasitism.
  - Mimicry occurs when one organism evolves to look similar to an unpalatable organism from another species.
- 3.4**
- Different hierarchical classification systems are used to describe the biotic and abiotic organisms in an ecosystem.
  - The Holdridge life zone system is a global system based on the local climate of an ecosystem.
  - Specht's classification of Australian vegetation uses the foliage cover by the tallest plants in an area and the height of those plants.
  - The Australian National Aquatic Ecosystem (ANAE) classification framework starts with a regional classification before classifying the specific details of the waterway.
  - The European Nature Information System (EUNIS) classifies natural and artificial habitats according to the topography of the land, the characteristics of the soil, climate or water quality, and the general appearance of the plants or animals.
- 3.5**
- Aquatic environments can be classified as either marine or fresh water.
  - Marine ecosystems can be divided into littoral (where the water meets land), neritic (shallow coastal water), bathyal, abyssal (deep water) or hadal (very deep water).

- Freshwater ecosystems can vary according to the depth of the water, the local temperatures, and the nutrient and oxygen levels.
- 3.6**
- Terrestrial ecosystems can be classified according to the nature of the soil, the geography of the land, the abiotic conditions or the dominant species.
  - Biomes are classified according to the dominant vegetation types.
  - Vertical stratification is the vertical layering of vegetation in a habitat.
  - Ecozones are large areas where organisms have been evolving in relative isolation over long periods of time. Each ecozone is separated by a physical barrier.
  - Ecoregions are geographically distinct communities based on geology, soils, climate and predominant vegetation within an ecozone.
- 3.7**
- The biodiversity within the ecosystem is an indication of the health of the system.
  - Species richness is a measure of the number of species, compared to the number of individuals found in a sample. The larger the sample, the more species are likely to be found.
  - Species diversity differs from species richness in that it considers both the numbers of species present and the evenness of species in relation to one another.
  - Simpson's Index (*D*) measures the probability that two individuals randomly selected from a sample will belong to the same species (or genus or family, etc.).
  - Simpson's Diversity Index (*SDI*) measures the probability that two individuals randomly selected from a sample will belong to different species (or genus or family, etc.).
- 3.8**
- Stratified sampling involves dividing an ecosystem into smaller components, so the abiotic and biotic components can be sampled.
  - Random, unbiased sampling provides the most accurate data about an ecosystem.
  - Equipment used to measurement the abiotic factors in the ecosystem should be calibrated.
  - Sampling methods for the biotic components of the ecosystem will depend on the type of environment and the species being counted.
- 3.9**
- Soils and coral reefs have diverse ecosystems.
  - Increased ocean temperatures have driven coral bleaching.
- 3.10**
- Old growth forests are niches for different life forms and have a large amount of CO<sub>2</sub> stored in them.

## Key terms

- |                 |                    |                |                    |
|-----------------|--------------------|----------------|--------------------|
| • abiotic       | • Berlese–Tullgren | • capture–     | • cooperation      |
| • abundance     | funnel             | recapture      | • cryptic organism |
| • abyssal zone  | • biome            | • carnivore    | • decomposer       |
| • amensalism    | • biosphere        | • commensalism | • detritivore      |
| • belt transect | • biotic           | • community    | • distribution     |
| • benthic       | • camouflage       | • competition  | • ecology          |
| ecosystem       | • canopy           | • consumer     | • ecoregion        |

- ecosystem
- ecozone
- environment
- foliage cover
- habitat
- herbivore
- heterotroph
- Holdridge life zone
- interspecific
- intraspecific
- Lincoln Index (N)
- line intercepts
- littoral zone
- microhabitat
- mimicry
- monoculture
- mutualism
- nekton
- neritic zone
- niche
- omnivore
- optimal range
- parasitism
- physiological stress
- pit-fall trap
- plan sketch
- plankton–nekton ecosystem
- plot
- population
- predator
- producer
- profile
- quadrant
- quadrat
- random sampling
- Simpson's Diversity Index (SDI)
- Simpson's Index (D)
- species diversity
- species richness
- stratification
- strip census
- symbiosis
- tolerance range
- transect
- vertical stratification
- zonation

## Key formulas:

Ecosystem formation	Ecosystem = community + physical surroundings
Species richness	$S = \frac{s}{\sqrt{N}}$
Simpson's Index	$D = \frac{\sum n(n-1)}{N(N-1)}$
Simpson's Diversity Index	$SDI = 1 - D$
Vertical height between two points	$\cos \theta = \frac{v}{l}$
Height of objects whose base can be seen	$\tan 45^\circ = \frac{\text{side opposite (height)}}{\text{side adjacent (horizontal distance)}} + \text{height of observer}$
Foliage cover	$\% \text{ foliage cover} = \frac{\text{number of foliage sites recorded}}{\text{number of observation sites}} \times 100$
Lincoln index	Size of population (N) = $\frac{M \times n}{m}$

## Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: \* = low; \*\* = medium; \*\*\* = high.

### Multiple choice

- 1 The organisms living in and on a decaying log can be described as:
- A a community
  - B a population

- C an ecosystem
  - D a society
- 2 The interaction between a particular kind of organism and its environment is described by the term:
- A community
  - B population
  - C niche
  - D ecosystem

- 3 A factor that distinguishes a community from an ecosystem is:
- A time
  - B space
  - C the biotic environment
  - D the abiotic environment
- 4 The data below was compiled from a student survey in a natural community along the south-east coast of Queensland.

Name of plant	Height (m)	Population density (plants per km <sup>2</sup> )
Brush box ( <i>Lophostemon confertus</i> )	25–30	20
<i>Banksia</i>	7–10	100
<i>Acacia</i>	2–3	50

The most suitable name for this community would be:

- A Brush box forest
  - B *Banksia* woodland
  - C Brush box – *Banksia* – *Acacia* community
  - D *Banksia* – *Acacia* low open forest
- 5 Which of the following statements is correct?
- A The environment of an organism describes the other organisms that share its space and many adaptations.
  - B Biomes are large community units that are always found at the same latitude, irrespective of species composition.
  - C Ecoregions are geographically distinct communities based on geology, soils, climate and predominant vegetation.
  - D Ecozones are an alternative name for a biome and are distinguished by climate and predominant vegetation.
- 6 Shrubs seldom grow successfully on the floor of a dense forest. Which of the following factors mainly accounts for this phenomenon?
- A They fail to compete with the extensive root system of the trees to obtain sufficient water and mineral salts.
  - B They fail to compete with the tall trees to obtain CO<sub>2</sub> from the atmosphere to support photosynthesis.
  - C They fail to compete with the extensive canopy of the trees to receive sufficient sunlight.
  - D They easily suffocate because most of the oxygen in the atmosphere has been absorbed by the leaves of the trees.
- 7 A species of thorny *Acacia* grows in rainforest clearings in Costa Rica where a tree fall has occurred. *Acacia* are low growing trees that require large amounts of sunlight to survive. They produce chemicals in their tissues that are toxic to leaf-eating insects. Ants that live in their hollow thorns actively cut off tendrils and branches of the rampant rainforest climbers that attempt to use the *Acacia* as a support. They also attack and sting any insects that they encounter on the tree. The plant secretes a sugary substance from glands on their fine branches, which is eaten by the ants. Small structures, high in protein, are formed on the tips of the leaflets. The ants collect these and take them back to their nests for food for their larvae. What is the symbiotic relationship between the *Acacia* and ants?
- A Commensalism
  - B Competition
  - C Cooperation
  - D Mutualism
- 8 Many plants in Western Australia grow in nutrient-deficient sandy soil, and experience hot, dry summers and winter rainfall. Some of these will grow in South Eastern Queensland, although their growth and reproduction is reduced. In South Eastern Queensland, these plants are growing in:
- A an intolerance zone
  - B a zone of physiological stress
  - C the optimal zone
  - D the subliminal zone

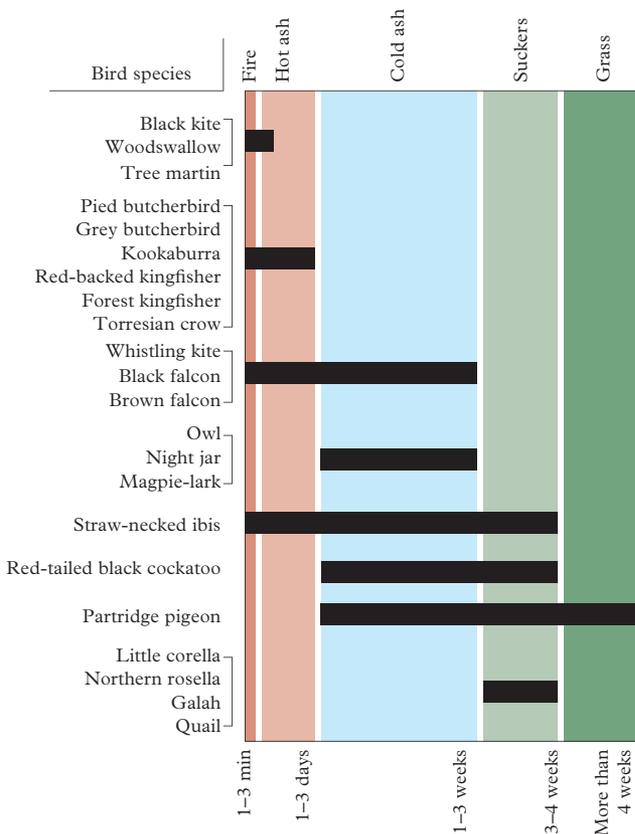
**Short answer**

**Describe and explain**

- ★ 9 **Explain** why random sampling is important when conducting a field study.
- ★★ 10 Several indices can be used to determine biodiversity of an ecosystem.
  - a **Explain** what the biodiversity of an ecosystem means.
  - b **Describe** the parameters that could be used to measure biodiversity of an ecosystem.

**Apply, analyse and interpret**

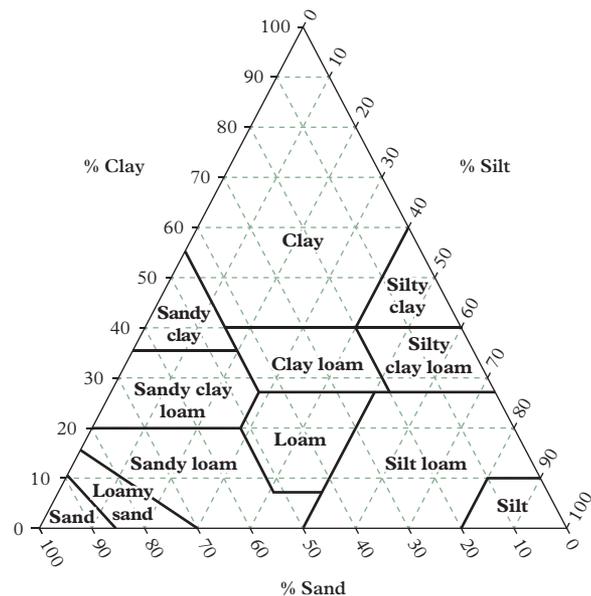
- ★★ 11 The mammals of the wallum area tend to be small and are either insectivorous or eat fruit, flowers and nectar. These include honey eaters, small insectivorous birds and a great variety of lizards and snakes. **Infer** reasons for the types of fauna found in these areas.
- ★★ 12 Different resources are used by different organisms. A study of the birds found at



**FIGURE 1** Occurrence of bird species in Kakadu National Park at various times after fire

various times after fire in Kakadu National Park (NT) was conducted. The results are given in Figure 1. From these:

- a **determine** the resources that each group of birds utilises
- b **distinguish** changes in community structure after a fire.
- ★★ 13 Soil types can be determined using a grid of percentage composition of sand, silt and clay as shown in Figure 2.
  - a A soil has been identified as a clay loam. It has a composition of 40% silt, 30% clay and 30% sand. **Determine** where within the clay/loam dimensions of the grid you place this soil.



**FIGURE 2** Soil types based on percentages.

- b A soil has a composition of 25% silt, 8% clay and 67% sand. Using the grid, **classify** this soil.
- ★★ 14 A student throws a 0.25 m<sup>2</sup> quadrat onto the school lawn. Figure 3 shows what was found.
  - a **Determine** the number of dandelions in 1 m<sup>2</sup>.
  - b If the lawn is 100 m × 50 m, **determine** the number of daisies in the entire lawn.

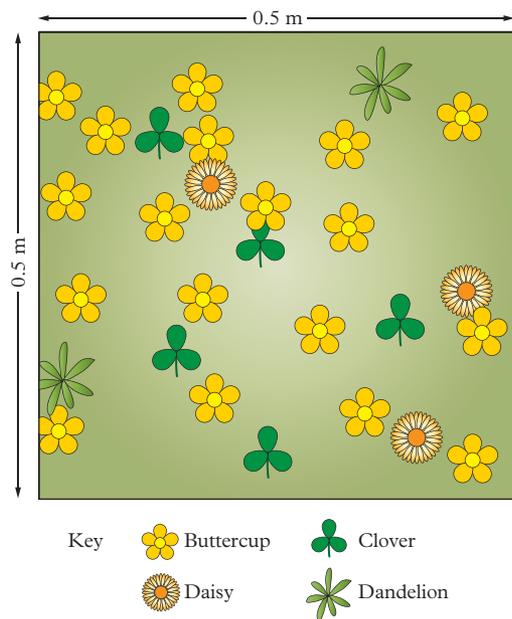


FIGURE 3 School lawn quadrat

★★★ 15 The siren wood wasp, *Sirex noctilio*, lays eggs by boring holes in the trunks of pine trees (*Pinus radiata*). The females of this wasp deposit eggs together with filaments of a symbiotic fungus *Amylostereum*. It is this fungus that may kill the tree. The siren wasp, therefore, threatens plantations of *Pinus radiata*.

Although birds kill adult wood wasps and their young, they are not able to effectively control them. Biologists have introduced two parasitic wasps to plantations, *Megarhyssa* and *Ibalia*. Both of these lay their eggs in the larvae of the siren wasp. When the parasitic wasp eggs hatch, these larvae eat their way through the developing siren, killing it. A species of the nematode worm genus *Deladenus* also parasitises all three of the mentioned wasps. It sterilises the females, which then lay only eggs packed with young nematode worms. These worms can also live in a free-living form that feeds on the fungus *Amylostereum*.

- Deduce** all of the different types of biotic relationships described above.
- A field worker noticed that in an area where large numbers of *Megarhyssa* were seen, few infections of the fungus *Amylostereum* were detected. Using the data, **explain** this observation.
- In an area where the parasites *Megarhyssa*, *Ibalia* and *Deladenus* had been introduced in large numbers some years previously, the existence of *Sirex noctilio* is still reported. **Determine** a hypothesis to explain this observation.

### Investigate, evaluate and communicate

- ★★★ 16 Choose a non-domestic animal and **investigate** its characteristics and distribution.
  - Classify** the abiotic and biotic features of its environment.
  - Construct** a concept map to demonstrate its ecological niche.
  - Deduce** one significant aspect of its environment and **predict** the outcomes for this species if that were to change.
- ★★★ 17 Rainforest soils retain few nutrients since they are utilised as soon as they become available from decomposer activity in order to support the large mass of plants in the community.
  - Predict**, with reasons, the viability of an agricultural enterprise based on cleared rainforest soil.
  - Generate** a short report on the advisability of clearing rainforest for farming purposes.
- ★★★ 18 'Soil moisture, temperature and nutrients have a direct influence on plant distribution and abundance, whereas altitude, rainfall and soil type affect these parameters indirectly.' **Discuss** this statement.

Check your obook assess for these additional resources and more:

» **Student book questions**  
Chapter 3 review

» **Revision notes**  
Chapter 3

» **assess quiz**  
Chapter 3 auto-correcting multiple-choice quiz

» **Flashcard glossary**  
Chapter 3 glossary



# FUNCTIONING ECOSYSTEMS

Living organisms are energy converters. Photosynthetic organisms convert radiant (light) energy to chemical energy. Heterotrophs obtain their energy from the chemical energy in the foods they eat as herbivores, carnivores or omnivores. Most heterotrophs do not digest all of the food they take in, so some chemical energy remains in the faeces that passes out of the body. All organisms lose some energy in the form of heat as they carry out life functions, and so must continually replenish their supplies of energy and food. The transfer of living matter through the ecosystem from producers through the various heterotrophs can be represented as energy-flow diagrams. As organisms eliminate waste matter or die, their organic chemicals are broken down, by decomposer organisms, into simple inorganic chemicals that are returned to the environment. During the conversion of complex to simple chemicals, chemical energy is also returned to the atmosphere as heat. Energy flows through an ecosystem while matter is recycled. Some species play a critical role in ecosystems, influencing the populations of all other species.

## OBJECTIVES

- Sequence and explain the transfer and transformation of solar energy into biomass as it flows through biotic components of an ecosystem, including
  - converting light to chemical energy
  - producing biomass and interacting with components of the carbon cycle
- Analyse and calculate energy transfer (food chains, webs and pyramids) and transformations within ecosystems, including
  - loss of energy through radiation, reflection and absorption
  - efficiencies of energy transfer from one trophic level to another
  - biomass
- Construct and analyse simple energy-flow diagrams illustrating the movement of energy through ecosystems, including the productivity (gross and net) of the various trophic levels
- Describe the transfer and transformation of matter as it cycles through ecosystems (water, carbon and nitrogen)
- Define keystone species and understand the critical role they play in maintaining the structure of a community

FIGURE 1 Energy flows in and out of a terrestrial ecosystem.

- Analyse data (from an Australian ecosystem) to identify a keystone species and predict the outcome of removing the species from an ecosystem
- Analyse data to identify species (including microorganisms) or populations occupying an ecological niche

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

## PRACTICALS



SUGGESTED  
PRACTICAL

**4.1A** A simplified food chain in leaf litter



SUGGESTED  
PRACTICAL

**4.1B** Measuring biomass



# 4.1

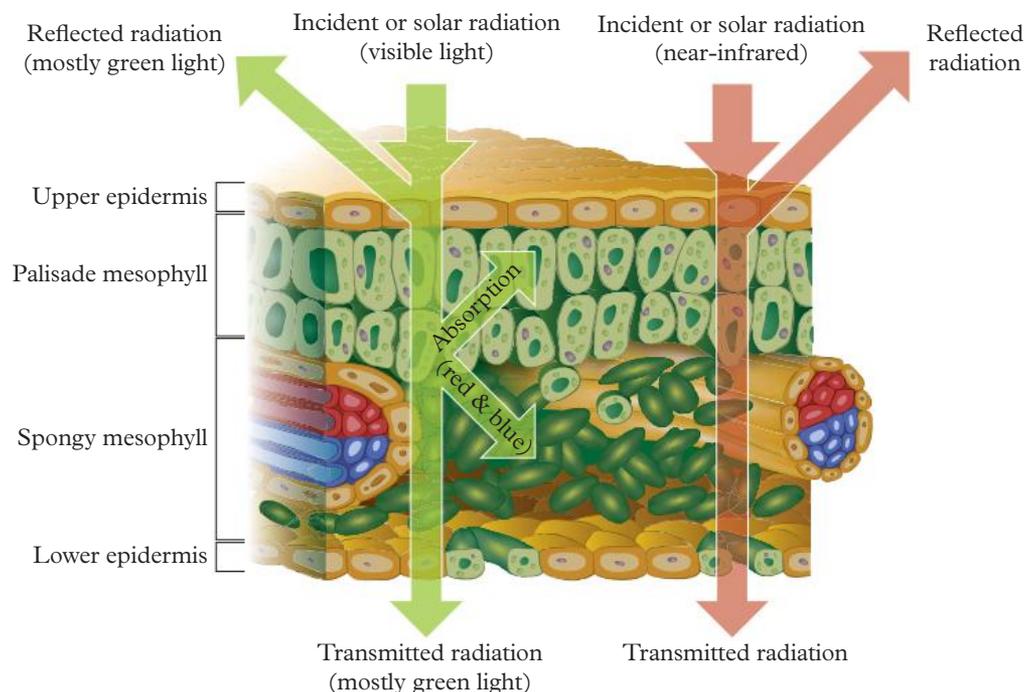
## Energy in ecosystems

### KEY IDEAS

- + Energy from the sun
- + Energy flow through food chains
- + Solar energy and photosynthesis
- + Photosynthetic efficiency
- + Productivity in an ecosystem
- + Producers and energy
- + Consumers and energy
- + Decomposers and energy
- + Trophic levels in a food chain
- + Recycled matter
- + Food webs and interlinking food chains

The energy that sustains the majority of living systems is solar energy. Some of the solar energy that radiates from the sun is reflected back into space by the atmosphere. The majority of the solar energy is absorbed by the Earth, with a small percentage (approximately 1%) absorbed by plants in the ecosystem.

Energy changes its form (is transformed) from solar light energy into chemical energy through the process of photosynthesis. The chemical energy is transferred from molecule to molecule in the biosphere before it is radiated into space as heat energy. The total amount of solar energy 'fixed' on Earth can determine the amount of chemical energy, and therefore the total amount of life. Only a small proportion of the total solar energy reaching the Earth's surface is transformed by photosynthesis into organic matter. Most solar energy is reflected back into space or absorbed by the Earth during the day and radiated back into the atmosphere at night. The patterns of flow of chemical energy can be tracked from molecule to molecule, and organism to organism in the biosphere.



**FIGURE 1** Solar radiation is absorbed by the leaf of a plant and transformed into chemical energy through photosynthesis. This energy can be transferred to herbivores when the plant is eaten, or radiated into the atmosphere as thermal energy.

## Food chains

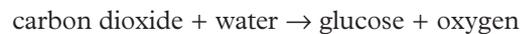
Autotrophs produce food (matter and chemical energy). The autotrophic producers are eaten by other organisms, which in turn are eaten. The path that the food takes from organism to organism through the ecosystem is called a **food chain**. Because the food chain shows the direction of movement of matter and energy, the arrows show their direction of movement – from consumed to **consumer**.

On the basis of the way they obtain food, organisms can be categorised into three groups: producers, consumers and decomposers.

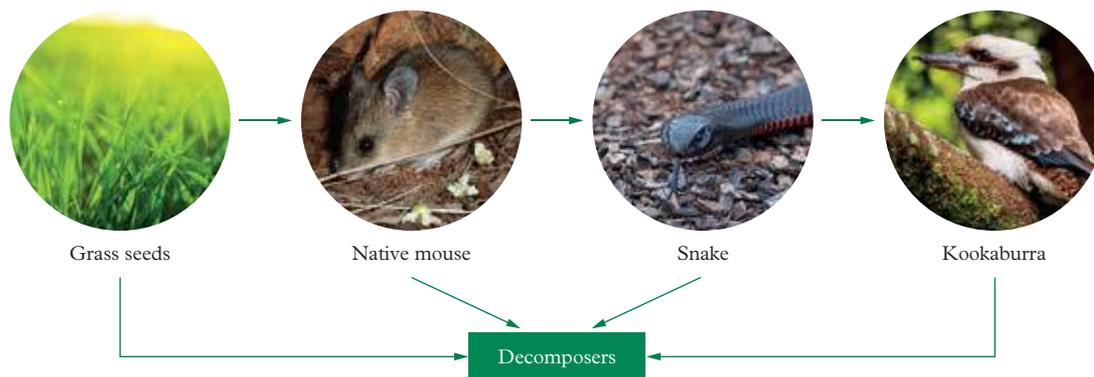
### Producers

Producers convert simple inorganic chemicals to complex organic molecules (molecules containing carbon and hydrogen together with other atoms). Most producers use solar radiation as an energy source. **Productivity** is measured by the amount of energy fixed within chemical compounds at each level in the ecosystem. In producers it can also be an indication of the amount the **biomass** (mass of all organic matter in an area) increases over a particular length of time. Photosynthesis is a chemical reaction. This means it is affected by the temperature of the environment. Higher temperatures cause the molecules to move faster, increasing the rate of photosynthesis and glucose production. Cold temperatures slow the rate that glucose is produced. The temperatures that determine the rate of photosynthesis change throughout the year because the production of glucose by plants and its conversion into other organic compounds (biomass) are influenced by season, latitude and altitude.

Productivity in producers is also influenced by other factors such as soil mineral availability and water. Although deserts may experience suitable temperatures for chemical reactions, there is little water present and as a consequence their productivity is low.



Plants and algae/phytoplankton also vary in their ability to convert light into chemical energy. This ability is the producer's **photosynthetic efficiency** – how effectively the producer in the ecosystem is able to produce glucose from sunlight. The total amount of organic matter in an ecosystem, which is produced as a result of photosynthesis or chemosynthesis, is called **gross primary production**. Not all of this energy can be used by the herbivore that eats the producer – some will be lost as heat and removed as waste products. The amount of energy the herbivore is able to gain when they eat the producer



Note: The direction of the arrows indicates 'eaten by' = direction of energy flow

FIGURE 2 A food chain

#### food chain

simple linear arrangement of organisms showing the flow of matter and energy from one organism to another through feeding relationships

#### consumer

organism that eats another living organism (or part of an organism) for nutrition

#### productivity

amount of energy fixed in organic compounds; measured by increase of biomass per unit of time

#### biomass

amount of organic matter in a system

#### photosynthetic efficiency

the fraction of light energy that plants and algae convert into chemical energy during photosynthesis

#### gross primary production

the total amount of organic matter in an ecosystem produced as a result of photosynthesis

**net primary production**

amount of energy available for herbivores in an ecosystem

**specialist feeder**

a heterotroph that can thrive only on a limited diet

**generalist feeder**

a heterotroph with a varied diet

**detritus**

organic debris from decomposing plants and animals

**detritivore**

an organism that feeds on detritus

**decomposer**

an organism (e.g. bacteria and fungi) that utilises dead organisms or waste matter for its nutrient, releasing simple inorganic molecules

(after subtracting the energy it took to digest the plants) is called **net primary production**. The productivity can be measured for each level in an ecosystem. An example of this is secondary productivity, which is a measure of the amount of new tissue (biomass) generated by the growing herbivores in an ecosystem.

## Consumers

Consumers use food produced by other organisms as their energy source. First-order consumers are herbivores, which eat plant material. Second-order consumers are carnivores that eat herbivores. Third and higher-order consumers are carnivores that eat other carnivores. These carnivores may be predators (killing other animals for food), parasites (feeding on living organisms) or scavengers (eating animals they have not themselves killed). Some consumers – the omnivores – may be both a first-order consumer and a higher-order consumer simultaneously. Consumers that are **specialists** eat a limited range of things. Koalas, for example, only eat the young leaves of specific eucalypts. Other consumers, the **generalists**, eat a wide variety of food. A bandicoot is a generalist that eats insects, spiders, earthworms, berries, grass seeds, and young stems and roots.

## Decomposers and detritivores

All organisms eventually die and fall to the environmental substrate of any ecosystem. This mixture of dead plant parts, skin, undigested food and dead organisms is called the **detritus**. The detritus is broken down by two groups of organisms. Organisms that obtain their nutrients by ingesting and digesting the nutrients in the detritus internally (i.e. worms) are called **detritivores**. Other organisms, **decomposers** (bacteria, fungi and some protozoans), have external digestion and will often excrete enzymes to break down the nutrients before absorbing them directly into the cell. Since only a finite amount of matter is available in the biosphere, it is recycled.



**FIGURE 3** A bandicoot is a generalist, eating both animals and plants.



**FIGURE 4** Fungi are decomposers, breaking down dead material on the forest floor.

### Study tip

The terms decomposer and detritivore are often used interchangeably.

## Trophic levels

**Trophic** (feeding) **levels** describe the relative positions of producers and consumers in a food chain. A food chain shows a series of organisms existing in any ecosystem, through which energy is transferred. Each organism in the series feeds on, and therefore derives energy from, the preceding one. In turn it is consumed by the next organism along the food chain, passing on the energy it has stored in its cells and tissues.

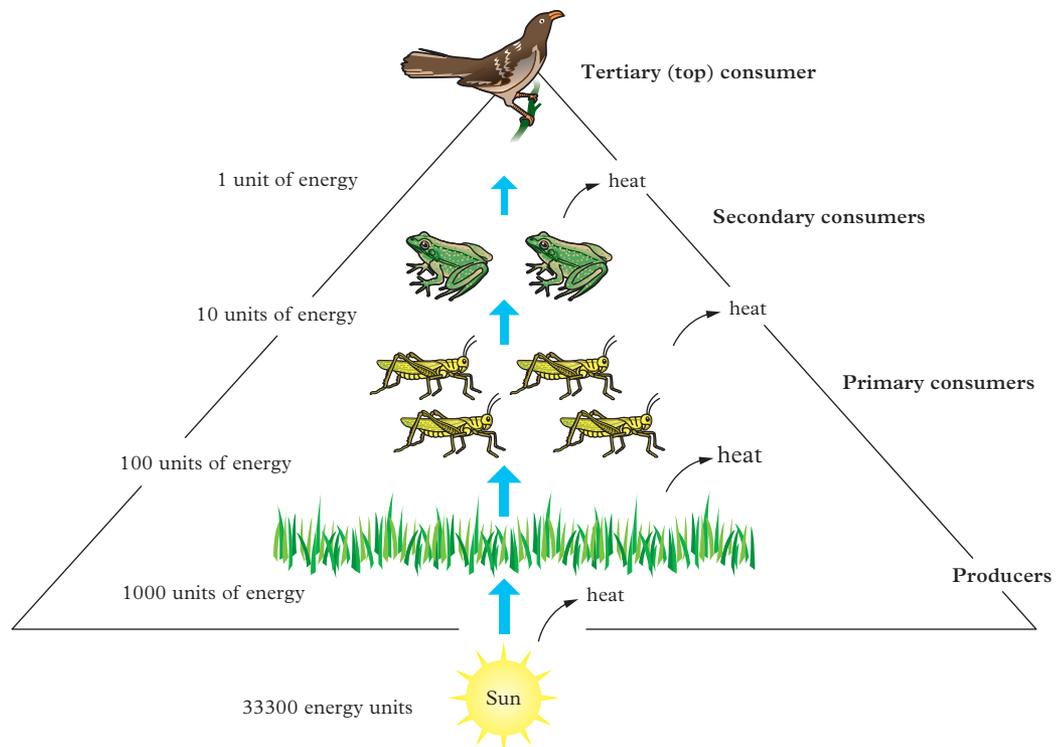
**trophic level**  
a feeding level in a food chain, e.g. producer, herbivore

## Energy transfer

There are very rarely more than six links in any food chain; usually there are only three to four. This is because energy is lost to the surrounding environment in the form of heat at each level of the food chain. It has been estimated that only 5 to 20% of the energy contained at one level of the food chain is transferred to the next level. For example, if 1000 units of energy is produced by grass through photosynthesis, and the energy transfer of grass is 10%, only 100 units of energy becomes incorporated into molecules of the grasshoppers. The other 900 units of energy will be used up in the energy-consuming activities of the grass, such as growing and flowering, which will release energy to the environment, either as heat or waste matter.

There is more energy stored in the lowest (producer) level of a food chain than in the third trophic level (consumers). Therefore, the closer a consumer is to the producer, the more energy is available to be transferred.

In most cases, higher-order consumers tend to be larger than lower-order consumers (particularly when they are carnivores). Food chains, therefore, generally have fewer members in each successive energy level. Because energy is released to the environment at each level, the number of levels in any food chain is limited. The energy released to the environment is eventually re-radiated into the atmosphere as heat. Energy is not recycled in an ecosystem, it flows through the ecosystem.



**FIGURE 5** The transfer of energy along a food chain is very inefficient.

## Food webs

A food chain is a simple linear series in which each organism is completely dependent on a single food source. However, more often, the range of plant species is sufficient enough for herbivores to have several alternative sources of food, and carnivores to prey upon a variety of animals. This can be represented by a diagram that contains a variety of food chains linked together (see Figure 6). This **food web** is a graphical representation of the many food chains that are interlinked to show the feeding relationships between organisms in an ecosystem.

In a complex food web there is greater stability, since most organisms have a variety of food sources to compensate for seasonal fluctuations.

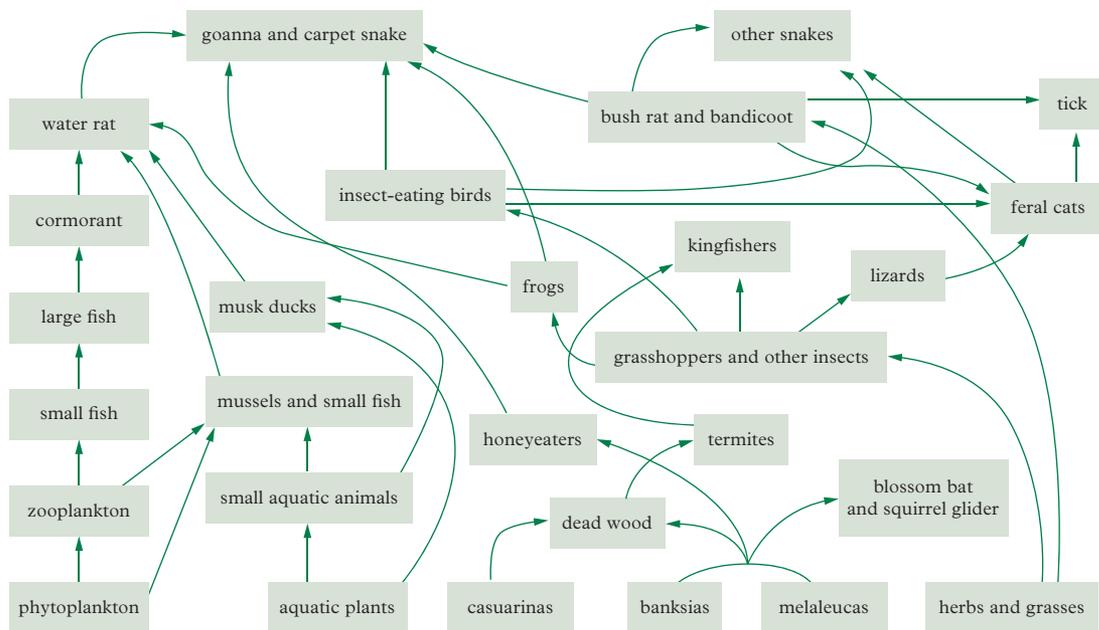
All waste and dead materials are acted upon by decomposers. The organic debris may be totally consumed by the bacteria, fungi and small animals, releasing carbon dioxide, water and heat. Alternatively, the organic molecules may enter other complex food webs when scavenging organisms such as crabs utilise the remains of dead animals and in turn are eaten by fish such as mullet. Ultimately, however, decomposer organisms release nutrients back into the environment. This process is not always complete, and only partially broken-down products such as methane and alcohol may be released.

Ecosystems conform to the **law of conservation of matter and energy**, which states that matter and energy cannot be created or destroyed but can be changed to other forms.

Although complex ecosystems (indicated by the variety of organisms at each trophic level, and therefore the types of feeding interactions) may contain changing population sizes, the same pattern of energy distribution is maintained in the system over very long periods of time.

**food web**  
all the possible feeding relations in an ecosystem

**law of conservation of matter and energy**  
matter and energy cannot be created or destroyed but can be changed to other forms



**Study tip**  
Energy flows through an ecosystem while matter is recycled.

**FIGURE 6** A simplified food web of major organisms found on Moreton Island, Queensland. (The decomposers have been omitted from the food web for the sake of simplicity.)

### CHECK YOUR LEARNING 4.1

#### Describe and explain

- Define** and give an example of a food chain.
- Explain** why simple food chains are rare in most ecosystems.
- Explain** why food chains usually do not have more than three or four trophic levels.

#### Apply, analyse and interpret

- Consider** the way energy and matter move through an ecosystem. **Determine** how they differ.
- Several large geckoes are found in Australian rainforests: for example, the banded gecko, the chameleon gecko and the leaf-tailed gecko. They feed on insects and other small animals, which

they encounter as they forage through the forest. These lizards blend into the general pattern of bark and leaves around them and are extremely difficult to observe when they are motionless. All geckoes are insectivorous, but will eat smaller lizards and sometimes frogs. They are nocturnal in habit.

- Identify** the position in the rainforest food web that a gecko would occupy.
- Discuss** abiotic requirements of these geckoes.
- Describe** an adaptation to the environment exhibited by the gecko.
- In terms of diet, **determine** whether geckoes are specialists or generalists. **Consider** the effect this would have on their survival.

#### Check your obook assess for these additional resources and more:

- |   |  |   |  |
|---|--|---|--|
| » Student book questions<br>Check your learning 4.1 | » Suggested practical<br>4.1A A simplified food chain in leaf litter | » Suggested practical<br>4.1B Measuring biomass | » Weblink<br>The Great Barrier Reef's food chain |
|---|--|---|--|



# 4.2

## Ecological pyramids

### KEY IDEAS

- + Ecological pyramids
- + Standing crop

### Graphical representation of energy flow

The flow of energy through a food chain is often depicted by a graph representing the quantity at each trophic level. At each level, energy is lost to the ecosystem through movement and heat. A similar loss in biomass (a measure of the amount of organic matter in a system) occurs when the organisms excrete matter through sweat and faeces. Each trophic level is smaller than the level before. For this reason, diagrams showing these quantitative relationships nearly always take the form of a pyramid.

### Types of ecological pyramids

There are three types of **ecological pyramids**: a **pyramid of numbers**, showing the numbers of individual organisms at each level; a **pyramid of biomass**, based on the total dry mass of the organisms at each level; and a **pyramid of energy**, showing the productivity of the different trophic levels. Productivity is measured by the amount of energy that is fixed in chemical compounds or by the increase in biomass during a particular length of time.

The shape of any particular pyramid tells a great deal about the ecosystem it represents. In a pyramid of numbers for a grassland ecosystem (Figure 1), the primary producers (usually grasses) are small, so it takes a large quantity of primary producers to support the primary consumers (herbivores).

In a food chain in which the primary producers are large (for instance, trees), one primary producer may support many herbivores (Figure 2).

A pyramid of biomass for a grassland ecosystem (Figure 3) takes the form of an upright pyramid.

#### ecological pyramid

a model of the relationships between different organisms in a food chain

#### pyramid of numbers

a model of the numbers of organisms at each trophic level of a food chain

#### pyramid of biomass

a model of the amount of living matter transferred through a food chain

#### pyramid of energy

a model of the amount of energy transferred through a food chain

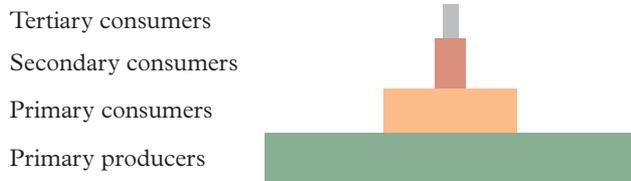


FIGURE 1 A pyramid of numbers – grassland ecosystem

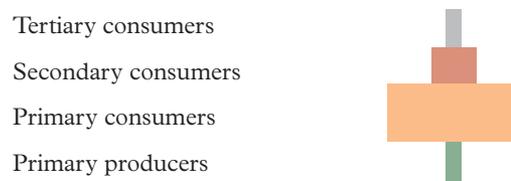


FIGURE 2 A pyramid of numbers – tree ecosystem

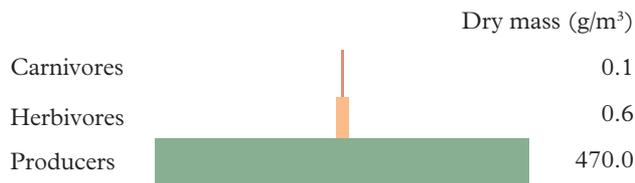


FIGURE 3 A pyramid of biomass – grassland ecosystem



FIGURE 4 A pyramid of biomass – ocean ecosystem

Inverted pyramids of biomass occur only when the producers and primary consumers are small. For example, in the ocean, the biomass of the phytoplankton is measured by the ‘standing crop’, which is the biomass at any particular moment. Because the phytoplankton are able to rapidly reproduce, their biomass in a short time period may be smaller than the biomass of the zooplankton feeding upon them (Figure 4).

**standing crop**  
biomass of an organism at any particular moment

Energy pyramids show the productivity relationships of the trophic levels. This means they are an indication of the amount of chemical energy that is stored in a set time period. Because energy cannot be created in the food chain, the amount of energy will decrease at each trophic level, generating an upright pyramid shape only (similar to Figure 3).

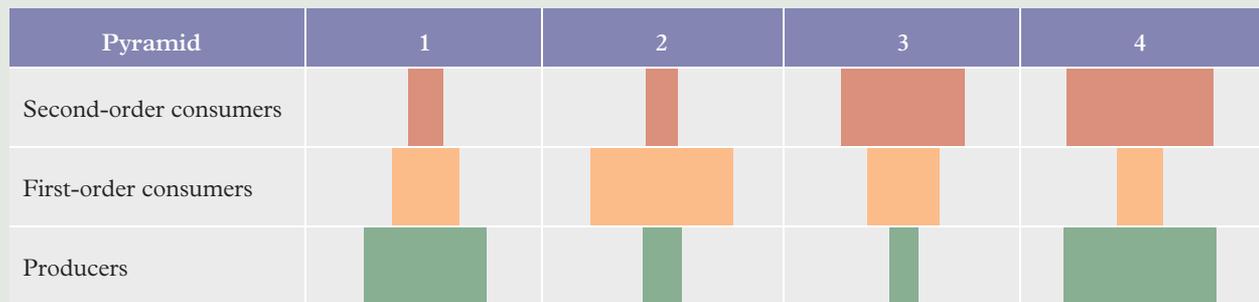
## CHECK YOUR LEARNING 4.2

### Describe and explain

- 1 **Define** the terms ‘biomass’, ‘productivity’ and ‘standing crop’.
- 2 **Describe** an ‘ecological pyramid’.
- 3 **Identify** which of the pyramids in Figure 5 would best show the relative numbers of individuals in a food chain containing:
  - a sheep, sheep ticks and grass
  - b a tree, caterpillars and insectivorous birds
  - c trees, beetles and frogs.

### Apply, analyse and interpret

- 4 If an ecological pyramid is drawn for the food chains involving a large tree as the producer, different-shaped pyramids can be obtained depending on the parameter used (e.g. number of organisms, biomass, energy flow). Giving specific examples, **interpret** why the pyramids for the same food chain may differ.



**FIGURE 5** The number of individuals of different species is often indicated by means of a pyramid of numbers diagram.

### Check your obook assess for these additional resources and more:

- |   |  |   |
|---|--|---|
| » Student book questions<br>Check your learning 4.2 | » Weblink<br>Trophic levels of coral reefs | » Weblink<br>Antarctica’s pyramid of energy |
|---|--|---|



# 4.3

## Biogeochemical cycles

### KEY IDEAS

- ✦ Elements are transferred and transformed
- ✦ The nutrient cycle
- ✦ Elements trapped in reservoir pools
- ✦ Cycling pools rapidly recycle elements

### General features

Chemical elements tend to circulate in the biosphere in characteristic paths, from the environment to organisms and back to the environment. These are known as **biogeochemical cycles** (*bio* = life; *geochemical* = the study of chemical exchanges between different parts of the Earth). There are approximately forty elements that are essential to living organisms. The pathway for a particular element between living and non-living components of an ecosystem is usually referred to as a **nutrient cycle**.

Biogeochemical cycles have two basic components: the **reservoir pool** and one or more **cycling pools**. The reservoir pool refers to a large, generally non-biological source of an element or a compound that has relatively little turnover. For example, a significant amount of carbon is pooled as fossils or in deep-sea sediments below the Earth's surface. The cycling pools are smaller, more active and are constantly exchanging their contents between the environment and organisms. Cycles in which the element is returned to the environment as rapidly as it is removed are said to be more perfect cycles.

Biogeochemical cycles are important because:

- They help retain necessary nutrients in usable forms for the living organisms of an ecosystem.
- They help to maintain a steady state (homeostasis) in ecosystems where populations do not undergo significant changes.

Many nutrient elements are washed out to sea and become part of the deep-sea sediments. Deep-sea currents and tectonic processes gradually move these sediments across the ocean floor, much of which becomes incorporated into sedimentary rock. Most of the minerals are therefore 'lost' to the ecosystem for great periods of time (millions of years), only entering the cycling pool once again when geological uplift or undersea volcanism takes place. Due to the movement of the ocean currents, some of these deep-sea sediments can be brought to the surface at particular places on Earth, where there are **upwellings** of deep waters. The surface waters of these areas, therefore, are rich in plant and animal life.

**TABLE 1** Cycling of some major macronutrients

Nutrients	Reservoir pool	Cycling pool
Water	Artesian, glacier, polar ice caps	Transpiration – evaporation – precipitation – uptake
Oxygen	Metal oxides	Photosynthesis – respiration
Carbon	Fossils, peat, coal, oil and gas, trees	Respiration – photosynthesis
Nitrogen	Deep-sea sediments	Nitrogen fixation – denitrification
Phosphorus	Phosphate rock, deep-sea sediments	Erosion – uptake – dephosphatising

#### biogeochemical cycles

circulation of chemical elements in the biosphere

#### nutrient cycle

cycling of a particular element between biotic and abiotic ecosystem components

#### reservoir pool

large abiotic component of a biogeochemical cycle in which matter is slowly exchanged with organisms

#### cycling pool

small compartment of a biogeochemical cycle with active exchange of matter between organisms and the environment

#### upwelling

upward movement of deep, cold water to replace warm surface water

## CASE STUDY 4.3

### Galapagos Islands

The marine environment surrounding the Galapagos Islands is very rich with life. This is largely due to their location at an intersection between five major ocean currents. Together with the air temperature at the equator, the ocean currents dictate the islands' climate and extensive food webs above and below the water. The largest of these currents is the Humboldt Current, which carries the cold water from the Antarctic, along the coast of South America, to the Galapagos Islands.

When ice periodically melts into the Southern Ocean, the water is cold and dense. As a result, this water sinks to the base of the Southern Ocean, sweeping up the nutrients (from dead organisms) stored as sediment on the ocean floor. These sediments (containing many essential minerals and nutrients) follow the current along the coasts of Chile and Peru, to the Galapagos Islands, where the current turns west. As a result of the upwelling, the many producers in the waters surrounding the islands are provided with a constant source of nutrition. As the seasons change, so too does the strength of the Humboldt Current. During the 'wet' season, warmer waters (from the Panama Current) arrive from the north. This current of warm water is less dense and doesn't carry as many nutrients from the ocean floor, slowing the growth of phytoplankton producers. As a consequence, the rest of the islands' food webs are affected.



**FIGURE 1** The diverse life of the Galapagos Islands

# The phosphorus cycle

Phosphorus is a rare element on Earth but is an essential nutrient needed in the formation of bones, teeth, nucleic acids (DNA and RNA) and other molecules containing phosphorus. The principal reservoir for the cycle is phosphate rock formed in past geological time. Erosion by rainfall dissolves phosphate out of the rock, forming a phosphate pool in the soil of the ecosystem. However, a large amount of phosphate escapes via run-off into streams and the sea, before it is taken up by plants.

Many plants have adapted to growing in phosphate-poor soils. Some enter into a mutualistic relationship with fungal mycorrhizae. Others are able to extract and recycle the phosphate from their leaves before they are shed. These plants tend to grow more slowly than those from more fertile soils, avoiding the need for large amounts of phosphate at any particular time. The phosphate is transferred to animals when they eat the plants. When the animals excrete waste products or die, the phosphate is transformed into another form of phosphate by phosphate-cycling bacteria, ultimately entering the dissolved phosphate pool once more.

In the past, huge colonies of seabirds have played an important role in returning a substantial amount of phosphate to the land. Their food consisted of fish and other organisms near the shore, which were rich in phosphates that had washed down from the land. The seabirds' excreta, deposited at their breeding areas on islands and on coastlines, built up over time into large deposits of soluble phosphate (**guano**), which has been mined and used as fertiliser. The rate of mining, however, far outweighs the rate of guano formation.

Human exploitation of many islands and coastal areas has disturbed a large number of the seabird breeding grounds. Modern fishing and the removal of much marine life from the area has also depleted the phosphate levels. Underwater currents and geological subsidence carry the majority of phosphate compounds to deeper marine sediments, where they may remain locked for millions of years.

**guano**  
sedimentary rock,  
rich in phosphates,  
formed from the  
build-up of seabirds'  
excreta

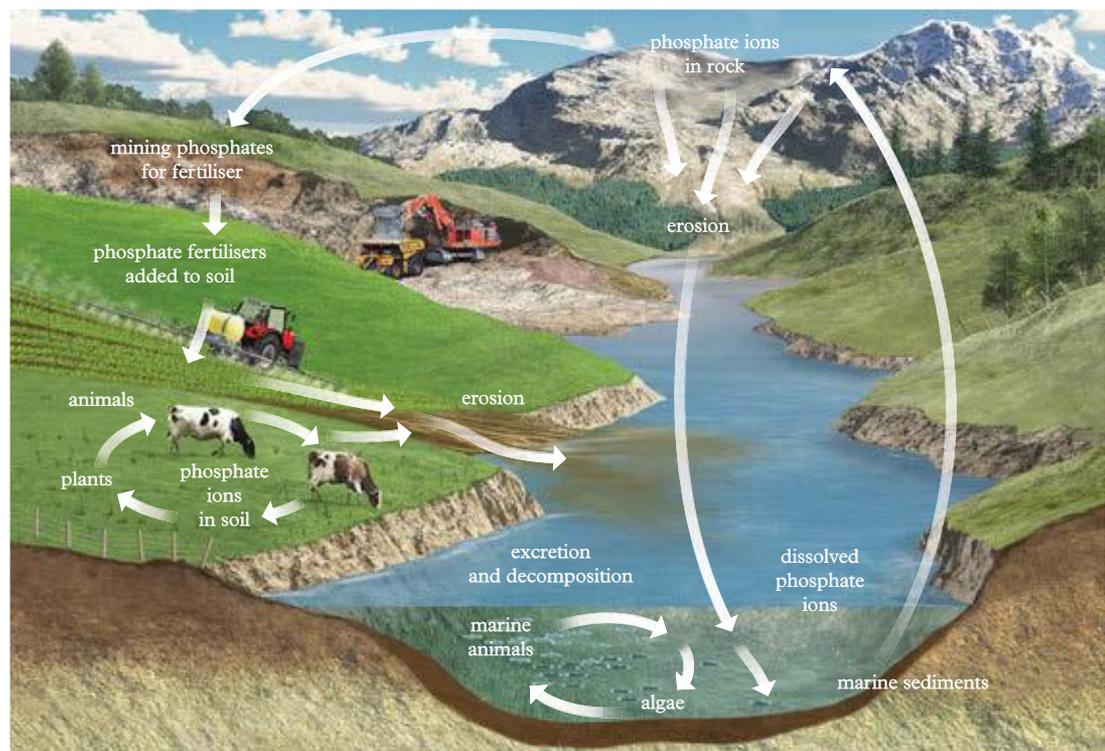


FIGURE 2 The phosphorus cycle

# The water cycle

All living things need water. It is a requirement for all cells, a solvent in which many metabolic reactions take place, a reactant in a large number of chemical reactions and a habitat for marine life. The distribution of plants and animals in terrestrial environments is therefore closely linked to the availability of water.

About 98% of the water on Earth is found in oceans, rivers, lakes and wetlands. The remainder can be found frozen as permafrost, in groundwater, incorporated in the bodies of living things and as water vapour in the atmosphere. Solar energy powers the evaporation of water from the oceans and, to a minor extent, from freshwater environments, soil and organisms (for example, transpiration from plant leaves). The water vapour is carried by air currents into the atmosphere. When it meets cool air the water vapour condenses and forms clouds of liquid water droplets or ice. When the volume of water in the clouds reaches a critical level, it falls to the ground as precipitation (rain or snow).

Most rain falls on the oceans. That which falls on land is pulled by gravity back to the sea in the form of surface run-off, streams, rivers and lakes. Some of the water soaks into the soil, percolating down until it reaches a zone of saturation, the upper levels of which form a water table. This groundwater also moves towards the oceans. Much of the water taken up by plants from the soil returns to the atmosphere during transpiration. Similarly, a very small amount of water returns to the atmosphere as it evaporates from the gas exchange surfaces of terrestrial animals. The majority of water cycles from the oceans and returns back.

On land, the amount of rainfall is determined by the prevailing wind direction, temperature (which determines evaporation rate) and topography. Mountain ranges close to continental edges force vapour-laden air to higher altitudes where clouds form. The ocean side of these ranges, therefore, have higher rainfall than the inland side. The further away from the ocean, the less rainfall will be experienced.

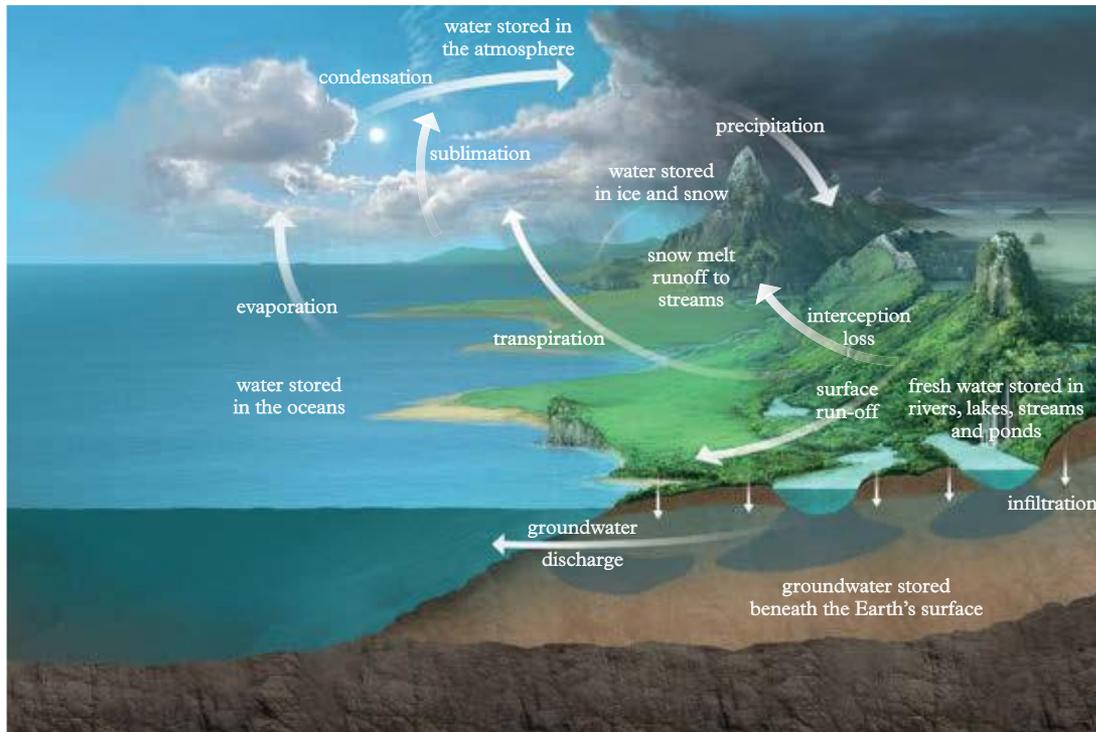


FIGURE 3 The water cycle

## Oxygen and carbon cycles

The carbon and oxygen cycles are interwoven. Photosynthesis incorporates carbon from atmospheric carbon dioxide into complex organic molecules and oxygen is released. These compounds are broken down during cellular respiration, to release carbon dioxide and water back into the atmosphere. A large amount of carbon is tied up in living matter within food chains, and organic carbon is also contained in the dead bodies of plants and animals and in excretory waste. Detrital organisms and decomposers are responsible for the final release of carbon back into the environment.

Over geological time, carbon is locked in a reservoir pool as coal and oil and in the wood of trees. As humans exploit this fossil fuel in combustion processes, carbon is returned to the cycling pool.

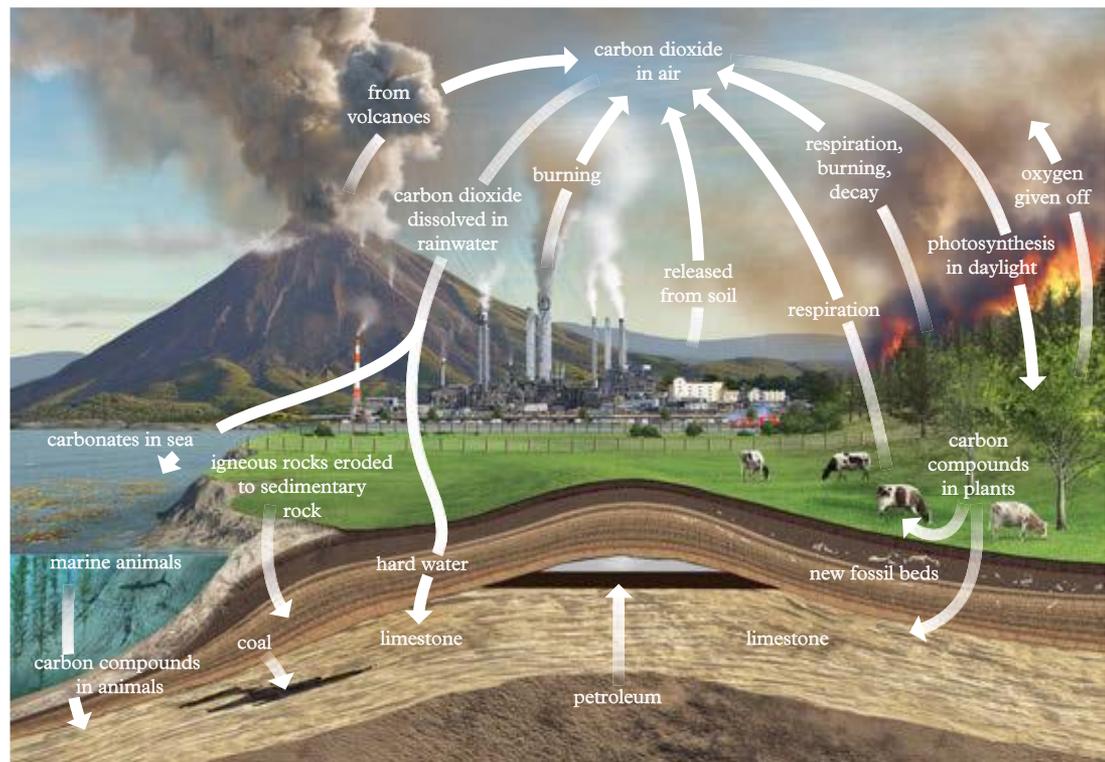


FIGURE 4 A simplified carbon cycle

## The nitrogen cycle

One of the most common gases in the atmosphere is nitrogen. This nitrogen, however, cannot be used directly by plants. As an essential component of amino acids, nitrogen limits the supply of food available in a food chain more than any other plant nutrient. **Nitrogen fixation** (conversion of atmospheric nitrogen,  $N_2$ , to soluble nitrate,  $NO_3^-$ ) is an essential process for life on Earth and is carried out by chemosynthetic microorganisms in the soil and the roots of certain plants.

The best-known nitrogen-fixing organisms are bacteria. They transform the free nitrogen gas in the soil in metabolic reactions to release nitrates ( $NO_3^-$ ), which are transferred to the plant to form proteins. The plant obtains the proteins necessary for life, while the bacteria receive protection and a supply of carbohydrates (from the plant's photosynthesis) for the synthesis of protein.

**nitrogen fixation**  
conversion of atmospheric nitrogen to nitrate by bacteria and cyanobacteria

Another important group of chemosynthetic organisms are **nitrifying bacteria**. These bacteria, such as *Nitrosomonas*, obtain energy by converting ammonia ( $\text{NH}_3$ ) to nitrite ( $\text{NO}_2$ ). Other nitrifying bacteria, *Nitrobacter*, convert nitrites to nitrates. Both forms of nitrogen can be absorbed and used by plants in the production of amino acids and proteins. These products are then available to animals as they pass from organism to organism in the food chain. The production of nitrites and nitrates releases energy, which is used by the bacteria to synthesise the organic compounds it needs.

Bacteria that remove nitrate from the soil are called **denitrifying bacteria** and tend to live in oxygen-depleted environments. By reducing nitrate to nitrite, ammonia or nitrogen, they liberate oxygen. The liberated oxygen is then utilised in aerobic respiration, and the released energy is used in the synthesis of organic compounds.

The cyclic conversion of gaseous nitrogen into nitrites and nitrates constitutes the nitrogen cycle.

**nitrifying bacteria**

bacteria that convert ammonia to nitrite and nitrite to nitrate

**denitrifying bacteria**

bacteria that convert nitrate to nitrite, or atmospheric nitrogen or nitrite to ammonia

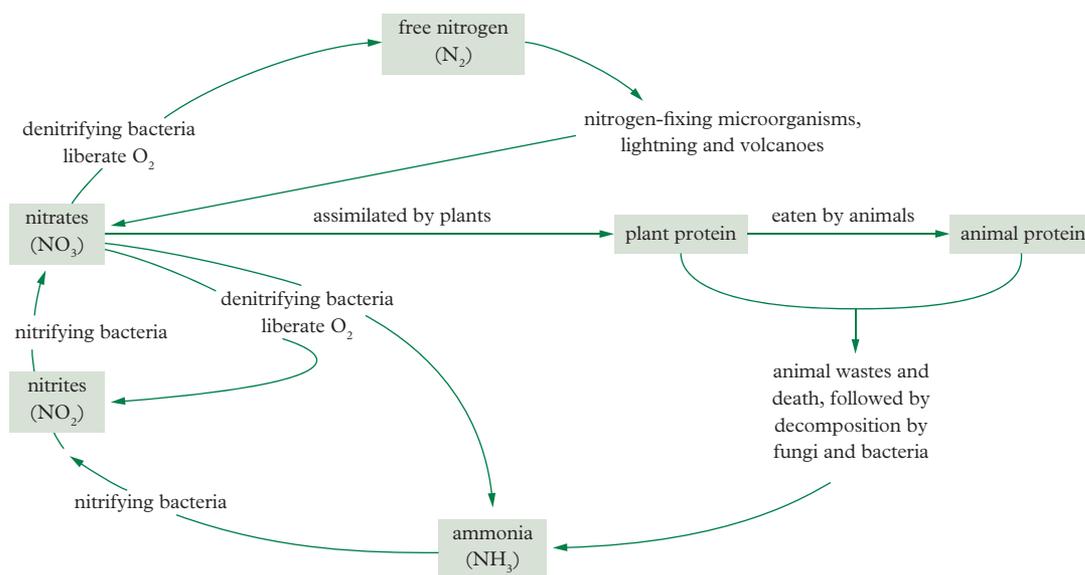


FIGURE 5 A simplified flowchart of the nitrogen cycle

**CHECK YOUR LEARNING 4.3**

**Describe and explain**

- 1 **Explain** why matter needs to be recycled in an ecosystem.
- 2 **Explain** why it is considered that the available phosphate reservoir pools of the world are being depleted.

**Apply, analyse and interpret**

- 3 Not all the carbon on Earth is being cycled continuously. **Determine** how carbon might be removed from the cycle for millions of years.
- 4 **Describe** the roles of reservoir and cycling pools using an example from one nutrient cycle.

Check your obook assess for these additional resources and more:

- » Student book questions Check your learning 4.3
- » Weblink The Humboldt Current
- » Weblink The deep carbon cycle



## 4.4

## Keystone species

## KEY IDEAS

- + Keystone species
- + Umbrella species
- + Flagship species

**keystone species**

a species that has a disproportionately large effect on its environment relative to its abundance by maintaining local biodiversity within a community either by controlling populations of other species that would otherwise dominate the community or by providing critical resources

**umbrella species**

species selected when making decisions about conservation because they are representative of other species, and protecting them indirectly protects other species in the same habitat

In some ecosystems, a particular species may be responsible for maintaining the balance of organisms. If this species is lost, it affects a number of other species in the community. Because this species holds a unique and crucial role in the way an ecosystem functions, it is called a **keystone species**.

Keystone species are often only identified after an ecosystem has been impacted. Some indicating features of a keystone species include:

- The ability to eat a variety of organisms in the ecosystem. This allows them to keep all populations under control.
- Its influence on other organisms is out of proportion to its biomass or abundance.
- The negative effects of removal of such a species (intentionally or unintentionally) from an ecosystem.

On the Great Barrier Reef, for example, the corals themselves are significant in maintaining the ecosystem as they not only form part of the food chain, but provide myriad microhabitats for other organisms through construction of their hard, skeletal structures. Parrotfish are the only fish, of thousands of reef fish, that scrape and clean off algal deposits from inshore coral reefs. If the parrot fish were removed, the coral would become overgrown with algae, affecting many of the other organisms living there. Therefore, both the coral and parrot fish could be considered keystone species for the reef ecosystem.

Some keystone species are mutualists, for example flying foxes, which are migratory, nomadic mammals that are significant in tree pollination and seed dispersal. Many forest plants are dependent on the flying fox for reproduction and spread of the species. With a more abundant supply of these fruiting trees, many other animals benefit. Flying foxes therefore drive biodiversity.

Other keystone species are carnivores. The northern quoll (*Dasyurus hallucatus*) is found across the northern part of Australia. It is an opportunistic feeder, consuming a wide range of organisms – insects, frogs, mammals, birds, reptiles and a variety of plants – and in doing so helps to maintain a balance within its habitat range. Threats to this species include cane toads (the poison of which has killed 30–40% of the population in toad-infested areas), feral cats and bushfires.

One group of keystone species can be defined as engineers because their behaviour ensures the continuance of a particular ecosystem. Earthworms are important engineers – their tunnelling activities in the soil improve soil aeration while simultaneously improving soil fertility.

In wildlife management, **umbrella species** are defined as those species that, through their conservation, protect many other species in that community, for example the bilby (*Macrotis lagotis*). Its resource requirements are similar to those of a wide range of other species in that habitat.





**FIGURE 1** Keystone species come in many forms: (a) the parrot fish eats algae on coral, (b) the flying fox pollinates flowers as pollen attaches to its facial fur, and (c) the carnivorous northern quoll controls populations.

**flagship species**  
a species chosen to raise support for biodiversity conservation in a chosen place or context

Conservation groups often use a particularly charismatic animal as a **flagship species** to drive the protection of particular habitats or for a particular environmental cause. The koala (*Phascolarctos cinereus*) and wombat (*Vombatus ursinus*) are such flagship species. Use of these species has the effect of gaining more community interest, enabling the generation of funds that can then be used in habitat conservation.

Flagship species are deliberately selected based on their human appeal. The grey nurse shark is a highly endangered species, but it is not used as a flagship species since many people fear sharks.

While a useful tool in wildlife management, there are some dangers in singling out a particular keystone, umbrella or flagship species in any ecosystem. Full knowledge of their significance is not always known. The difficulty in determining a possible keystone species can lead to mistaking the exact influence the species may have. The influence exerted by a species may be seasonal, depending on climatic conditions or migratory behaviour of other species. The distribution and abundance of these species may change with cyclic weather events and migration of other species.



**FIGURE 2** This wombat was used as the flagship species in a campaign to use recycled toilet paper and save trees.

#### CHECK YOUR LEARNING 4.4

##### Describe and explain

- 1 **Identify** an example of a keystone species that is:
  - a a mutualist
  - b an engineer
  - c a carnivore.
- 2 **Explain** why most keystone carnivores are generalist feeders.

##### Apply, analyse and interpret

- 3 **Distinguish** between a keystone and a flagship species.
- 4 **Consider** difficulties that might arise when attempting to identify a keystone species in a particular ecosystem.

#### Check your obook assess for these additional resources and more:

- |                          |                               |                               |
|--------------------------|-------------------------------|-------------------------------|
| » Student book questions | » Weblink<br>Umbrella species | » Weblink<br>Keystone species |
| Check your learning 4.4  |                               |                               |

# Review

## Chapter summary

- 4.1**
  - The majority of energy in ecosystems is generated from the sun.
  - Energy flows through food chains.
  - Solar energy is fixed as biomass in photosynthesis and is a measure of productivity.
  - Photosynthetic efficiency is the fraction of sunlight plants convert into organic molecules during photosynthesis.
  - Productivity is a measure of how much organic matter is generated at each trophic level in an ecosystem. It can be a gross measurement (the amount of energy captured) or net (the energy that is stored as cells and tissue).
  - Producers use photosynthesis or chemosynthesis to generate organic molecules.
  - Consumers gain their energy by eating other organisms.
  - Decomposers and detritivores gain energy through consuming the detritus.
  - The number of trophic levels in a food chain is limited.
  - Matter is recycled.
  - Food webs are a diagrammatic representation of interlinking food chains.
- 4.2**
  - Ecological pyramids represent organism numbers, biomass and energy at trophic levels.
  - Standing crop is the amount of biomass available at a point in time.
- 4.3**
  - Elements are transferred and transformed between the biosphere and geosphere.
  - The nutrient cycle is the pathway a particular element travels between the living and non-living components in an ecosystem.
  - Elements can become trapped in reservoir pools for millions of years.
  - Cycling pools rapidly recycle elements through the living and non-living components of an ecosystem.
- 4.4**
  - Keystone species are important in maintaining the balance of an ecosystem.
  - Umbrella species ensure the protection of a wide range of other species.
  - Flagship species can be used to promote conservation and wildlife management.

## Key terms

- |                         |  |                             |                      |
|-------------------------|--|-----------------------------|----------------------|
| • biogeochemical cycles | • flagship species                         | • net primary production    | • pyramid of energy  |
| • biomass               | • food chain                               | • nitrifying bacteria       | • pyramid of numbers |
| • consumer              | • food web                                 | • nitrogen fixation         | • reservoir pool     |
| • cycling pool          | • generalist feeder                        | • nutrient cycle            | • specialist feeder  |
| • decomposer            | • gross primary production                 | • photosynthetic efficiency | • standing crop      |
| • denitrifying bacteria | • guano                                    | • productivity              | • trophic level      |
| • detritivore           | • keystone species                         | • pyramid of biomass        | • umbrella species   |
| • detritus              | • law of conservation of matter and energy |                             | • upwelling          |
| • ecological pyramid    |  |                             |                      |

## Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: ★ = low; ★★ = medium; ★★★ = high.

### Multiple choice

- Decomposers are considered to be important within an ecosystem because:
  - large quantities of dead plant and animal matter would not otherwise be consumed
  - the dead plant and animal matter would otherwise harbour dangerous decay organisms
  - they release nutrients, otherwise locked up in the dead matter, for the use of producers
  - the food web of the community is a dynamic, continuously changing system
- Gross primary production refers to:
  - the amount of food available for carnivores in a food chain
  - the rate at which solar energy is converted into chemical energy by autotrophs
  - the amount of energy available to an organism for growth
  - the amount of energy passed on to herbivores by producers
- A study of an estuary showed that after a storm, large quantities of eelgrass were washed up along the shore line. With the aid of microorganisms, the eelgrass became broken down into small pieces and was consumed by beach worms. These worms were eaten by small fish, such as whiting, which in turn were eaten by large fish. Which of the following organisms has the greatest biomass?
  - Eelgrass
  - Beach worms
  - Small fish
  - Large fish
- The standing crop of oceanic phytoplankton can be smaller than the biomass of zooplankton since:
  - phytoplankton are larger than zooplankton
  - the growth rate of phytoplankton is greater than that of zooplankton
  - there are few zooplankton compared with phytoplankton
  - zooplankton feed on a variety of organisms, including phytoplankton
- A nutrient cycle describes:
  - the pathway of a particular element between living and non-living parts of the ecosystem
  - the study of chemical exchanges between different parts of the substrate
  - how an organism utilises a particular element
  - the pathway of a particular element in a food chain
- Which of the following is a significant feature of a nutrient cycling pool?
  - The formation of coal and oil from fossil organisms
  - Evaporation and transpiration
  - Underwater currents and geological settling
  - Nitrifying bacteria reducing nitrates to nitrites to release oxygen

### Short answer

#### Describe and explain

- ★ **Explain** why simple food chains are rare, and how food webs provide greater stability in ecosystems.
- ★ **Describe** the roles of reservoir and cycling pools using an example from one nutrient cycle.
- ★ **Explain** the meaning of an 'engineer' when related to keystone species.
- ★★ **10** Some species in an ecosystem are 'specialists' and some are 'generalists'. **Define** these two terms and explain which of the two types has greater survival potential.

#### Apply, analyse and interpret

- ★★ **11** Caves are frequently inhabited by bats, which go out at night to feed on flying insects and live inside the cave during the day, clinging to the rocky walls. On these cave walls are

generally found small blood-sucking flies and bat bugs, which suck the blood of bats. The droppings of bats accumulate on the cave floor and form a suitable medium for certain fungi, particularly moulds. These moulds provide food for the cave crickets, which themselves are eaten by other insects, spiders and scorpions. These 'other insects' may also fall victim to the spiders.

- a **Construct** a food web to show the relationships that exist in such a cave community.
- b **Determine** what constitutes the boundary of such a community.

\*\*\* 12 *Frankia* are bacteria that can provide nitrogen to a plant. Trees in a forest plantation were treated in three different ways. The results are shown in Figure 1.

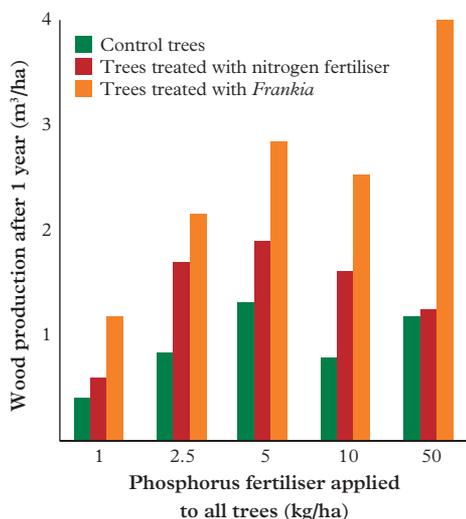


FIGURE 1 Response of forest trees to phosphorus, nitrogen and *Frankia*

- a **Distinguish** the experimental conditions of the 'control' trees from those of the other trees.
- b **Explain** the rationale for the treatment of the 'control' trees.
- c Using supporting evidence from the graph, **generate** a conclusion from these results.

\*\*\* 13 In an experiment investigating the rate of disappearance of leaf litter, uniform discs were cut from leaves, placed in nylon mesh bags and

buried in newly cultivated pasture. The table shows the disappearance of the leaf discs from bags made from 7 mm and 0.5 mm mesh from June of one year to April of the next.

TABLE 1 Leaf disc disappearances from June to April

Month	Percentage (%) of leaf area remaining in bags of mesh size:	
	7 mm	0.5 mm
June	100	100
August	81	94
October	30	91
December	13	66
February	9	62
April	6	60

- a **Construct** a graph (on graph paper) of the data.
- b **Describe** the effect of mesh size on the rate of disappearance of leaf litter between June and October. **Determine** causes for this.
- c **Explain** the variation in the rate of disappearance of litter from the 0.5 mm mesh bags during the period of the experiment.

#### Investigate, evaluate and communicate

- \*\* 14 Herbivores have generally been considered to have a negative impact on their plant prey. However, a controlled study of a natural community provides evidence to the contrary. The crustacean herbivore *Daphnia pulex* was fed on planktonic algae, and it was shown that the *Daphnia* had a stimulatory effect on the algal populations that approximately balanced its impact on algal mortality. **Predict**, with justification, mechanisms for the *Daphnia*-induced stimulation of algal growth.
- \*\* 15 Phytoplankton are the autotrophs of the ocean surfaces. In addition to being the major oxygen supply for Earth, many small animal plankton (zooplankton) feed on them. These two groups of organisms are the basis for most oceanic food webs. The biggest of all animals, the blue whale, depends entirely on plankton found in Antarctic seas and seals, penguins and other birds feed on

small fish that eat the zooplankton. In recent years, krill (zooplankton) oil has become a popular remedy for arthritis and the krill themselves have become an important food for commercially reared prawns. Japanese and Russian ships are harvesting millions of tonnes of krill from these cold southern waters.

**Predict**, with reasons, the possible effects of this unnatural predation on stocks of krill on Antarctic ecosystems.

★★★ 16 For several decades after the Second World War, giant tritons (*Charonia tritonis*) were avidly removed from the Great Barrier Reef by shell collectors. This large, carnivorous mollusc is one of the few animals known to feed on the crown-of-thorns starfish (*Acanthaster planci*), which in turn feeds on coral polyps. By the 1960s the numbers of crown-of-thorns starfish had increased to such an extent that large sections of the reef were becoming bleached due to the death of the polyps. At that time, it was considered that the giant triton was a keystone species for the reef, maintaining the crown-of-thorns starfish populations at low, non-destructive levels. Further research indicated that the triton had never been common and so had little impact on the crown-of-thorns starfish. In 2017, however, a breeding program for the giant triton was established for the purpose of releasing these molluscs onto the reef to control the crown-of-thorns starfish.

**Investigate** the possible causes for crown-of-thorns outbreaks. To what extent can you **determine** the impact of decreasing triton

numbers on increases in crown-of-thorns populations? **Evaluate** the basis on which the triton breeding program for reef restoration is justified.

Write a fully justified response to whether or not the giant triton can be considered a keystone species for the Great Barrier Reef.



FIGURE 2 Giant triton feeding on crown-of-thorns starfish

★★★ 17 **Design** an experiment to test whether the amount of leaf litter that accumulates in water-filled hollows depends on their depth. If the experiment showed a correlation between depth of hollow and amount of leaf litter, discuss the implications for the development of leaf litter food webs.



FIGURE 3 A typical food chain for eucalypt woodland detritus

Check your **obook assess** for these additional resources and more:

» Student book questions  
Chapter 4 review

» Revision notes  
Chapter 4

» **obook assess** quiz  
Chapter 4  
auto-correcting  
multiple-choice quiz

» Flashcard glossary  
Chapter 4 glossary



# POPULATIONS

A population refers to the members of the same species occupying a given area at the same time. Populations of all species have some common characteristics related to environmental factors. These factors determine where the populations are found, how they increase in number and the total number of individuals. Growth of a population can be either density-dependent or density-independent. Competition for resources and predator–prey relationships are significant in limiting population growth for some species. To cope with these and other factors, different species use different population growth strategies.

## OBJECTIVES

- Define the term *carrying capacity*.
- Explain why the carrying capacity of a population is determined by limiting factors (biotic and abiotic).
- Calculate population growth rate and change (using birth, death, immigration and emigration data).
- Analyse population growth data to determine the mode (exponential growth J-curve, logistic growth S-curve) of population growth.
- Discuss the effect of changes within population-limiting factors on the carrying capacity of the ecosystem.
- Describe the classification system for methods of reproduction (*asexual, sexual – K and r selection*).
- Define *ecological niche* in terms of habitat, feeding relationships and interactions with other species.
- Understand the competitive exclusion principle.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

FIGURE 1 A population of emus on a beach in Western Australia

## PRACTICALS



SUGGESTED  
PRACTICAL

**5.1** Plant distribution and abundance using quadrants



SUGGESTED  
PRACTICAL

**5.4A** Competitive exclusion in *Paramecium*



SUGGESTED  
PRACTICAL

**5.4B** Relationship between predator and prey



SUGGESTED  
PRACTICAL

**5.5** Population study of yeast

# 5.1

## Distribution and abundance

### KEY IDEAS

- + The distribution of organisms
- + The abundance of a species
- + Biotic and abiotic factors in an ecosystem

### population

number of individuals of a species living in a particular place at a particular time

### distribution

regions in which a species is found

### abundance

number (of a species) in a specific area at any time

### population density

number of an individual species living in a particular place at a particular time per unit area

### random distribution

an unpredictable spacing of individuals; where the position of each individual of a species is independent of the other individuals of the species in a given environment

### evenly spaced distribution

a distribution where individuals are more or less equally spaced throughout the entire area

### clumping

distribution where individuals are found clustered in groups in particular parts of the habitat

A **population** refers to the members of the same species occupying a given area at the same time. Each species has specific environmental requirements and so will only be found in particular places. If all of these requirements fall within the optimal range, the numbers of individuals will be high. The numbers of individuals may also increase if several of the requirements are within the species tolerance range rather than the optimum range.

## Distribution of populations

**Distribution** refers to the region in which one or more members of the species may be found; **abundance** refers to the numbers of each species in that region at that time. In any particular locality, abundance can be referred to as **population density** – the number of individuals per unit area. Both distribution and abundance are affected by the biotic and abiotic factors in an ecosystem.

The individuals of a population may be distributed at random, evenly spaced or clumped in some way.

### Random distribution

**Random distributions** are found only in uniform surroundings where the abiotic and biotic factors do not vary significantly across the ecosystem. Such distributions usually occur only for a short time while the widely spread resources are greater than the demand. For example, weed seeds blown by wind over a bare fertile soil will produce a random distribution of seedlings if the soil surface is even.

### Even spacing

**Evenly spaced distributions** are also fairly rare in nature and usually result from intense competition for space. Seeds from trees in a forest need to compete for sunlight, water and soil nutrients. Any available space on the forest floor will be populated by saplings competing for resources. Over time, one sapling will dominate, clearing the surrounding area of any competing plants. In some mature forests the large trees may have an almost uniform distribution (spaced at regular intervals) because of competition for sunlight and soil nutrients.

In contrast, some animals need to compete for mates, resulting in territorial behaviour. This may play a significant role in even distribution across the ecosystem.

### Clumping

**Clumping** is by far the most common pattern of distribution of plants and animals in nature, for the following reasons:

- Environmental conditions are seldom uniform throughout, even in a small area.
- Reproductive patterns frequently favour clumping (e.g. young animals often stay with their parents).

- Animals often exhibit behaviour patterns that lead to active congregation in loose groups, schools, flocks and herds.

A clumped distribution may increase competition for nutrients, food, space or light. Trees growing together may compete more for nutrients and light than they would if they were spread apart; however, they may also be better able to withstand strong winds. For some animals (e.g. the hyena), hunting in a pack makes it possible to bring down large prey, which a single individual cannot do alone. Once the prey is killed, the solitary hyena must compete with other scavengers for food.

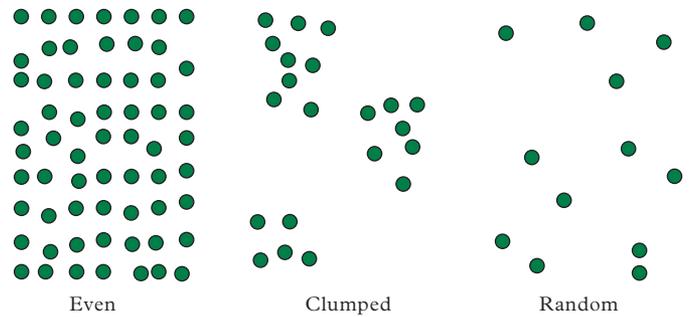


FIGURE 1 The three distribution patterns seen in nature.

## Population density

Population density is one way of measuring the abundance of an organism. It is a measure of the number of organisms in a population found in a predetermined area of an ecosystem. This can be determined by dividing the population by the size of the area.

$$\text{Population density} = \frac{\text{population size}}{\text{size of the area}}$$

For example, an ecosystem that is 100 m × 100 m was found to have 15 possums living within its boundaries. This means the population density is 15 possums for every 10 000 m<sup>2</sup>.

The population density of these possums (or any other species) can be related to the features of the environment, including the accessibility of habitats, possible competition and predators, or the chemical elements present (Figure 2).

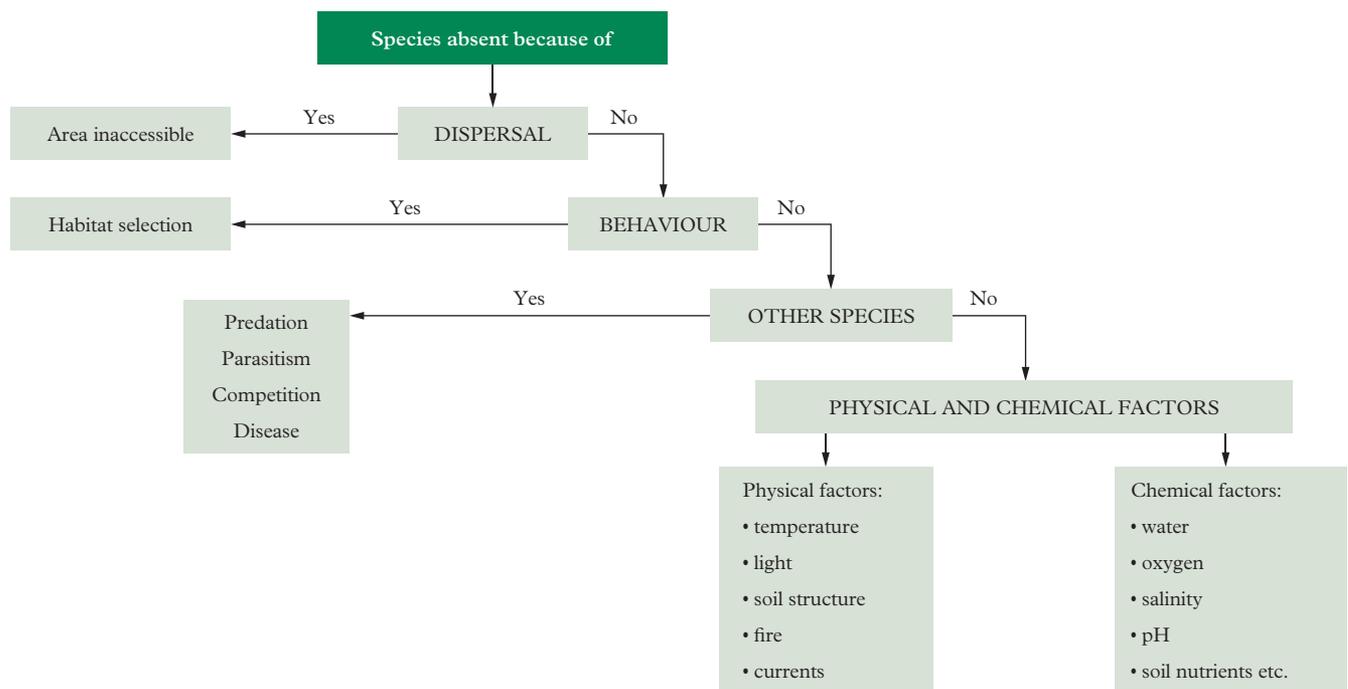


FIGURE 2 The distribution of an organism depends on both biotic and abiotic factors.

## CASE STUDY 5.1

### Possum and glider distribution in the Eden (NSW) forest

A study by CSIRO scientists revealed a patchy distribution of eight species of possums and gliders in forests near Eden in New South Wales. They found that 63% of the possums and gliders were found in only 9% of the forest area studied; none were found in 52% of the area.

Further investigation showed that there was a close correlation between the distribution of these animals and that of peppermint eucalypts. Analysis of the nutrient levels of various trees showed that the peppermint eucalypts were rich in nutrients, particularly potassium, nitrogen and phosphorus. These trees, as distinct from other species in the forest, had wide tree trunk bases, were found in areas that had not been subjected to recent fire, and grew only in fertile soils. This meant that the distribution of both the trees and the arboreal mammals was related to the underlying rock types, which produced high-nutrient soils.



FIGURE 3 Gliding possums in NSW are often referred to as just gliders.

## CHECK YOUR LEARNING 5.1

### Describe and explain

- 1 **Explain** how distribution and abundance of a species are measures that reflect the environmental conditions in which it is found.
- 2 Distribution of a species may be random, evenly spaced or clumped. **Describe** each of these conditions and provide a possible reason for the distribution.

### Investigate, evaluate and communicate

- 3 **Examine** the 10 m × 10 m plot shown in Figure 4.
  - a For each of the three plants illustrated in the figure, **determine** (giving reasons):
    - i type of distribution
    - ii population density.
  - b **Summarise** abiotic differences that might account for the distribution patterns.
  - c **Identify** the dominant plant.
  - d **Determine** a name for this community.

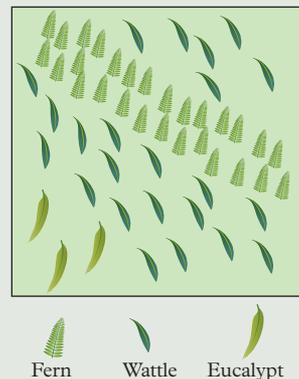


FIGURE 4 Distribution of different Australian plants



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|--------------------------|--|-------------------------------|
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|--------------------------|--|-------------------------------|

# 5.2

## Population growth

### KEY IDEAS

- + Rate of change in population size
- + Density-independent factors
- + Environmental limiting factors and environmental resistance

### Change in population size

Population size can vary significantly from time to time, particularly in animal species. For example, there are periodic mouse plagues on the Darling Downs in Queensland. Not only do they lead to devastation of crops, they also cause considerable damage as the mice infest homes. Numbers can also decline rapidly: the mouse population may be massive in April but may be insignificant in July.

The size of a population depends on the rates of birth, death, immigration and emigration. If the number of deaths or emigration out of a population increases, the size of the population will decrease. In contrast, if the number of offspring born (births) increases, or a large number of organisms immigrate into an area, the population will increase.

### Population growth rate

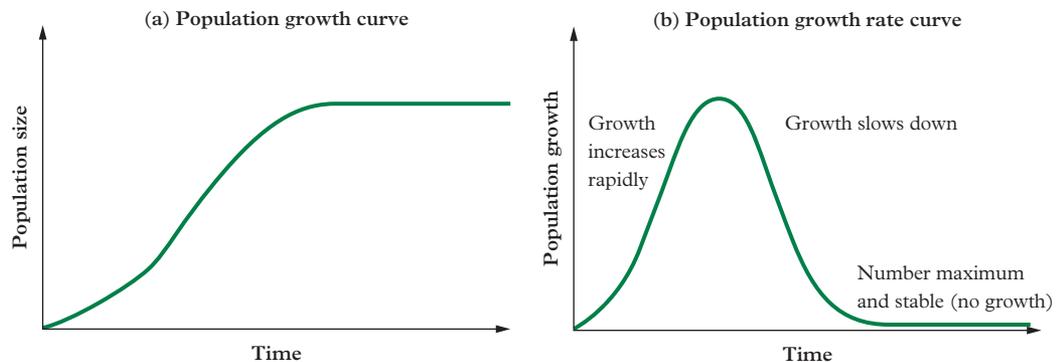
The speed that a population changes is called the **population growth rate**. This is different to the **population growth**, which calculates the number of organisms in a population at identified times. The rate of a population's increase or decrease is a measure of how fast the change in population is occurring ( $r$ ). It can be calculated by:

$$r = (b + i) - (d + e)$$

where  $b$  = number of births,  $i$  = number of immigrants,  $d$  = number of deaths and  $e$  = number of emigrants.

The graphs in Figure 1 show the relationship between population growth (actual numbers in the population) and population growth rate (change in numbers in the population).

Each population has specific limiting factors that influence its growth. The range of tolerance to light, temperature, available water, salinity, nesting space and required nutrients differs from species to species. Regardless of other factors, if any essential requirement is in short supply for a particular species, or an environmental feature is too extreme, the population cannot increase. It will either remain the same size or decrease.



**FIGURE 1** Comparison of (a) the growth curve and (b) the growth rate curve for the same population. Graph (b) reflects the gradient of graph (a).

**population growth rate**  
the rate of change in a population over a particular range of time

**population growth**  
increase in the size of a population in a particular habitat over time

## Density-independent factors

Birth rates and death rates may vary regardless of population density. The density of a population is, in this case, independent of the size of a population. A small population may be spread over a very large area and have a low density. Alternatively, it may be limited to a very small area, causing the organisms to be crowded together in a high-density environment. Both of these environments (high density or low density) present their own challenges to the survival of an organism. Factors that affect a population regardless of their density are termed **density-independent factors**.

### density-independent factor

an abiotic factor (that is independent of the density of the population) that affects the size of a population

## Tolerance of abiotic factors

All organisms have a range of factors that can affect their survival. The availability of water or nutrients, or the temperature of the ecosystem, must be in the optimal range for the organism in order for it to survive and reproduce. If an abiotic condition is outside the tolerance range (see Chapter 3) of an organism, then the organism will die, increasing the mortality of a population. For example, a high temperature that is outside an organism's tolerance range will cause the organism to die. This will occur whether the organism lives in a high-density environment or a low-density environment. The **limiting factor** of temperature will restrict the size of a population independent of the density of a population. Other population-independent limiting factors include the availability of water, nutrients, sunlight, pH, salinity and humidity.

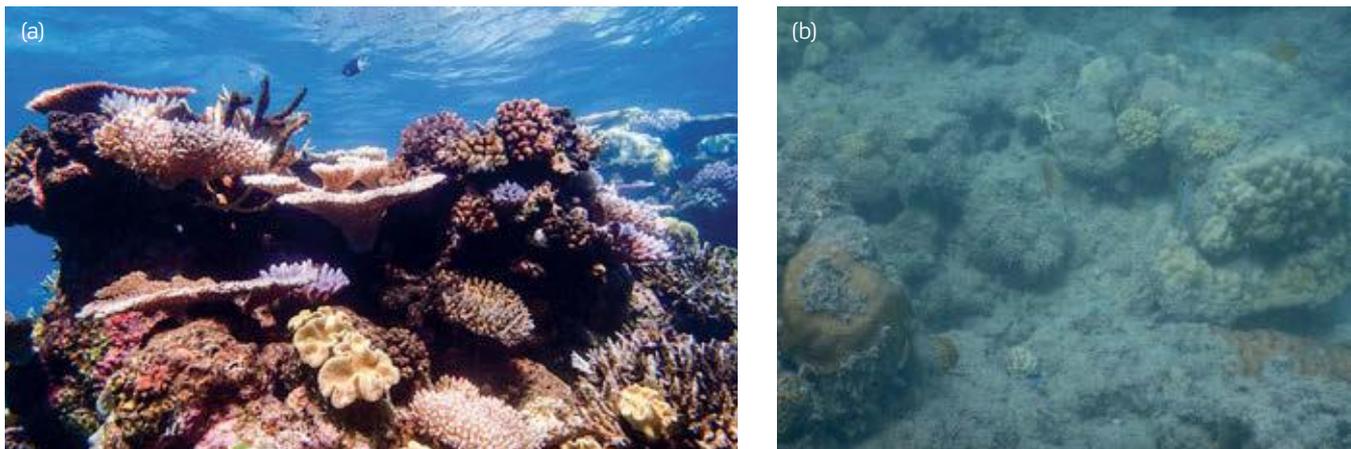
### limiting factors

conditions that limit the growth, abundance or distribution of an organism or a population of organisms

## Environmental disasters

Many density-independent factors are associated with environmental changes. In some cases, these changes are natural, such as the sudden flooding of an area, or destruction from volcanic eruptions. Although flooding may appear to have a negative effect on an ecosystem (as it does in many examples), it can also have positive effects. Floodwater can wash out excess salt or chemicals from the soil or from rivers, and may also clear debris. This enables fish and birds to breed, increasing the birth rate of the population. The floodwaters will also soak into the soil, increasing the amount of groundwater. This can provide a long-term water supply to plants in the ecosystem. Many ecosystems are dependent on regular floodwaters to maintain their communities.

Other environmental disasters are a result of extreme climatic events. Drought, cyclones, fires and enhanced climate change are all examples of events that will affect the size of a population, independent of the density of the population.



**FIGURE 2** The Great Barrier Reef was heavily affected by the Yasi cyclone in 2011. Here is the reef before (a) and after (b) the environmental disaster.

## Pollution

High-density human populations can also affect the population of other organisms, independent of the organism's density. For example, clearance of the ecosystem or the release of chemicals into the ecosystem can have a detrimental effect on the population of marine organisms, independent of the density of the marine population.



FIGURE 3 A protest against pollution in Brisbane.

### CHECK YOUR LEARNING 5.2

#### Describe and explain

- 1 Many organisms undergo a periodic population explosion followed by a dramatic decline in numbers. **Identify** three density-independent factors that contribute to both the increase and the decrease in numbers.
- 2 **Describe** the difference between population growth and population growth rate.

#### Apply, analyse and interpret

- 3 **Identify** the four factors that determine population size for a species.

- 4 **a** At the beginning of a year, a population contained 2000 individuals. During the year 1700 individuals died, 240 migrated out of the area, 601 moved in and 870 were born. **Determine** the overall change that occurred.  
**b Deduce** the overall rate of change during the year.
- 5 **Investigate** another environmental disaster that has had an effect on land near you. **Consider** how this might have changed the biodiversity in your selected area.

#### Check your obook assess for these additional resources and more:

- |   |  |                                      |
|---|--|--------------------------------------|
| » Student book questions<br>Check your learning 5.2 | » Increase your knowledge<br>Density-dependent and density-independent worksheet | » Weblink<br>Environmental disasters |
|---|--|--------------------------------------|

# 5.3

## Population growth strategies

### KEY IDEAS

- + Population growth patterns
- + *r*-strategists are opportunists
- + *K*-strategists have fewer offspring

Many species have evolved reproductive strategies to maximise their chances of dominating an ecosystem. This can be illustrated by the rate of their population growth.

### *r*-strategists

#### *r*-strategist

a species that occupies unstable environments and uses the evolutionary strategy of maintaining a high growth rate, occupying less-crowded ecological niches, and producing many offspring

Some species, the ***r*-strategists**, have an ability to produce large numbers of offspring (often asexually) with little parental investment. This is important to those species that live in unstable environments where predation may be high. By flooding the habitat with offspring, regardless of mortality or predation, at least some of the progeny will survive to reproduce. Their population growth is typically 'boom' and 'bust'. The bust phase of the curve is primarily due to density-independent limitations. These organisms are generally small, mature rapidly and are short-lived. Examples of *r*-strategists include bacteria, grasses, corals, insects and small mammals such as rodents.

### *K*-strategists

#### *K*-strategist

a species whose population fluctuates at or near the carrying capacity (*K*) of the environment in which it resides

Other species, the ***K*-strategists**, tend to live in more stable environments and their population densities are as high as the ecosystem will allow. Their population is often affected by the overall density of the species (density-dependent). These organisms have a long life expectancy, produce few offspring in which they invest extensive parental care, and have the ability to compete successfully for limited resources. Although they are generally large (e.g. elephant), some long-lived, small species such as Arctic terns are *K*-strategists.



**FIGURE 1** In *r*-strategists, many offspring are born at each breeding period and the offspring mature at a very young age.



**FIGURE 2** Elephants have a long gestation period, which usually results in a single offspring to which high parental care is given over a long period of time.

**TABLE 1** General characteristics of *r*- and *K*-strategists

<i>r</i> -strategists	<i>K</i> -strategists
Short-lived	Long-lived
Tend to be small in size	Tend to be large in size
Fast maturation	Slow maturation
Reproduce at an early age	Reproduce at a late age
Produce many offspring	Produce few offspring at a time
Little care of offspring	Extensive parental care
Not strongly competitive for resources	Strongly competitive for resources

## Modifications of *r*- and *K*-strategies

Many organisms adopt an intermediate strategy between these two extremes. Trees, for example, are large and long-lived, and are strongly competitive for resources – *K* attributes. They tend, however, to produce a large number of seeds that are dispersed away from the parent plant, which is an *r* trait.



**FIGURE 3** A grass tree is a plant with both *K* and *r* attributes.

Some organisms can even alternate between the two strategies depending on the local conditions at any one time, in order to give them the best chance of survival under a broad range of conditions. **Biofilms**, for example, are colonies of prokaryote, algae or protozoa enclosed in a matrix that adheres to surfaces. Prokaryote biofilms are large and grow slowly compared with other prokaryote colonies (i.e. weeks rather than minutes). By producing a fluid matrix around their cells, the biofilm can resist predation and chemical attack. New colonies are formed when fragments break off and attach to a new surface away from the main colony. Since many biofilms are composed of more than one type of prokaryote, the waste products of one species (which could accumulate and inhibit their growth) are often the substrate for another species. In all of these features, the biofilm is a *K*-strategist.

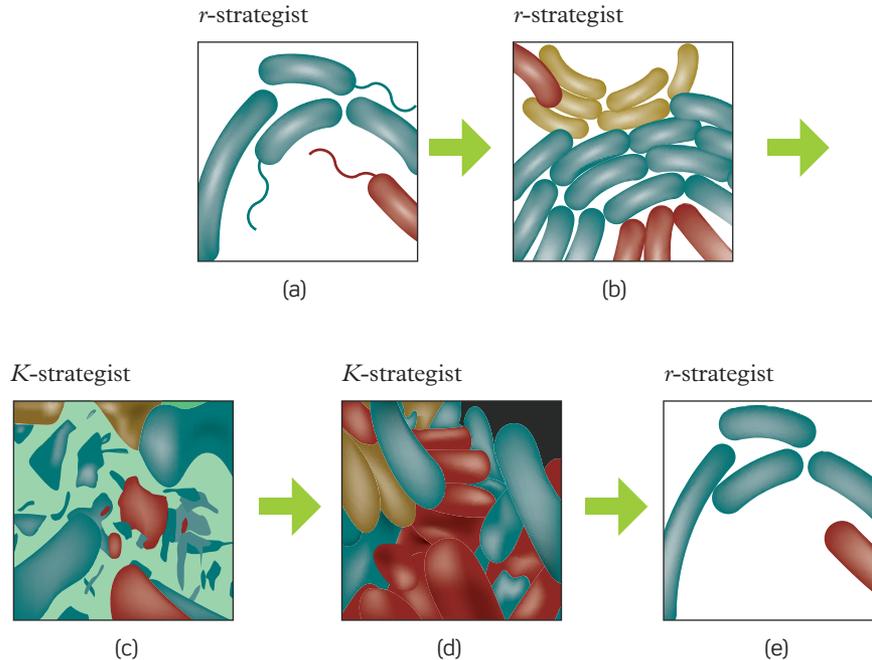
When these biofilms receive an influx of particular nutrients, certain cells in the matrix become mobile. They modify their protein production to no longer produce pili that hold the cells in position, and instead each prokaryote forms a whip-like flagellum. These mobile cells are released from the matrix and reproduce exponentially at the maximum rate possible in that environment. Although the chances of any one cell finding a suitable surface on which

### **biofilm**

a layer on a solid matrix composed of microscopic bacteria, algae and protozoa in a complex polymer-linked assemblage

to establish a new biofilm is small, the numbers of cells are enormous. This motile form is a typical *r*-strategist.

When a large quantity of nutrients is available, the biofilm cells maximise the opportunity for dispersal and establish new biofilms as *r*-strategists. When more stable environmental conditions prevail, they become *K*-strategists.



**FIGURE 4** Biofilms are formed by (a) the attachment of motile prokaryotes to a surface. (b) They undergo exponential growth as an *r*-strategist, losing their flagellum in the process. (c) On maturation, growth slows down and the prokaryotes act as *K*-strategists. They also secrete a slimy extra-cellular matrix of proteins and polysaccharides that protects the biofilm from many chemicals, including antibodies and antibiotics. (d) When particular nutrients are available, some cells become motile and detach from the surface of the biofilm. (e) These cells attach to a new surface and again become *r*-strategists.

### CHECK YOUR LEARNING 5.3

#### Describe and explain

- Distinguish** between an *r*-strategist and a *K*-strategist.
- Describe** the formation of a biofilm.
- Identify** whether each of the following are *r*- or *K*-strategists.
 

a rabbit	c whale
b cat	d clown fish

#### Apply, analyse and interpret

- Using the *r*- and *K*- categories, **determine** how you would classify a human.
- Determine** the advantage to an organism of being able to alternate between *r*- and *K*- modes of population growth.



Check your obook assess for these additional resources and more:

» Student book questions

Check your learning 5.3

» Weblink /K-strategists

» Weblink Biofilms

# 5.4

## Density-dependent factors

### KEY IDEAS

- + Density of a population
- + Competition is a density-dependent factor
- + Organisms in similar niches need to diversify
- + The size of a predator population
- + Increased predator numbers
- + The prevalence of disease or parasites

### density-dependent factor

any factor influencing population regulation that has a greater impact as the density increases

### competition

rivalry between individuals, of the same or different species, for specific resource(s)

### competitive exclusion principle

two species are unable to compete for the resources in the same niche

### niche

a species' role and position in its environment; a species' interactions with the biotic and abiotic factors of its environment

### character displacement

the evolutionary divergence of characteristics displayed by two or more species with the same niche in a particular habitat

### resource partitioning

division of environmental resources by coexisting species populations to avoid competition for resources

As a population grows it may deplete its food supply, leading to increased competition for food among the members. Factors that affect population growth as the number of individuals increases are termed **density-dependent factors**.

Limiting factors are the factors (abiotic or biotic) that can restrict the size of an organism's population. This may be the availability of water, food supply, sunlight or mates. When these factors are limited it results in increased competition between members of the population.

## Competition

**Competition** is one of the chief density-dependent limiting factors of population size.

The continued healthy existence of most organisms depends upon abiotic factors such as food, water, space or light. As the population density increases, the competition for these resources becomes more intense and, as a result, can limit population growth and lead to increased mortality or decreased birth rates.

The **competitive exclusion principle** states that two species cannot simultaneously occupy the same **niche** in the same place for very long. This principle has been supported by both laboratory and field studies. The niche of a species is an expression of its total environment and way of life in the community. A niche is defined by its:

- abiotic limitations
- amount of food and other resources
- inhabitants' behavioural patterns.

If two species occupy the same niche in the same habitat, one of them is more likely to be more competitively superior. The inferior competitor is eliminated. The different species might move to separate habitat patches (spatial separation) of the same environment or may be more prevalent at different times (temporal separation) of the day or during different seasons. One species of bird may eat ground insects, while the other would eat insects on the trunk of the tree. These variations would enable both bird species to survive because they have different niches. This is the competitive exclusion principle.

Often one or both species may evolve to occupy different niches, minimising competition between the species. Divergence in those characteristics that overlap is known as **character displacement**. This may lead to the species dividing the resources in a niche to avoid competition (**resource partitioning**). For example, the restless flycatcher (*Myiagra inquieta*) hovers a metre or so above the ground, emitting a grinding call that disturbs insects. It then suddenly becomes silent as it pounces on an insect, which it takes back to a perch to eat. The leaden flycatcher (*Myiagra rubecula*) takes insects from the leaves of trees or chases and captures flying insects. Thus, the two species, whose requirements are otherwise similar, are able to live together in the same woodlands and open forests along the east coast of Australia.

## Predation

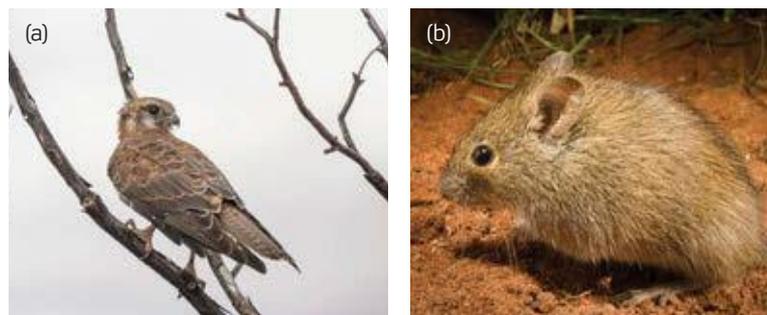
Density-dependent factors increase the mortality rate of a population. A high density of a particular population may also attract predators to the area. For example, a large number of rabbits in a particular area will be of interest to foxes, dingos, wild dogs and predatory birds. These predators will be attracted to the easily accessible food supply. Often the increase in food will encourage the birth rate of the predator population, causing further stress on the prey population. This can start a cyclic pattern of an increasing predatory population causing a decrease in the prey population. The decreasing number of prey causes the predators to start competing against each other for food, which results in a decrease in their population. When the predator population decreases, the prey population will decrease its mortality, allowing the cycle to start again.

An example of this cycle is the relationship between populations of desert mice (*Pseudomys desertor*) and brown hawks (*Falco berigora*). The population size of desert mice is normally limited by the scarce supply of food (grass seed, etc.) and by the brown hawk, which preys upon it. At cyclic intervals the desert is supported by monsoonal rain carried by channels. The increased water supply leads to rapid growth of plants, allowing the mouse population to increase dramatically. The sudden abundance of mice can result in the immigration of hawks or owls from surrounding areas and greater survival of their chicks. This increases the mortality of the mice, decreasing the mouse population. The predator hawk and owl populations can no longer be sustained by the decreased food supply and so they must either emigrate from the area or starve. Removal of the predation pressure allows the mouse population to return to the norm for the environmental conditions, until another influx of water to the area results in another large increase in population size and sets off the cycle again.

Usually the predator–prey relationship is not as simple as the example given, since few organisms rely on a single source of food. A decrease in one source of food for the predator is often offset by an increase in another. Similarly, it has been shown that in natural situations

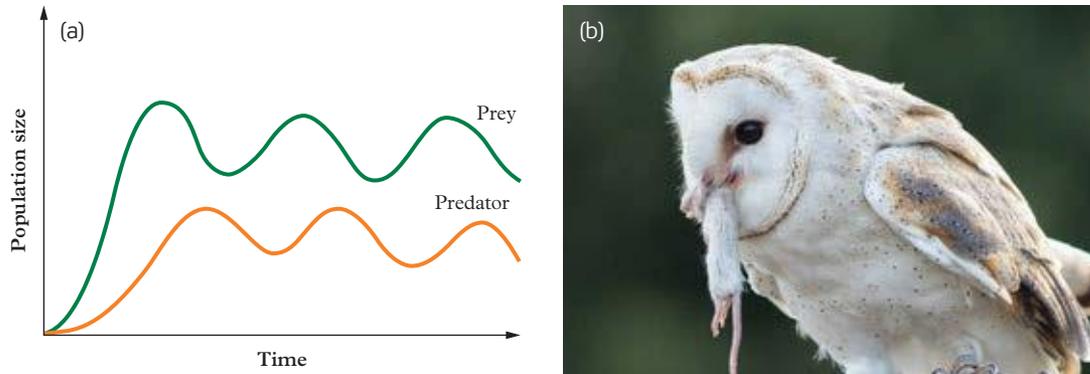


**FIGURE 1** (a) The restless flycatcher (*Myiagra inquieta*) and (b) leaden flycatcher (*M. rubecula*) have overcome the problem of very similar niches by resource partitioning.



**FIGURE 2** (a) Brown hawk (*Falco bengora*) and (b) desert mouse (*Pseudomys desertor*)

predation may alter the age structure of the population because young, diseased or aged members are more easily captured. It has been argued that sudden declines in numbers may be associated more with the stress of overcrowding (which may result in a decreased reproductive rate), or with a time lag in response to density-dependent factors, than solely as a result of predation.



**FIGURE 3** Graphing predator–prey relationships indicates that an increase in prey populations is followed by an increase in predator populations. Note: The number of prey will always be greater than the number of predators.

## Infection

High-density populations are also vulnerable to the spread of infection. Crowded conditions can result in simple infections being easily spread through contact, food supply or water. Although not all infections cause death, an increase in sickness can cause a decrease in the birth rate of a population. The rapid spread of an infection with high mortality will result in a decrease the size of a species' population.

### CHECK YOUR LEARNING 5.4

#### Describe and explain

- 1 **Define** the following terms.
  - a Niche
  - b Competitive exclusion
  - c Resource partitioning
  - d Character displacement
- 2 Many organisms undergo a periodic population explosion followed by a dramatic decline in numbers. **Identify** factors that contribute to both the increase and the decrease in numbers.

- 3 **Explain** why predators are not considered to be the main contributors to the maintenance of a stable population size of their prey.

#### Apply, analyse and interpret

- 4 Many species living in the same area appear to have the same resource requirements. **Determine** how they can coexist in this community.

#### Check your [obook assess](#) for these additional resources and more:

- |   |   |   |
|---|---|---|
| » Student book questions<br>Check your learning 5.4 | » Suggested practical 5.4A Competitive exclusion in <i>Paramecium</i> | » Suggested practical 5.4B Relationship between predator and prey |
|---|---|---|

# 5.5

## Carrying capacity

### KEY IDEAS

- ✦ Environmental limiting factors
- ✦ The ability of a population to increase under optimum conditions
- ✦ The carrying capacity of an ecosystem
- ✦ The J-shaped curve
- ✦ Population equilibrium and an S-shaped curve

**environmental limiting factor**  
any factor that limits the growth of a population

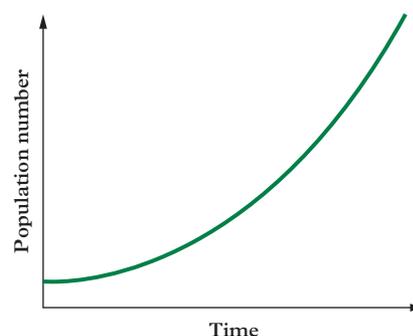
**biotic potential**  
number of offspring capable of being produced by individuals of a species

**carrying capacity**  
the total population able to be supported by a particular environment

**environmental resistance**  
sum total of all environmental limiting factors

**J-shaped population curve**  
the graphical representation of the change in population density of an organism as it increases rapidly and then stops suddenly, due to environmental or other factors

If a population does not have any limiting factors, then the population will start to increase. At first a new, small, active population grows slowly. This is due to the difficulty of individual organisms finding a mate. Since there are few individuals in a suitable environment, resources will be plentiful, and predators, parasites and disease will be few. Those factors that would normally inhibit population growth – **environmental limiting factors** – will be non-existent, and as a consequence the death rate will be very low. Over time, the population will increase, slowly at first, and then at an increasing rate. This is described as an exponential growth of the population. This is because the new members of the population contribute their powers of reproduction as well as adding to the numbers by their own presence. The species then realises its full reproductive **biotic potential** (the ability of a population to increase under optimum environmental conditions). If this were to continue indefinitely, the population would continue to rise without limit, as shown in Figure 1.



**FIGURE 1** Exponential growth of a population. After an initial slow phase, the population grows at a constant rate.

## Carrying capacity

Each environment has a particular **carrying capacity** for a population – the size of the population that can be supported indefinitely on the available resources of that ecosystem. For example, the house fly (*Musca domestica*) can produce seven generations in one year. Each female can lay 120 eggs. On the assumption that each fly lives only one generation, and that half the eggs hatch into females, a total of 5 598 720 000 000 flies (over 5 quadrillion) can be produced in 1 year from one original pair of flies. This is prevented by **environmental resistance** (the sum total of all environmental limiting factors) such as lack of resources; increase in predators, parasites and disease; accumulation of toxic wastes; or other factors such as overcrowding. As a result, the population of the house fly will be restricted to the carrying capacity of the environment in which it lives.

There are two possible outcomes for the initial unrestricted growth of the house fly population. The species may continue with rapid population growth until either they are above the carrying capacity of the environment, some climatic factor dramatically reduces the population, or most migrate. This results in a **J-shaped curve** – a ‘boom and bust’ situation (Figure 2). In nature, short-term growth patterns of this type are characteristic of opportunistic species, such as weeds or insects, which invade an area, rapidly use up the local resources and then either enter a phase of dormancy, die out or move on.

An alternative possibility for some species is the increasing density of the population smoothly slows down the rate of growth as environmental resistance increases, and the carrying capacity is reached. The results are reflected in the formation of an **S-shaped population curve**.

For animals, the carrying capacity may be determined by factors such as available shelter or nest sites, while for plants access to sunlight might be the limiting factor. This type of growth pattern is typical of density-dependent species (Figure 3).

There is usually a time lag before the organisms respond to environmental resistance. This may be due to individual growth rates, or by the gap of a generation before the reproduction rate decreases. As a result, the population growth curve fluctuates around the carrying capacity. Figure 4 shows this pattern.

**S-shaped population curve**

the graphical representation of the change in population density of an organism when it initially increases slowly and then rapidly as it approaches an exponential growth rate, but then decreases and levels off as the environmental carrying capacity is reached

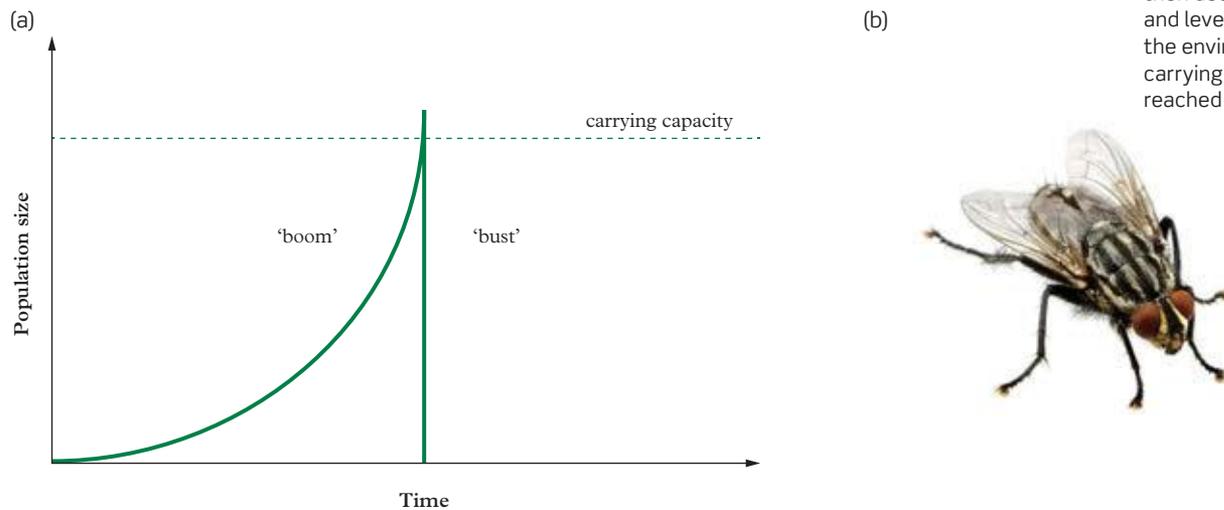


FIGURE 2 A population growth curve of the house fly (density-independent) (a) and a typical house fly (b).

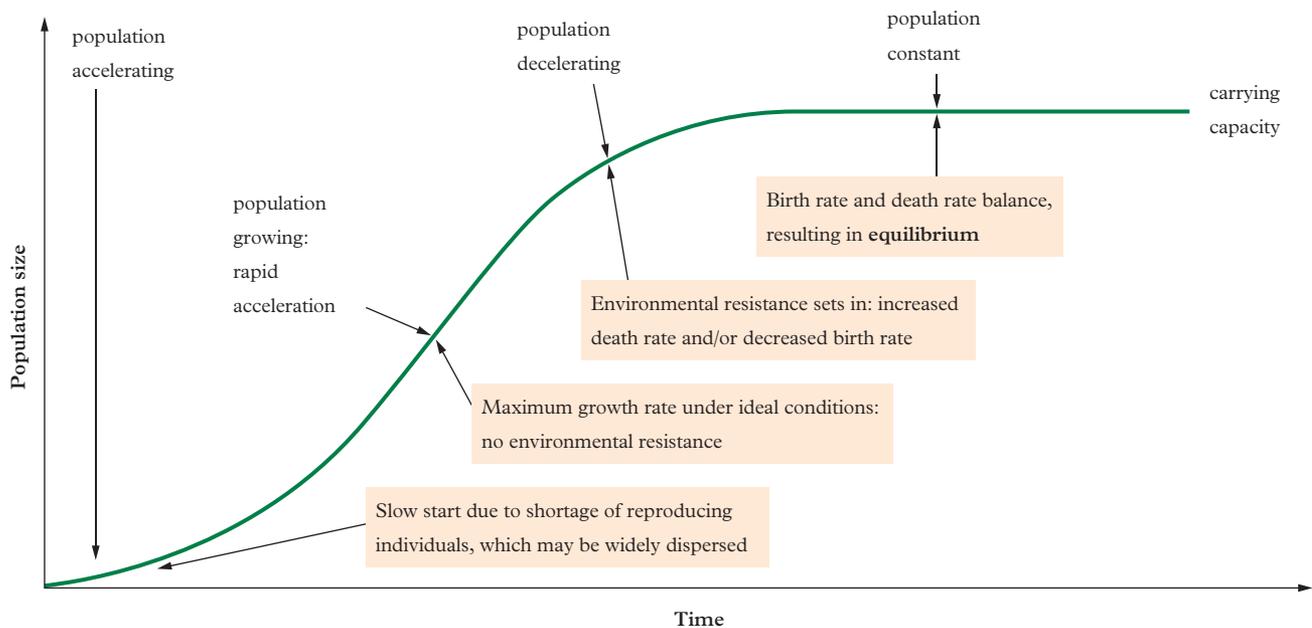
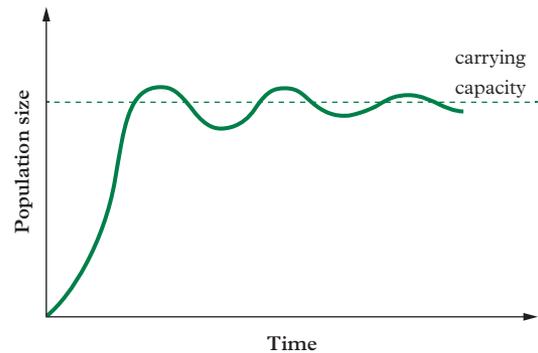


FIGURE 3 Generalised graph of density-dependent population growth resulting in an S-shaped curve

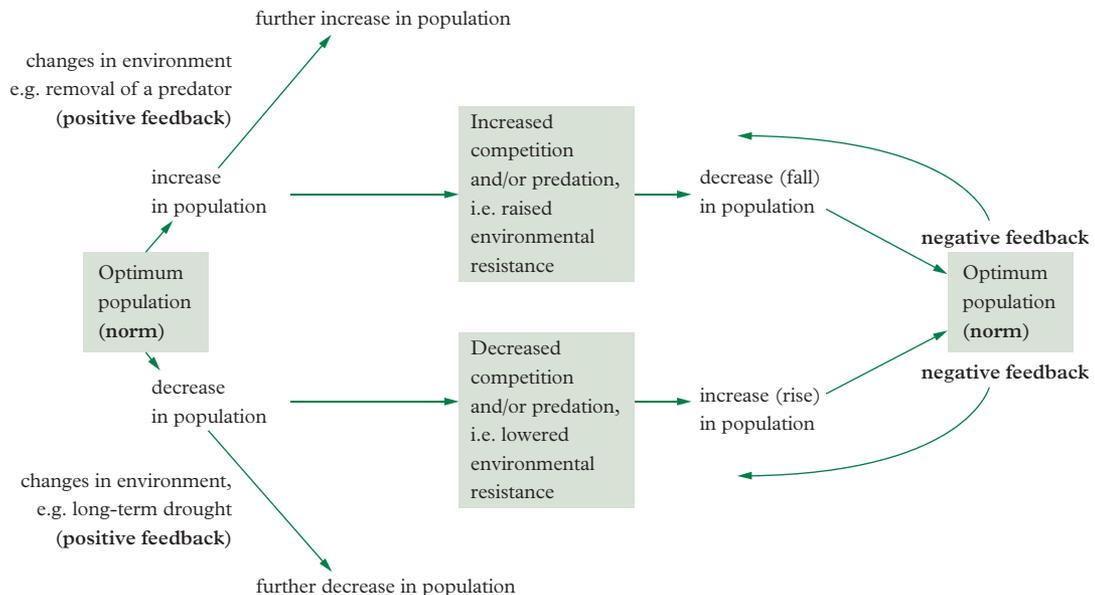
# Homeostatic control of population size

For a given species in a particular environmental situation there will be a certain optimum population that the environment can support. This is the **equilibrium** or set point. If the population rises above the equilibrium point, competition, predation or increased disease takes place to such an extent that the population falls. If it falls below the equilibrium point, environmental resistance is relieved temporarily and the population again rises. This means the population will tend to fluctuate around a set point, as shown in Figure 4. This is an example of **ecological homeostasis**.



**FIGURE 4** Typical response of a density-dependent population at carrying capacity

An increase or decrease in population sets into motion reverse processes (negative feedback), which keep the population at the carrying capacity of the environment. Occasionally the environmental conditions can change. As a result, the carrying capacity changes to reflect the environmental conditions during any period. A long-term drought, for example, will bring about progressively more and more deaths in a population, which will continue until the drought is broken. This is a form of positive feedback, in which the changed conditions result in a progressive change in the carrying capacity of an ecosystem.



**FIGURE 5** Homeostatic control of population growth ('norm' may be interpreted as 'equilibrium')

Seasonal changes can alter, for example, the nutrients available for a period of time. This could either increase or decrease the population depending on the circumstances. Since different populations in a community are interdependent, any change in one population has a flow-on effect on other populations. The sum of population-limiting factors of all populations in a community will therefore affect the carrying-capacity of their ecosystem.

## equilibrium (set point)

point at which a system can be maintained, e.g. population size for a specific environment

## ecological homeostasis

maintenance of a population size commensurate with environmental limiting factors, mediated by feedback systems



**FIGURE 6** The world's human population grows by more than 1% each year.

### CHECK YOUR LEARNING 5.5

#### Describe and explain

- 1 **Identify** resources (both biotic and abiotic) that would act as environmental resistance. Which of these resources could be classified as density-independent?
- 2 **Define** the following terms.
  - a Ecological homeostasis
  - b Environmental resistance
- 3 **Explain** why the carrying capacity of an ecosystem is influenced by population-limiting factors.
- 4 **Describe** the shape of the curve of population growth for a *K*-strategist.

#### Apply, analyse and interpret

- 5 **Determine** whether each of the following statements is true or false. If it is false, rewrite it as a correct statement.
  - a Clumped spacing of members of a population is more common than uniform or random spacing.
  - b A population with more offspring per generation will always have a faster growth rate ( $r$ ) than a similar population with fewer offspring per generation.
  - c Predation usually acts as a density-independent limiting factor on populations.
- 6 **Compare** a J-shaped and an S-shaped population growth curve.

#### Check your obook assess for these additional resources and more:

- |   |  |                                     |                                |
|---|--|-------------------------------------|--------------------------------|
| » Student book questions<br>Check your learning 5.5 | » Suggested practical<br>5.5 Population study of yeast | » Weblink<br>Ecological homeostasis | » Weblink<br>Carrying capacity |
|---|--|-------------------------------------|--------------------------------|



# Review

## Chapter summary

- 5.1**
  - The distribution of organisms can be random, evenly spaced or clumped.
  - The abundance of a species can be described by the population density.
  - Many biotic and abiotic factors affect the abundance and distribution of an organism in an ecosystem.
- 5.2**
  - The rate of change in population size can be calculated.
  - Density-independent factors are the abiotic conditions in an ecosystem that can limit the growth of a population.
  - Environmental limiting factors and environmental resistance limit population size.
- 5.3**
  - Different species have different population growth patterns.
  - *r*-strategists are opportunists with high reproduction and dispersal rates.
  - *K*-strategist have fewer offspring that require more care.
- 5.4**
  - Some factors that affect a population are dependent on the density of a population.
  - Competition is a density-dependent factor that affects the size of a population.
  - The competitive exclusion principle states that two species cannot simultaneously occupy the same niche in the same place for very long.
  - Organisms in similar niches need to diversify to prevent density-dependent inter-species competition.
  - The size of a predator population is dependent on the density of their prey.
  - Increased predator numbers can limit the population of their prey.
  - The prevalence of disease or parasites can affect the size of a population.
- 5.5**
  - Environmental limiting factors are factors that would inhibit the growth of a population. The sum of these factors is the environmental resistance.
  - The ability of a population to increase under optimum conditions is its biotic potential.
  - The carrying capacity is the size of a population that can be supported indefinitely on the available resources and services of that ecosystem.
  - Unlimited growth of a population forms a J-shaped curve.
  - Most introduced species will reach a population equilibrium (as represented by an S-shaped graph). This equilibrium is maintained by ecological homeostasis.

## Key terms

- abundance
- biofilm
- biotic potential
- carrying capacity
- character displacement
- clumping
- competition
- competitive exclusion principle
- density-dependent factors
- density-independent factors
- distribution
- ecological homeostasis
- environmental limiting factors
- environmental resistance
- equilibrium (set point)

- evenly spaced distribution
- J-shaped population curve
- *K*-strategist
- limiting factor
- niche
- population density
- population growth
- population growth rate
- random distribution
- resource partitioning
- *r*-strategist
- S-shaped population curve

## Key formulas

Population density

$$\text{population density} = \frac{\text{population size}}{\text{size of the area}}$$

Population growth rate

$$r = (b + i) - (d + e)$$

## Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: ★ = low; ★★ = medium; ★★★ = high.

### Multiple choice

- A population is made up of:
  - all individuals of any species
  - groups of individuals of any species in an area
  - all groups of organisms in an area at a given time
  - individuals of the same species in an area at a given time
- The highest rate of reproduction of a population under ideal conditions is called the:
  - biotic potential
  - environmental resistance
  - carrying capacity
  - birth rate
- A particular country has negligible immigration and emigration. In 2017 its population size increased from 50 million to 51 million. If the birth rate was 30 individuals per thousand, then the death rate (per thousand) in 2017 was:
  - 10
  - 20
  - 30
  - 40
- The capture–recapture method of measuring a population would be most likely be used for measuring the population of:
  - wedge-tailed eagles
  - soil bacteria
  - Eucalyptus maculata*
  - dairy cattle
- If two male and eighteen female wallabies are introduced onto a brush and grass covered island where there are no natural enemies or other large animals, what will happen in future years?
  - The wallaby population will remain at 20.
  - The wallaby population will get smaller.
  - The wallabies will die from diseases.
  - The population will continue to rise until there is little grass left.
- There has been an exponential growth in the world-wide human population over the past 1000 years. The main reason for the rapid increase in numbers is:

- A** the dramatic reduction in the death rate during the past 1000 years
  - B** the high reproductive potential of humans
  - C** the ability of humans to alter their environment
  - D** none of the above could be considered a major reason for the increase
- 7 An organism is small in size and has a short life span. It is fast maturing and produces many offspring at a young age. The young stay with the mother for only a short period of time. It is likely that this organism is:
- A** a *K*-strategist
  - B** an *r*-strategist
  - C** initially an *r*-strategist and becomes a *K*-strategist at maturity
  - D** intermediate between an *r*- and *K*-strategist

### Short answer

#### Describe and explain

- ★ **8 Define** the term carrying capacity of an environment.
- ★ **9 Describe** how limiting factors determine the carrying capacity of an environment.

#### Apply, analyse and interpret

- ★★ **10** Feathertail gliders are adapted to live in tall, well-watered eucalypt forests. They are normally active at night throughout the year, moving swiftly along branches and leaping through the uppermost foliage. When temperatures become too cold they go into torpor (i.e. lower their metabolic rate



FIGURE 1 A feathertail glider

and become inactive) but can only sustain this condition for up to 48 hours. They are predominantly insectivorous in habit and have a wide range of predators (e.g. owls, snakes, native cats). They are communal animals living in groups of about 16 in nests of dried, overlapping eucalyptus leaves in hollow trees or old nests of other animals.

- a Identify** one density-dependent factor and one density-independent factor that affects the population size of the feathertail glider.
  - b** Using the example, **distinguish** between the terms distribution and abundance.
- ★★ **11** It is extremely difficult to accurately determine the population density of some organisms, but an estimate can be calculated. One method used with small animals is that of capture–recapture. The animals are caught, marked and released. On subsequent occasions, more animals are caught and the numbers of marked versus unmarked animals are compared. The density can then be calculated.
- Deduce** a formula that could give an estimated population *density* using the capture–recapture method.

#### Investigate, evaluate and communicate

- ★★★ **12** A knowledge of population growth curves can help in controlling pests as well as in the conservation of endangered species.
  - a Discuss** the most effective time to control a rat outbreak in a racing stables complex. **Justify** your answer.
  - b** A minimum viable population is the size of a population below which numbers of a species must not fall if the species is to survive in the long term. How would you estimate the minimum viable population size necessary to save an endangered species such as the ghost bat (*Macroderma gigas*), the bilby (*Macrotis lagotis*) or the dusky hopping mouse (*Notomys fuscus*)? **Explore** and **evaluate** the requirements of the species you select.

★★★ 13 In a study of competition among frogs, a zoologist manipulated the numbers of frogs in several isolated farm dams. Fifteen almost identical dams without any frogs were stocked with tadpoles at five different densities (three dams for each density) in the early spring. In this area, rainfall is predominantly over spring–summer. The number of adult frogs in each dam is determined by sampling on three successive years. The mean adult abundance for each treatment is given in the table below.

Initial stocking density in each dam	Mean adult abundance for each stocking density		
	2016	2017	2018
10	8	0	0
20	30	30	80
40	60	40	100
80	60	80	100
160	20	30	60

- a Discuss** these results in the context of intraspecific competition and a variable environment.
- b Investigate** other experiments that could be conducted to explore the possibility that resources are limiting.



FIGURE 2 A striped marsh frog

★★★ 14 The data below was collected as a result of concerns over the numbers of kangaroos in particular areas and the possibility of overgrazing.

- a** On the basis of this data, which area is in most need of culling? **Justify** your answer from calculations of the data.
- b Evaluate** other factors that could influence your decision.

Location/number at beginning of year	Area (ha) and condition	Migrants		Births	Deaths		
		In	Out		Dingoes	Licensed shooters	Disease, starvation, roads
Simpson Desert / 7318	23 000 ha – drought declared	1274	4392	346	84	746	329
Rervan area / 279	450 ha – pasture available	427	32	192	22	0	47

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Chapter 5 review

» Revision notes  
Chapter 5

» obook assess quiz  
Chapter 5 auto-correcting multiple-choice quiz

» Flashcard glossary  
Chapter 5 glossary



# Changes in ecosystems

Ecosystems are dynamic entities that experience both short-term and long-term changes. Long-term changes usually result from succession, with a pioneer community altering the environment in such a way as to make it progressively unsuitable for themselves but suitable for other species until a relatively stable climax community is achieved. This succession can be primary, from bare ground, or secondary when an existing community is destroyed. Fossil records can be used to determine past ecosystems and changes in biotic and abiotic conditions over time. Human activity has a large impact on biodiversity and is a prime driver in changes to ecosystems.

## OBJECTIVES

- Explain the concept of ecological succession (refer to pioneer and climax communities and seres).
- Differentiate between the two main modes of succession: primary and secondary.
- Identify the features of pioneer species (ability to fixate nitrogen, tolerance to extreme conditions, rapid germination of seeds, ability to photosynthesise) that make them effective colonisers.
- Analyse data from the fossil record to observe past ecosystems and changes in biotic and abiotic components.
- Analyse ecological data to predict temporal and spatial successional changes.
- Predict the impact of human activity on the reduction of biodiversity and on the magnitude, duration and speed of ecosystem change.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

**FIGURE 1** Deforestation and new plantations have a substantial effect on ecosystems.

# PRACTICALS



MANDATORY  
PRACTICAL

## 6.4 Appraisal of an ecological surveying technique



# 6.1

## Interactions between natural ecosystems

### KEY IDEAS

- ✦ Ecosystems undergo dynamic change
- ✦ Ecosystems interact with each other

The number and types of organisms that make up the community in an ecosystem are constantly changing. These changes may be over the short term or the long term. Some plants will grow and reproduce with the seasons, responding either to rainfall patterns and/or to temperature. This results in changes to the number and types of species that are present at different times of the year.

### Seasonal changes

Temperature changes affect land plants and animals more than water organisms. This is because the air temperature changes faster than the water temperature – it takes more energy to change the temperature of water than air. For example, the daytime temperature of central Australia is usually over 20 degrees warmer during the day than overnight. At the coast of Queensland, the temperature will usually only vary by 10 degrees. Temperatures also change from season to season. Many animals respond to seasonal temperature changes (and the accompanying changes in plant life) by migrating to new areas. Some of these animals will travel large distances using celestial clues (sun or stars) or the Earth's magnetic field.

Other animals respond to changes in climate and food availability by going into a state of torpor. Torpor is a short-term involuntary lowering of the body temperature and metabolic rate, which may last a few hours or a few days. The lower body temperature means the animal does not need to expend as much energy to stay warm and decreases the need for

nutrients and oxygen. The length of time that this state can be maintained varies from organism to organism. Other animals will voluntarily enter a state of hibernation where their 'sleep-state' is much deeper and lasts longer. It can last for several days, weeks or months, with the animal only rousing briefly to eat, drink or defecate before returning to the low energy state. For a hibernating animal, waking completely can take several hours and use most of the animal's energy. In contrast, an animal waking from a state of torpor can do so within an hour, using much less energy.

Some animals go into aestivation in very dry conditions. Like hibernation and torpor, aestivation is a period of inactivity and lowered metabolic rate that reduces heat production. As a result, the animal is able to stay cool and prevent water loss. For example, the water-holding frog (*Cyclorana platycephala*) of Central Australia digs a deep subterranean burrow where it lies bloated with water contained in subcutaneous lymph sacs and an extended bladder. It remains in this burrow until such time as adequate rain falls – sometimes for years.



**FIGURE 1** The water-holding frog as it is dug from its burrow

# Boundaries between ecosystems

The boundaries between ecosystems are rarely precise; they usually merge into each other. A mangrove ecosystem, for example, forms a buffer between an estuary and the land, with species from both areas interacting in this buffer zone.

## CASE STUDY 6.1

### The mangrove ecosystem

**Mangrove** is the name applied either to an individual species or to a whole community of plants. These plants grow together in habitats along tropical and subtropical coasts where there are quiet tidal waters, areas of silt around the mouths of rivers, or swampy areas inundated by tides. All areas are protected from strong wave action and currents.

The plants occupy the areas between the low and high tide levels, rarely extending beyond the limit of high tide as they rely on water for seed dispersal. Their roots and trunk bases are covered by sea water at high tide, and at low tide the roots are subjected to rain and freshwater seepage. A number of plant families are found in these habitats. Each species is found in fairly well-defined zones according to the ability of its roots and trunk to withstand one or more of the following factors:

- salt water
- the degree of submersion
- the frequency of submersion
- the soil conditions.

Soils in this zone are poorly drained, saline, anoxic and usually consist of fine-grained sediments. They are poorly consolidated and can range from coarse shell fragments through sands to clayey muds. The soils are rich in organic materials that originate from the deposition of plant debris from the mangroves. This organic debris is broken down by microorganisms such as bacteria, moulds and cyanobacteria. The anaerobic conditions below the soil surface provide a home for sulphate-reducing bacteria which convert the organic sulphates from debris and soil water to hydrogen sulphide gas, giving mangroves their pungent odour.

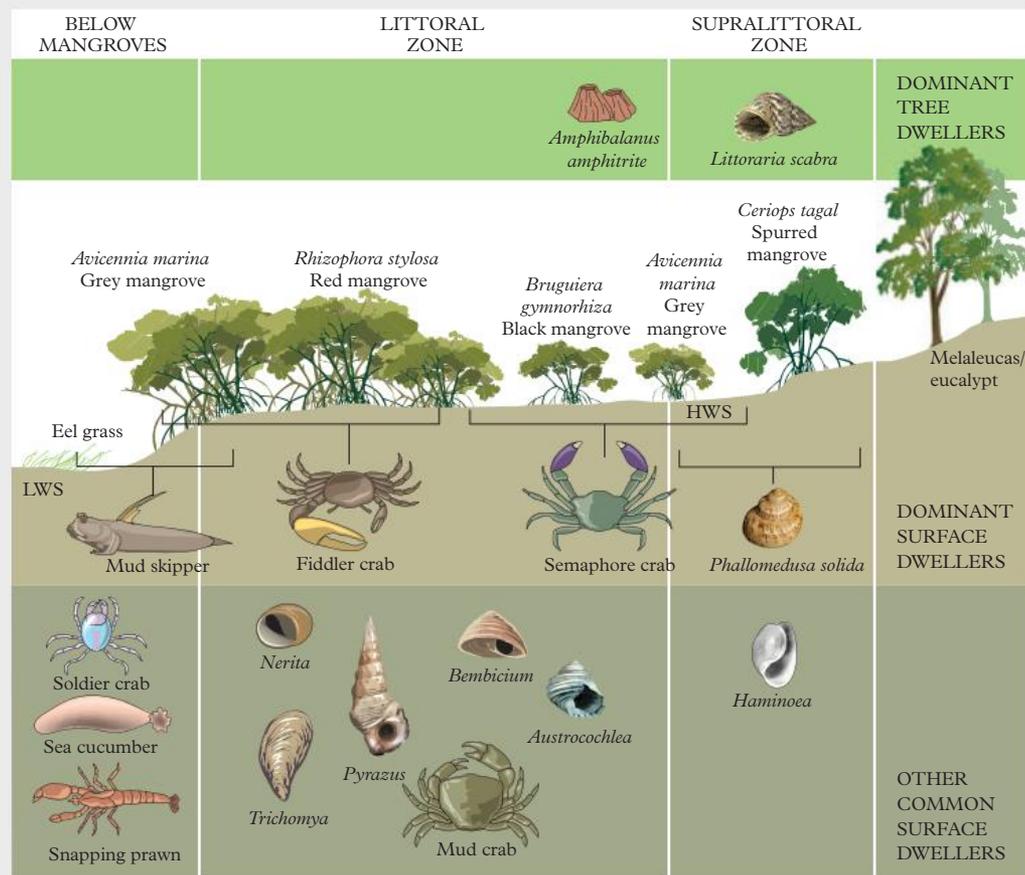
Mangrove species are facultative halophytes. A halophyte is a plant adapted to grow in salt and brackish water. Mangroves grow best in saline conditions but do not need salt to grow. Many adaptations are required for survival in this unstable, anaerobic, saline habitat.



**FIGURE 2** The mangrove ecosystem at low tide, Cape Tribulation Beach, Daintree National Park, Queensland

**mangrove**  
ecosystem in tropical  
and subtropical  
coastlines of quiet  
tidal waters

Although mangroves are predominantly found along the shore line, they form an important buffer zone between the marine estuarine community (which merges with the oceanic community) and the woodlands directly adjacent on the landward side. Mangroves comprise of two main zones that transect the shoreline – the supralittoral zone (the splash zone above the high spring tideline), and the littoral zone (the coastline area that is always or only tidally submerged). Above the high-water level the type of plants change from the halophytic (salt-loving) vegetation to the paperbarks (*Melaleuca*), which are adapted to wet, swampy freshwater soils, or to woodlands and forests in areas where no swamps exist.



**FIGURE 3** Cross-section through a mangrove community in south-east Queensland showing the dominant species. In northern Australia, the trees are generally taller with a closed canopy. There is greater species diversity, making the zones more complex.

### latitudinal zonation

changes in plant community structure due to climatic conditions associated with latitude

### altitudinal zonation

bands of vegetation communities showing adaptations to particular environmental conditions associated with altitude

## Changes with altitude and latitude

Temperature varies with altitude (height above sea level) and latitude (location relative to the equator). As an ecosystem occurs higher above sea level, the mean temperature decreases. The further away an ecosystem is from the equator (and the closer to the poles), the lower its average temperature. These temperature changes result in changes in wind, rainfall and humidity and therefore in different distributions of organisms. There is, therefore, a continuous progression of community types from the equator to the poles (**latitudinal zonation**), which is paralleled by changes in communities with height above sea level (**altitudinal zonation**).

## Changes in the environment caused by organisms

All organisms require specific resources, including food, to survive. They must obtain nutrients and eliminate unwanted substances. This can cause changes in the ecosystem around the organism. For example, the bandicoot (*Isoodon macrourus*) digs up the ground when searching for food or building nests. It eats insects, spiders, earthworms, berries, grass seeds, plant fibres, and respire aerobically. The eliminated undigested matter and excreted metabolic wastes are different from materials taken in. This means the bandicoot has an effect on plants and animals, as well as contributing to changes in the physical and chemical aspects of its environment.

Organisms therefore bring about changes in their environment because they may:

- provide food or habitat for others
- remove water or nutrients
- add organic matter through waste elimination
- absorb light or provide shade
- alter carbon dioxide or oxygen levels.

Sometimes the changes an organism makes to its environment will negatively impact the rest of the population, or the whole community. It may also change the environment in such a way that a more competitive species is able to move in. An example of this is an invasive exotic weed called lantana. This weed has replaced billions of hectares of understorey plants in woodlands, eucalypt forests and dry rainforests. It has made these habitats unsuitable for many species of birds, insects and small mammals. Those birds that do eat the fruit spread the seeds further afield. The dense litter produced by these plants changes the mineral content of the soil, making it unsuitable for native species of plants but highly suitable for further lantana development.

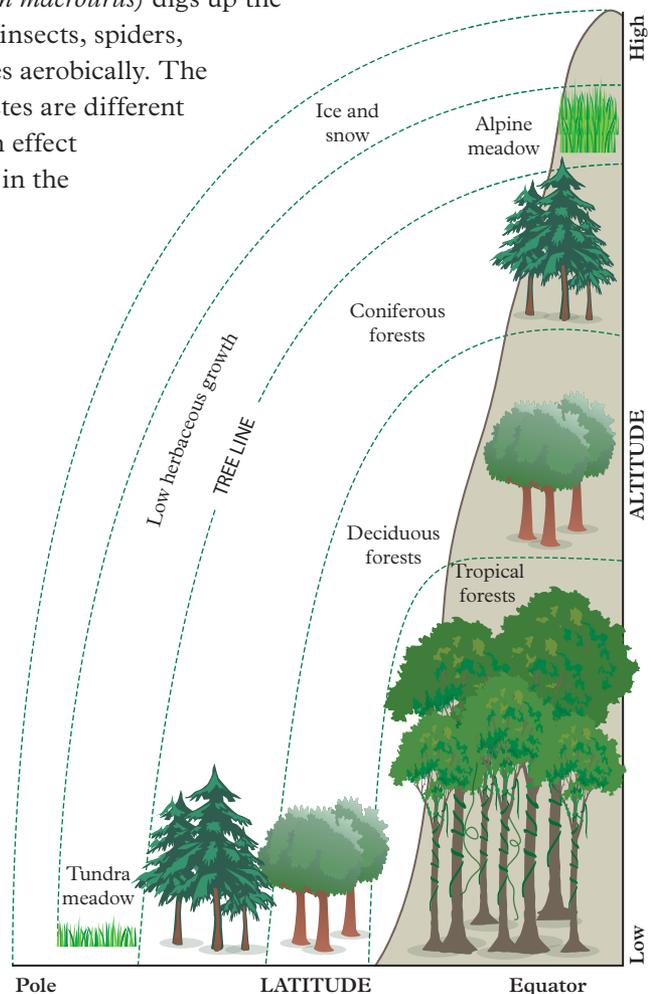


FIGURE 4 Latitudinal zonation is paralleled by altitudinal zonation.

### CHECK YOUR LEARNING 6.1

#### Describe and explain

- 1 Using a specific example, **explain** how species composition in any particular ecosystem can change seasonally.

- 2 **Describe** how the actions of organisms can influence the environment.
- 3 **Explain** why altitudinal zonation would parallel latitudinal zonation.

Check your **obook assess** for these additional resources and more:

» Student book questions

Check your learning 6.1

» Weblink Mangroves

» Weblink Alpine ecosystems

# 6.2

## Changes in natural communities

### KEY IDEAS

- ✦ A sere in an ecosystem
- ✦ Primary succession
- ✦ Secondary succession
- ✦ Climatic communities contain *K*-strategists
- ✦ Disclimax communities are stable non-climatic ecosystems

## Ecological succession

Ecological succession is the process of the gradual evolution of an ecosystem. Many environments start with bare soil before being colonised by grasses. Over time the grasses are replaced by a succession of larger plants and trees until the final, relatively stable, climax community is reached. Each of these community stages has recognisable characteristics and is termed a **sere**.

### sere

an intermediate community found in ecological succession in an ecosystem advancing towards its climax community

### CASE STUDY 6.2

#### Colonisation of Rakata

In a series of violent volcanic eruptions in 1883, much of the island of Krakatoa (between Sumatra and Java, Indonesia) was destroyed. All life on the remainder (now called Rakata) and nearby islands was buried under a deep layer of hot ash and pumice stone. In 1930 a new volcanic island arose from the sea nearby. Since it originated from the sunken crater of Krakatoa, it was named Anak Krakatoa (Krakatoa's child).

These two islands have been the subject of considerable investigation since they provide natural laboratories for observing colonisation of bare land, relatively free from human interference.

On Rakata, the first plants to become established in the volcanic ash were grasses. The seeds could have been windblown from Sumatra or Java, or accidentally carried by birds (attached to their legs or feathers). By 1930 much of the grassland had been replaced by she-oak woodland and trees of the open forest. In parts of the forest the canopy (upper leafy layer) was beginning to close over as a result of colonisation by new tree species. A closed canopy is typical of rainforest. Light penetration to the



**FIGURE 1** An artist's impression of Krakatoa erupting in 1883

forest floor is obscured by the heavy foliage of these trees, limiting the growth of plants (grasses, herbs and shrubs) in these areas.

By 1980, however, the extent of the closed forest was still limited. The animal life on the island, too, is restricted to those animals that can cross the water. Therefore, insects, birds, bats and a few reptiles (presumably crossing to the island on organic debris) form the nucleus of the island fauna. Their survival on the island was dependent on the availability of suitable resources.

## Primary succession

The change observed from bare volcanic ash to closed forest on the island of Rakata is a process called **primary succession**. Colonisation is initiated by the dispersal, usually by wind, of spores or seeds of hardy autotrophs (**pioneer species**). These autotrophs are able to survive in areas where limiting factors often include very high light intensity, and low water-holding capacity of the soil due to a lack of organic matter. These plants therefore have one or more of the following features:

- are tolerant of extreme conditions
- are able to photosynthesise
- have rapid spore or seed germination
- use wind pollination and/or dispersal of spores or seeds
- have the ability to fix nitrogen from the air
- are opportunists or *r*-strategists that disperse rapidly, have a large number of offspring and a short life cycle.

Lichens, a mutualistic relationship between fungi and photosynthetic algae, are often the pioneer species of bare rock. A product of their metabolism is an acid that may cause the rock to become eroded. Temperature differences (day and night, or seasonal) cause expansion and contraction of the rocks, creating cracks and fragmentation. As lichens age and die, decomposing bacteria break down small amounts of organic matter that collect in rock cracks, which begins the formation of soil.

**primary succession**  
development and change in plant communities over time, leading eventually from bare ground to a climax community

**pioneer species**  
species of plants that colonise bare ground



**FIGURE 2** Lichens are the first species to start the breakdown of rocks.

The gradual build-up of soil makes these places unsuitable for rock-dwelling lichens, but suitable for the colonisation of mosses. Further soil enrichment is provided by the decomposition of the mosses as they in turn die. Over time, more complex plants are able to grow, progressing from ferns to grasses, to shrubs, to small trees and finally a forest. At each successive change in vegetation type, the replacement plants are better able to compete for resources than their predecessors. The larger shrubs and trees that begin to dominate the area are *K*-strategists that may release chemicals to prevent the germination of their seed in close proximity. This decreases competition for light, nutrients and water and increases life expectancy.

With changes in vegetation there are changes in the animal life found in the area. Bacteria, decomposer fungi and worms become more abundant in the ever-deepening soil. Insects and birds above ground level aid dispersal and pollination of flowering species of plants. Denser vegetation also provides habitats for reptiles and mammals. Over time, the bare rock becomes covered in increasingly deep soil that supports a growing biodiversity of organisms and increases the overall amount of biomass in the ecosystem.

Succession also occurs on sand and coral islands. The area near the sea, just above the high tide level, is not an easy place for plants to live. Spray is blown onto them by the wind, and fresh water is in short supply. The sand is unstable, unable to retain water and tends to move with wind action. A few plants are able to cope with these conditions and begin to colonise the area. These pioneer plants include the grass *Spinifex hirsutus*, which sends out runners, and the prostrate creeper *Ipomoea pes-caprae*. The seed heads of the spinifex grass form large round bundles that are rolled by the wind, and so disperse the seed. Once established, the pioneer plants trap wind-blown sand around them and the dune begins to build up and stabilise.



**FIGURE 3** Worms are large contributors to the formation of soil.



**FIGURE 4** *Ipomoea pes-caprae* is more commonly known as bayhops or goat's foot and is often one of the first to colonise sandy dunes.

Stabilised areas out of direct contact with sea water can support other species of plants such as *Pandanus*, *Casuarina*, stunted wattles and banksias. These plants increase the humus layer within the sand, and the soil is able to retain moisture better. Wattles, through their symbiotic nitrogen-fixing bacteria, also add nitrogen to the soil. Blade grass (*Imperata cylindrica*), couch and vines such as *Hibbertia scandens* form ground cover in these areas.

Animals, living in and on these plants, add to the nutrient value of the soil through their excretions and decomposition when they die. With further increases in humus, and thus water retention, other plants such as heath and forest species can grow. The community seen inland will depend upon general climatic conditions, the humus build-up in the soil and the seeds dispersed by birds, ocean currents and wind.

## Coastal dunes – succession or zones of environmental difference?

A walk from an open sandy beach on the mainland, across the dunes to forest behind, shows different zonation. These zones are often described as illustrating the stages of succession through which the vegetation behind the dunes would have passed during its development. Other scientists claim that these zones merely reflect different environmental conditions. Since the zones along the coastline remain fairly stable over time, they most likely result from gradients in salinity, wind, availability of fresh water, and erosion from storms as distance from the surf increases.

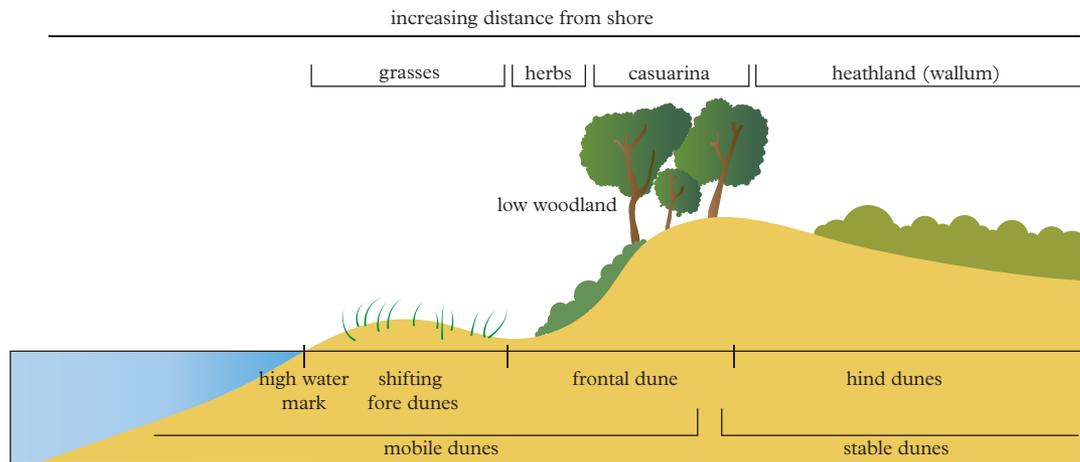


FIGURE 5 Sand dune zonation

## Climax community

During succession, each stage changes the abiotic and biotic conditions of the environment. This paves the way for another species to colonise the area through dispersal from an adjoining area. For example, larger plants cast shadows that result in subtle changes in temperature, moisture and light in some parts of the community. These slight differences result in the formation of **microenvironments**, which will support some species but not others. Eventually, a relatively stable, complex community is reached. This community of organisms has reached an equilibrium where the populations and overall biomass do not vary a great deal. Usually a particular plant, the **dominant species**, is prevalent. This stage is termed the **climax community**, since it tends to remain much the same over long periods of time. Forests developed in this way are termed **primary forests**.

### microenvironment

an area within a general habitat with specialised environmental conditions, e.g. a hollow log

### dominant species

the most common species in a community

### climax community

a more or less stable plant community

### primary forest

climax forest formed as a result of primary succession

## Secondary succession

### secondary succession

successive, natural changes in plant communities in an area where a previous community has been removed

### secondary forest

climax forest formed due to secondary succession

### disclimax community

final community formed after succession as a result of degrading environmental factors

### desertification

formation of desert conditions, usually resulting from overgrazing of susceptible areas

Primary succession starts with bare rock and is the first to colonise an area. Secondary succession is the 'second time' the area has been colonised. When the dominant species of a plant community is removed (e.g. by natural disasters such as fire, disease or violent storm activity, or from interference by humans) and the area is left to natural interactions, **secondary succession** will occur.

Abandoned grazing land will become overgrown with weeds and small shrubs, and trees such as wattles. Eventually the wattles will be replaced by the climax open forest community. Secondary succession is invariably faster than primary succession because there is already existing soil, and species of plants and animals present in the area that is being colonised. Forests formed as a result of secondary succession are called **secondary forests**.

## Disclimax communities

A **disclimax community** results from degradation of a community due to activities of organisms. Typical of this process are the changes resulting from overgrazing of natural grassland. As grasses are depleted, the water cycle (evaporation from plants, condensation and rain) is disrupted, and the area becomes even more arid than normal. The grasses have soil-binding roots, which aid in preventing wind and water erosion. As the grasses decrease, erosion increases, and this accelerates the change process. Ultimately only desert plants can survive in the artificially stable area. Grazing practices in Australia have resulted in this country having the highest rate of **desertification** in the world.



**FIGURE 6** Overgrazing causes significant land degradation and ultimately desertification.

## CHECK YOUR LEARNING 6.2

### Describe and explain

- 1 **Define** the following terms.
  - a Pioneer species
  - b Sere
  - c Climax community
  - d Disclimax community
  - e Primary succession
  - f Secondary succession

- 2 **Describe** some of the adaptations that are an advantage to pioneer species.

### Apply, analyse and interpret

- 3 **Determine** why being an *r*-strategist would be an advantage to a pioneer species but not to a plant in a climax community.



### Check your obook assess for these additional resources and more:

» Student book questions

Check your learning 6.2

» Weblink

Rakata colonisation

» Weblink

Coastal dunes

## 6.3

# Ecosystem changes in the past

### KEY IDEAS

- ✦ Changes in ecosystem biotic and abiotic factors
- ✦ Fossils provide evidence of past changes in ecosystems
- ✦ Pollen and spores are indicators of ecosystem changes

Since ecosystems are dynamic entities, it is reasonable to assume that there have been dramatic changes in them over Earth's long history. Earth has experienced periods of climate change with dramatic alternations due to global cooling (periods of glaciation) and warming. It has been subjected to large meteor damage, resulting in mass extinctions over a large scale of the surface, and volcanic activity in which everything in the vicinity of the eruption and lava flow is killed. Scientists have devised ways to measure some abiotic and biotic changes that have occurred in the past.

The length and severity of climate change events can be determined, for example, from carbon dioxide levels in the ice of the polar ice caps. As snow falls, it traps atmospheric carbon dioxide. The snow compacts as ice and, like the growth rings of a tree, forms a layer each season of snowfall. By taking core samples of polar ice, scientists can determine:

- the age of each layer
- the depth of each layer and thus the duration of the extreme cold period
- the level of carbon dioxide present in each layer. The higher the global temperature, the more carbon dioxide is found in the atmosphere.

Similar techniques are used when examining deep-sea sediments. Two slightly different forms of oxygen isotopes exist:  $^{16}\text{O}$  and  $^{18}\text{O}$ .  $^{18}\text{O}$  has two more neutrons than  $^{16}\text{O}$  and so is a little heavier. Because  $^{16}\text{O}$  is lighter it is more easily evaporated from the oceans, particularly during cold phases. Analysis of the ratio of  $^{18}\text{O}:^{16}\text{O}$  in deep-sea sediments therefore gives a strong indication of climate variations. If the  $^{18}\text{O}$  is higher, it indicates a cold period occurred when the  $^{16}\text{O}$  was able to evaporate. In contrast, a higher  $^{16}\text{O}$  (when compared to the  $^{18}\text{O}$ ) indicates warmer temperatures occurred during that time period.



**FIGURE 1** (a) A scientist taking ice core samples and (b) International Ocean Discovery Program (IODP) drilling for subseafloor sediments

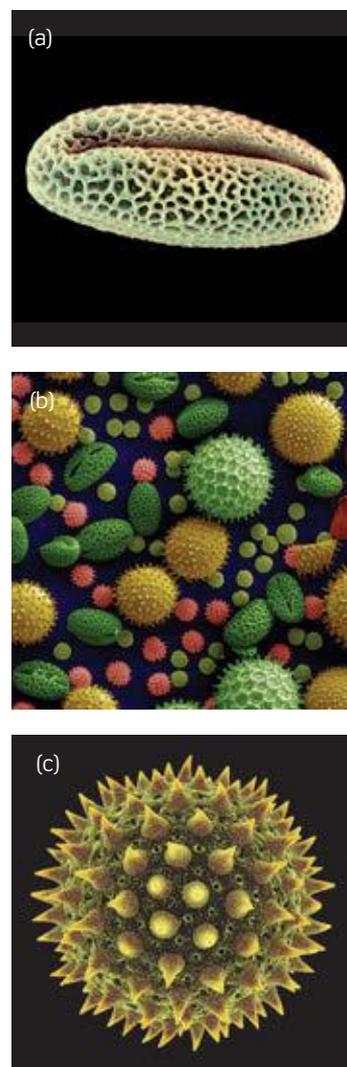
These changes in climate also affected the different species of plants and animals that were able to grow and reproduce during that time. The fossilised remains or traces of organisms that existed during that period can also provide an indication of how the ecosystem has changed. The presence or absence of particular species can provide more evidence of the components of an ecosystem. Since all organisms depend upon other organisms either directly or indirectly, the presence of particular fossils at a site provides good evidence of other organisms that were able to survive in the environment. Unfortunately, fossil records are inherently incomplete since conditions for fossil formation are not uniform in any environment. Fossils are most commonly found in areas where, on death, their remains are protected from predatory consumption or bacterial decomposition. Boggy marshes, floodplains or estuaries, where the remains are rapidly covered by silt and where oxygen is limited, are significant areas of preservation. As silt accumulates over the fossils, the remains become deeper and deeper. Generally, the further the fossil is found from the surface, the older it is. Places that have rapid burial events, such as landslides, are also good fossil preservation locations.

Pollen grains and spores are extremely resistant to decay and are produced in large quantities. Pollen walls are composed of a very strong and stable chemical. Since they are dispersed by wind or water, they may be distributed widely from their source. Pollen can accumulate on any undisturbed surface and has been found in sediments from peat bogs, lake beds, alluvial deposits, ocean bottoms and in ice cores. The actual amount of pollen or spores found in an area may not be indicative of the relative abundance of the plant since different species produce different amounts of pollen or the pollen has different dispersion rates.

The pollen grain of each species has its own unique size and shape. Scientists can therefore determine from core samples of sediments the exact species that existed in that area at any particular time. Using pollen grain analysis, vegetation maps of an area can be produced that show changes over hundreds of thousands of years. Comparison with recent trends in vegetation can also assist in determining the impact of human activities on ecosystems.

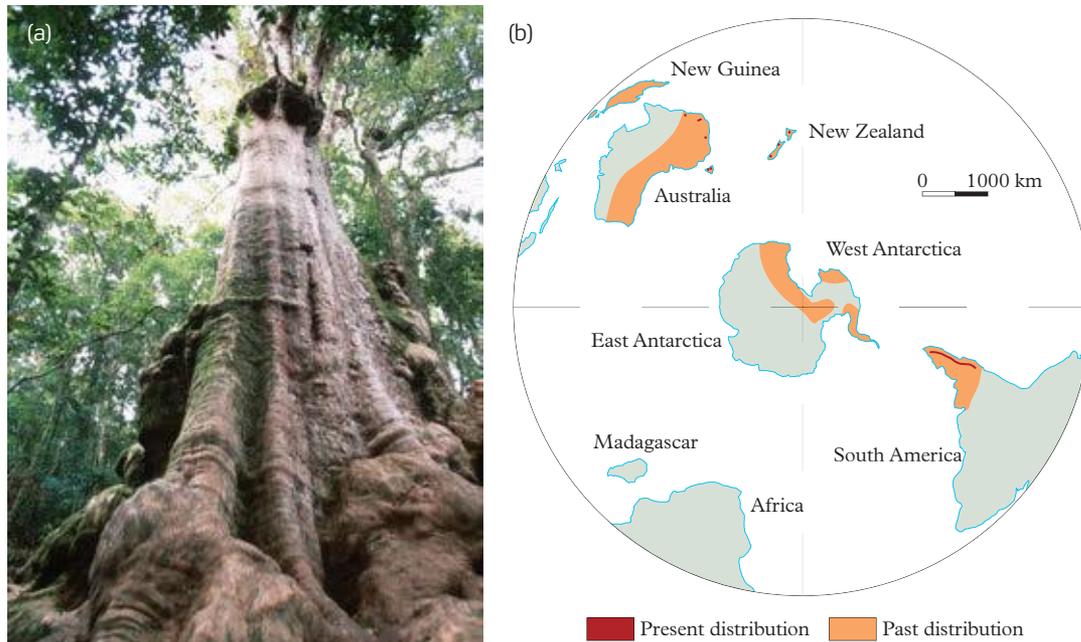
A deep core soil/rock sample taken from a mature dry forest may reveal that the area was once a deep lake that gradually became filled with silt. The fossilised plant remains would have progressively changed from floating forms to submerged species as the water level decreased. With further loss of water, the fossils would indicate a prevalence of plants found at the edges of waterways – spores of mosses and ferns and seeds of sedges. Higher strata would show progression from herbs and grasses to shrubs and then a series of trees until the most recent community is achieved.

Similarly, fossils can show degradation of forests due to cataclysmic events, such as climate change, large meteor showers and volcanic activity. As seen in Chapter 2, fossils also indicate mass movements of the Earth's tectonic plates.



**FIGURE 2** Pollen grains for individual species of plants have unique features that enable plant identification.

Fossil samples (pollen, cupules that hold the fruit, and leaves) of the southern beech (*Nothofagus* sp.) have been found in South America, south and eastern Australia, New Guinea, New Zealand, New Caledonia and Antarctica. The pattern of distribution suggests that the spread of the genus occurred before Gondwana separated into Antarctica, South America and Australasia and the trees were more widely dispersed than they are currently.



**FIGURE 3** (a) *Nothofagus moorei* found on the southern edge of the Lamington Plateau, south-east Queensland; (b) past and present distribution of *Nothofagus*

Although the southern beech is now only found in isolated pockets in cool, high-altitude environments in tropical and subtropical regions (for example *N. moorei* at the southern edge of the Lamington Plateau in south-east Queensland, *N. gunnii* in Tasmania and *N. nitida* in the southern regions of South America), the fossil record shows that in the past it survived in warmer climates than those it now occupies.

### CHECK YOUR LEARNING 6.3

#### Describe and explain

- 1 Explain** why global temperature changes bring about changes in ecosystems.
- 2 Recall** two ways that scientists can determine past global temperatures.
- 3 Describe** the features of pollen and spores that make them good indicators of past ecosystems.
- 4** Global temperature changes brought about broad changes in vegetation in various parts of the world. **Describe** how scientists determine the specific types of vegetation change.

Check your obook assess for these additional resources and more:

» Student book questions

Check your learning 6.3

» Weblink

Ice cores

» Weblink

Gondwana fossils



# 6.4

## Human impact on biodiversity

### KEY IDEAS

- ✦ Humans and over-exploitation, habitat clearing, monoculture and pollution
- ✦ Eutrophication
- ✦ Introduced species affect the equilibrium of a climax community
- ✦ Land, water and air pollution affect the biodiversity of an ecosystem

### Humans as consumers

Humans are consumer organisms and are therefore dependent upon the same sorts of resources as other consumers. They require suitable water, food and shelter. The first humans, recorded from fossils that are approximately 150 000 years old, were hunter-gatherers. Since their numbers were small and they were nomadic, they had little impact on the environment other than through fire. Fires were used both for cooking and in flushing out prey. Fires may also have been used deliberately to maintain open grasslands, which supported herds of grazing animals. In time, in many parts of the world, the hunting mode was succeeded by domestication of some animals (e.g. sheep, goats, cattle, llamas). Eventually forests were cleared to increase the pastures for flocks. In some areas this led to overgrazing, decreasing soil fertility and increasing erosion.

It was only a small step to the actual cultivation of land, with deliberate sowing of seed, to produce more pastures and make collecting edible plant products easier. Cultivating land was associated with more permanent settlements, and trees were felled for timber to construct solid buildings. The development of towns and cities, and a society with division of labour and industrialisation, have further added to destruction of the natural environment.



**FIGURE 1** Indigenous Australians first colonised Australia over 65 000 years ago. These first settlers were hunter-gatherers, and their use of fire contributed to a change in vegetation to predominantly fire-tolerant woodlands and grasslands.



**FIGURE 2** An ‘island’ of natural vegetation surrounded by agricultural land.

The first European settlers (1788) brought domesticated animals (sheep, goats, cattle, pigs, poultry and horses), plant cuttings (mostly from Cape Town, their last port of call) and seeds to Australia. They proceeded to convert grasslands and woodlands into suitable pastures for their stock, to clear forests and to build towns with little thought of the impact on the ecosystem.

## The effects of land clearing

Regardless of the human requirements (agricultural, mining or urban development), the first step is invariably clearing the natural vegetation from the land. With modern machinery, huge tracts of land can be cleared in a relatively short amount of time. This has immediate catastrophic effects on the biodiversity of the area. With loss of a range of trees, there is no food, or nesting sites for insects, birds and arboreal mammals. Those that cannot relocate, perish. Pasture grasses, crops or a ‘concrete jungle’ replace the natural understory and grasses, so further diminishing biodiversity.

## Habitat fragmentation

As a result of the contours of the land, some areas are more suitable for human development than others. Patches of clearing occur in some places, leaving fragments of natural vegetation in the more inaccessible or less fertile areas. This process is called **habitat fragmentation**. These areas are often too small to support viable populations of once abundant species. In this way, the distribution and abundance of many species (e.g. the koala) has been greatly altered by vegetation clearing. The shape and size of the remaining fragmented islands of vegetation are important factors in determining which species can survive and/or remain in the area. The outer edges of each vegetation island receive more sunlight and are more prone to wind disturbance. Some species are therefore abundant at the edges of these ‘islands’, whereas others will be found only in their interior.

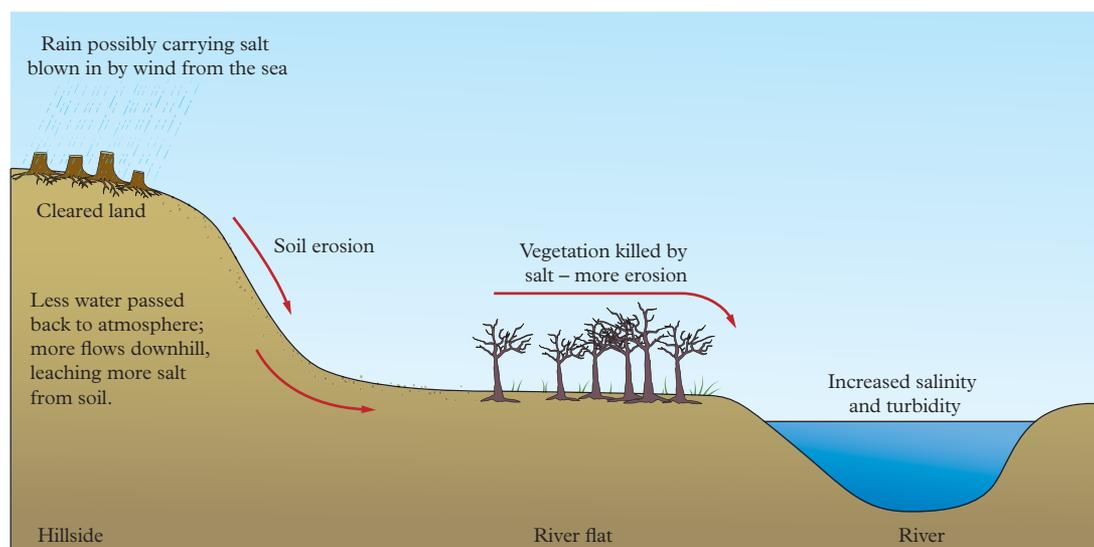
While the vegetation islands can be important for isolated species, it is important that appropriate ‘corridors’ be left, joining tracts of natural vegetation between cleared lands to allow movement of native fauna and maintain biodiversity.

**habitat fragmentation**  
division of a habitat into smaller, isolated portions as a result of human activities in the intervening spaces

## Land degradation

Clearing land in an area can bring about changes to a number of ecosystems far from the zone of origin. Reduced vegetation results in less organic matter being returned to the soil, thus causing nutrient depletion. The rain also causes soil compaction, reducing its ability to absorb water. This increases the surface run-off that results in erosion. If the soil has been ploughed, small watercourses may develop, eroding further to form enlarged gullies. This water- or wind-eroded topsoil can end up contaminating marine ecosystems.

The lack of vegetation can result in less water being absorbed by plant roots. This will cause an increase in the height of the water table, leaching minerals and bringing salt water to the surface. The high concentration of salt can further degrade the soil.



**FIGURE 3** Possible effects of erosion on a slope as a result of vegetation clearing

## Land pollution

Land pollution occurs through land clearing, from the extraction of raw materials for industry and from the disposal of wastes, as well as from agriculture. The great bulk of solid waste is placed on unused land at the edges of cities. Apart from aesthetic undesirability, two side effects can result: air pollution from burning refuse and water pollution as organic matter reacts to form acid that leaches into the soil. As the landfill begins to compact and decompose, large amounts of methane gas are generated. If this gas escapes to the atmosphere it contributes to enhanced global warming.

## The effect of fertilisers

Much of the soil in Australia is poor in nitrates and phosphates. Trace elements necessary for plant and/or animal growth may also be absent in many areas. The use of fertilisers to overcome these soil nutrient deficiencies is therefore standard practice.

After heavy or repeated applications, fertilisers can be washed by rain into dams, lakes and streams, increasing the concentration of nutrient ions in the water. **Eutrophication** is a natural process during which mineral nutrients (particularly nitrates and phosphates) build up in a body of water. As long as the increase is not excessive, these nutrients are taken up by plants at an increased rate and passed through the community so that there is a balance between inputs and outputs.

### **eutrophication**

build-up of nutrients in water; may result in oxygen depletion

Excessive use of fertilisers can cause a rapid population growth in water-based producers. Photosynthesis during the day produces enough oxygen for the producer's cellular respiration. At night, there is no sunlight, and therefore no photosynthesis or oxygen production. As a result, the water can become oxygen deficient overnight and many water-borne organisms die. This contributes to an increased population of decomposer bacteria, which further creates a **biological oxygen demand** (BOD). The natural balance of the freshwater ecosystem is thereby destroyed and may even result in the 'death' of that body of water.

The use of fertilisers is not restricted to agricultural ventures. Fertilisers are heavily used in both public and private gardens. Additionally, many phosphate-based cleaning products used in the urban environment may add to problems with eutrophication.



**FIGURE 4** Eutrophication results in extreme build-up of algae and cyanobacteria, which may produce toxins. Oxygen deficiency in the water creates a biological oxygen demand that results in the death of the aquatic plants and animals.

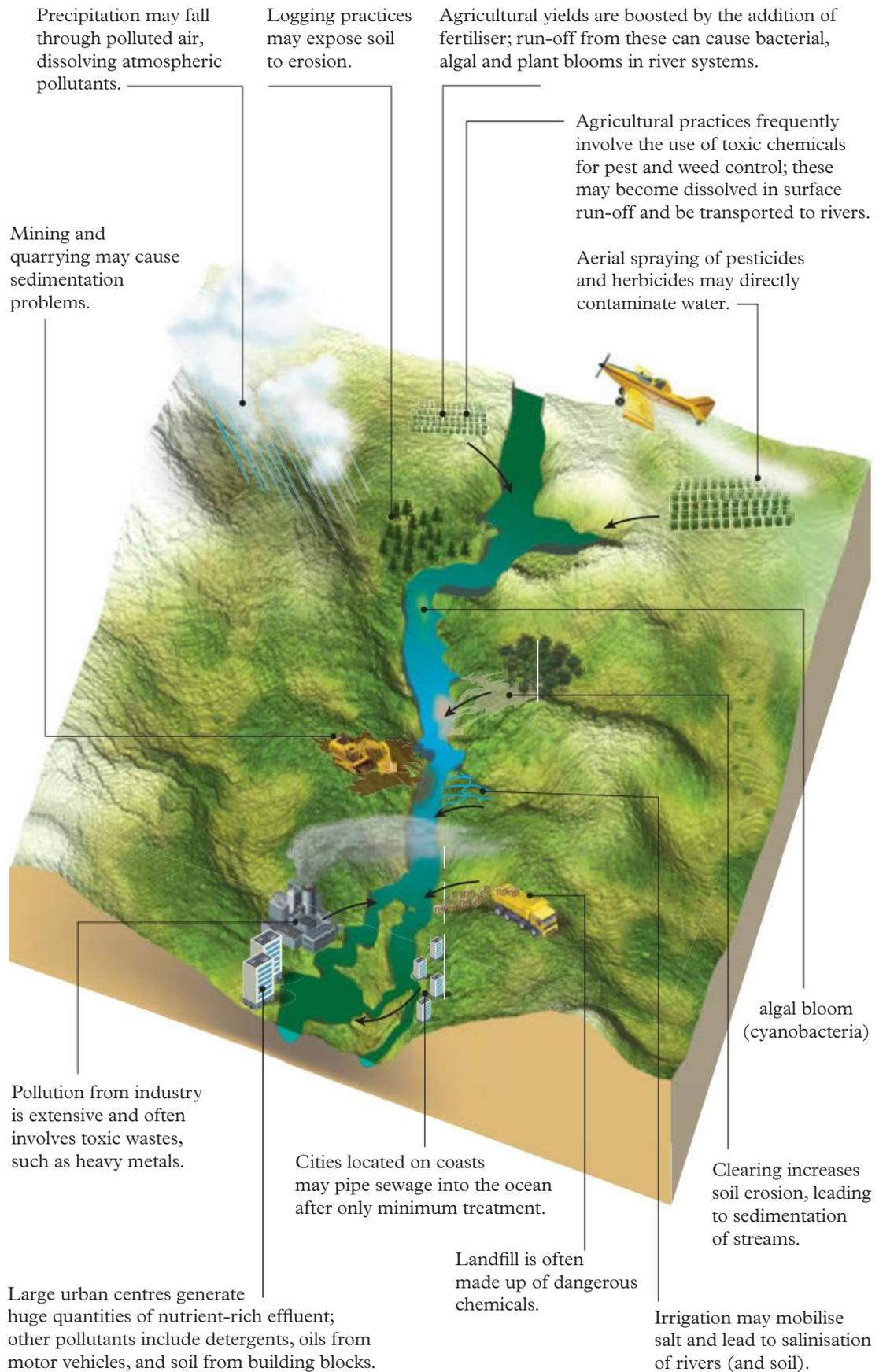
### **biological oxygen demand (BOD)**

a measure of the quantity of oxygen used by microorganisms (e.g., aerobic bacteria) in the oxidation of organic matter in aquatic environments; the higher the BOD, the less oxygen is available for other organisms

## **Building dams**

Most of the Australian continent is dry. Water resources for urban communities, irrigation and stock have been increased by dams in valleys, and on rivers and streams. Damming of rivers has also been used to control flooding downstream, and so increase the amount of usable farmland there. Often this is associated with dredging of the river to remove debris. Although this has been beneficial to humans in the short term, the long-term environmental effects are severe. These include:

- **Erosion** of banks caused by dredging of rivers to increase movement of water.
- **Decreased biodiversity** as waterways are effectively destroyed in many of these areas. In addition, the fertile silt normally carried in floodwater and deposited across the flood plains is no longer available, and so the productivity of these areas decreases.
- **Water temperature changes** as dams destroy the normal cycles of temperature, turbidity, flow rate and flooding. This negatively affects the natural flora and fauna of the river system.



**FIGURE 5** Sources and types of water pollution

- **Increased soil salinity** due to irrigation of crops, which has raised the natural water table and increased the leaching of mineral salts from the rocks and soil. As the surface waters evaporate, they leave behind a high salt concentration in the surface soil, which eventually destroys the crops that the water was designed to aid.

Industry is often situated close to towns beside rivers. Water is needed for many processes. Some of these (for example coal-fuelled power stations) release hot water back into the river, creating a biological oxygen demand among the animals living there. Other industries have released wastes (that may be toxic) into rivers, creating further pollution problems.

## Introduced species and pests

European colonists brought with them to Australia a variety of plants and animals, either deliberately (for food, recreation or aesthetic reasons) or accidentally (e.g. the cane beetle). These species are termed **exotics**. Many such species have had a major impact on the terrain, making it unsuitable for other organisms (burrowing rabbits or feral pigs, for example). Exotic species such as the cane toad and the Indian myna bird may directly impinge upon endemic (native) species through predation and/or competition for resources. In Australia, introduced animals that have become pests include fallow deer, Asian water buffalo, rabbit, hare, fox, camel and European carp. Plants include lantana, water hyacinth, prickly pear, salvinia, tamarisk (athel pine), blackberry and the giant sensitive plant (*Mimosa pigra*).

In the widest sense, **pests** are organisms that cause harm to humans or their resources, either directly or by competing with organisms that humans wish to produce. Whether they are recognised as pests depends on their numbers and the tolerance of the desired product organism. Pests may be animals or plants (usually called weeds).

A wide range of weeds compete for water, light and mineral nutrients with natural communities, crops, pasture and suburban garden plants. Some release powerful chemicals from their roots, which can inhibit the growth of other plants. Others carry crop diseases. Many agricultural systems involve a monoculture – a single crop or stock kept at high density. These conditions favour population growth of consumers, further reducing the productivity of the crop and/or causing disease.

**exotic**  
describes organisms not naturally occurring in a particular region

**pest**  
an organism that causes direct or indirect harm to humans or their resources; an organism in the 'wrong' place



**FIGURE 6** Rural land damaged by rabbits

## Pesticide control

The need to control both weeds and other pests has led to the large-scale use of pesticides. Unfortunately, pesticides cause widespread pollution of the environment, seeping into rivers, killing fish, and contaminating groundwater, drinking water and food. Many pesticides, such as the herbicides DDT and atrazine, mimic the female hormone oestrogen causing feminisation in a number of species of amphibians, birds and mammals. This results in low reproductive rates and possible extinction of species.

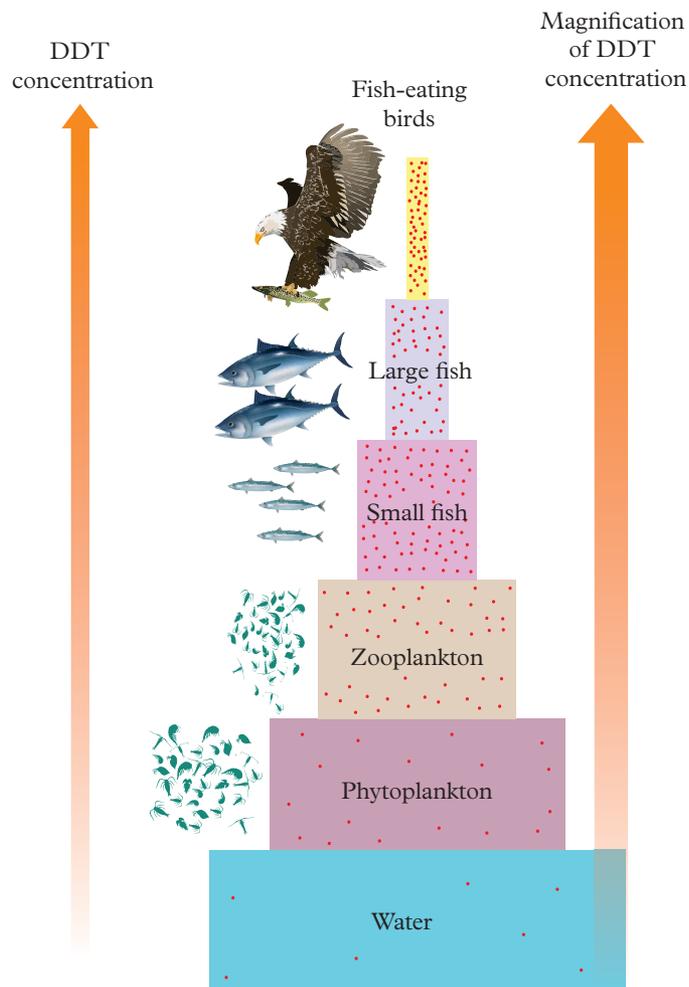
Several indices are used when measuring the effects of pesticides on the environment:

- **biodegradability:** Can the pesticide be broken down to a harmless form by organisms during their metabolic activities?
- **biological magnification:** Is the pesticide passed from organism to organism along the food chain? If biological magnification occurs, each trophic level accumulates more and more of the chemical.

In Clear Lake, California, for example, in an attempt to clear the lake of midges, enough DDT to give a concentration of 0.02 ppm (parts of DDT per million parts of water) was dumped into the lake. Over time, the DDT levels were found to accumulate in organisms further along the food chain (biological magnification) as it cannot be excreted and is stored in fat tissues.

**biodegradable**  
able to be broken down by organisms

**biological magnification**  
concentration of substances within the tissues of organisms as they pass along a food chain



**FIGURE 7** Increasing concentrations of DDT in a food chain and biological magnification of the DDT concentration

- **Half-life:** The half-life of a chemical is the time it takes for half of any given quantity of the substance to break down to something else. In the case of harmful chemicals, the half-life would refer to the breakdown to a harmless form. Some non-biodegradable pesticides have a long half-life and persist in the environment for a long time. For example, DDT has a half-life of 15 years. After spraying 10 g of DDT on an area, 1.25 g would still be present 45 years later.
- **Persistence:** The length of time that measurable residues of the pesticide are found in the environment is termed persistence. It is related to half-life.

**half-life**  
the time taken for a quantity, for example of a radioactive isotope or a chemical, to break down to half its original value

**persistence**  
length of time a measurable chemical residue remains in the environment

## Air pollution

There are various types of air pollution, coming from a number of sources. A **primary pollutant** is one present in its original form and has a direct effect on the atmosphere. Smoke, dust, and oxides of sulphur or nitrogen are examples. A **secondary pollutant** is formed as a result of the interaction between wastes and the atmosphere (e.g. acid rain or smog).

**primary pollutant**  
substance that has a direct adverse effect upon the environment

**secondary pollutant**  
a pollutant formed as a result of the interaction between wastes and the environment



**FIGURE 8** Smog in Sydney causes respiratory issues for many people.

## Photochemical smog and temperature inversions

### photochemical smog

secondary pollutant produced by chemical reaction between nitrogen oxides and hydrocarbons in the presence of sunlight

### temperature inversion

trapping of a cooler layer of air in the atmosphere under a warm layer, preventing the dispersal of heat and other pollutants

### microclimate

climate of a very small or restricted area, especially when this differs from the climate of the surrounding area

**Photochemical smog** is a secondary pollutant produced by chemical reactions between nitrogen oxides and hydrocarbons in the presence of sunlight. The formation of photochemical smog depends not only on the concentrations of the primary pollutants in the atmosphere, but also on the weather conditions. It forms when the air is calm, at suitable levels of ultraviolet light, and when there is a temperature inversion.

**Temperature inversions** can have a number of causes, but in cities with an air pollution problem, the effects are serious. Under normal weather conditions the pollution produced by a city is dispersed as it rises and is blown away. When a temperature inversion occurs, the pollution particles remain trapped in the cold air closest to the ground.

## Urban microclimates

People have created **microclimates** in urban areas. These microclimates vary according to the 'built environment', for example, between park areas, and near glass and concrete buildings.

Concrete city surfaces absorb more heat during the day than the surrounding countryside. This makes the city and urban areas resemble a warm 'island' projecting out of the cool 'sea' (the air) of the surrounding landscape. In central city areas, rows of tall buildings are usually only separated by narrow roads. This creates wind tunnels that spread the heat further. The effects are numerous. Plants in cities have been shown to bud and bloom earlier, and some birds are attracted to this warmer area.

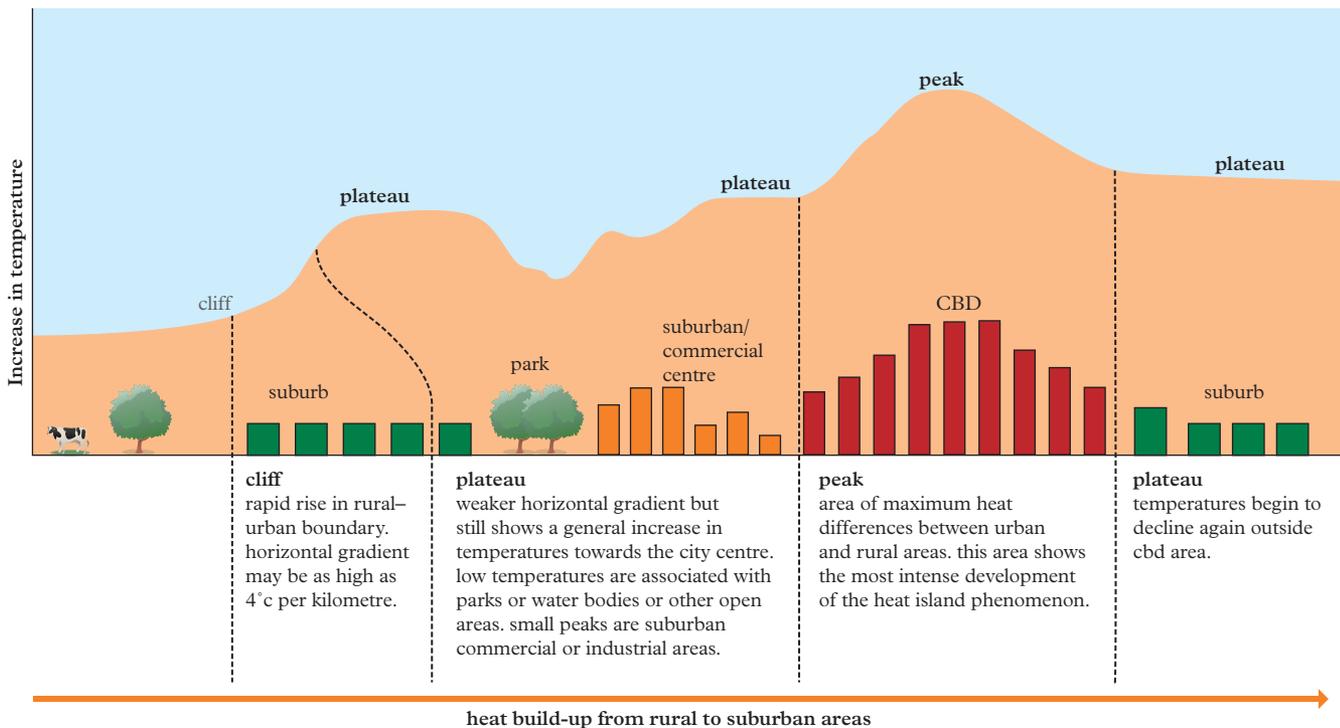


FIGURE 9 Microclimate changes in the urban heat island

## Natural, agricultural and urban ecosystems

Humans have been able to manipulate their environment by growing crops and rearing animals, wearing clothes, building houses, lighting fires and producing electricity. However, their activities have released polluting chemicals, which have had effects on water, soil and climate. The need to feed, clothe and house the world population adds a tremendous pressure to the environment. Ultimately there is a decrease in biodiversity that may result in disclimax succession.

The biosphere, therefore, has to support three types of ecosystems – natural, agricultural and urban. For an ecosystem to be sustained there must be a cycling of matter and a flow of energy. Although short-term imbalances may result from climatic changes, a self-sustaining system is one in which the inputs and outputs are balanced over the long term.

### CHECK YOUR LEARNING 6.4

#### Describe and explain

- Describe** the possible consequences, in relation to the soil, associated with removal of vegetation.
- Define** the following terms:
  - biological magnification
  - biodegradable
  - half-life
  - pesticide
  - pest
  - eutrophication
- Describe** how irrigation of crops can lead to increased salinity of soils and adjoining waterways.
- Explain** how the application of fertilisers to farmland can result in the death of organisms in nearby freshwater ecosystems.
- Explain** how habitat fragmentation can influence species diversity.

#### Apply, analyse and interpret

- Determine** which region in the hillside shown in the cross-section below is most susceptible to erosion. **Justify** your answer.

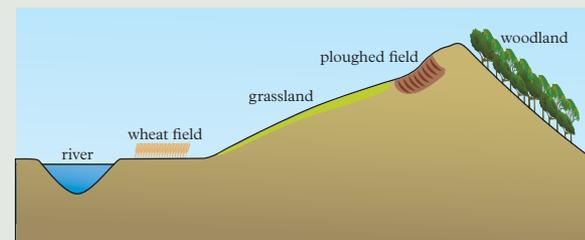


FIGURE 10 Varying landscapes exposed to erosion

- Distinguish** between a primary and a secondary air pollutant.
- Urbanisation has created changes in climate that affect whole settlements and also microclimates within specific parts of them. **Consider** how this might occur and what environmental effects it might have.

#### Check your obook assess for these additional resources and more:

- |   |  |                                      |
|---|--|--------------------------------------|
| » Student book questions<br>Check your learning 6.4 | » <b>Mandatory practical</b><br>6.4 Appraisal of an ecological surveying technique | » <b>Weblink</b><br>Land degradation |
|---|--|--------------------------------------|

# Review

## Chapter summary

- 6.1**
  - Ecosystems undergo dynamic change.
  - Ecosystems interact with each other.
- 6.2**
  - There are a series of community changes (seres) that occur in an ecosystem undergoing succession.
  - Primary succession results in the build-up of nutrients in soil, colonisation by *r*-strategist pioneer species, and an increase in biomass.
  - Secondary succession occurs after community disruption.
  - Climax communities contain *K*-strategists, and high biodiversity in a relatively stable biotic and abiotic environment.
  - Disclimax communities result from degradation of a community due to biotic and/or abiotic factors.
- 6.3**
  - Past global climate changes influenced changes in ecosystems due to biotic and abiotic factors.
  - Fossils provide evidence of past changes in ecosystems.
  - Pollen and spores are strong indicators of ecosystem changes.
- 6.4**
  - Humans can decrease biodiversity through over-exploitation, habitat clearing, monocultures and pollution.
  - Eutrophication is caused by large amounts of nutrients washing into a body of water, resulting in dense plant growth and a decrease in oxygen concentrations. This increases the mortality of aquatic animals.
  - Introduced species can affect the equilibrium of a climax community.
  - Land, water and air pollution can affect the biodiversity of an ecosystem.

## Key terms

- altitudinal zonation
- biodegradable
- biological magnification
- biological oxygen demand (BOD)
- climax community
- desertification
- disclimax community
- dominant species
- eutrophication
- exotic
- habitat fragmentation
- half-life
- latitudinal zonation
- mangrove
- microclimate
- microenvironment
- persistence
- pest
- photochemical smog
- pioneer species
- primary forest
- primary pollutant
- primary succession
- secondary forest
- secondary pollutant
- secondary succession
- sere
- temperature inversion

## Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: ★ = low; ★★ = medium; ★★★ = high.

### Multiple choice

The paragraph below is used for questions 1–3.

In 1883 a volcanic explosion removed all life from the island of Krakatoa, near Java in East Indonesia. After only three months 11 species of ferns and 15 species of flowering plants had returned. Ten years later there were 263 species of animals on the island, which were mainly insects. Less than 50 years after the explosion, the whole island was covered with a dense forest.



**FIGURE 1** An artist's impression of Krakatoa erupting in 1883.

- 1 The above paragraph is a description of:
  - A succession
  - B an ecosystem
  - C a community
  - D evolution
- 2 Which of the following factors would **least** influence the rate at which organisms reappeared on the island?
  - A temperature
  - B ocean tides
  - C spontaneous generation
  - D the distance from another island
- 3 The first organisms to reappear on the island were plants. Identify which of the statements below helps to explain this.
  - A Plants are able to make their own food.
  - B Seeds and spores are easier to disperse than animals.
  - C If animals reached the island first they would die from lack of food.
  - D All of the above.
- 4 Select the statement that best completes this sentence. The climax stage of a biotic succession:
  - A persists until the environment changes significantly
  - B changes rapidly from time to time, seldom remaining at any stage for more than a decade or so
  - C is the first stage in the reclamation of land from a lake bottom
  - D is the stage in which trees are always dominant
- 5 Which of the following is **not** a requirement for a colonizing species?
  - A an available niche in the new area
  - B a favourable climate
  - C physiological potential to survive in the new area
  - D an active means of locomotion for dispersal
- 6 The effects of an algal bloom in waterways are collectively called:
  - A biological magnification
  - B nutrient recycling
  - C eutrophication
  - D decomposition

- 7 The most serious threat to native animals by human activity is:
- A hunting of animals for pelts and pet food
  - B bushfires
  - C off-road vehicles
  - D the clearing of their native habitat
- 8 Human activities have increased atmospheric carbon dioxide levels by 15% in the last century. This is mostly due to:
- A clearing forests
  - B automobiles
  - C burning fossil fuels
  - D the exhaled air of the large population of humans
- 9 The biosphere can be divided into three main groups of ecosystems: natural, agricultural and urban. Of these it is not true to say:
- A an urban ecosystem has little recycling and low heat output
  - B an agricultural ecosystem has some recycling and a large output of organic matter
  - C a natural ecosystem has much recycling, with organic input approximately equal to organic matter output
  - D all three ecosystems rely on light as one source of energy input

### Short answer

#### Describe and explain

- ★ 10 **Explain** the statement: 'Ecological succession cannot occur without dispersal'.
- ★ 11 **Describe** the different ecological boundaries of an Australian mangrove.
- ★ 12 **Explain** how altitude can affect an ecosystem.
- ★ 13 **Define** primary succession.
- ★★ 14 **Explain** how microenvironments form and provide an example of one.
- ★★ 15 **Describe** how ice cores can be used to determine past ecosystems.
- ★★★ 16 In the early settlement of Brisbane in the 19th century, most of the Big Scrub along the Brisbane River was heavily logged. The blackbean, silky oak, red cedar and most eucalypts trees were used for construction as

the settlement grew. Mangroves were burnt for their ash to produce soap. Similarly, most of the lowland areas were cleared for farming. Over time much of this land was deemed unproductive and farming ventures were abandoned. Just over 100 years later, most of these areas not part of urban development are covered in well-established secondary dry sclerophyll forests. **Explain** why they are called secondary forests, the process of their formation and why forests returned after such a short time period.

#### Apply, analyse and interpret

- ★★ 17 Can any natural ecosystem be isolated from other ecosystems? **Structure** your answer by providing examples.
- ★★ 18 Figure 1 displays population numbers for three different organisms. In 2012 hot water was emptied into the river, and in 2014 there was pollution from a chemical factory. The three organisms were a kind of algae, a fish and a herbivore that ate algae. **Identify** the organism that each graph (A, B and C) represents, giving reasons for your choice.

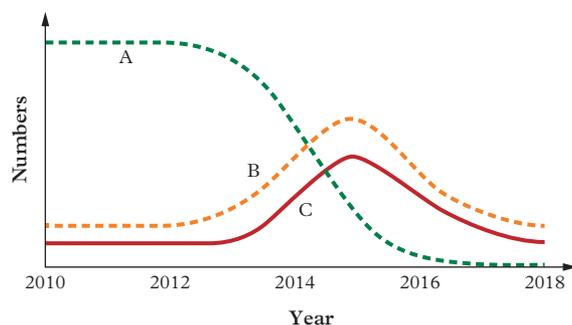


FIGURE 2 The population numbers of three different organisms in a river

- ★★★ 19 Many amateur conservations believe that climax communities are the final, most well adapted community in an area. Any changes to the area are adamantly opposed for fear that the species composition will not be preserved.
  - a Are their fears real? **Justify** your response.
  - b **Determine** whether their premise of a climax community is correct.

### Investigate, evaluate and communicate

★★★ 20 One of the biggest problems facing the Wildlife Conservation Society of Tanzania is the naturalisation of a black wattle (*Acacia mearnsii*). As a means of boosting a poor economy, farmers were encouraged to develop plantations of these low trees on the many plateaux (about 2000 m altitude) in the area. The trees are an important source of tannins (chemicals in the bark, used in tanning leather), construction timber, and charcoal. Experience in South Africa, however, showed that this species rapidly escaped the plantations. Because they are more competitive in obtaining water than indigenous tree species, they readily took over large areas and have been declared a noxious weed, and the cost of eradication is very high. Wildlife officers



FIGURE 3 A black wattle tree

have noticed a similar trend in southern parts of Tanzania. Faced with an ailing economy, and because the plantations are financially lucrative, the government is reluctant to ban the cultivation of the black wattle.

**Generate** a scientific report to the government to convince it that short-term gains could lead to long-term crippling of the economy if it does not reverse its current policy. As part of your argument **generate** a list of the broad environmental effects of replacement of native vegetation on the plateaux by an invading monoculture.

★★★ 21 **Investigate** the effects of agricultural run-off on the corals of the Great Barrier Reef. Tabulate your findings under the headings:

- Types of run-off
- Effects on coral organisms
- Effects on other reef organisms.

**Generate** a short report using this data to predict the long-term effects on this significant ecosystem if changes to current agricultural practices are not implemented. Taking natural climatic factors into account, **predict** some changes that could reduce this problem.

★★★ 22 a For your local area, **generate** a table showing likely sources of pollution and the types of pollutants originating from these sources.

b Use critical evaluation of your findings to **decide** methods to limit the most damaging source of pollution.

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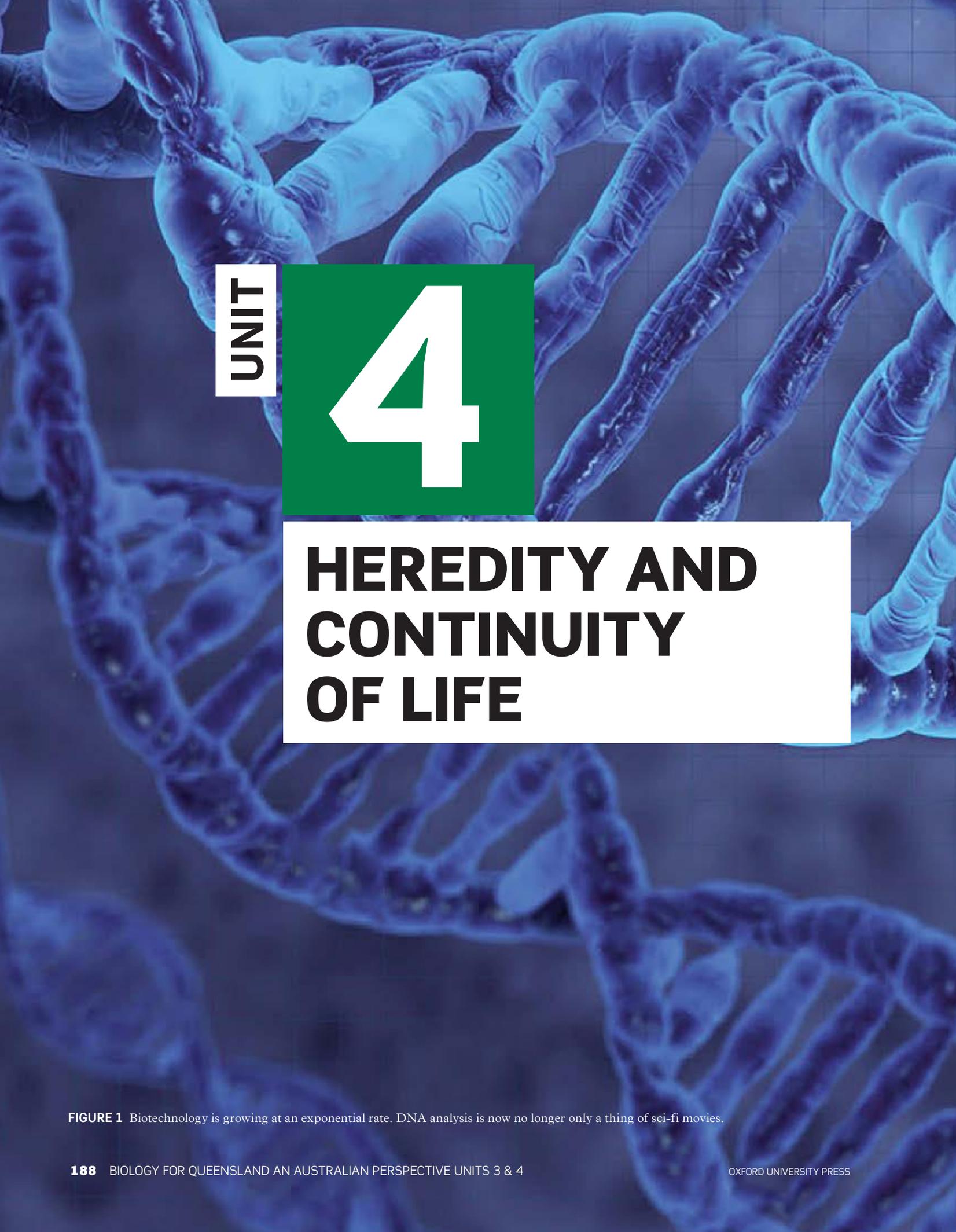
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**UNIT**

# 4

## **HEREDITY AND CONTINUITY OF LIFE**

**FIGURE 1** Biotechnology is growing at an exponential rate. DNA analysis is now no longer only a thing of sci-fi movies.

Deoxyribonucleic acid (DNA) is the molecule that carries the genetic code of the majority of organisms. The actual genes inherited from parents (genotype) may differ from the way an individual appears (phenotype). An understanding of the structure and action of the DNA molecule has allowed the development of many technologies such as transgenic organisms (using recombinant DNA), identification of species and individuals, and genetic screening for disease and drug production.

The DNA molecule and its ability to mutate and pass variations on to offspring is the basis for evolution.

Fossil evidence has shown emergence and extinction of species over time. Organisms with a phenotype that suits them to a particular environment at a particular time have a greater chance of reproducing and passing on their genes to the next generation (i.e. natural selection occurs). Since the environment is never static, different phenotypes will be more successful than others at different time periods and in different places. These small changes accumulate over time. New species usually arise when gene flow between adjoining populations is prevented by geographic or intrinsic isolating mechanisms.

## Unit 4 - Topics

Topic 1	DNA, genes and the continuity of life	Chapters 7–12
Topic 2	Continuity of life on Earth	Chapters 13–15

## Unit objectives

- Describe and explain DNA, genes and the continuity of life, and the continuity of life on Earth.
- Apply understanding of DNA, genes and the continuity of life, and the continuity of life on Earth.
- Analyse evidence about DNA, genes and the continuity of life, and the continuity of life on Earth.
- Interpret evidence about DNA, genes and the continuity of life, and the continuity of life on Earth.
- Investigate phenomena associated with DNA, genes and the continuity of life, and the continuity of life on Earth.
- Evaluate processes, claims and conclusions about DNA, genes and the continuity of life, and the continuity of life on Earth.
- Communicate understandings, findings, arguments and conclusions about DNA, genes and the continuity of life, and the continuity of life on Earth.

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# DNA STRUCTURE AND REPLICATION

The model of the structure of the DNA double-helix molecule as proposed by Watson and Crick was based on chemical analyses undertaken by Franklin and Wilkins. This model has stood the test of time and explains how DNA can be replicated and transmitted from one cell or generation to the next.

## OBJECTIVES

- Recall the structure of DNA, including:
  - nucleotide composition
  - complementary base pairing
  - weak, base-specific hydrogen bonds between DNA strands.
- Understand that deoxyribonucleic acid (DNA) is a double-stranded molecule that occurs bound to proteins (histones) in chromosomes in the nucleus, and as unbound circular DNA in the cytosol of prokaryotes, and in the mitochondria and chloroplasts of eukaryotic cells.
- Explain the role of helicase (in terms of unwinding the double helix and separation of the strands) and DNA polymerase (in terms of formation of the new complementary strands) in the process of DNA replication. Reference should be made to the direction of replication.

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## SUGGESTED PRACTICAL



SUGGESTED  
PRACTICAL

7.1 Extraction of DNA from strawberries



**FIGURE 1** The double helix structure of DNA is the building block for all life on Earth and even influences architecture such as the Helix bridge in Singapore.

# 7.1

## The chemical structure of nucleic acids

### KEY IDEAS

- ✦ DNA has a ribose sugar–phosphate backbone with complementary nucleotide bases bonded together with hydrogen bonds
- ✦ DNA is double stranded with a deoxyribose sugar and four nucleotides
- ✦ RNA is single stranded with a ribose sugar and four nucleotides

### deoxyribonucleic acid (DNA)

thread-like chain of nucleotides carrying the genetic instructions in a double helix of antiparallel strands

### ribonucleic acid (RNA)

thread-like chain of nucleotides carrying the genetic instructions for forming a protein in a cell

### sugar–phosphate backbone

the structural framework of nucleic acids, composed of alternating sugar and phosphate groups

### condensation polymerisation

the formation of a polymer by the reaction between two monomers, with the loss of a small molecule (e.g. water)

Nucleic acids are the macromolecules (large molecules) that make up the genetic material of all living organisms. There are two types of nucleic acids: **deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA)**. Each nucleic acid strand is a chain of nucleotides that consists of a sugar (5C) ring, a phosphate and a nitrogen base. The phosphate of one nucleotide forms a strong covalent bond with the sugar ring of the next nucleotide to form a continuous polymer chain. This chain is called the **sugar–phosphate backbone** of the nucleic acid. The chemical reaction that joins the nucleotides together is called **condensation polymerisation** because water is produced (condensed) when the nucleic polymer is formed (polymerised).

DNA is often called the ‘blue print of life’. It is responsible for structural features and all cell activities through coding for proteins. DNA is also responsible for passing on genetic information during reproduction, and during cell replication.

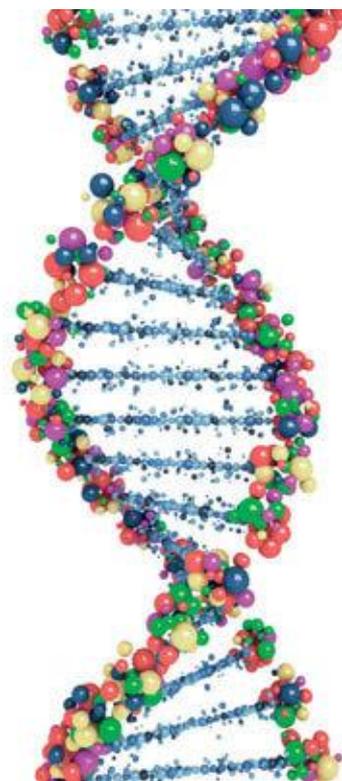
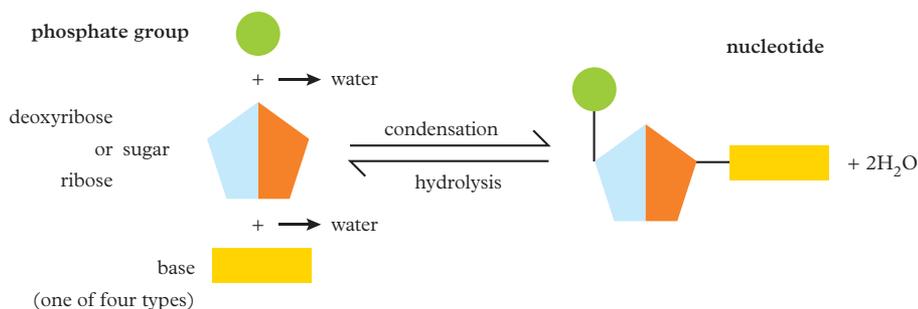


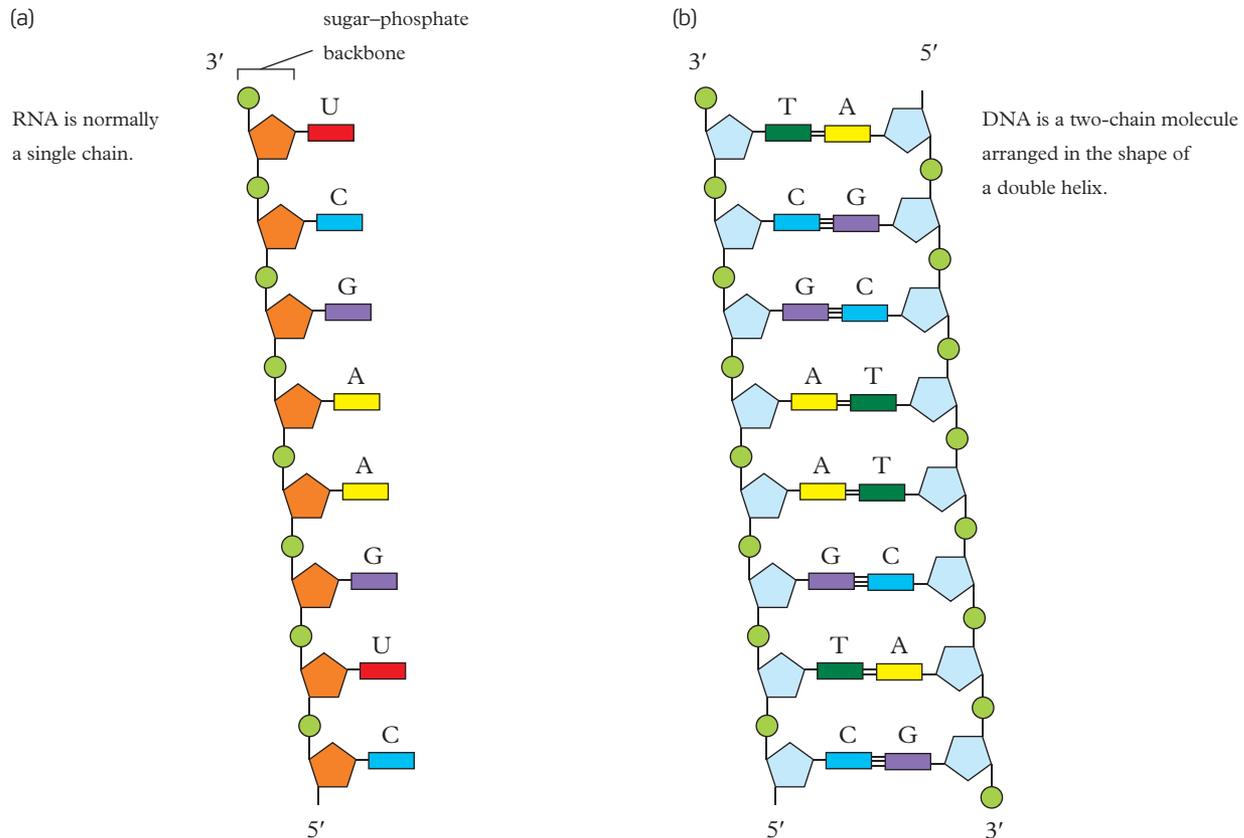
FIGURE 1 3D model of the double helix



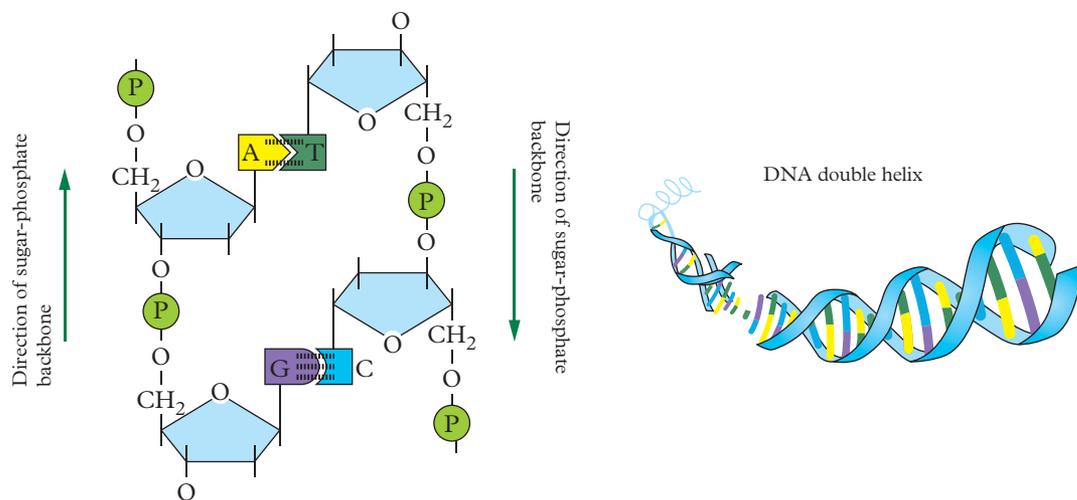
DNA = A, T, C, G

RNA = A, U, C, G

**FIGURE 2** A nucleotide contains a pentose sugar that is made of carbon atoms. The phosphate group is connected to the fifth carbon atom (5′). The phosphate group attaches to the third carbon atom (3′) on the adjoining nucleotide.



**FIGURE 3** Individual nucleotides bond together in a condensation polymerisation reaction to form sugar-phosphate backbones. (a) RNA; (b) DNA



Purines: A = adenine; G = guanine  
Pyrimidines: T = thymine; C = cytosine

**FIGURE 4** DNA consists of antiparallel strands of nucleotides with a sugar-phosphate backbone and complementary nitrogen base pairs.

DNA and RNA differ in several ways. The sugar in DNA is deoxyribose, whereas the sugar in RNA is ribose. The RNA molecule is most commonly composed of a single strand of nucleotides, whereas that of DNA consists of two strands held together by the pairing of

### Study tip

A polymer is a long chain of repeating chemical units called monomers. It can be visualised as a necklace of identical monomer beads linked together.

### antiparallel

two biopolymers that run parallel to each other but with opposite alignments, e.g. the two strands of the DNA molecule

### Study tip

The different types of RNA are written as mRNA, tRNA and rRNA, with lowercase letters defining each type.

the nitrogen bases between adjacent strands. The two strands are **antiparallel**, meaning that that one strand starts with a (3') sugar, while the other strand is facing the opposite direction and has a (5') phosphate at the end. This gives a ladder-like structure to the DNA molecule, which twists on its axis, forming a double helix.

There are five different types of bases found in nucleic acids. In DNA these bases are adenine, guanine, thymine and cytosine. In RNA, the thymine is replaced by uracil. Each base has a particular type of structure and linking of atoms. Adenine and guanine (purines) are similar in structure, and thymine, cytosine and uracil (pyrimidines) are similar. The structure of guanine is complementary to that of cytosine, forming three (relatively weak) hydrogen bonds between the two molecules. Similarly, the nitrogen base adenine is complementary to either thymine (DNA) or uracil (RNA). In DNA, the adenine on one strand will form two hydrogen bonds with the thymine on the complementary strand.

Because only these combinations of bases (adenine–thymine, cytosine–guanine) can form hydrogen bonds, the two strands of the DNA molecule are always complementary strands.

There are three major types of RNA: messenger (m), transfer (t) and ribosomal (r) RNA, all of which are involved in translating the DNA code into the proteins that are needed by the cell.

TABLE 1 Comparison of DNA and RNA

Feature	DNA	RNA
Sugar	deoxyribose	ribose
Bases	adenine, thymine, guanine, cytosine	adenine, uracil, guanine, cytosine
Chains	double	usually single

## CHECK YOUR LEARNING 7.1

### Describe and explain

- 1 **Identify** the three components of a nucleotide.
- 2 **Identify** the differences in structure between DNA and RNA.
- 3 **Explain** the functions of nucleic acids.
- 4 Figure 4 shows part of a polynucleotide strand.
  - a **Identify** the chemical groups labelled X, Y and Z.
  - b **Explain** which nitrogen base pairs with thymine in DNA.
  - c **Explain** how the bases of the two adjacent strands of DNA are held together.

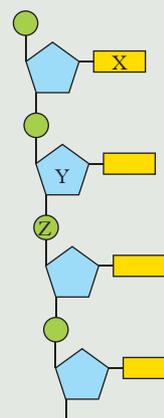


FIGURE 4 Part of a polynucleotide strand



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7.1 Extraction of DNA from strawberries

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RNA

# 7.2

## The chemical structure of DNA

### KEY IDEAS

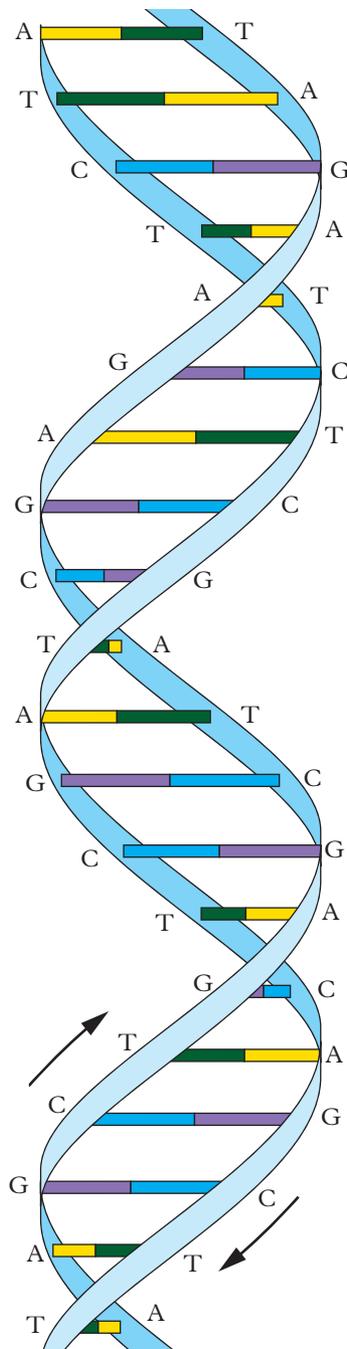
- ✦ DNA winds around histone proteins
- ✦ Nucleosomes are DNA–histone complexes
- ✦ Prokaryotic chromosomes are double stranded, circular strands of DNA
- ✦ Eukaryotic chromatin can be wound tightly to form linear paired chromosomes
- ✦ Molecular units of heredity

#### nucleosome

a length of DNA coiled around a core of eight histone protein molecules

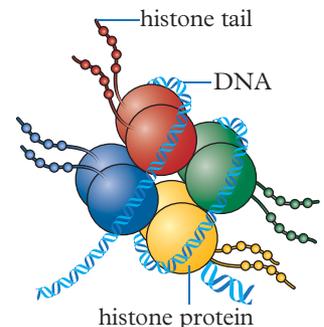
#### epigenetic factors

a chemical tag that determines the degree of coiling of the DNA around the nucleosome and thus gene expression



The average human cell contains almost two metres of DNA. To organise the DNA and prevent it from tangling, each DNA strand is wound, at intervals, one and three-quarter times around eight proteins called histones forming a DNA–histone complex called a **nucleosome**. Molecules of DNA may contain millions of nucleotides. The two chains of each strand are base-paired and fully complementary throughout the entire DNA molecule. The eight histone proteins have chemical tails that are exposed. The tails can be chemically modified by binding with **epigenetic factors** so that the nucleosome tails are tied to each other. This locks away the DNA (chromatin) so that it cannot be copied to make protein. If the DNA needs to be copied (DNA synthesis) or make a protein (gene expression), the histone tails are freed and drawn into the histone protein (and so are not in contact with the tails of other nucleosomes).

Before a cell can divide, the DNA needs to be replicated. This occurs in the later stages of the interphase period of the cell cycle (Unit 1, Section 5.2). This means there will be a total of 4 metres of DNA in the soon-to-be-divided cell. To prevent tangling or breaking of the DNA, the DNA–histone components begin to coil even more closely together. As the coiling becomes tighter and tighter the chromatin becomes shorter and this tightly coiled DNA–histone complex forms a chromosome. This is important in both mitosis and meiosis.

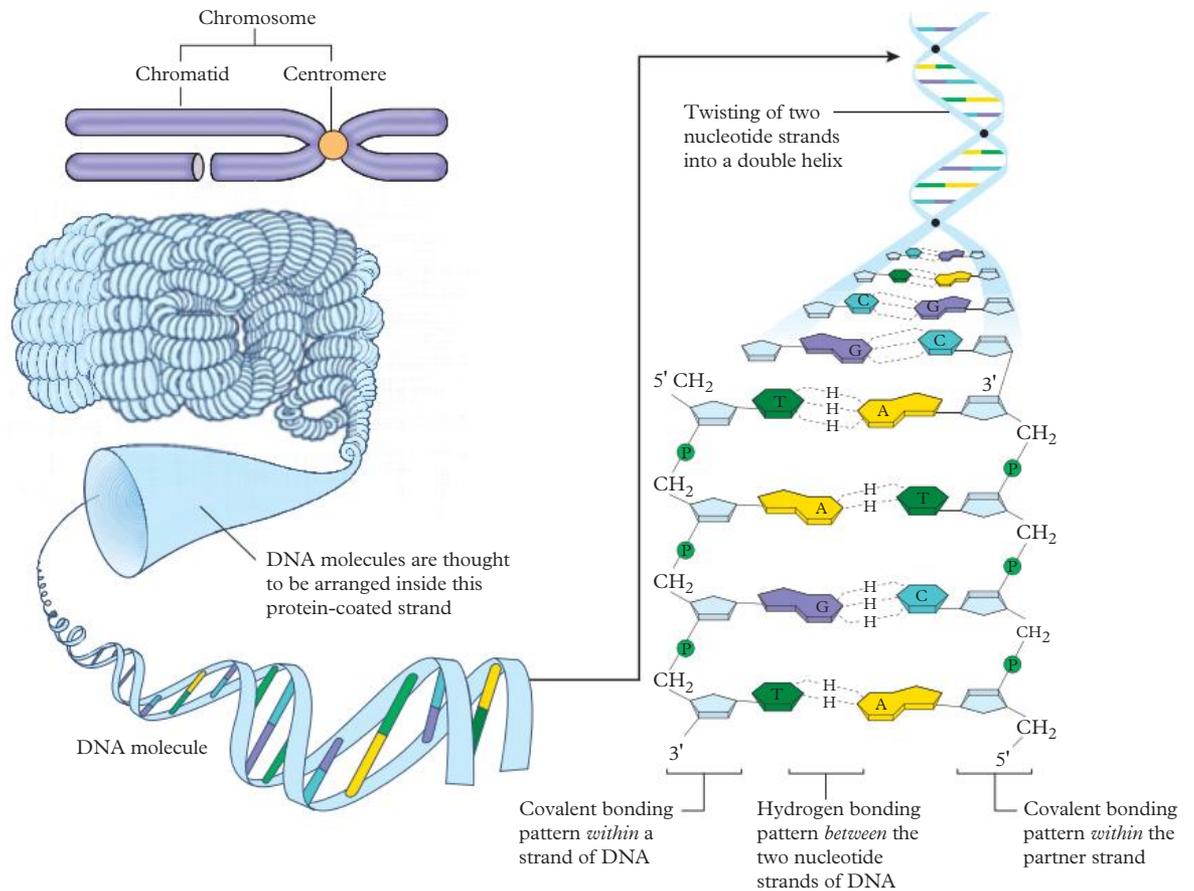


#### DNA bases

Adenine	Thymine
Guanine	Cytosine

FIGURE 1 The DNA molecule

FIGURE 2 Model of the DNA–histone complex (nucleosome).



**FIGURE 3** Coiling of the DNA helix.

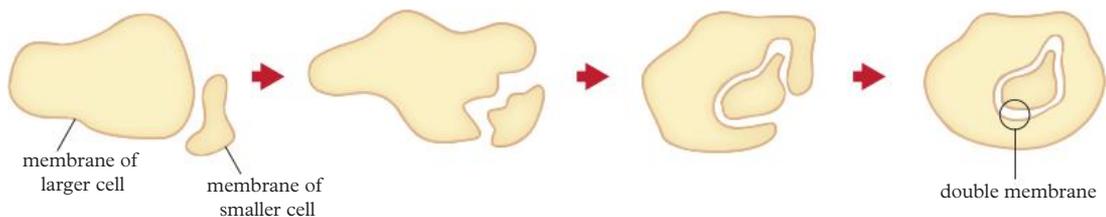
## Prokaryotic chromosomes

Prokaryotes do not have a nucleus. Instead their genetic material is a single chromosome (made of DNA) that floats freely in the liquid cytosol of the cell. The DNA is:

- circular, double stranded
- not bound to histone proteins.

## Mitochondrial and chloroplast genetic material

Like prokaryotes, mitochondria and chloroplasts have their own genetic material. Similar to prokaryotes, the DNA found in these organelles is circular, double stranded and not bound to histones. The similarities in DNA structure that exist in prokaryotes, mitochondria and chloroplasts contribute to the evidence that supports the endosymbiotic theory for the formation of eukaryotic cells.



**FIGURE 4** Endosymbiosis resulting in organelles

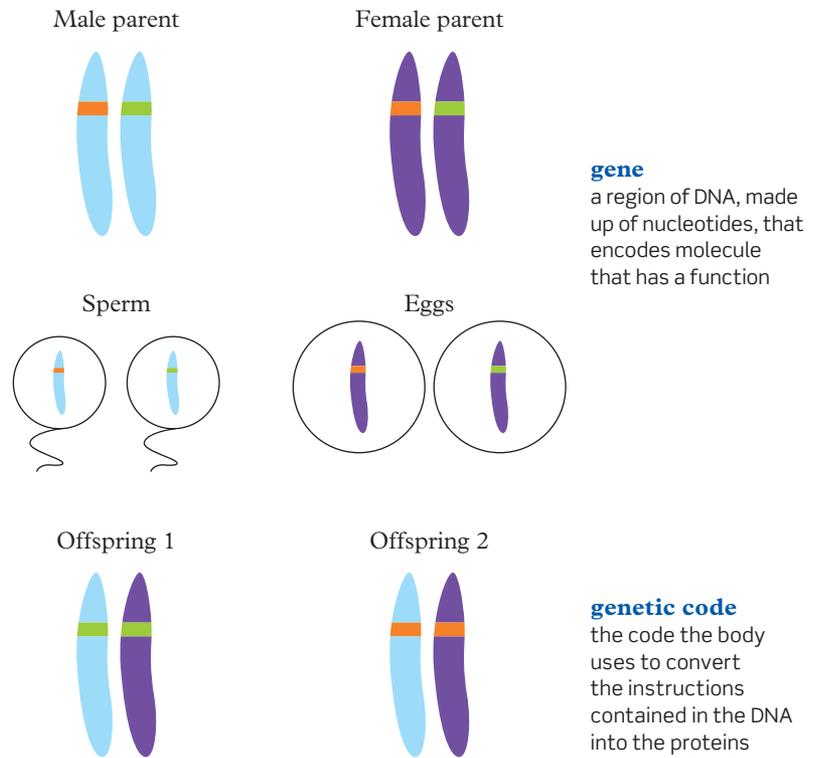
## Eukaryotic chromosomes

In eukaryotes, the DNA is present in chromosomes that are in linear pairs (diploid) and arise through sexual reproduction. One chromosome of each pair comes from the male parent via the sperm and the other from the female parent via the ovum. When the two sets of chromosomes are combined (fertilisation), a zygote is formed. This develops into an individual by repeated cell division and differentiation. The number of chromosome pairs present in the cells of an individual depends on the species.

## Genes

Each DNA molecule is made up two strands of paired nucleotides (nitrogen base pairs). Short segments of these paired nucleotides (from 200 to 2 000 000 base pairs) have a specific function and are called **genes** (the units of heredity). Although all of the DNA is made up of the four key nucleotides (adenine, thymine, cytosine and guanine), the order of these nucleotides along the length of each DNA molecule differs from chromosome to chromosome and from species to species.

Each chromosome contains a number of different genes that can carry the code for different proteins. These differences account for variations within and between species. The total number of genes in each cell represents the organism's **genetic code**. Each species has a different code. The DNA molecule is therefore responsible for transmission of the genetic code from one generation to the next and for controlling the actions of the cell through protein synthesis.



**FIGURE 5** Each person inherits half their chromosomes from their female parent and half from their male parent.

### CHECK YOUR LEARNING 7.2

#### Describe and explain

- Describe** a nucleosome.
- Explain** the difference between chromatin threads and chromosomes.
- Describe** the difference(s) between the DNA found in prokaryotes and eukaryotes.
- Explain** how the differences observed between species are related to nucleotide sequences.

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Prokaryotic chromosomes

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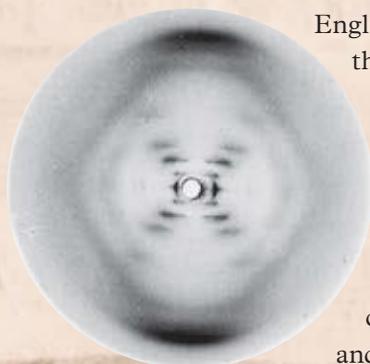
Eukaryotic chromosomes

## 7.3

## The development of the double-helix model

## KEY IDEAS

- ✦ The double-helix model and James Watson, Francis Crick, Rosalind Franklin and Maurice Wilkins.

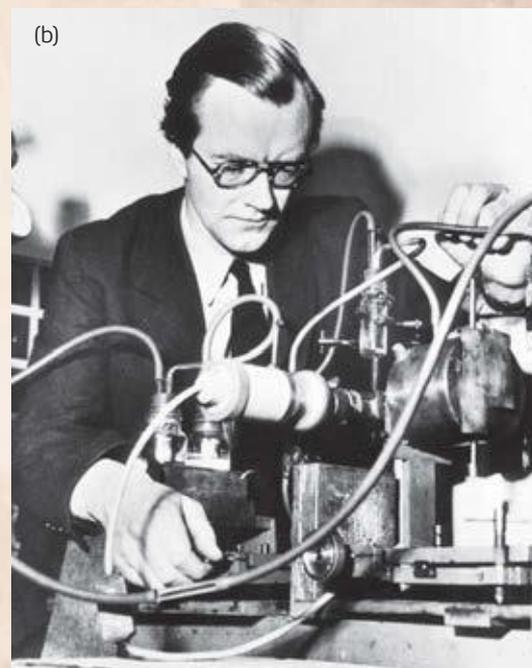


**FIGURE 1** The X-ray crystallography that provided a clue to the double-helix nature of DNA

English biochemists Rosalind Franklin and Maurice Wilkins spent many years analysing the DNA molecule using crystallographic studies. By 1935, Franklin determined the components and their proportions in the molecule and from X-ray diffraction images stated that DNA was a helix.

American geneticist James Watson had previously worked with eminent chemist Linus Pauling, who had been studying DNA structure. Pauling (working with dried DNA) thought the molecule was triple stranded, but Franklin (working with fresh DNA) found it was double stranded. By 1950, it was also known from work done by Erwin Chargaff that the four nitrogen bases, adenine, cytosine, thymine and guanine, always show up in paired proportions – the same proportion of adenine as thymine, and cytosine as guanine.

Watson travelled to the United Kingdom and started working with Francis Crick, a physicist at Cambridge University. Without Franklin's knowledge, Wilkins passed on her findings to them. Watson and Crick never did experiments themselves. Instead they re-interpreted other people's data. As a result, they were able to determine the double-helix structure of DNA in 1953. Franklin died of cancer in 1958.



**FIGURE 2** Rosalind Franklin (a) and Maurice Wilkins (b) were involved in the development of the structure of DNA.

Watson, Crick and Wilkins were awarded a Nobel Prize for this finding in 1962. Posthumous Nobel Prize awards are not granted and so Franklin was not credited for her massive contribution in her lifetime or after her death. A few years later Watson and Crick, with contributions from George Gamow, explained the sequence of protein synthesis from DNA to mRNA to protein.

The working model of the DNA molecule that was formulated by Watson and Crick was achieved by the incorporation of X-ray crystallography to a vast array of known data on the chemical constituents they had studied.

They discovered that DNA is a complex molecule consisting of three units:

- a five-carbon sugar (deoxyribose)
- phosphate groups
- bases containing nitrogen.

The three parts combine to form subunits called nucleotides, each nucleotide being named according to the base it contains. The phosphate group on one nucleotide forms a strong covalent bond with the ribose sugar on another nucleotide. This forms the sugar-phosphate backbone of the molecule.

The DNA model proposed by Watson and Crick is built like a ladder, consisting of two strands of nucleotides joined together. The uprights are composed of the sugar and phosphate parts of the nucleotides, and the rungs are the nitrogen bases (adenine paired with thymine, cytosine paired with guanine). The entire structure is twisted around a common central axis, forming a double helix.



**FIGURE 3** James Watson and Francis Crick with their DNA model at Cavendish Laboratories in 1953.

### CHECK YOUR LEARNING 7.3

#### Describe and explain

**1 Describe** the contribution each of the following scientists made to the identification of the structure of DNA.

- |                            |                         |
|----------------------------|-------------------------|
| <b>a</b> Rosalind Franklin | <b>c</b> Francis Crick  |
| <b>b</b> James Watson      | <b>d</b> Erwin Chargaff |
| <b>e</b> Maurice Wilkins   |                         |

**2 Describe** a scientific model.

**3 Determine** what facts Watson and Crick hoped to explain by constructing a model of DNA. Did they succeed?

#### Investigate, evaluate and communicate

**4** Many people argue that Rosalind Franklin should have been awarded a Nobel Prize along with James Watson, Francis Crick and Maurice Wilkins. **Consider** why the Nobel committee did not award her one and **discuss** your own thoughts on their decision.

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Rosalind Franklin

» **Weblink**

Maurice Wilkins



# 7.4

## Replication of DNA

### KEY IDEAS

- + DNA replication is semiconservative
- + DNA helicase unwinds DNA and separates hydrogen bonds
- + DNA polymerases are enzymes that bond new nucleotides to the 3' end
- + The leading strand of DNA forms a continuous strand of new DNA
- + The lagging strand of DNA forms in a series of Okazaki fragments joined together by DNA ligase

### DNA helicase

an enzyme that breaks down the hydrogen bonds holding two DNA strands together

### semiconservative replication

replication of DNA resulting in two copies that each contain one of the original strands and one new strand

### 3' (three-prime) end

one end of a DNA strand in which the C<sub>3</sub> carbon atom of the sugar molecule in the DNA's sugar backbone has a 'free' OH (hydroxyl) group that is not linked to another chemical group

### 5' (five-prime) end

one end of a DNA strand in which the C<sub>5</sub> carbon atom of the sugar molecule in the DNA's sugar backbone has a 'free' phosphate group that is not linked to another chemical group

### DNA polymerase

a type of enzyme that is responsible for assembling nucleotides to form new copies of DNA

DNA replication occurs in four main steps:

- separation of DNA strands
- initiation
- elongation
- termination.

All of these steps involve complex enzyme-controlled and coordinated processes.

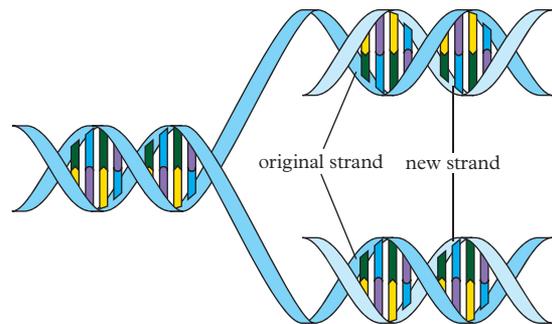


FIGURE 1 Semiconservative replication of DNA

## Separation of DNA strands

In the interphase period, before a cell can divide, enough chemicals must be accumulated to make more nucleotides available for DNA replication. Before replication can happen, the DNA must first be unwound and unzipped by an enzyme called **DNA helicase**. This enzyme separates the two strands of parent DNA by breaking the hydrogen bonds between the nitrogen bases. Other enzymes (DNA polymerases) start moving along generating new DNA strands that are complementary to the 'original' template strands.

This DNA replication is termed **semiconservative replication** because each replicated DNA contains one strand of the original DNA and one new strand. Free nucleotides, which are formed in the cytoplasm, pass through the pores of the nuclear membrane to be available for DNA replication (or the formation of messenger RNA for protein synthesis). A variety of cellular processes occur to prevent mutations or mistakes in replication. These involve proofreading and error checking to ensure that replicated DNA are exact copies of the parent DNA.

From Figure 2, it can be seen that the two DNA strands have directionality. Each strand has a **3' (three-prime) end**, named after the C<sub>3</sub> carbon atom of the sugar molecule that has a 'free' OH (hydroxyl) group that is not linked. The opposite end of each strand ends in a **5' (five-prime) end**, named after the C<sub>5</sub> carbon atom of the sugar molecule that is linked to the phosphate. Each nucleotide on the complementary strand is reversed. The strands of the double helix therefore run from 3' to 5' on the left strand and from 5' to 3' on the opposite strand – they are antiparallel. This directionality is important in DNA replication because the enzyme **DNA polymerase** can only synthesise DNA in one direction, by adding nucleotides to the 3' end of the template DNA.

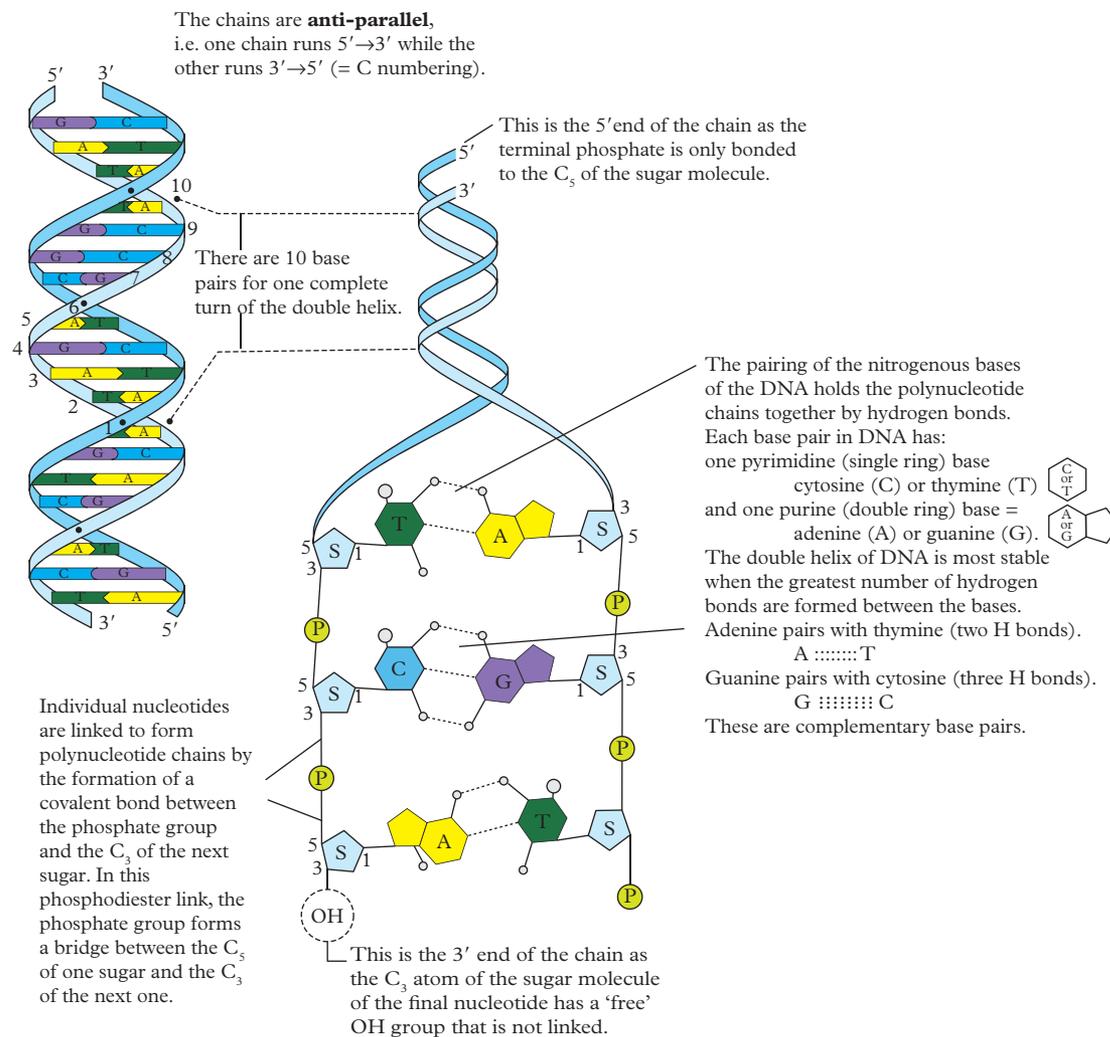


FIGURE 2 The structure of DNA

## Initiation

Initiation does not start at one end of the double-helix strand and finish at the other end.

There are particular initiation points, which are termed the **origins of replication**, all along the strands. These are targeted as the origin points for unzipping DNA to start replication.

The DNA helicase enzymes attach at these origin points, unzipping and unwinding the DNA by breaking the hydrogen bonds holding the two DNA strands together. The two released DNA strands provide original templates of DNA from which the new complementary strands can be formed. The unzipped DNA forms a **replication fork**, which moves apart (in two directions) forming a **replication bubble**. This means that there can be many sections of the DNA replicating at once, thus speeding up the process.

## Study tip

Everything always happens at the 3' end. The primer and then the DNA polymerase binds to the 3' end of the original strand and attaches a complementary nucleotide. Any new nucleotides are then added on to the 3' end of the previous nucleotide, synthesising the new strand of DNA from 5' to 3'.

### origin of replication

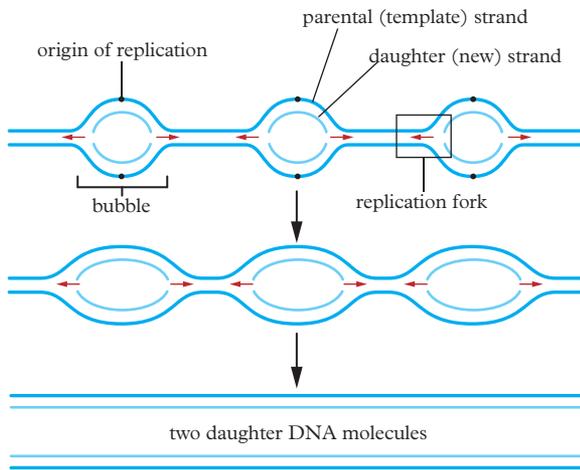
a particular sequence in the DNA molecule at which replication is initiated

### replication fork

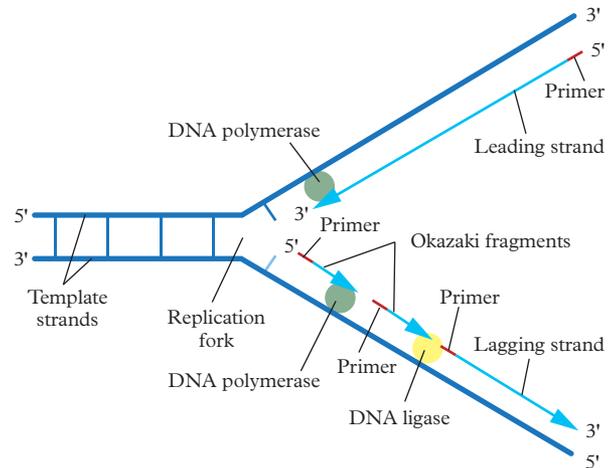
structure with two branching sections that is created when DNA helicases break the hydrogen bonds holding the two DNA strands together at a certain point

### replication bubble

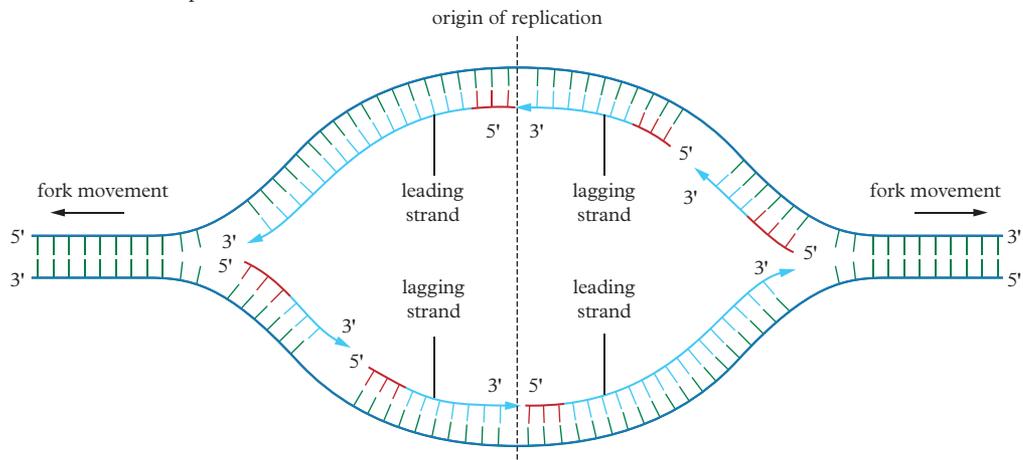
an unwound and open region of DNA in which DNA replication occurs, created when the enzyme DNA helicase separates the two strands of DNA



**FIGURE 3** Points of origin in DNA replication showing replication bubbles and the resultant semiconservative replication



**FIGURE 4** Schematic diagram of a replication fork



**FIGURE 5** A replication bubble

### leading strand

DNA template from the middle of the replication bubble (point of origin) to the fork

### lagging strand

DNA template from the fork to the middle of the replication bubble (point of origin)

### Okazaki fragments

fragments of DNA that are formed on the lagging strand of replicating DNA

### DNA ligase

a specific type of enzyme that facilitates the joining of DNA strands together

## Elongation

Before DNA replication can occur, an RNA primer (a short strand of RNA) must bind to the starting point of replication. This occurs at set recognition points along the DNA template strands. DNA polymerase can only add new nucleotides to the 3' end of the previous nucleotide. This means the formation of the new complementary DNA strand will start from the 3' end of the RNA primer and move in opposing directions for each DNA template.

The **leading strand** of DNA is always formed from the middle of the fork. The DNA polymerase starts adding new nucleotides to the 3' end of the RNA primer. This allows it to continuously extend the new complementary DNA molecule from the primer (it leads the way).

The **lagging strand** is formed from the fork towards the centre of the bubble. It receives several RNA primers, starting at the replication fork on the 3' side. Since the DNA polymerase starts adding the complementary nucleotides to the 3' end of the primer, the new strand of DNA is replicated in the opposite direction to the leading strand. The DNA polymerase extends short sections of DNA from each primer, generating fragments of DNA called **Okazaki fragments**. These fragments appear to 'lag behind' the leading strand. When the Okazaki fragments cover the whole length of the lagging strand template, the RNA primers are then removed and replaced with DNA by an enzyme called **DNA ligase**.

# Termination

The termination of DNA replication occurs when the replication fork is stopped or blocked. This occurs when a special protein binds to the **termination sequence** site in the DNA. The result of replication is two DNA strands that are exactly like the original.

In many cases, the two identical double-stranded DNA molecules remain joined by the centromere, a special kinetochore protein. This produces the X-shaped bivalent chromosome (with two chromatids) that is seen during mitosis and meiosis (Chapter 8).

**termination sequence**  
a section of a nucleic acid sequence that marks the end of a gene or replication site

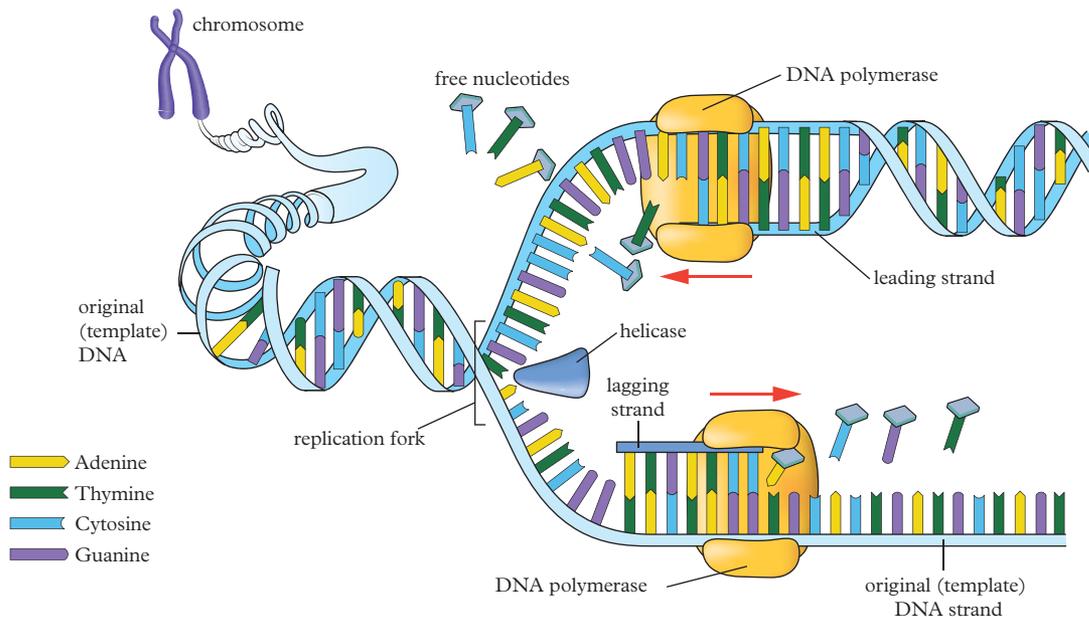


FIGURE 6 DNA replication

## CHECK YOUR LEARNING 7.4

### Describe and explain

- Sketch** a segment of a molecule of DNA that is sixteen base pairs long.
  - Describe** how this segment of a DNA molecule replicates.
  - Explain** why this process is necessary.
  - Describe** what would happen during mitosis if this process did not occur.
- Describe** a replication bubble.
- Explain** why the different strands of replicating DNA are called lagging or leading in a replication bubble.
- Explain** how the presence of replication bubbles speed up the process of DNA replication.
- Describe** the role of the following enzymes in DNA replication.
  - DNA helicase
  - DNA polymerase
  - DNA ligase

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» **Weblink**  
Elongation

» **Weblink**  
Termination



# Review

## Chapter summary

- 7.1**
  - The structure of DNA consists of a ribose sugar–phosphate backbone with complementary nucleotide bases bonded together with hydrogen bonds.
  - DNA is double stranded with a deoxyribose sugar and four nucleotides (thymine, adenine, guanine and cytosine).
  - RNA is usually single stranded with a ribose sugar and four nucleotides (uracil, adenine, guanine and cytosine).
- 7.2**
  - DNA winds around eight histone proteins to form a DNA–histone complex, each of which is called a nucleosome.
  - Nucleosomes can be bound tightly together by epigenetic factors.
  - Prokaryotic chromosomes (like those of chloroplasts and mitochondria) are double stranded, circular strands of DNA (without histones) found in the cytoplasm.
  - Eukaryotic chromatin can be wound tightly to form linear paired chromosomes when a cell divides.
  - A gene contains a specific nucleotide sequence that forms a molecular unit of heredity.
- 7.3**
  - The development of the double-helix model was made through the contributions of James Watson, Francis Crick, Rosalind Franklin and Maurice Wilkins.
- 7.4**
  - DNA replication is semiconservative (one original strand and one newly formed strand).
  - DNA helicase unwinds DNA and separates the hydrogen bonds that join the double strands of DNA.
  - DNA polymerases are enzymes that bond new nucleotides to the 3' end of an existing nucleotide polymer.
  - The leading strand of DNA is able to form a continuous strand of new DNA.
  - The lagging strand of DNA forms in a series of Okazaki fragments that must be joined together by DNA ligase.

## Key terms

- 3' (three-prime) end
- 5' (five-prime) end
- antiparallel
- condensation polymerisation
- deoxyribonucleic acid (DNA)
- DNA helicase
- DNA ligase
- DNA polymerase
- epigenetic factors
- gene
- genetic code
- lagging strand
- leading strand
- nucleosome
- Okazaki fragments
- origin of replication
- replication bubble
- replication fork
- ribonucleic acid (RNA)
- semiconservative replication
- sugar–phosphate backbone
- termination sequence

## Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: ★ = low; ★★ = medium; ★★★ = high.

### Multiple choice

- A chromosome is composed of:
  - a double chain of DNA forming a spiral strand, composed of sugars, phosphates and nitrogen bases
  - two chains of nucleotides linked by hydrogen bonds to form a double helix of DNA
  - a protein (histone) wound around a strand of DNA
  - a condensed strand of DNA–histone complex
- Figure 1 represents a portion of a \_\_\_\_\_ molecule.

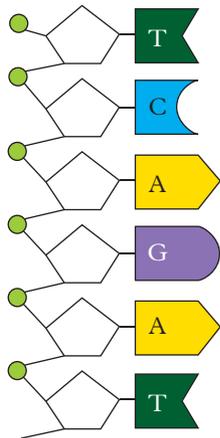


FIGURE 1 Molecule

- double-stranded RNA
  - single strand of RNA
  - single strand of DNA
  - protein
- A nucleotide always consists of:
    - a pentose sugar and the nitrogen base guanine
    - a triose sugar, phosphate and a nitrogen base
    - a pentose sugar, phosphate and a nitrogen base
    - a pentose sugar, phosphate and the nitrogen base thymine
  - In a formation of a nucleotide:
    - the sugar bonds with a nitrogen base and with a phosphate by condensation polymerisation
    - the phosphate bonds with a sugar and nitrogen base by condensation polymerisation
    - hydrogen bonds form between the sugar, nitrogen base and phosphate in any order
    - bonds between the sugar and phosphate form by condensation polymerisation
  - In eukaryote cells:
    - the DNA is found as chromosomes in the non-dividing cells
    - nucleosomes are composed of proteins
    - a DNA–histone complex is formed
    - chromosomes revert to chromatin by coiling around a group of eight histone molecules
  - DNA of prokaryotes, chloroplasts and mitochondria is a:
    - single-stranded, straight molecule
    - double-stranded molecule bound by histone proteins
    - circular, double-stranded molecule bound by histone proteins
    - circular, double-stranded molecule not bound by histone proteins
  - Semi-conservative replication of DNA means that:
    - proofreading ensures no errors are ever made
    - each of the two DNA molecules formed is composed of an original strand and a new strand
    - all new strands of the DNA molecule start at the 3' end of one template and the 5' end of the complementary template
    - DNA ligase matches free nucleotides to the templates

8 During DNA replication the following events occur.

- i Winding brings about the formation of two double helices.
- ii Nitrogen bases of free nucleotides bond with complementary bases on the DNA chains.
- iii Hydrogen bonds break, allowing DNA strands to unzip.
- iv New nucleotides bond with the 3' end of new DNA strand.

The correct order in which these processes occur is:

- A 1, 3, 2, 4
- B 1, 2, 3, 4
- C 3, 2, 4, 1
- D 3, 4, 2, 1

9 The accompanying set of results shows the analysis of the DNA bases contained in the cells of a cow's pancreas.

% base composition			
X	guanine	Y	Z
28.2	21.5	21.2	27.8

Which of the following is a possible correct identification of these bases?

- |            |          |          |
|------------|----------|----------|
| X          | Y        | Z        |
| A cytosine | adenine  | thymine  |
| B thymine  | adenine  | cytosine |
| C adenine  | cytosine | thymine  |
| D cytosine | thymine  | adenine  |

10 A replication bubble refers to

- A one segment of unzipped DNA
- B a missed section of DNA that is not replicated.
- C the point of origin at which replication is initiated.
- D another term for an Okazaki fragment.

11 A structural gene is

- A that part of the genome that codes for the physical structure of an organism.
- B a segment of DNA that controls a specific characteristic.
- C a segment of DNA that regulates production of a specific protein.
- D an essential part of the chromosome that maintains its structure.

### Short answer

#### Describe and explain

- ★ 12 Describe the role of DNA polymerase in DNA replication.
- ★ 13 Explain what is meant by the 'antiparallel strands of DNA'.
- ★★ 14 Figure 2 is a model of an untwisted segment of DNA.  
Based on this figure:
  - a Identify and sketch a single nucleotide.
  - b Identify three observations that verify the structural constituency of DNA.

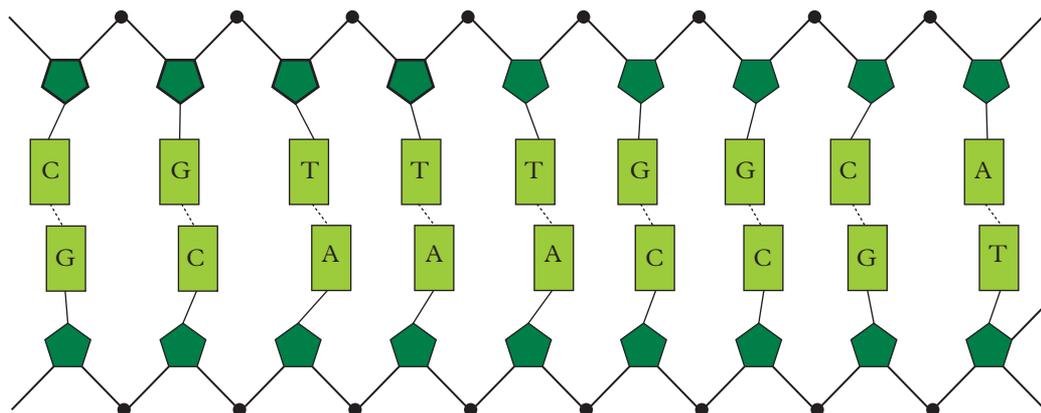


FIGURE 2 DNA

★★ 15 DNA is regarded as a genetic information keeper and a carrier. Briefly **describe** those features of DNA that enable it to:

- a serve as a keeper of genetic information
- b transmit identical information to cells produced as a result of mitosis.

**Apply, analyse and interpret**

- ★ 16 **Determine** how Okazaki fragments are formed.
- ★ 17 **Classify** the three steps of DNA replication.
- ★★ 18 **Determine** which form of replication occurs when the daughter DNA is formed from the replication of one original DNA strand and one synthesised strand.
- ★★ 19 **Deduce** how the double helix structure for DNA was determined.
- ★★ 20 **Differentiate** between the following pairs of terms
  - a gene and genetic code
  - b code and anti-codon
  - c DNA helicase and DNA polymerase

★★ 21 Analysis of a sample of DNA extracted from a tissue showed that 38% of the bases were adenine. **Determine** what percentage of the bases in the DNA would be guanine. Show how you arrived at your answer.

★★ 22 **Determine** what problem would arise with a DNA model that had nitrogen bases as the sides of the ladder and sugars and phosphates as the rungs.

**Investigate, evaluate and communicate**

★★★ 23 Bacterial cells were supplied with nutrients that contained radioactively labelled nitrogen. After division, the DNA strands of the daughter cells were found to contain labelled nitrogen. These daughter cells were then fed on normal food and, when they in turn divided, it was found that only half of the 'granddaughter' cells they produced contained DNA with radioactive nitrogen atoms. **Justify** an explanation for this finding.



FIGURE 3 DNA in test tubes

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# CELLULAR REPLICATION AND VARIATION

In sexually reproducing animals, sperm are produced in the testes by the process of spermatogenesis, and ova (eggs) in the ovaries by oogenesis. Both processes involve mitotic and meiotic cell divisions and are under hormonal control.

In order to maintain the correct number and types of chromosomes in each individual cell of a sexually reproducing species, the egg and sperm cells must contain a single copy of each chromosome. This is achieved by the process of meiosis in the gonads.

The genes carried on a specific chromosome are inherited together (linked). Alternative forms of a gene are termed alleles. The allele for a gene on one chromosome may be different from the allele on the homologous chromosome. The combination of the two alleles present is termed the genotype for that characteristic.

During meiosis I, adjacent chromatids of a pair of homologous chromosomes may intertwine and swap segments at one or more places. In this way recombination of genetic material can occur.

Several technologies have been developed to detect problems in embryos. A karyotype showing all the chromosomes of an individual can be used in species identification, determining gender or detecting chromosomal anomalies.

## OBJECTIVES

- Within the process of meiosis I and II:
  - recognise the role of homologous chromosomes
  - describe the processes of crossing over and recombination and demonstrate how they contribute to genetic variation
  - compare and contrast the process of spermatogenesis and oogenesis (with reference to haploid and diploid cells).
- Demonstrate how the process of independent assortment and random fertilisation alter the variations in the genotype of offspring.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

**FIGURE 1** Meiosis is a type of cell division that results in four daughter cells.

# 8.1

## Cell division and replication

### KEY IDEAS

- + Phases in meiosis
- + Homologous chromosomes and chiasmata
- + Formation of haploid cells
- + Formation of the karyotype
- + Uses of karyotypes

### homologous chromosomes

chromosomes of the same type; usually a pair

### diploid

cellular condition in which there are two of each type of chromosome present in the nucleus

### haploid

cellular condition in which there is one of each type of chromosome present in the nucleus

### mitosis

nuclear division resulting in daughter cells having the same number and type of chromosomes as the parent cell

### meiosis

nuclear division resulting in daughter cells having half as many chromosomes, but the same types, as the parent cell; a reduction division, from the diploid to the haploid condition

### chromatid

a replicated chromosome, still attached to the original at the centromere

Each species has a specific number of chromosomes, each carrying different sorts of genetic information. A dividing parent cell must ensure that the new cells have both the same number and the same types of chromosomes as the original.

Usually the cells of the adult organism contain pairs of chromosomes. There are two of each type of chromosome (e.g.  $2 \times$  chromosome 1), which carry the same kinds of genetic information. Pairs of matching chromosomes (that carry the same genes) are called homologous chromosomes. Cells that carry **homologous chromosomes** are said to be **diploid** (two complete sets of each chromosome) and are represented as  $2n$ , where  $n$  is the number of types of chromosomes. Each diploid cell has one set of chromosomes from the male parent (father) and one set from the female (mother). This means the sex cells from each parent (the egg and sperm cells) contain only one of each type of chromosome. These cells are described as **haploid** cells and are represented as  $n$ .

Cell division in eukaryotic cells is initiated by the division of the nucleus. Two types of nuclear division occur: mitosis and meiosis.

**Mitosis** takes place during the growth of an organism and is the basis of growth, repair, budding and vegetative propagation in multicellular organisms. It yields daughter cells that have the same number and types of chromosomes as the parent cell. This process was described in Chapter 5, Unit 1 of *Biology for Queensland An Australian Perspective Units 1 & 2*.

**Meiosis** generally takes place in the formation of gametes (sex cells – eggs and sperm), although in plants it occurs in the formation of spores. During sexual reproduction, a gamete from each of two different parents fuses to form the zygote, the start of a new individual. In order to maintain species continuity, the zygote must have the same number and types of chromosomes as the adults. This means the gametes must have half the number but the same types of chromosomes as an adult cell. During meiosis, therefore, diploid cells, each containing two sets of chromosomes, divide to form haploid cells with one set of each chromosome. When haploid cells fuse during fertilisation the diploid condition is restored and species continuity is assured.

## Interphase

Most cells spend a majority of their time (90%) carrying out their normal functions: producing protein, repairing damage, etc. This phase of their life is called interphase G1. Before a cell can divide through either meiosis or mitosis it must first replicate its DNA (Chapter 7). This is called the synthesis (S) phase of interphase. As a result of this process, there is twice the amount of DNA (as each DNA molecule has been replicated); however, the number of chromosomes (or chromatin) remains the same. This is due to the DNA being described as a single chromosome whether it is a single or bivalent (**chromatid**) molecule.

DNA synthesis (S phase) is followed by the G<sub>2</sub> phase of interphase during which there is further growth of the cell and replication of the organelles. After this the cell is ready to undergo the cell division of mitosis or meiosis.

## Meiosis

In meiosis, there are two successive divisions. The first (meiosis I) involves the separation of the pairs of bivalent chromosomes into separate cells and the second (meiosis II) involves separation of the sister chromatids, at the joining point called the centromere.

## Meiosis I

### Prophase I

During prophase I the nucleolus (place of ribosome production) disappears and the nuclear membrane breaks down as in mitosis. In animal cells the centrioles migrate to opposite poles (ends) of the cell and spindle fibres form. The bivalent chromosomes, each consisting of two chromatids joined at the centromere, become visible (condense). As they do so, they align themselves in pairs of homologous chromosomes. This can be seen by the paired chromosomes having identical lengths, positions of centromeres and location of genes (banding). Homologous chromosomes consist of four sister chromatids (Figure 1), which are termed a **tetrad**.

These chromatids may become very entwined and occasionally join together at points called **chiasmata**. At this point genetic material can be exchanged (crossing over) between the chromatids (see Figure 3, Section 8.3). This means the chromosome that originally came from the organism's father can exchange genes with the chromosome from the organism's mother. The significance of this will be discussed later in this chapter.

### Metaphase I

During metaphase I the homologous chromosomes arrange themselves along at the equator (middle) of the cell. The kinetochore proteins, which link the two chromatids together at the centromere, attach to the spindle fibres. Each homologous bivalent chromosome (containing two chromatids) aligns itself towards an opposite pole.

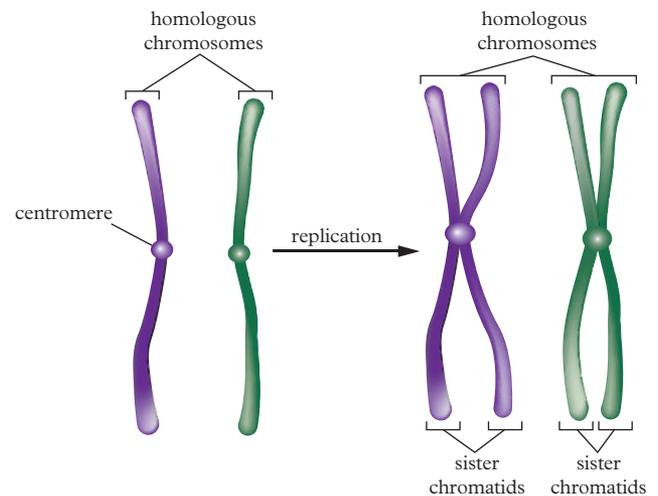
### Anaphase I

Contraction of the spindle fibres separates the homologous chromosomes and pulls them towards opposite poles of the cell. At each end of the cell there is one of each type of bivalent chromosome, each consisting of two chromatids.

### Telophase I and cytokinesis I

The cell divides across the equator of the spindle. The spindle fibres break down. The cell divides to form two complete cells. Some cells may then go into a short interphase or they may proceed directly to the second meiotic division. A nuclear membrane is not formed around the chromosomes at this stage.

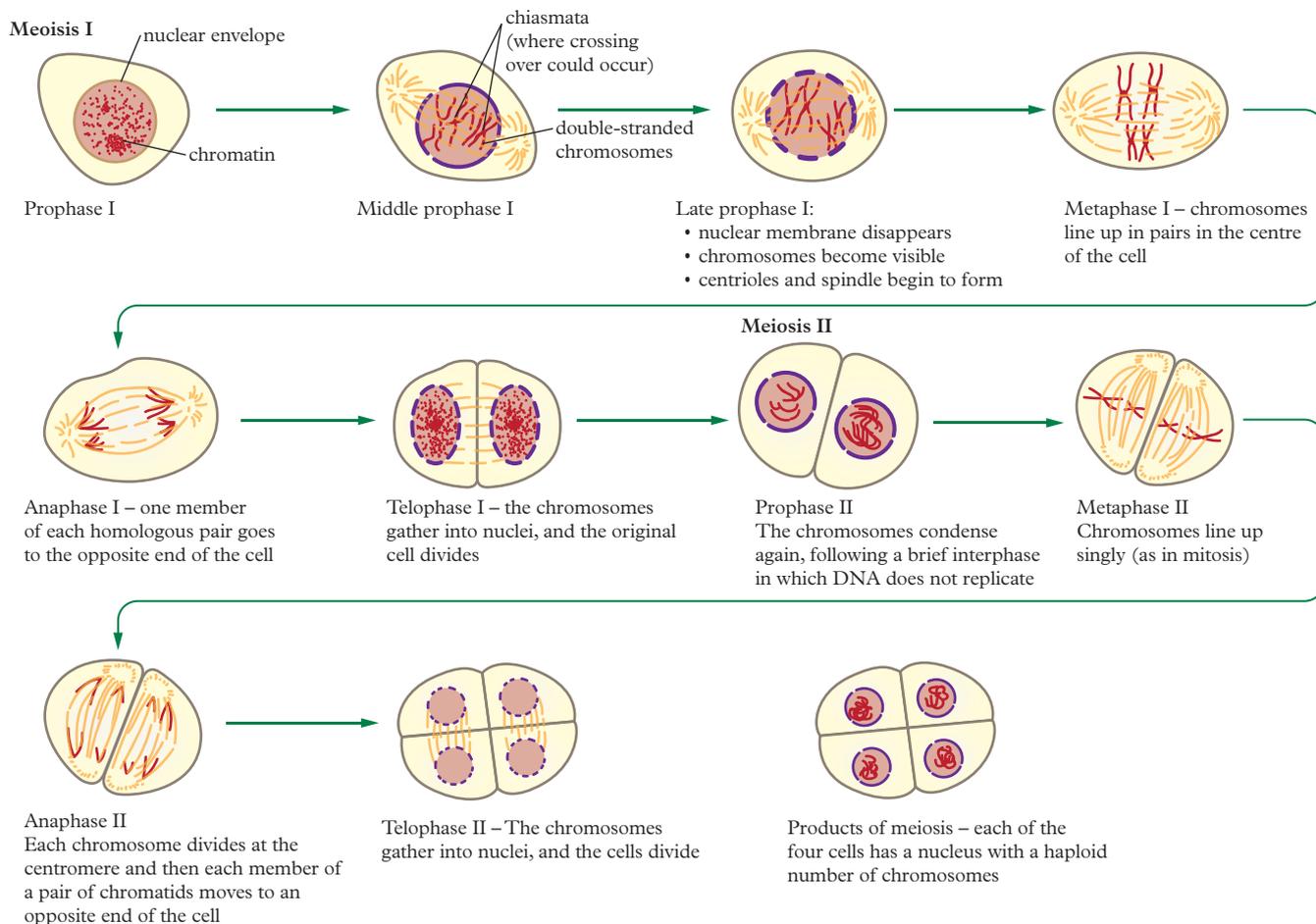
Each of these cells proceeds to meiosis II.



**FIGURE 1** Chromosomes may be single or bivalent (containing two sister chromatids).

**tetrad**  
homologous chromosomes, each consisting of two chromatids, lying side by side

**chiasma (plural chiasmata)**  
connection between non-sister chromatids of homologous chromosomes during meiosis, where interchange occurs during crossing over



**FIGURE 2** Stages of meiosis

## Meiosis II

### Prophase II

A new spindle is formed perpendicular to that of the original cell.

### Metaphase II

Individual chromosomes, each consisting of two chromatids, migrate to the equator of the spindle and attach at the kinetochore proteins that surround the centromeres.

### Anaphase II

Contraction of the spindle fibres separates the kinetochore protein and the chromatids separate at the centromere. Each sister chromatid is pulled to the opposite poles of the cell.

### Telophase II and cytokinesis II

The spindle fibres disappear, the cell divides across its equator and a new nuclear membrane is formed around the chromosomes.

Significant features of meiosis are:

- There are two successive divisions.
- The first division separates homologous chromosomes into separate cells.
- The second division, like mitosis, separates the chromatids into separate cells.
- Four haploid daughter cells are produced, each containing one complete set of chromosomes.

# Karyotype

A karyotype is a pictorial display of the total complement of a species' chromosomes. A photograph is taken of the specially prepared chromosomes. These are then enlarged and can be colour enhanced. In the karyotype of a normal non-dividing diploid cell, the chromosomes are cut out digitally and arranged with the autosomal chromosomes in pairs going from the largest to the smallest; the sex chromosomes are placed at the end. If done during prophase I, the position of the centromere, and therefore the length of the 'arms' of the chromatids, are used to identify the homologous pairs. This means a karyotype can be used to identify species, determine gender and detect certain anomalies, such as an extra chromosome or piece of chromosome. A karyotype can also be prepared of the haploid sperm and ovum.

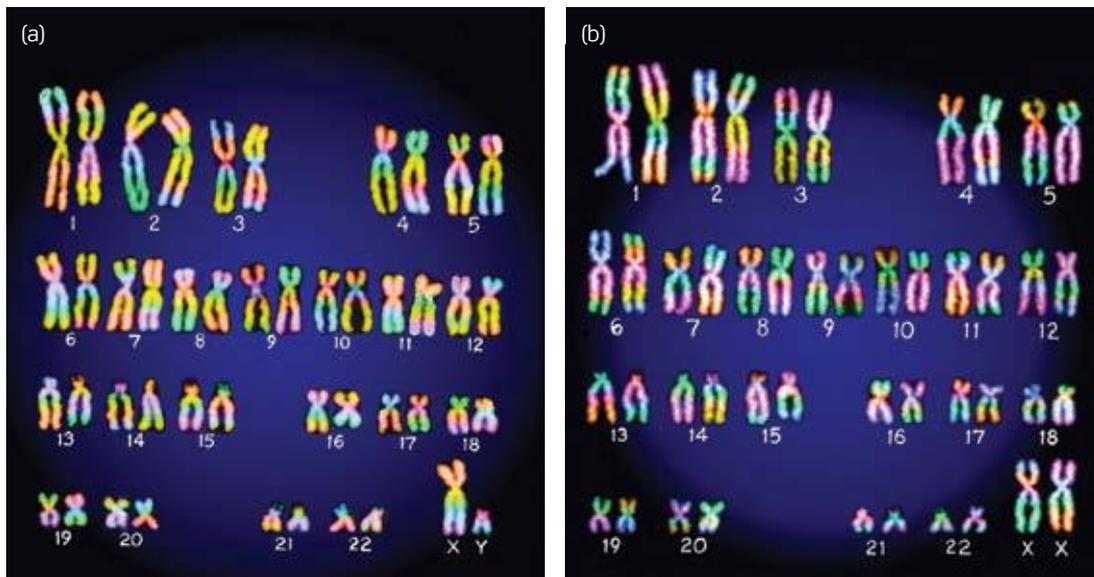
In humans there are forty-six chromosomes. These include twenty-two pairs of homologous chromosomes, called **autosomes**. The structure of the remaining two chromosomes differs between males and females – these are termed the **sex chromosomes**. In females the two sex chromosomes, the **X chromosomes**, are similar, whereas males have one X chromosome and a smaller **Y chromosome**.

**autosome**  
non-sex chromosome

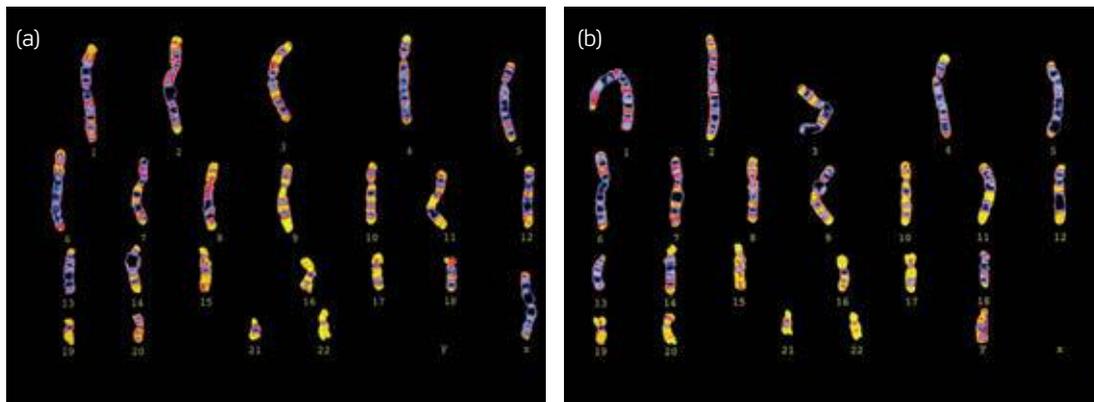
**sex chromosomes**  
chromosomes carrying information that determines the sex of the individual

**X chromosome**  
female sex chromosome in vertebrates and some other animals

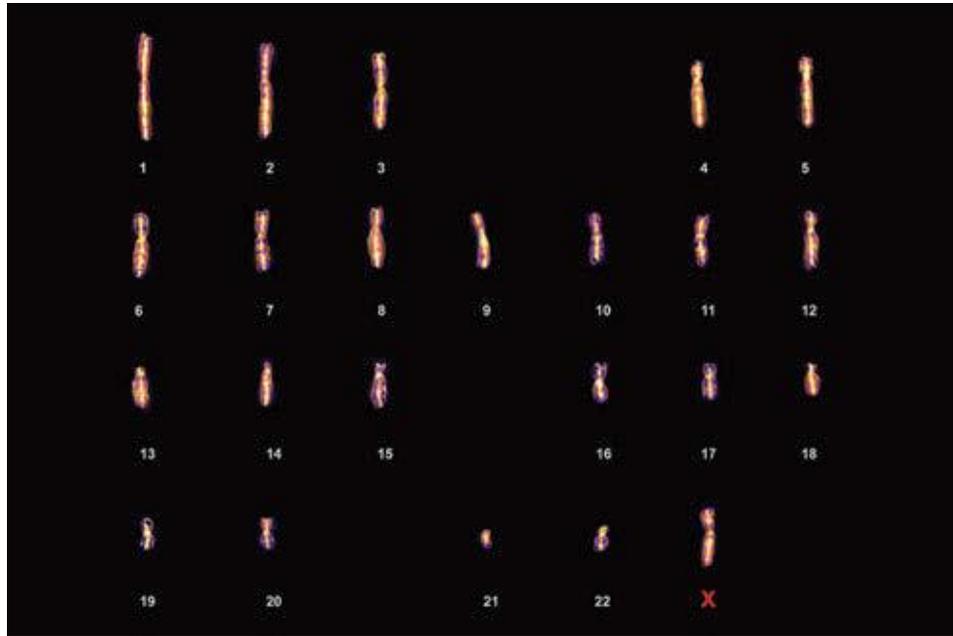
**Y chromosome**  
male sex chromosome in vertebrates and some other animals



**FIGURE 3** (a) Normal human male and (b) female colour-enhanced karyotypes showing replicated bivalent chromosomes. There are 92 chromatids joined at their centromeres in the 46 replicated chromosomes.



**FIGURE 4** Colour-enhanced karyotypes for normal human male sperm that are (a) haploid and carrying the X or the (b) Y sex chromosome.



**FIGURE 5** Colour-enhanced karyotype for a normal human female ovum, which is diploid and only carries the X sex chromosome

### CHECK YOUR LEARNING 8.1

#### Describe and explain

- 1 There are two types of nuclear division: mitosis and meiosis. For each type of division **describe**:
  - a the chromosomal condition before and after cell division
  - b the possible functions of the division.
- 2 **Describe** what would occur during sexual reproduction in animals if meiosis had not occurred.
- 3 **Explain** what happens to homologous pairs of chromosomes during meiosis.
- 4 The 'nucleus' divides only once during mitosis but twice during meiosis. **Explain** this difference.
- 5 **Identify** whether each of the following is the result of mitosis or meiosis.
  - a Two diploid cells
  - b Four haploid cells

c Repair of damaged skin cells

d Gamete formation in dogs

- 6 **Describe** a karyotype.
- 7 **Explain** the difference between a female and male karyotype.
- 8 **Describe** the information that can be obtained from a karyotype.

#### Apply, analyse and interpret

- 9 **Distinguish** between an autosome and a sex chromosome.
- 10 In Figure 3 there are 92 chromatids.
  - a **Determine** whether this occurs in both types of cell division. **Explain** your answer.
  - b **Identify** at what phase of cell division(s) this karyotype would be seen.



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Karyotypes

# 8.2

## Gametogenesis

### KEY IDEAS

- + Spermatogenesis and oogenesis
- + Diploid and haploid cells in gametogenesis
- + Formation of haploid cells

**gametogenesis**  
formation of gametes

**spermatogenesis**  
formation of spermatozoa in animals

**oogenesis**  
formation of ova in animals

**spermatogonium (plural spermatogonia)**  
germ (or stem) cell in a layer lining the tubules in the testes

**primary spermatocyte**  
diploid cell formed from mitosis of a spermatogonium, which undergoes meiosis I to produce two haploid secondary spermatocytes

**secondary spermatocyte**  
haploid cell that undergoes meiosis II to form spermatids

**spermatid**  
immature spermatozoon

**Sertoli cell**  
cells in the epithelium of tubules of the mammalian testes that protect and nourish the developing spermatozoa

**spermatozoon (plural spermatozoa)**  
small, motile male gamete

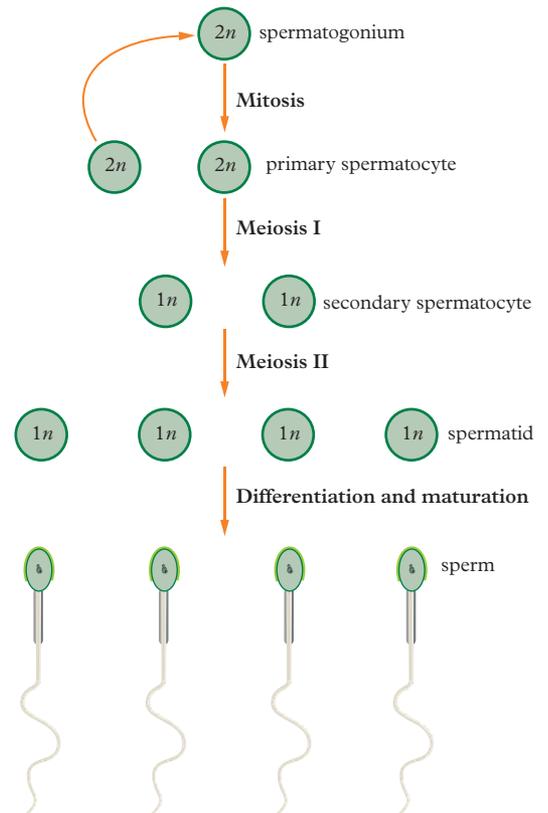
**Gametogenesis** is the series of mitotic and meiotic divisions that occur in the gonads resulting in the formation of gametes. Although mitosis and meiosis are both present in this process, gamete formation only begins with meiosis. Spermatogenesis and oogenesis are both forms of gametogenesis. **Spermatogenesis** is the formation of sperm cells in male testes, while **oogenesis** is the formation of eggs (ova) in female ovaries. While these two processes both result in gamete production, they vary in many aspects.

## Spermatogenesis

At puberty (the onset of sexual maturity) in males, this process starts in the diploid germ (or stem) cells in the testes called **spermatogonia**. These stem cells are formed during gestation and are present at birth through to the beginning of adolescence in an inactive state.

During adolescence, hormones from the anterior pituitary gland cause the activation of these cells and the production of viable sperm. The spermatogonia go through mitosis; each mitotic division produces one **primary spermatocyte** (diploid) that will proceed to gamete formation while the other diploid cell is retained as a diploid stem cell. In this way the stem cells are maintained, and so males can produce sperm from puberty to death.

At the first meiotic division (meiosis I), the primary spermatocyte produces two haploid cells called **secondary spermatocytes**. These cells then proceed through the second meiotic division (meiosis II), each cell producing two haploid **spermatids**. Four spermatids are produced from one primary spermatocyte. Specialised protective ‘nurse’ cells in the male tubules in the testes, called **Sertoli cells**, protect and provide nourishment for the spermatids, which mature into **spermatozoa**. These cells are needed to protect the haploid cells from the body’s defensive mechanisms. It takes approximately six weeks for the spermatids to differentiate into mature spermatozoa.



**FIGURE 1** Spermatogenesis showing the cell types and divisions involved

The mature spermatozoa (sperm) are released when fully developed into the tubules of the testes, ready for delivery to the female. The spermatozoa have a head containing the haploid nucleus and enzymes to dissolve the protection coating the ovum. The tail (flagellum) provides propulsion to reach the ovum.

In males, spermatogenesis begins at puberty and continues into old age.

## Oogenesis

The production of a female gamete or **ovum** (plural, ova) is termed oogenesis. It occurs in the ovaries of the female. The process begins during the early embryonic development and is completed only after the ovum is fertilised. During development of the female foetus, germ or stem cells called **oogonia** (singular, oogonium) undergo repeated mitotic division to form diploid **primary oocytes**. These primary oocytes begin to undergo meiosis I but this cell division is halted at prophase I. Each of the primary oocytes is enclosed in a single layer of follicle cells forming a **primary follicle**. At birth a female has a finite number of these follicles, which are inactive and suspended from continuing meiosis I. Although approximately 200 000 primary follicles are present in the ovaries at birth, only about 450 ever develop.

From puberty, hormones are cyclically released from the anterior pituitary gland. These stimulate one primary oocyte within a primary follicle to complete the meiosis I cycle. The division of the cytoplasm at the end of meiosis I is uneven, producing a large haploid **secondary oocyte** and a small haploid **polar body**. The polar body often degenerates, although it may proceed through meiosis II to produce two haploid polar bodies. The large secondary oocyte progresses through

meiosis II as far as metaphase II before its development is halted again. The secondary oocyte is released from the ovary in the process of **ovulation**.

After ovulation, this released secondary oocyte travels toward the uterus through the oviduct. If the secondary oocyte is fertilised, the cell completes meiosis II, producing a second smaller polar body and a fertilised egg containing the haploid set of chromosomes from the ovum and the haploid set from the sperm. Fertilisation of the ovum by the sperm results in a diploid zygote. At the completion of meiosis II all the polar bodies disintegrate.

The production and release of a secondary oocyte is cyclic – it usually occurs once each month (approximately every 28 days).

**ovum**  
haploid female gamete

**oogonium**  
a small diploid cell in the ovary that forms a primary oocyte in a female foetus

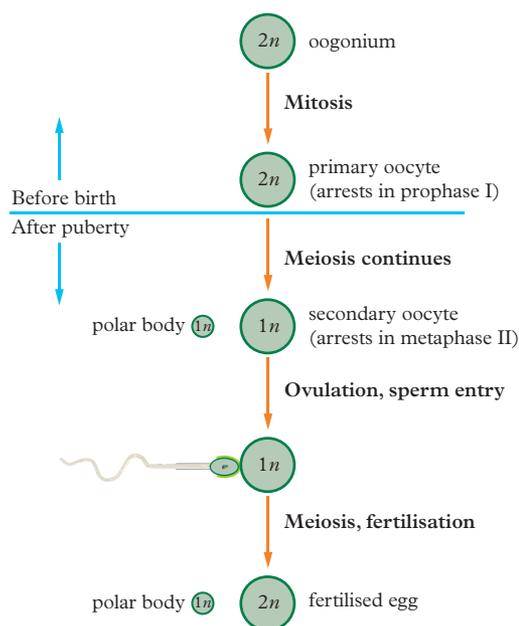
**primary oocyte**  
a diploid cell developed by an ovarian germ cell in mammals, which may later develop into an ovum

**primary follicle**  
a single-layered structure in the mammalian ovary containing the primary oocyte

**secondary oocyte**  
a large haploid cell produced during meiosis I of the primary oocyte

**polar body**  
small haploid cell produced from both meiosis I and II during oogenesis as a result of uneven cell division

**ovulation**  
release of the secondary oocyte that has started meiosis II from the ovary



**FIGURE 2** Oogenesis, showing the cell types and divisions involved

**TABLE 1** The properties of gametogenesis

Spermatogenesis	Oogenesis
Production of sperm cells (gametes) in males	Production of an ovum (gamete) in females
Occurs in male testes	Occurs in female ovary
Starts from a primary spermatocyte	Starts from a primary oocyte
Results in four functional spermatozoa from a primary spermatocyte	Results in a single ovum and three polar bodies from a primary oocyte
All four sperm are the same size and very small	Ovum is large, whereas three polar bodies are small and disintegrate
Sperm cells are motile	Ovum is immotile
Sperm cell does not contain any nutrients	Ovum contains nutrients
Completed inside the testis	Final stages of meiosis II occur outside the ovary (in the oviduct) if the egg is fertilised
Begins at puberty	Begins before birth, during the embryonic developmental stages
Results in billions of sperm cells	Results in only one ovum per month (it occurs in a cyclic pattern)
Involves a short growth phase	Involves a long growth phase
Diploid cell produces four haploid sperm	Diploid gamete mother cell produces one haploid egg cell
Meiosis completed in days or weeks	Completion of meiosis delayed for months or years
It is a continuous process and is completed in 74 days	It is a discontinuous process and is completed in a few days or years

## CHECK YOUR LEARNING 8.2

### Describe and explain

- Define** gametogenesis.
- Describe** three major differences between spermatogenesis and oogenesis.
- Describe** how spermatogenesis and oogenesis are similar.
- Explain** the types of cell division involved in gametogenesis.
- Compare** the process of spermatogenesis and oogenesis (with reference to haploid and diploid cells).

Check your **obook assess** for these additional resources and more:

» **Student book questions**

Check your learning 8.2

» **Weblink**  
Spermatogenesis

» **Weblink**  
Oogenesis



# 8.3

## Genes, alleles, gene linkage, and variation

### KEY IDEAS

- ✦ The processes of crossing over and recombination in meiosis
- ✦ Factors contributing to genetic variation
- ✦ Processes of independent assortment and random fertilisation

A gene is a region of DNA that has a function. A gene may be directly or indirectly involved in the production of protein. This protein may then be responsible for a particular physical or chemical characteristic of an organism or may work in conjunction with other proteins in the formation of the characteristic.

The order of nucleotides in each type of chromosome is different. Each type of chromosome, therefore, carries genes that are unique to that chromosome. The total number of genes in a cell is far greater than the number of chromosomes, so each chromosome carries many different genes. Genes that are located on the same chromosome are said to be linked. This phenomenon is known as **gene linkage**. Since sexually reproducing organisms have homologous pairs of chromosomes, one from each parent, they have two of each type of gene.

**gene linkage**  
location of genes on the same chromosome

### Alleles

The protein that is produced from a gene is not always identical due to slight variations in the sequence of nucleotides in the gene. An **allele** is an alternative form of a gene that is found at the same location on the same chromosome. Although there may be a number of different alleles for a gene, a single individual can only carry two, one on each homologous chromosome. For example, a person may have two genes for hair colour, one version (allele) from their mother, and another from their father.

**allele**  
one of two or more forms of a gene located in equivalent positions on homologous chromosomes

If the two alleles for a gene are the same, the individual is said to be **homozygous** for that gene. If the two alleles are different, the individual is described as **heterozygous** for that gene. How the two alleles combine to form a particular characteristic is dependent on the type and amount of protein that is produced by each. For example, there is a gene that carries the code to produce an ion channel found in membranes. Although most people have the allele to produce a fully functioning ion channel protein, approximately one person in twenty-five has one copy of an allele that produces a malformed version of this protein.

**homozygous**  
describes a condition in which both alleles for the gene are the same

**heterozygous**  
each allele for the characteristic exhibiting a different expression

If the person is heterozygous (carries one normal allele and one allele that produces the malformed protein) then their cells will still have enough of the functioning ion channel to be healthy. If the person inherits two copies of the allele that produces the malformed protein (one from their mother and one from their father), then they are unable to produce a fully functioning ion channel protein. As a result, their membranes are unable to control the movement of ions (and hence water) across their membrane. This is the mechanism of cystic fibrosis by which individuals can have difficulty with thick mucus in their lungs or digestive system.

**recessive allele**  
an allele found on a chromosome that can be masked by its dominant form in the heterozygous condition; can be autosomal or sex-linked

In this situation, an individual needed to have two copies of the allele (homozygous) before the trait (cystic fibrosis) was evident. The trait is said to be recessive and the alleles are described as ‘alleles for the recessive trait’ or **recessive alleles**.

Sometimes only a single gene is responsible for a characteristic. One allele exerts full control over another allele in a heterozygous condition – this is the **dominant allele**. The allele for freckles results in a high level of the brown protein melanin being produced in the skin. This coloured protein dominates any other proteins that may be produced. This means only one copy of the allele is needed for the **dominant trait** to be evident. A person with a dominant trait may be either homozygous or heterozygous for that trait.

The **genotype** names each allele that is present in an individual. Each gene is represented by a letter (or group of letters). The different alleles are indicated by capital (dominant traits) or lower-case (recessive traits) letters. For example, if the gene for freckles is given as either F or f, then the allele for freckles will be F (dominant trait) and the allele for no freckles (recessive trait) will be f.

The **phenotype**, however, indicates the way in which the gene is chemically or physically expressed. This is determined by the types of alleles that are present (the genotype), as well as the environmental conditions of the individual. For example, a person may have the genotype of a tall person, but if they experience low nutrition levels they may never achieve their full height.



**FIGURE 1** The number of freckles you have is determined by genetics.

## Law of segregation

An understanding of the process of meiosis and the structure of DNA and the gene was not known when Mendel undertook his ground-breaking studies of the inheritance of characteristics in the pea plant in the mid-nineteenth century. By chance, the features he studied were each controlled by a single gene and were on different chromosomes or behaved as though they were on different chromosomes. From his intensive work, he proposed two laws.

The **law of segregation** states that during the production of gametes, the two copies of each hereditary factor segregate so that offspring acquire one factor from each parent. This means a set of parents have two copies of each gene in their cells (one from their mother and one from their father). When the gametes were formed in the mother (or father), one copy of each chromosome went into each gamete (they segregated).

The **law of independent assortment** states that when two or more characteristics are inherited, individual hereditary factors assort independently during gamete production, giving different traits an equal opportunity to occur together. This suggests that the chromosomes that are inherited from the mother were a mix of her parents' (the maternal grandparents' chromosomes). This law only holds when the genes are found on different chromosomes and when there is no swapping of information between homologous chromatids.

### Study tip

It is the physical expression of the alleles that is described as a recessive trait, rather than the alleles.

#### **dominant allele**

an allele for a gene that overrides the effects of the recessive allele in the heterozygous condition; can be autosomal or sex-linked

#### **dominant trait**

the particular trait of a characteristic that is expressed in the phenotype of a heterozygous individual

#### **genotype**

the genetic makeup of an individual

#### **phenotype**

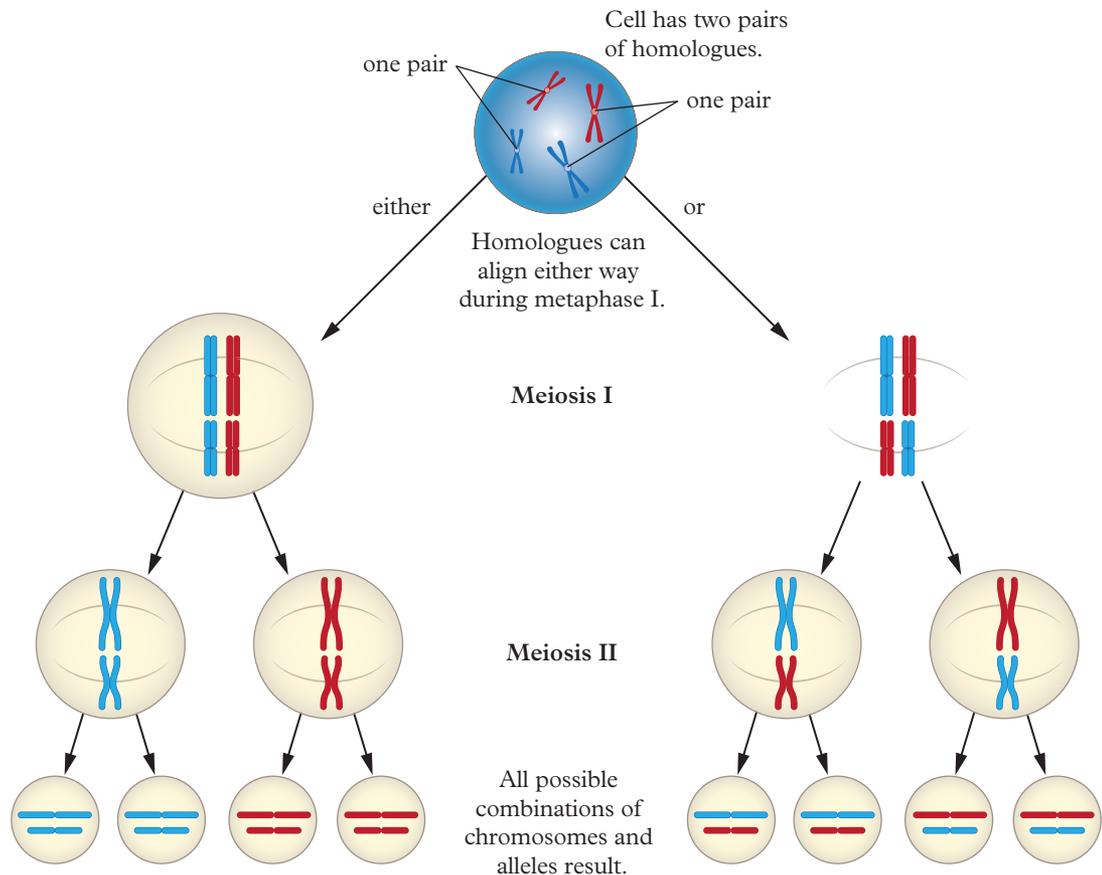
actual expression of the genotype

#### **law of segregation**

Mendelian law that states that genes for a characteristic occur in pairs in an individual, one inherited from each parent, and are separated when the reproductive cells are formed

#### **law of independent assortment**

Mendelian law that states that each allele pair segregates independently during gamete formation; applies when genes for two traits are located on different pairs of homologous chromosomes



**FIGURE 2** Segregation and independent assortment in a cell with two pairs of homologues. The blue homologues are paternal in origin while the red homologues are maternal in origin. The way the homologues are distributed provides variation in the next generation of gametes and thus in the genotype of the offspring.

### crossing over

breaking and rejoining, with exchange of DNA, between non-sister adjacent chromatids of homologous chromosomes during meiosis I

**Crossing over** occurs when there is an exchange of segments of DNA between homologous chromatids during prophase I. It may occur at one or more places along the chromosome.

During prophase I, the homologous chromosomes pair and the four chromatids lie side by side. They are positioned so that the alleles of one chromosome are beside alleles for the same trait on the other chromosome. Adjacent segments of chromatids from the homologous chromosomes break off and rejoin with the partner chromatid. By the end of metaphase I, this process is completed, so that segments of one chromatid from each of the homologous chromosomes may have interchanged.

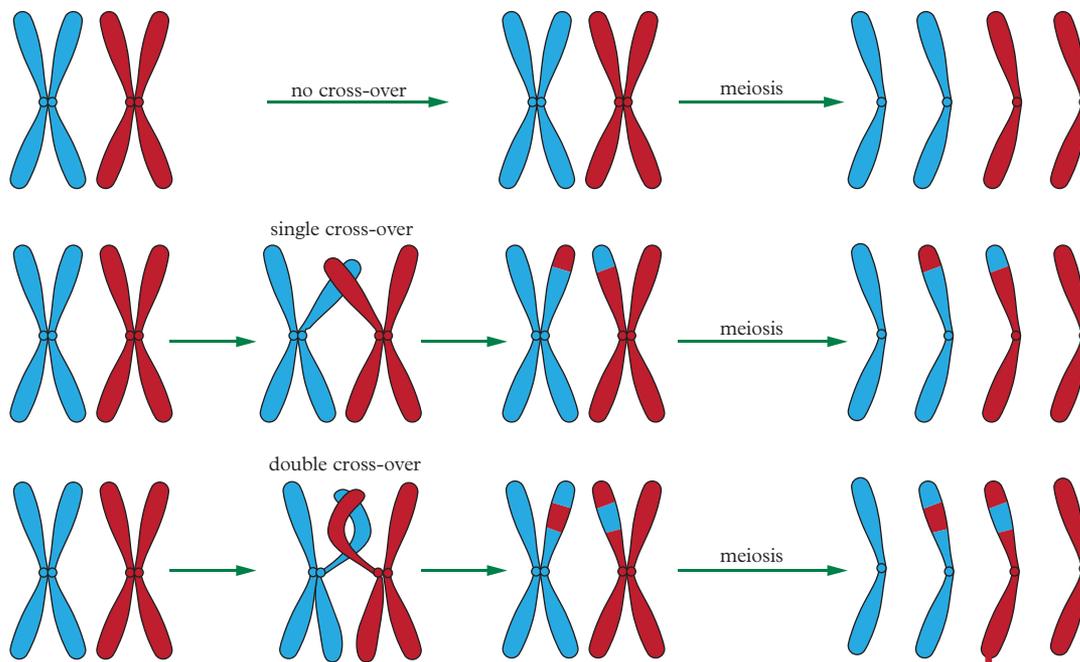
Separation of the homologous chromosomes in meiosis I and subsequent separation of the chromatids in meiosis II may result in four possible allele arrangements in the gametes – two similar to each of the original chromosomes, and two that will have different combinations.

Crossing over has survival value for the individual since some of the gametes have combinations of linked genes that are different from the parental combination. These gametes are called **recombinant gametes**. This helps explain why offspring can have different genotypes (and phenotypes) to those of their parents.

The processes of segregation, independent assortment and crossing over have the possibility of giving rise to a vast array of different allele combinations in the gametes produced. These factors are extremely important in their contributions to genetic variation

### recombinant gametes

gametes produced as a result of crossing over of the chromatids of homologous chromosomes during meiosis



**FIGURE 3** The differences in genetic make-up of gametes produced with no cross-over, a single cross-over and two cross-overs

and the random nature of fertilisation. Oogenesis results in only one ‘ovum’ being available for fertilisation because other possible combinations are lost in the polar bodies.

In spermatogenesis, vast quantities of sperm are produced, with millions of possible gene combinations, but only one will actually achieve fertilisation to produce a zygote. The more chromosome pairs there are in a cell, the more variation is possible. This means the process of fertilisation is totally random in natural conditions. It is impossible for sexually reproducing organisms to produce an identical clone to either parent. The offspring of sexual reproduction are similar to their parents but not identical to either parent. The main advantage of sexual reproduction is that it gives rise to many variations in the genotype of the offspring upon which natural selection may act.

### CHECK YOUR LEARNING 8.3

#### Describe and explain

- 1 Describe** the processes of crossing over and recombination.
- 2 Explain** at what phase of meiosis crossing over is likely to occur.

- 3 Explain** the difference between the law of segregation and the law of independent assortment.

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» **Student book questions**

Check your learning 8.3

» **Weblink**  
Alleles

» **Weblink**

Law of segregation



## 8.4

## Technologies used to detect problems in embryos

## KEY IDEAS

- + Pre-implantation technologies
- + Post-implantation technologies

**in vitro fertilisation (IVF)**

a complex series of procedures used to assist with the conception of a child, where mature eggs are collected from the ovaries and fertilised by sperm in a laboratory

**pre-implantation genetic diagnosis (PGD)**

a procedure used prior to implantation to help identify genetic defects within embryos

**pre-implantation genetic screening (PGS)**

the set of techniques for testing whether embryos (obtained through IVF) have abnormal chromosome numbers

**ultrasound**

a type of imaging technique that uses high-frequency sound waves

**amniocentesis**

a surgical procedure for obtaining a sample of amniotic fluid from the amniotic sac in the uterus of a pregnant woman

**chorionic villus sampling**

a prenatal test in which a sample of chorionic villi is removed from the placenta for testing

There are two main divisions in technologies that are used to detect problems with embryos: pre-implantation and post-implantation. With the introduction of **in vitro fertilisation (IVF)**, techniques have been developed so that genetic testing can be done before implantation into the mother's womb. IVF is a significant biotechnology that assists couples with low reproductive success (infertility), as well as those with a known history of genetic abnormalities, have a healthy baby. There are two divisions in pre-implantation technologies, **pre-implantation genetic diagnosis (PGD)** and **pre-implantation genetic screening (PGS)**.

Post-implantation technology involves using technology to determine the health of the embryo. This can involve the use of **ultrasound**, **amniocentesis** and **chorionic villus sampling**.

**Pre-implantation genetic diagnosis (PGD)**

Pre-implantation genetic diagnosis (PGD) is a technique that is used to identify a known genetic defect in embryos produced during IVF. It is done before embryos are implanted in the female and is used if one or both parents have or may carry a genetic abnormality. In this way it is possible to establish whether the embryo has a genetic abnormality.

A number of embryos are produced using IVF in which the 'eggs' are harvested, fertilised by the male's sperm and then allowed to divide into multiple-celled embryos outside the female's body. This usually takes between three and five days. At this point PGD is started, using the following steps:

- 1 A single cell is removed from some of the embryonic cell groups.
- 2 The remaining embryonic cell groups are frozen.
- 3 The DNA of the selected cells is analysed to assess whether there are any genetic problems.  
This procedure usually takes a week but can take up to two weeks.
- 4 If these cells are free of genetic disorders, the usual IVF procedure will continue.  
The frozen embryonic cells that form an embryo will be inserted into the uterus.
- 5 If the embryo successfully implants into the uterine wall, a pregnancy occurs.
- 6 As many embryos are produced from one 'egg' collection, all will go through the above procedures. All of the embryos that are free of genetic disorders are stored in a frozen state.

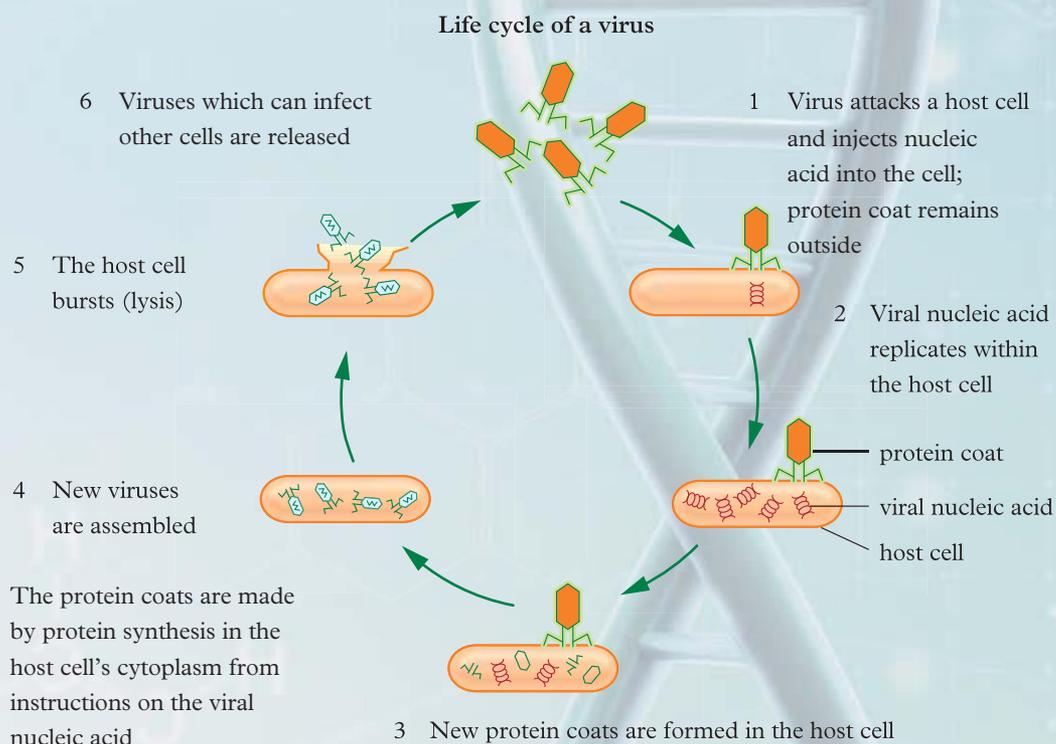
**Pre-implantation genetic screening (PGS)**

Pre-implantation genetic screening (PGS) refers to techniques in which embryos that are produced by IVF are screened for any potential genetic diseases. While PGS uses a similar technology to PGD after IVF, it is used in cases of repeated miscarriages, failure of implantation or infertility. This screening is used to check for abnormal chromosomal

numbers from chromosomally normal genetic parents. As this is determined by a karyotype, the time taken is much shorter than PGD. The aim is to screen, identify and remove the embryos that are chromosomally abnormal. Embryos that are chromosomally normal can either be transferred to the mother's uterus, improving the chances of a successful pregnancy, or be stored for use at a later date.

## CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats)

CRISPR were originally discovered in the prokaryotic archaea. These are naturally occurring enzyme systems whereby prokaryotes protect themselves against viruses. Figure 1 shows the life cycle of a virus, which leads to the destruction of a prokaryote cell after it has produced and assembled replicates of the original virus.



**FIGURE 1** Replication phases of a bacteriophage – a virus that attacks bacteria

Over many millions of years these prokaryotes have developed a way of protecting themselves from viruses. When an archaea detects the presence of the injected viral DNA, it produces a small complementary RNA copy of the viral DNA. This complementary RNA strand is able to recognise and bind to sections of the viral DNA and so acts as a guide. The RNA binds with a nuclease (digests nucleotides) enzyme called *Cas9* (CRISPR-associated protein). The complementary RNA recognises a section of the viral DNA sequence where it attaches, allowing the *Cas9* enzyme to act. The *Cas9* cuts the viral DNA so that it cannot reproduce new viral particles. In this way the archaea can protect itself from viral attacks.

Using the CRISPR system, it is possible to target certain genes in the cells using specific RNA recognition guides and the *Cas9* nuclease to cut out the defective section of DNA and/or replace it with the correct DNA gene sequence. The main aim of CRISPR/*Cas9* is to form the basis of a genome editing system that is able to permanently modify DNA by editing and repairing genes.

The CRISPR process has potential in a vast array of medical conditions where genetics has an influence, such as breast and other cancers, cystic fibrosis, Duchenne muscular dystrophy, Huntington's disease and retinitis pigmentosa.

Figure 2 shows how CRISPR/*Cas9* can be used to recognise and locate the damaged sections in the embryonic cell using specially prepared RNA segments to cut it out. The cell's repair mechanism then steps in to repair the DNA. Using this technique, it is possible to replace a defective gene.

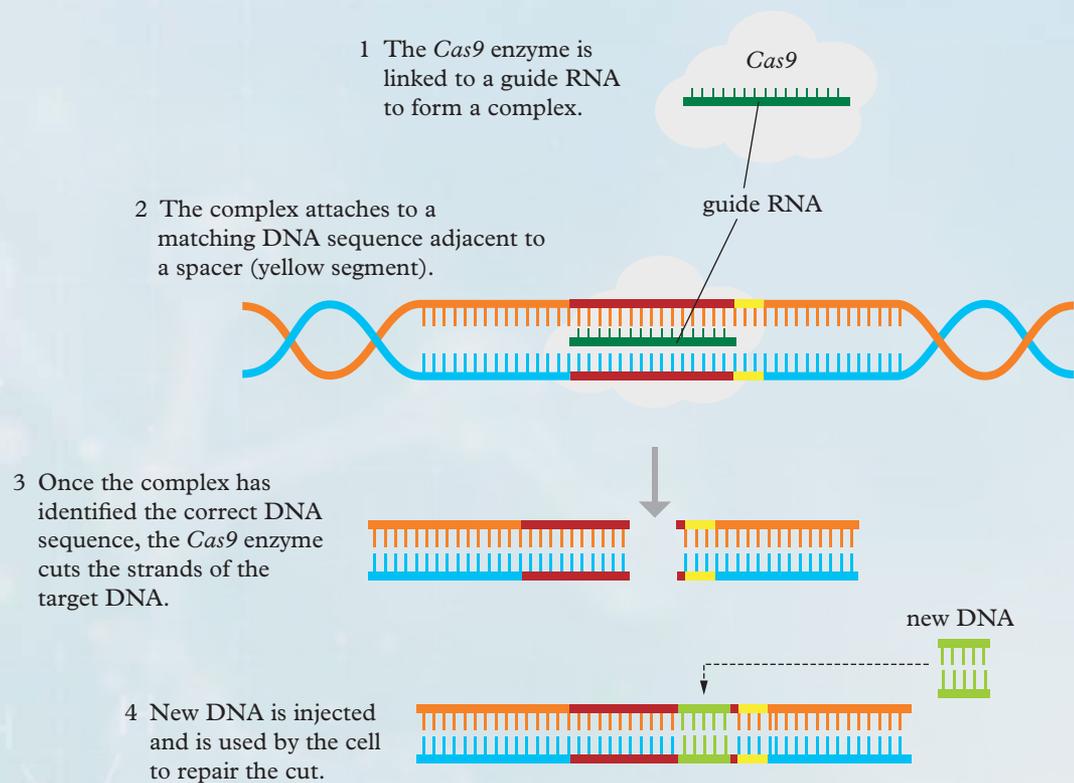


FIGURE 2 How CRISPR *Cas9* works

## Post-implantation genetic diagnosis

### Ultrasound

This process is carried out as an essential part of prenatal care as it can be used to detect physical and genetic defects in the human foetus from about three months of development. In ultrasound, high-frequency sound waves are passed through the uterus across the mother's abdomen. Reflected waves are picked up and transmitted to a video screen in the form of an image called a sonogram. The size of the foetus, beating of its heart and other movements, as well as general external physical development, can be observed on the sonogram. Refining and advancing of ultrasound equipment has allowed the obtaining of very realistic 3-D pictures of the foetus. A further extension of this is **foetoscopy**, involving the insertion of a small but enlarging device (an **endoscope**) into the uterus, usually through an incision in the abdominal and uterine walls. Direct viewing of the foetus can be achieved with little disturbance.

#### foetoscopy

technique for looking directly at the foetus within the uterus (using an endoscope)

#### endoscope

a lighted optical instrument that is used to look inside the body

## Amniocentesis

In amniocentesis, the position of the foetus is determined by ultrasound. While the sonogram is being observed, amniocentesis can be performed. A thin needle is inserted through the mother's abdominal and uterine walls into the amniotic cavity, and a sample of amniotic fluid is removed. This fluid contains living cells sloughed off from the foetal skin. The cells are cultured and induced to divide, and then a karyotype can be produced. The results may show whether the foetus has a chromosome anomaly. The parents then have the choice of whether or not to medically abort the foetus at an early stage. After four months of foetal development, however, the abortion could be both risky and traumatic for the mother.

## Chorionic villus sampling

Chorionic villus sampling can be performed at a much earlier stage in foetal development. A tiny piece of the chorion of the placenta (genetically identical to the cells of the embryonic baby) is removed. The DNA from these cells is extracted and, by using **gene probes** (pieces of radioactively labelled DNA), several disorders can be identified.

Using this method, doctors can identify conditions such as chromosomal abnormalities, cystic fibrosis, Huntington's disease, muscular dystrophy and blood diseases such as haemophilia and thalassaemia. New probes have been developed for even rarer diseases such as neurofibromatosis (the affliction of the 'Elephant Man'), phenylketonuria, Alzheimer's disease and bipolar disorder.



FIGURE 3 A 3-D ultrasound image of a foetus

### gene probe

a single-stranded DNA or RNA fragment used in genetic engineering to search for a particular gene or other DNA sequence

## CHECK YOUR LEARNING 8.4

### Describe and explain

- 1 **Explain** the advantages of PGS over PGD, stressing when PGS is used.
- 2 **Explain** how CRISPR may change pre-implantation technologies.
- 3 **Explain** why ultrasound detection is used while performing amniocentesis and chorionic villus sampling.

- 4 **Identify** some of the conditions that can be detected using prenatal screening.

### Apply, analyse and interpret

- 5 **Distinguish** between amniocentesis and chorionic villus sampling.
- 6 **Discuss** why chorionic villus sampling is considered to be a safer alternative to amniocentesis.

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Check your learning 8.4

» **Weblink**  
IVF

» **Weblink**  
CRISPR



# Review

## Chapter summary

- 8.1**
- Meiosis has two stages of division (meiosis I and meiosis II).
  - Homologous chromosomes have the same length, banding and position as the chromosome.
  - The genetic material is doubled in a cell during the S phase of interphase.
  - The stages of meiosis are prophase I, metaphase I, anaphase I, telophase I and cytokinesis, prophase II, metaphase II, anaphase II, telophase II and cytokinesis.
  - Crossing over occurs in prophase I.
  - Karyotypes are used to identify species, the genetic sex of an organism and abnormalities in chromosome numbers.
- 8.2**
- Spermatogenesis is the production and differentiation of four haploid spermatozoa from a diploid stem cell.
  - Oogenesis is the production and differentiation of a single haploid ova and three polar bodies from a diploid stem cell.
  - The development of the ova is arrested at metaphase II of meiosis II unless it is fertilised.
- 8.3**
- Genes on the same chromosome are said to be linked.
  - Crossing over (the exchange of genetic material between homologous chromosomes) occurs in prophase I.
  - Recombination of chromosomes increases the genetic diversity of a population.
  - The process of independent assortment results in chromosomes (and hence many alleles) separating during gamete production.
  - Fertilisation between different genetic combinations of gametes is random and increases the genetic diversity of a population.
- 8.4**
- Pre-implantation technologies, such as pre-implantation diagnosis and pre-implantation screening, can be used to identify potential genetic anomalies in embryos.
  - Post-implantation technologies, such as ultrasound, amniocentesis and chorionic villi sampling, can be used to identify potential genetic abnormalities in a foetus.

## Key terms

- allele
- amniocentesis
- autosome
- chiasma (plural chiasmata)
- chorionic villus sampling
- chromatid
- crossing over
- diploid
- dominant allele
- dominant trait
- endoscope
- foetoscopy
- gametogenesis
- gene linkage
- gene probe
- genotype
- haploid
- heterozygous
- homologous chromosomes
- homozygous
- in vitro fertilisation (IVF)
- law of independent assortment
- law of segregation
- meiosis
- mitosis
- oogenesis
- oogonium
- ovulation
- ovum
- phenotype
- polar body
- pre-implantation genetic diagnosis (PGD)
- pre-implantation genetic screening (PGS)
- primary follicle
- primary oocyte

- primary spermatocyte
- secondary spermatocyte
- recessive allele
- recombinant gametes
- secondary oocyte
- Sertoli cells
- sex chromosome
- spermatid
- spermatogenesis
- spermatogonium (plural spermatogonia)
- spermatozoon (plural spermatozoa)
- tetrad
- ultrasound
- X chromosome
- Y chromosome

## Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: ★ = low; ★★ = medium; ★★★ = high.

### Multiple choice

- When a normal mother diploid cell undergoes complete meiosis, it will produce:
  - four haploid cells
  - four diploid cells
  - two diploid cells
  - two haploid cells
- The chromosomes of a human cell were analysed. The scientist found 22 chromosomes plus a Y chromosome. From this information the scientist could conclude that the cell was a:
  - normal male cell
  - normal female cell
  - female gamete
  - male gamete
- The structure labelled 4 that holds together the two bead-like strings is called a:
  - centrosome
  - centromere
  - chromosome
  - centriole
- The chromosome number of the cell nucleus is:
  - 2
  - 4
  - 8
  - 16
- The number of chromatids visible in the cell is:
  - 4
  - 8
  - 12
  - 16
- When comparing normal meiosis in human males and females:
  - equal numbers of functional gametes are formed from each participating cell
  - each egg and sperm contain a single sex chromosome
  - each egg produced contains one more autosome than a sperm cell
  - all sperm contain the same kind and amount of DNA
- Oogenesis:
  - is the equivalent of spermatogenesis except that it occurs in the ovary
  - occurs from adolescence through to old age

Questions 3–5 will use the diagram of the cell below.

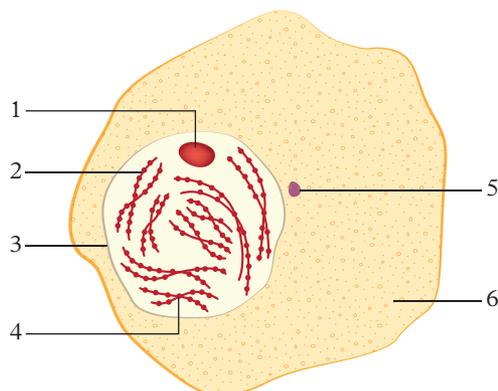
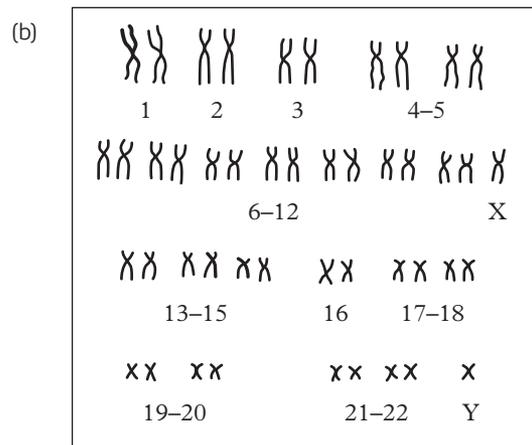
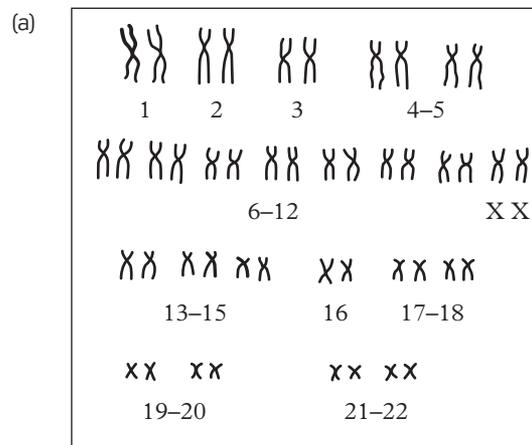


FIGURE 1 A diagram of a cell

- C** produces one ovum and three polar bodies from a single primary oocyte
  - D** results in the monthly release of an ovum from the ovary
- 8 A bivalent chromosome:
- A** consists of sister chromatids resulting from growth during interphase
  - B** is one of a homologous pair of chromosomes in a cell nucleus
  - C** results from replication of DNA during anaphase
  - D** is composed of two sister chromatids held together at the centromere
- 9 Consider the two diagrams of arranged and numbered chromosomes in Figure 2. These chromosomes came from individuals who are twins.

From this data it would **NOT** be reasonable to assume that:



**FIGURE 2** Two different karyotypes from a pair of twins

- A** the twins are of different sex
  - B** the twins are chromosomally normal
  - C** the twins have arisen from a normal zygote that split into two parts
  - D** each twin has the same number of autosomes and sex chromosomes
- 10 In gametogenesis, meiosis is undergone on diploid gamete mother cells to form:
- A** diploid egg cells
  - B** haploid egg cells
  - C** diploid gametes
  - D** haploid gametes

### Short answer

#### Describe and explain

- ★ **11 Describe** the importance of each division in meiosis.
- ★ **12 Explain** why meiosis must occur in sexually reproducing organisms.
- ★ **13 Describe** the production of gametes by the mammalian ovary.
- ★ **14 Describe** how a karyotype of an individual is produced.
- ★ **15 Explain** why siblings with the same parents can have different phenotypes.



**FIGURE 3** These siblings do not share the same DNA.

#### Apply, analyse and interpret

- ★ **16 Distinguish** between the diploid and haploid conditions in cells.
- ★ **17 Compare** the phenotype and genotype of an individual.
- ★ **18 Deduce** genetic advantages that a diploid organism would have over a haploid organism.

### Investigate, evaluate and communicate

- ★★ 19 An individual argued that an allele cannot be described as dominant or recessive.  
**Consider** their point of view and **decide** whether you agree or disagree.
- ★★ 20 **Discuss** the factors that result in genetic diversity in gametes and thus the genotypes and phenotypes of an individual.
- ★★ 21 An individual was found to exhibit trisomy of an autosomal chromosome. **Propose** how and when this condition arose.
- ★★ 22 Two allelic versions of different genes were found to always be inherited together.  
**Propose** a conclusion about their relative positions on the chromosome.
- ★★★ 23 In a study of the menstrual cycle, a Canadian researcher performed daily ultrasound scans on 63 women who had normal menstrual cycles over a period of six weeks. This allowed them to measure the diameter of every follicle in the ovary and its waves of growth. They discovered up to 20 follicles develop prior to ovulation, but that generally one is larger and

as it ruptures to release the ovum, the others degenerate. The researcher also found that all of the women had two growth waves in a cycle and half of them had three. Regardless of the number of growth waves, however, the actual ovulation differed between the women. Fifty of the women ovulated once, seven did not ovulate and six ovulated twice over a month and on separate days. This would explain why 10% of conceptions are non-identical twins. It has been suggested that those women who have three follicular growth waves in a cycle would run out of primary follicles at a faster rate than women who have two waves. This would therefore explain why the onset of menopause is earlier in some women than others.

- a Critically **evaluate** the experimental protocol in this study.
- b **Design** an experimental procedure to determine whether the number of follicular waves per cycle is related to time of menopause and if this is an inherited characteristic.



FIGURE 4 External ultrasound being performed

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# Gene expression

The genome is composed of coding and non-coding DNA. A structural gene is a segment of DNA that produces a specific protein. Each amino acid in the polypeptide chain has a DNA code of three nitrogen bases. Sequences of codes are transcribed as complementary triplet codons of mRNA and translated at the ribosomes of the rough endoplasmic reticulum to form a polypeptide chain.

Gene expression is controlled by a number of factors. Many of these are a result of non-coding regulatory genes involved in transcription and post-transcriptional processes. Epigenomic factors and specific developmental genes (e.g. homeotic genes and sex-determining genes) are also involved in gene expression.

## OBJECTIVES

- Define the terms *genome* and *gene*.
- Explain the process of protein synthesis in terms of:
  - transcription of a gene into messenger RNA in the nucleus
  - translation of mRNA into an amino acid sequence at the ribosome (refer to transfer RNA, codons and anticodons).
- Understand that genes include ‘coding’ (exons) and ‘non-coding’ DNA (which includes a variety of transcribed proteins: functional RNA (i.e. tRNA), centromeres, telomeres and introns. Recognise that many functions of ‘non-coding’ DNA are yet to be determined.
- Recognise that the purpose of gene expression is to synthesise a functional gene product (protein or functional RNA); that the process can be regulated and is used by all known life.
- Identify that there are factors that regulate the phenotypic expression of genes:
  - during transcription and translation (proteins that bind to specific DNA sequences)
  - through the products of other genes
  - via environmental exposure (consider the twin methodology in epigenetic studies).
- Recognise that differential gene expression, controlled by transcription factors, regulates cell differentiation for tissue formation and morphology.
- Recall an example of a transcription factor gene that regulates morphology (*Hox* transcription factor family) and cell differentiation (sex-determining region Y).

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FIGURE 1 A 3-D illustration of twins in the womb



# 9.1

## Protein synthesis

### KEY IDEAS

- ✦ Genome and genes
- ✦ The steps in protein synthesis
- ✦ Translation of the mRNA to an amino acid sequence to proteins at the ribosomes in the cytoplasm

### genome

the complete set of nucleotide sequences encoded in the total DNA of an organism

### structural gene

sections of DNA that carry the instructions for production of a protein

### gene expression

the ability of a gene to be transcribed

### genetic code

the code the body uses to convert the instructions contained in the DNA into the proteins essential for life

### non-coding DNA

the greater part of the DNA molecule that does not contain structural genes

### regulatory gene

a non-coding segment of DNA that produces transcription factors for gene expression

The **genome** is all of the genetic material (genes and DNA sequences) found in the chromosomes of an organism. Every cell (except red blood cells and gametes) in the body of an organism contains a full ‘blueprint’ – genome – and has the ability to reproduce that body. This means the skin cells in fingertips have the genetic material to develop into eye cells, and the nerve cells in the brain have the genetic material to develop a tooth.

A **structural gene** is a segment of DNA that controls a specific characteristic. It is the molecular unit of heredity. For example, there is a gene (*TYR*) in mammals that is responsible for producing the enzyme tyrosinase. This enzyme causes the production of melanin, the brown pigment responsible for eye, skin and hair colour (phenotype).

Some people have a different allele for this gene that produces a malformed enzyme. If a person has two copies of this recessive allele (homozygous recessive), they cannot produce melanin, resulting in an albino appearance. If a person is heterozygous (has one copy of each of the dominant and recessive allele in their genotype) then only the dominant allele that produces the tyrosinase enzyme is said to be expressed. **Gene expression** is the most fundamental level at which the genotype gives rise to the phenotype, i.e. observable trait.

If a gene is being expressed, the **genetic code** stored in DNA is ‘interpreted’ and translated into the organism’s phenotype. Such phenotypes are often expressed by the synthesis of proteins that control the organism’s shape, or that act as enzymes catalysing specific metabolic pathways characterising the organism.

## Non-coding DNA

Not all sections of DNA are responsible for producing protein. Recent studies have shown that vast quantities of **non-coding DNA** have a variety of biochemical and structural functions, which include:

- producing RNA (mRNA, rRNA, tRNA and non-coding RNAs that influence gene expression)
- regulating gene expression
- adding the end caps to each chromosome (telomeres)
- forming the centromere (points of attachment of chromatids during replication)
- developing the origin and terminus sequences involved in chromosome replication.

If the segments of non-coding DNA are responsible for controlling structural genes, they are termed **regulatory genes**.

## The role of DNA in protein synthesis

DNA contains information for protein synthesis. Proteins include structural components of the cell, hormones, antibodies and enzymes. Like DNA, protein is a polymer – a long chain of

repeating monomer units called amino acids. While DNA has only four types of nucleotides, twenty amino acids can be arranged in a variety of combinations to form different proteins.

Since there are twenty amino acids and only four kinds of bases in DNA, a single base cannot determine which amino acid will be used in a protein sequence. Instead, the nucleotides in DNA are grouped into threes (a triplet). Each triplet contains the code for a single amino acid. The allele must therefore contain at least three times as many nucleotides as there are amino acids in the protein. This series of nucleotide triplets forms the basis of the genetic code.

## Triplet combinations

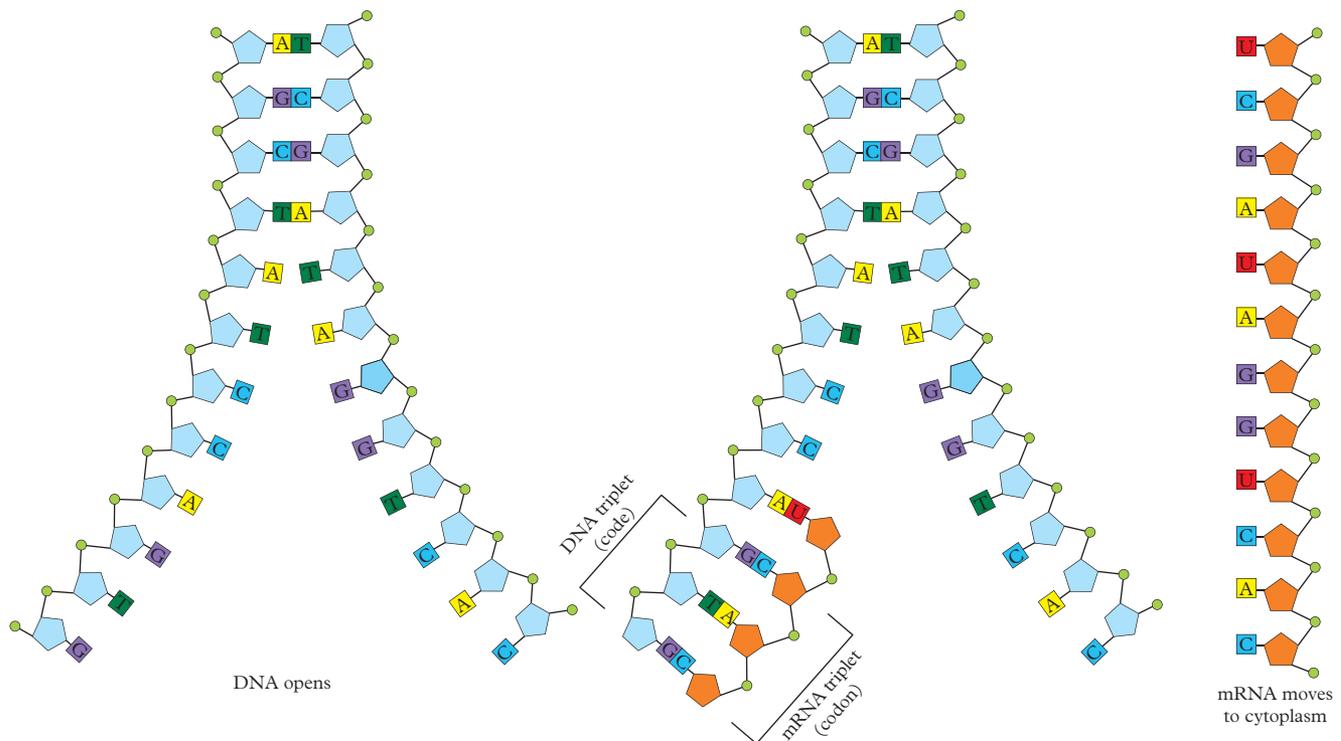
There are sixty-four possible triplet combinations. Of these, all but three combinations have been found to correspond with an amino acid. Those that do not are the ‘punctuation marks’ (e.g. stop or start signals) of the code. Since sixty-one triplets code for twenty amino acids, some amino acids have more than one triplet code. For example, the triplets AAA and AAG will both code for the amino acid phenylalanine.

## Transcription

The DNA does not leave the cell’s nucleus during protein synthesis. Instead the code must be transcribed (copied) into another nucleic acid, **messenger RNA (mRNA)**. The process of transferring the code from DNA to mRNA is called **transcription**.

**mRNA**  
messenger RNA; RNA molecule formed during transcription

**transcription**  
first step of gene expression, in which a particular segment of DNA is copied into mRNA



**FIGURE 1** Transcription: the formation of messenger RNA

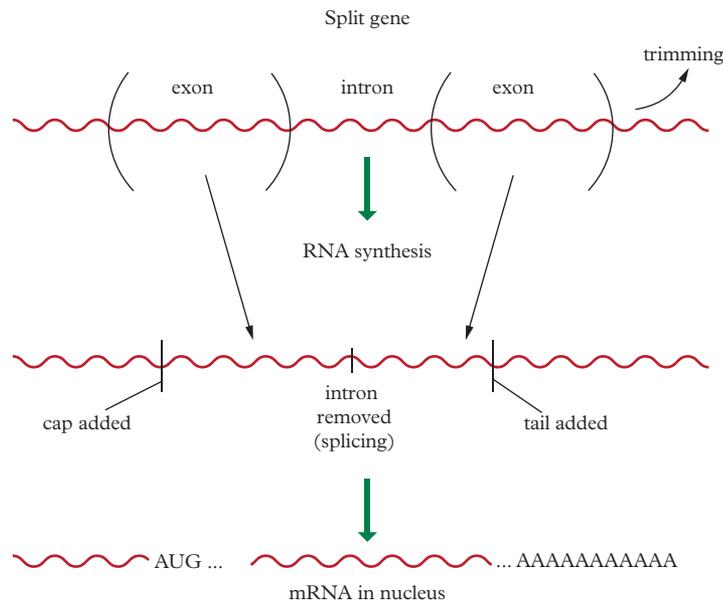
This starts with part of the DNA molecule ‘unzipping’ to expose the nitrogen bases that will form the template for the mRNA. Each gene has a specific recognition sequence of nucleotides that is able to bind to an enzyme called RNA polymerase. As the RNA polymerase moves along the template DNA strand, it adds an RNA nucleotide that is complementary to the DNA. RNA molecules do not have thymine, instead uracil is used as a complement to adenine. When the messenger RNA is complete, it is able to detach and the two DNA chains then re-join. The triplets on DNA have now been transcribed into **codons** on the mRNA.

DNA base sequence (triplet codes): GTG ACC TAT CGA  
 mRNA base sequence (triplet codons): CAC UGG AUA GCU

## Post transcriptional modification

In bacteria, the mRNA is now ready to be translated into a protein. In eukaryotes the mRNA can contain small non-coding sections that are not needed to produce a functioning protein (**split gene**). These non-coding **introns** are removed by enzymes in the nucleus. The remaining coding **exons** are re-joined to form mature mRNA.

Before the mature mRNA can leave the nucleus after transcription there are extra nucleotides at the beginning and end that need to be removed (**trimming**). The start of the mRNA is then **capped** with methyl-guanine and a long ‘tail’ of adenines is added to the other end (**tailing**). These caps and tails are thought to aid the binding of the mRNA to the ribosomes and make it more stable.



**FIGURE 2** Splicing, capping and tailing of mRNA in eukaryotic cells

## Transfer RNA

Certain genes produce another type of RNA called **transfer RNA (tRNA)**. The chain of nucleotides in tRNA is folded into a clover-leaf arrangement. The open end of the chain is the site for attachment of a specific amino acid (determined by the base sequence). Each tRNA links with only one type of amino acid in a reaction that requires a specific enzyme and ATP. As a result, there are many different types of tRNA. At the central loop of the ‘clover leaf’ is a triplet of unpaired bases. These three bases serve as an **anticodon** to match a specific

### codon

triplet of nucleotides on mRNA specifying an amino acid

### split gene

a gene that contains sections of non-coding DNA called exons (expressed as RNA and protein) interrupted by sections of DNA called introns

### intron

a non-coding section of DNA within a split gene

### exon

a coding section of DNA within a split gene

### trimming

removal of non-coding sections at the beginning and end of mRNA

### capping

the addition of methyl-guanine at the start of the trimmed mRNA

### tailing

the addition of a long tail of adenines at the end of mRNA

### tRNA

small segments of RNA that transport specific amino acids to the mRNA attached to a ribosome during translation

### anticodon

triplet of nitrogen bases found on tRNA

mRNA codon. This means the tRNAs must line up to match the codons on the mRNA. As a result, the amino acid sequence will exactly match the correct codon sequence of the mRNA (which matches the triplet code on the DNA).

## Translation

When protein synthesis begins, mRNA has become associated with the ribosomes (composed of **ribosomal RNA, rRNA**) on the rough endoplasmic reticulum in the cytoplasm. Translation of the mRNA into protein is initiated by an untranslated region followed by the 'start' codon, AUG. This is also the code for the amino acid methionine. Any AUG codon after the 'start' is read as methionine in the polypeptide sequence. The ribosome moves along the mRNA strand, one codon at a time. It acts as a pointer to the appropriate tRNA. As the ribosome moves to each new codon position, a tRNA carrying its specific amino acid approaches. If the tRNA's anticodon is complementary to the codon, it links to the mRNA. The ribosome holds the two amino acids in place so that a peptide bond forms between them in a condensation polymerisation reaction. The formation of the bond releases the first tRNA that can now join with another amino acid in the cytoplasm.

As the ribosome moves along the mRNA, more and more amino acids are added to the growing polypeptide chain. This process is repeated until the ribosome reaches the end of the mRNA, where it drops off and liberates its polypeptide chain. The end of the mRNA strand contains one of three codons – UAG, UAA or UGA – which stops the ribosome reading the 'message'. The polypeptide chain undergoes changes to form a functional protein in the cytoplasm or is released into the endoplasmic reticulum canals for further reactions. Some proteins are transferred to the Golgi apparatus where they are further processed. They are enclosed in membranes, forming cellular vesicles, or may be secreted.

Since many ribosomes (**polysomes**) can move along the mRNA simultaneously, each synthesising a polypeptide chain, a large number of polypeptides can be assembled on a single mRNA strand in a comparatively short time. After a period of time the mRNA is broken down and production of that specific polypeptide ceases. The interaction of mRNA, tRNA and ribosomes to form a polypeptide is called **translation**. The newly made polypeptide chain is then assembled into a protein by spiralling, folding or combining with other groups of chemicals.

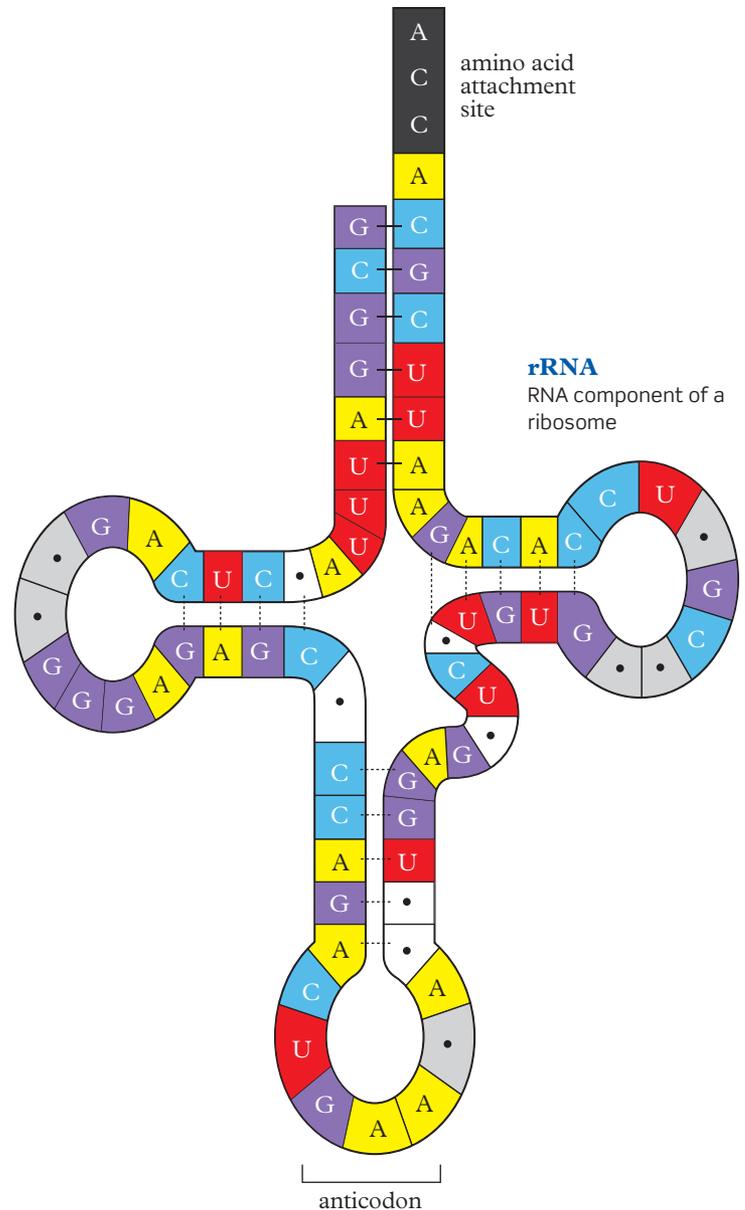
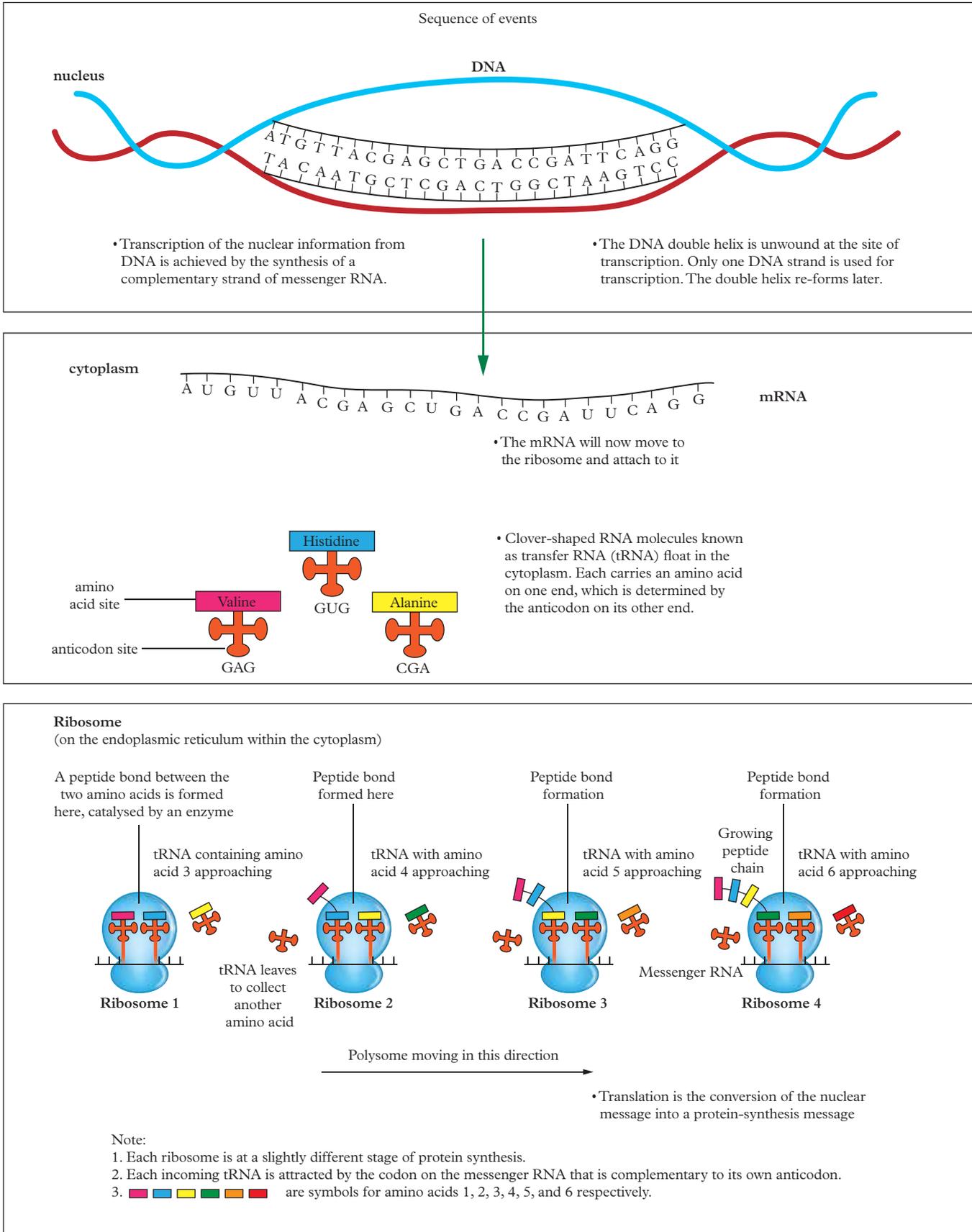


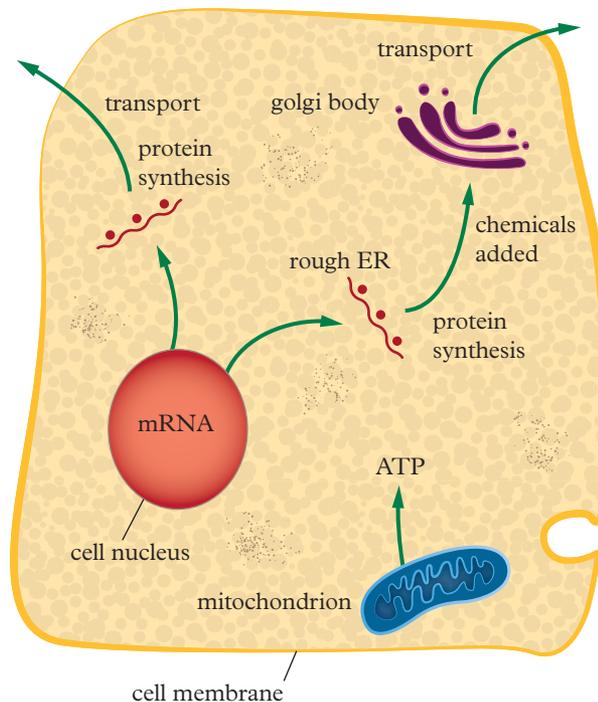
FIGURE 3 Structure of a tRNA molecule

**polysome**  
chain of ribosomes that 'read' mRNA

**translation**  
production of a polypeptide sequence from a sequence of mRNA codons



**FIGURE 4** Protein synthesis



### Study tip

The non-coding DNA used to be called 'junk' DNA, but it is now known that many of these small sections of DNA are important in controlling how genes are expressed, or the length of time mRNA can survive in the cell.

FIGURE 5 Post-translation fates of the proteins in a eukaryotic cell

## CHECK YOUR LEARNING 9.1

### Describe and explain

- 1 Transcription and translation are two phases in protein synthesis. **Explain** what these two terms mean.
- 2 **Describe** the difference between mRNA and tRNA
- 3 **Describe** the roles played by each of the following in protein synthesis.
  - a DNA
  - b Structural gene
  - c mRNA
  - d tRNA
  - e Amino acids
  - f Endoplasmic reticulum

**g** Polypeptide chain

**h** Golgi apparatus

- 4 **Explain** why the term 'junk DNA' is no longer used.
- 5 **Categorise** each of the following organelles into the correct pathway for the production, transport and secretion of a cellular glycoprotein: ribosomes, endoplasmic reticulum, DNA, mRNA, vacuoles, Golgi apparatus, cell membrane.

### Apply, analyse and interpret

- 6 If a DNA codon is represented by AAT, **determine** the anticodon on the appropriate tRNA.

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rRNA

# 9.2

## Control of gene expression

### KEY IDEAS

- ✦ Gene expression is regulated
- ✦ Gene regulation at the pre-transcription, post-transcription and translation stages
- ✦ Epigenetics
- ✦ Epigenetic studies and twins
- ✦ Epigenetic control of transcription
- ✦ Inheritance of epigenetic factors

Any particular cell requires different polypeptides at different times and in different amounts. Some genes in all cells constantly transcribe proteins that are involved in basic metabolic functions. Other genes are only active under particular circumstances. The expression of some genes and not others results in cell differentiation. For example, the active genes of muscle cells only transcribe the polypeptides that are essential for muscle cell operation. Genes that are important in nerve cells are 'switched off' in a muscle cell. If all the genes were continuously activated (expressed), the muscle cell would use a lot of energy and resources to produce unnecessary proteins. Regulation of gene expression is therefore important in cell differentiation.

### Gene regulation

Genes can be regulated at different stages: pre-transcription, post-transcription and translation.

#### Pre-transcriptional control

Transcription occurs only during interphase when the chromosomes exist as chromatin threads. This is initiated when the DNA coding for a specific polypeptide 'unzips' to expose the nucleotide bases and its starting point to which the RNA polymerase attaches. Regulatory genes associated with the functional gene can produce functional RNA or proteins that act as **transcription factors**. These factors can attach to the start of a structural gene to either:

- block the attachment of RNA polymerase, and so block the expression of that gene
- alter (accelerate or decrease) the rate at which the gene is expressed.

In some situations, gene expression is altered by the environment influencing the regulatory gene. The presence of a large amount of glucose, for example, would result in an increased expression of the gene coding for insulin, and block the gene for glucagon. In contrast, minimal amounts of glucose would block insulin production and enhance glucagon production in pancreas cells.

#### Post-transcriptional control

Once the mRNA has been produced, cells are capable of controlling the amount of protein produced. This is achieved by modifying the post-transcriptional process, or the longevity of the mRNA. Non-coding DNA can alter the rate or block the trimming, capping and tailing of the mRNA. For example, if the non-coding introns are not removed correctly, the resulting mRNA may be broken down by enzymes.

#### transcription factor

a protein produced by regulatory genes that controls gene expression

Some small non-coding RNAs may bind to the mRNA to form a double-stranded RNA (either by true pairing with the nucleotides or imperfectly pairing), which then cannot be translated. It is thought that since some viruses have double-stranded RNA, this activates defence mechanisms in the cell that then destroy the mRNA.

Once the mRNA is completed it must pass through the nuclear pores to the cytoplasm. This is an active process that requires the recognition of the transcript by receptors lining the interior of the nuclear pores. This allows further control, and gene expression can be achieved by alteration of pore receptors.

## Translational control

Ultimately, any particular mRNA will be enzymatically degraded. Gene expression can be regulated by controlling the length of time the mRNA survives before it is degraded.

Many different proteins and amino acids are involved in the translation process. By controlling the amounts of these molecules, the rate of gene expression can accelerate or decrease.

Even after a polypeptide chain has been formed, chemical modification is required before the final protein is produced. Again, the availability of additional chemical groups, or enzymes, will therefore affect the complete expression of the gene.

## Epigenetic control of gene expression

Studies of identical twins (with exactly the same genome) determined that environmental factors play a large part in the control of the transcription of a gene. Over the past 20 years, a great deal of research has been undertaken in this area to determine the extent to which the environment affects gene expression, how this is achieved and whether or not these factors are inheritable.

The **epigenome** ('above the genome') is a set of factors that affect which part of the DNA is activated. These factors may occur as a result of intra-cellular or extra-cellular stimuli, by neighbouring cells, by physiology, or entirely by the environment to which the organism is exposed.

Each cell type in an individual's body has its own epigenome. Muscle cells (that only express the genes they need) can only replicate to form muscle cells. Throughout the individual's life the DNA in all cells remains constant (excluding chance mutations), but the epigenetic factors in each cell may change. This may be due to puberty, the stage of the menstrual cycle, or as a result of environmental stress or lifestyle.

The epigenome acts by producing chemical tags or factors (methyl or acetyl groups) that do not change the DNA 'blueprint', but determine which genes are switched on (expressed) and which are switched off (repressed). This can occur at several levels.

## Histone modification

Each DNA molecule in the non-dividing cell nucleus is found as fine threads of chromatin that at intervals are wrapped around four pairs of histone protein molecules to form nucleosomes. There are two different forms of chromatin:

- **heterochromatin**
- **euchromatin**.



**FIGURE 1** During the phase of puberty, epigenetic factors in your cells change.

**epigenome**  
a system of gene control outside of the DNA ('above the genome')

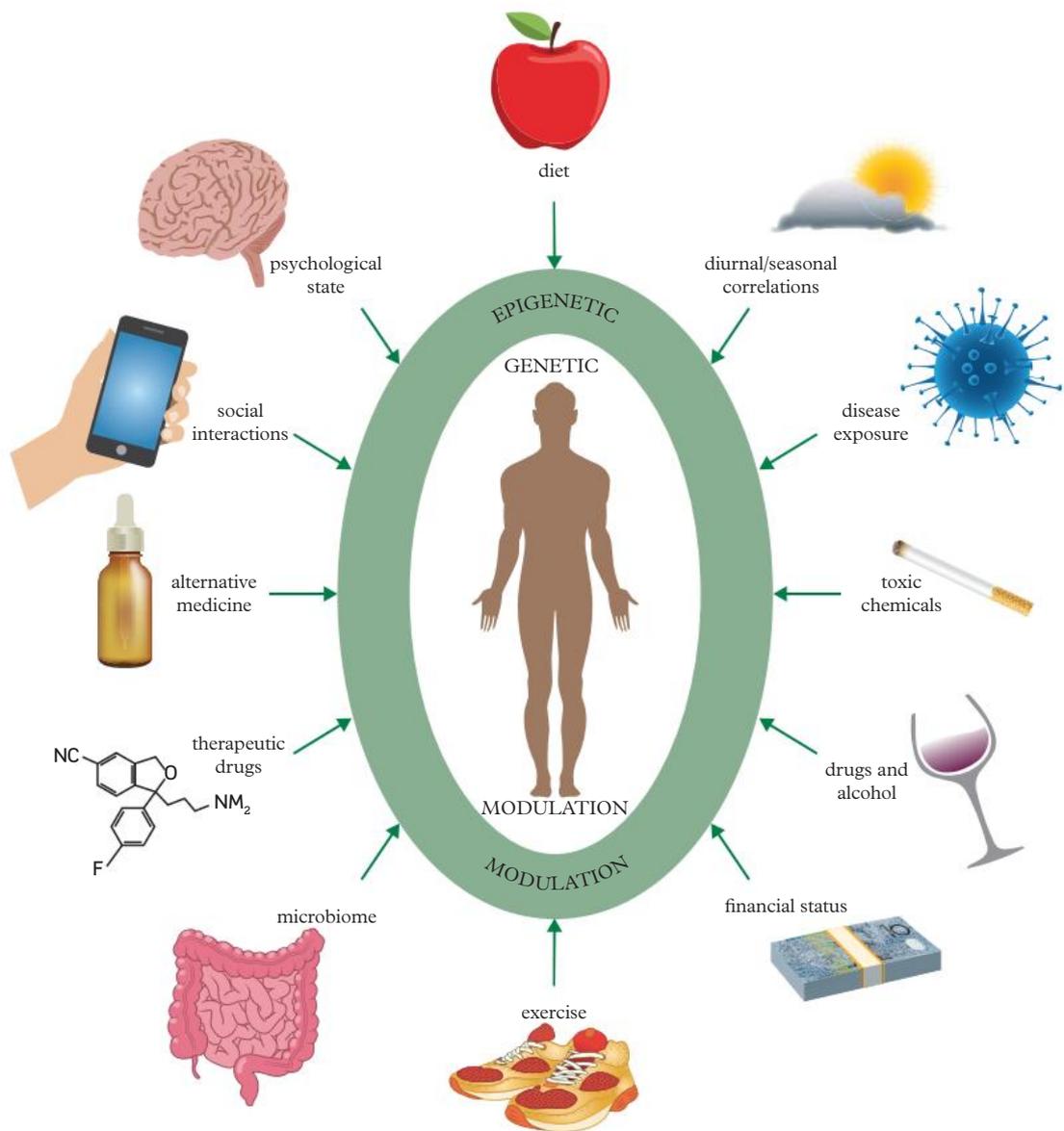
**heterochromatin**  
chromatin tightly coiled around histone proteins in the nucleosome

**euchromatin**  
'relaxed' chromatin that contains genes that can be transcribed

Heterochromatin is tightly coiled around the histone proteins whereas euchromatin is not so condensed, allowing the DNA to be loosely packed. Euchromatin contains most of the active genes of an organism and so is actively involved in the transcription of DNA to mRNA.

The nucleosomes can be spaced tightly together or far apart. The spacing is controlled by the presence or absence of chemical tags attached to the tails of the histone proteins that either pull the nucleosomes closer together or allow the structure to be more open.

When an acetyl group tag attaches to specific amino acids on the tails of the histone molecules in a nucleosome, the histone structure relaxes, and the nucleosomes move further apart. This section of the DNA is more easily accessed by transcription – the gene is switched on. Methyl group tags on other sites of the tails of histone molecules of the nucleosome make the coiling of the chromatin tighter and the nucleosomes closer together. The DNA between the nucleosomes cannot be accessed and any genes contained in those sections cannot be read. The genes are switched off in those pieces of DNA.



**FIGURE 2** Environmental factors affecting epigenetic control in humans

**Histone modifications** are often transitory and can be reversed according to the chemical environment of the cell at any particular time. Studies have suggested that tags associated with histone modification are not inherited.

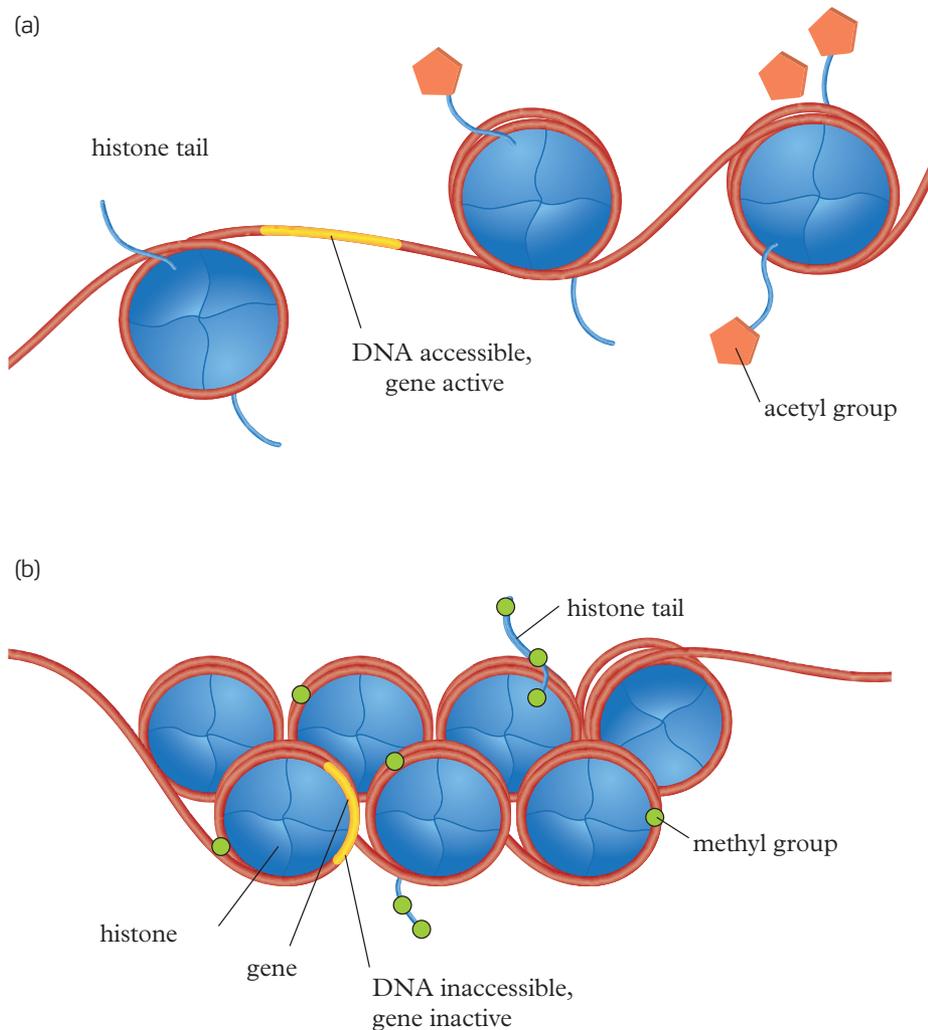
## DNA tags

A chemical tag (**DNA methylation**) can also be attached to the start of the functional gene. By blocking the attachment of RNA polymerase, the gene cannot be transcribed.

Some tags are environmentally induced, but generally the pattern of DNA tags is a stable epigenetic marker set in early development. During fertilisation and the first few rounds of cell division, most of the DNA tags are removed so that the cells in the early embryo are able to express any of their genes. These are totipotent stem cells. Some of the remaining tags on certain genes of either the mother or father may be retained. Sometimes other DNA tags are not completely removed and are passed down from parent to offspring. The inheritance pattern may, therefore, be unpredictable.

**histone modification**  
addition of chemical tags that vary the width between nucleosomes and so determine whether or not a gene can be transcribed

**DNA methylation**  
the addition of a chemical tag (a methyl group) to the start of a structural gene to block transcription



**FIGURE 3** Histone modification. (a) When one chemical tag (an acetyl group) attaches to histone tails, the nucleosome coiling is loose and the gene can be expressed; (b) when another chemical group (methyl) attaches to the histone tails, the nucleosomes pack tightly together to bring about gene inactivation.

## CASE STUDY 9.2

### Identical twins

Twins result when two embryos develop simultaneously. Twins can be either monozygotic or dizygotic.

#### **dizygotic twins**

each twin develops from a separate egg and each egg is fertilised by a separate sperm cell

#### **fraternal twins**

an alternative name for dizygotic twins

#### **monozygotic twins**

twins that develop from one zygote, which splits and forms two embryos; since they have the same genotype, they are considered to be identical

**Dizygotic** (two zygotes) **twins** result when two ova are fertilised in one cycle.

They are commonly called **fraternal twins**. Since two eggs are released, two different sperm are involved in fertilisation. The twins will therefore have different combinations of their parental genes. Not only will they look and behave differently, they may be of different genders.

**Monozygotic** (one zygote) **twins** result from changes during early cell division of a single zygote. These twins have the same genetic information, so must be the same gender and can be termed 'clones'. Twinning occurs during the early development of the embryo, but different timing of separation gives rise to several forms of monozygotic twins.

If separation occurs between four and eight days after fertilisation, these twins are completely identical. If separation occurs after the eighth day, then these twins are mirror-images of each other, e.g. one will be right-handed while the other will be left-handed. It is as though they are facing a mirror. If the twinning process occurs after the thirteenth day, the separation is not complete. These twins remain co-joined physically at any part of the body, often sharing one or more organs. These twins are commonly called 'conjoined' twins.

Although monozygotic twins are genetically identical (i.e. clones), there are often considerable differences between the individuals, such as height, head shape and size. This is because the pre-natal and post-natal environments in which two individuals develop may be different. If twins share a common placenta, there may be competition between them for nutrient supply and waste removal, resulting in serious imbalances in the weight and size of each individual that may persist for life. Also, contrary to popular belief, identical twins do not have identical fingerprints.

Studies of identical twins reared apart have shown how significant the genes are in development. One set of twins, separated at birth and reared in different countries, both wore rubber bands around their wrists, sneezed loudly to get attention and clipped their moustaches in a particular way. Similar studies suggest that other traits such as leadership ability, imagination and vulnerability to stress are strongly influenced by heredity. This genetic phenomenon has been seen in most separated twins.

**FIGURE 4** (a) Dizygotic (fraternal) twins; (b) monozygotic (identical) twins; (c) mirror-image twins



## Inheritance of epigenetic factors

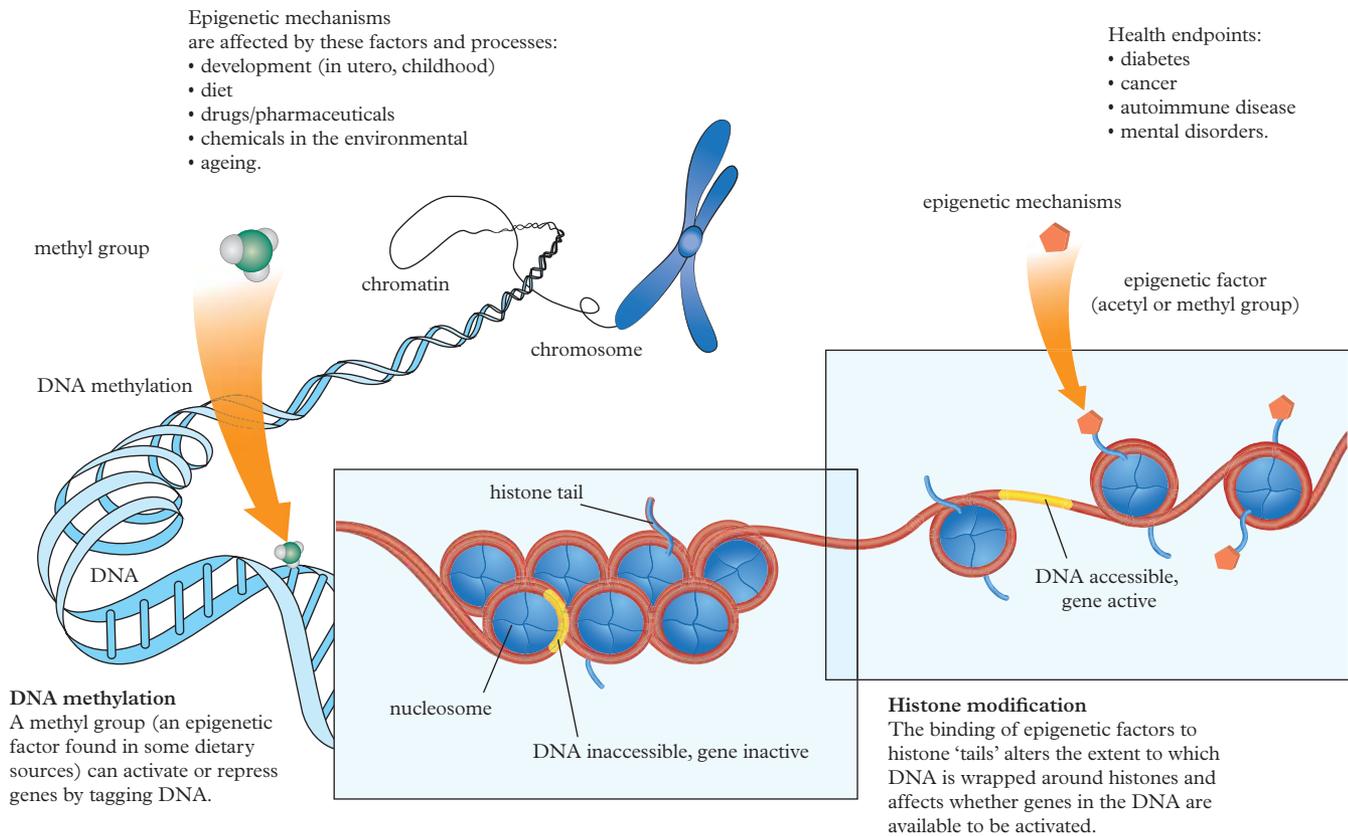
During World War II Nazi troops occupied the Netherlands, and from 1944 to 1945 a German blockade was used to cut off food supplies to the country. It has been found that children conceived during this time had increased rates of coronary heart disease and obesity compared with children whose mothers were not exposed to famine during pregnancy. These problems were found to be associated with less DNA tagging of insulin-like growth factor II. This epigenetic control has been shown to be inherited over at least three generations.

Similarly, a study of children born after World War II to Holocaust survivors with post-traumatic stress syndrome (PTSS) found they were more likely to develop this condition or depression compared with children born to adults who had not experienced PTSS. They shared epigenetic tags with their parents that made them more reactive to stress.

It is not exactly clear how these epigenetic tags are inherited across generations, but since the basic DNA tags are laid down during development, the environment or diet of the pregnant mother can potentially have subtle effects upon the DNA tagging patterns of the epigenomes during pre-natal and early post-natal development. It is also likely that the mother's epigenomes can affect the germ cells of the developing foetus. In females, the lifetime supply of eggs is created in the foetus, as are the sperm stem cells of a male. The activity of a pregnant woman could, therefore, affect the lives of her grandchildren.



**FIGURE 5** Holocaust survivors likely passed down genetic stress syndromes to their children.



**FIGURE 6** Representation of the chromatin structure (incorporating histones and DNA, which can become accessible to epigenetic mechanisms) and is a summary of epigenetic control of gene expression. Note that not all epigenetic effects are negative.

## CHECK YOUR LEARNING 9.2

### Describe and explain

- 1 **Describe** two post-transcriptional processes that influence gene expression.
- 2 **Define** the epigenome.

### Apply, analyse and interpret

- 3 **Compare** histone modification and DNA methylation.

### Investigate, evaluate and communicate

- 4 **Evaluate** the following statement. 'The DNA of a cell remains constant throughout an individual's lifetime, but the epigenome may change.'
- 5 **Investigate** other environmental factors that may have altered your gene expression.



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# 9.3

## Transcription factors significant in development

### KEY IDEAS

- ✦ Transcription factors and differential gene expression
- ✦ *Hox* genes and *Hox* proteins
- ✦ *SRY* gene is on the Y chromosome; it produces *SRY* protein

There are many transcription factors that regulate gene activity. Some are produced by non-coding DNA while others are produced by structural genes. The overall development of the body plan (morphology) and sex determination in animals are two examples of how transcription factors influence the development of the organism.

### *Hox* transcription factor family

Every sexually produced organism starts life as a single cell. Over the first few hours and days of life, this cell first multiplies, before the cells start specialising into heads, limbs and tails.

**Homeotic genes** are genes in the cells that determine which anatomical structures of the body the cells will differentiate into. The term '*Hox*' is a contraction of **homeobox**, which is a DNA sequence of approximately 180 base pairs within the genes. These are involved in the regulation of anatomical development in animals, plants and fungi.

***Hox* genes** (a subset of homeotic genes) are a group of related genes that control the body plan of an embryo along the head–tail axis. In animals they control the formation of the segmentation of the embryonic body plan. After these segments have formed, the ***Hox* proteins** (the products of the *Hox* genes) act as transcription factors that determine the type of appendages that will form on a segment. *Hox* proteins control the identity of the body segments through gene regulation, but do not form the actual segments themselves.

The *Hox* genes were first discovered in fruit flies where developmental errors were seen (for example, legs appearing on the head instead of antenna due to an error in the antenna gene). Mutations in any one of the *Hox* genes may cause the growth of an extra and sometimes non-functioning body part, e.g. a set of wings on each of two thoraxes (homeotic mutation). The normal body plan has one thorax.

Although there are a very large number of genes involved in morphological animal development, the most powerful influence is exerted by the *Hox* genes. They are the master controllers that can turn genes on or off using transcription factors, and so control gene expression. The sequencing and positioning of the *Hox* genes on the chromosomes indicate a common ancestor for the fruit fly, the mouse and human beings.

The segmentation of the body of the fruit fly is very evident but, in the humans, it is only evident in the vertebra and spinal nerves of the vertebral column, although a well-developed muscular person can show segmentation as a 'six pack' in their abdominal muscles.

#### homeotic gene

any of a group of related genes that control the body plan of an embryo along the head–tail axis during early embryonic development

#### homeobox

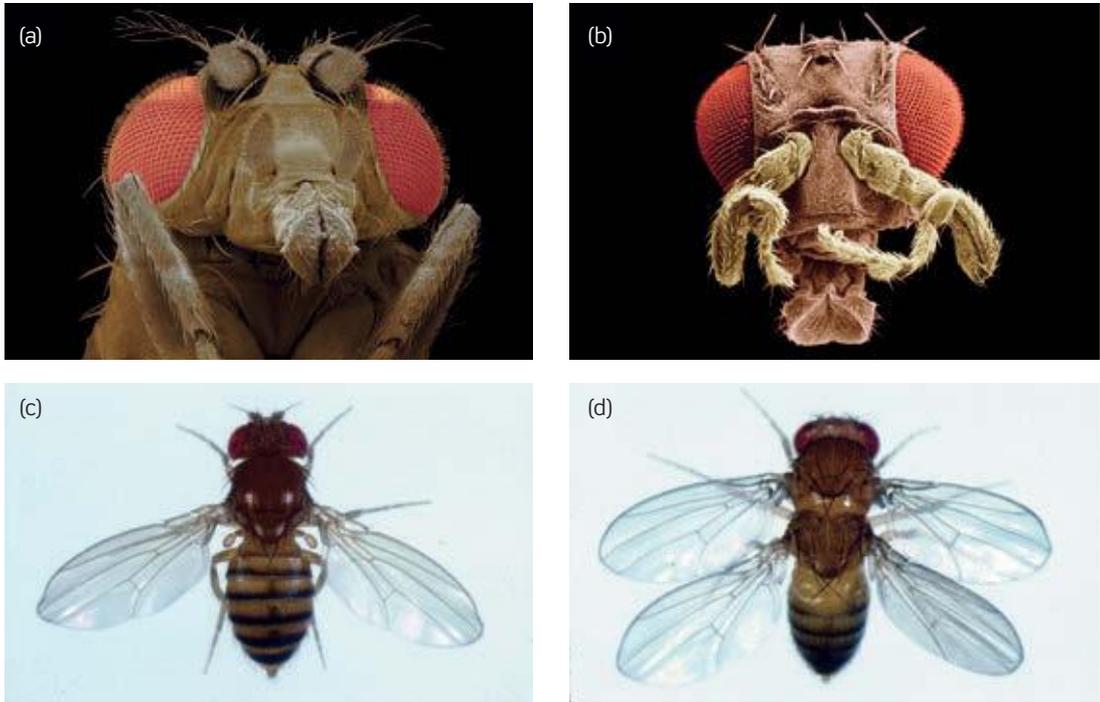
DNA sequence (of about 180 base pairs) contained in a gene (e.g. the *Hox* gene) that is highly conserved and can bind to DNA to control gene expression

#### homeobox (*Hox*) genes

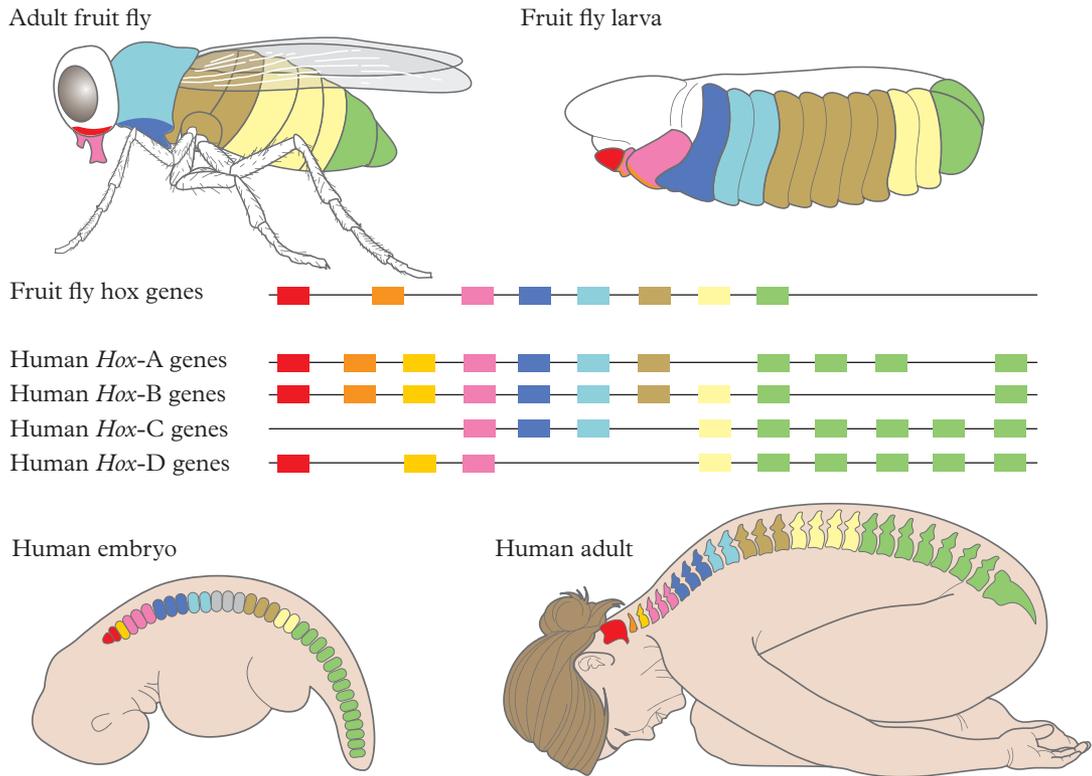
a sub-group of homeotic genes that control the body plan of an embryo along the head–tail axis

#### *Hox* protein

a transcription factor produced by a *Hox* gene



**FIGURE 1** (a) Normal fruit fly; (b) fruit fly with mutation in antenna gene; (c) normal fruit fly; (d) fruit fly with a homeotic mutation that gives it two thoraxes



**FIGURE 2** *Hox* genes in fruit flies and humans. Fruit flies have one set of eight *Hox* genes whereas humans have 38 *Hox* genes arranged in four sets. Each box in the above diagram shows the *Hox* genes. These *Hox* genes control the organisation of the head to tail of embryonic body development. The head *Hox* genes are to the left, through the middle section, with tail *Hox* genes to the right.

## Cell differentiation by the sex-determining region Y

Regardless of the genetic sex (XX versus XY), all embryos initially have the potential to develop phenotypically either as male or female. Primordial components of both male and female reproductive tracts are present in all early embryos. The pattern for female development is expressed initially as it is the default mode. If a male is to develop, this female default mode must be actively overridden by secretions of the foetal testes.

The **SRY gene** is the male sex-determining region that is found on the Y chromosome. This gene produces a transcription factor that attaches (binds) to specific regions of DNA and helps control the activity of other genes. It is responsible for the production of the SRY protein, which starts processes that cause a foetus to develop male gonads (testes).

As SRY protein production increases, the male testes start to develop (weeks 6–8 in embryo development). Specialised cells within the testes begin to make testosterone, which inhibits other hormones and begins to override the production of female reproductive organs.

Between weeks 9 to 12 of embryonic development there is a peak in the production of these hormones. This coincides with the differentiation of the male internal genitalia, and differentiation of external genitalia occurs between weeks 8 and 12. This differentiation is determined by the presence of male sex hormones, which are present due to the SRY gene.

During this time, if there is no overriding testosterone present, or if the testosterone receptors are blocked, the embryo will continue to develop female internal reproductive structures and external genitalia.



**FIGURE 3** A well-developed muscular person's abdominal muscles show an indication of body segmentation.

**SRY gene**  
the gene on the Y chromosome responsible for initiating male sex determination in humans

### CHECK YOUR LEARNING 9.3

#### Describe and explain

- 1 **Describe** the role of homeotic genes.
- 2 **Explain** how *Hox* genes act.
- 3 **Identify** the chromosome location of the *SRY* gene.
- 4 **Describe** the action of the *SRY* gene.

#### Apply, analyse and interpret

- 5 **Determine** whether *Hox* genes would influence the adult body plan.
- 6 **Determine** the stage at which male testes are formed in the womb.

Check your **obook assess** for these additional resources and more:

» **Student book questions**

Check your learning 9.3

» **Weblink**  
*Hox* gene

» **Weblink**  
*SRY* gene

# Review

## Chapter summary

- 9.1**
- The genome is all the genetic material found in the chromosomes of an organism.
  - Transcription involves the transfer of the genetic information of DNA triplets (codes) into messenger RNA codons by RNA polymerase.
  - Transfer RNA has an anticodon that is complementary to the mRNA's codon. Each tRNA carries a specific amino acid.
  - Translation of the mRNA to an amino acid sequence at the cytoplasmic ribosomes (rRNA) produces a polypeptide. The polypeptide will fold to form a functional protein.
- 9.2**
- Gene expression must be regulated to prevent wasting energy or chemical substrates.
  - Gene regulation can occur at the pre-transcription, post-transcription and translation stages.
  - Epigenetics is the study of how gene expression is controlled by the environment.
  - Studying identical twins who are brought up in different environments enables the study of epigenetics.
- 9.3**
- Transcription factors regulate differential gene expression. This controls cell differentiation for tissue formation and morphology.
  - *Hox* genes produce *Hox* proteins that act as transcription factors for genes that regulate body plan morphology.
  - The *SRY* gene on the Y chromosome produces *SRY* protein. This protein is responsible for the development of male testes.

## Key terms

- |                   |                                 |                      |                        |
|-------------------|---------------------------------|----------------------|------------------------|
| • anticodon       | • gene expression               | • <i>Hox</i> protein | • split gene           |
| • capping         | • genetic code                  | • intron             | • <i>SRY</i> gene      |
| • codon           | • genome                        | • monozygotic twins  | • structural gene      |
| • dizygotic twins | • heterochromatin               | • mRNA               | • tailing              |
| • DNA methylation | • histone modification          | • non-coding DNA     | • transcription factor |
| • epigenome       | • homeobox                      | • polysome           | • translation          |
| • euchromatin     | • homeobox ( <i>Hox</i> ) genes | • regulatory gene    | • trimming             |
| • exon            | • homeotic gene                 | • rRNA               | • tRNA                 |
| • fraternal twins |                                 |                      |                        |

## Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number:

\* = low; \*\* = medium; \*\*\* = high.

### Multiple choice

- The genetic code is generally accepted as being provided by the linear arrangement of:
  - amino acids in chromosome proteins
  - sugar units in DNA
  - nucleotide bases in DNA
  - nucleotide bases in RNA
- The synthesis of specific proteins by an organism is determined by the:
  - number of ribosomes present in a cell
  - organism's genes
  - RNA present in the cell
  - fatty acids in the cell
- Transcription is the process whereby:
  - a piece of messenger RNA is produced complementary to the DNA code for a gene
  - amino acids in the cytoplasm are placed, by transfer RNA, into the correct sequence for protein synthesis
  - the DNA for a gene unzips
  - the Golgi apparatus converts the polypeptide chain into a specific protein

The next 3 questions (Questions 4–6) refer to Figure 1.

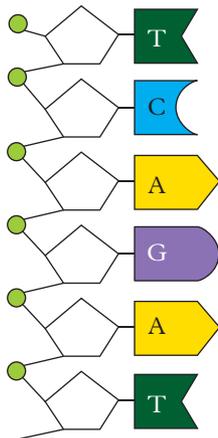


FIGURE 1 Part of a DNA molecule

- The correct sequence of lettered parts in the missing half of this molecule is:
  - TAGACT
  - AGTCTA
  - TCAGAT
  - GACTGC
- If the molecule portion were being transcribed, the correct sequence of lettered parts in the new molecule would be:
  - AGUCUA
  - UGTCTU
  - UAGUGA
  - AUCUGA
- The highest number of amino acids coded for by the molecule shown is:
  - 1
  - 2
  - 3
  - 6
- Genes mainly exert their control over cellular activity by:
  - preventing the passage of materials into the cell through its membrane
  - producing transcription factors that block production of mRNA
  - contributing to epigenetic histone modification
  - controlling cellular metabolism
- A particular tRNA molecule attaches to a specific:
  - amino acid
  - genome
  - protein
  - ribosome
- In relation to gene expression, translation is the process:
  - where certain environmental stimuli are required before a set of genes is expressed
  - in which a protein is synthesised with an amino acid sequence determined by the mRNA nucleotide sequence
  - where the energy from ATP is used by RNA polymerase

**D** in which the sense strand of DNA is used by RNA polymerase to synthesise an mRNA molecule

**10** DNA methylation is a process that:

- A** is instigated by regulatory genes to increase the rate of transcription
- B** epigenetically blocks expression of a gene
- C** tightens the coiling of a nucleosome
- D** works in the same way as a histone modification

### Short answer

#### **Describe and explain**

- ★ **11 Explain** why a codon is composed of three nucleotides rather than any other number.
- ★ **12** The epigenome is defined as 'above the genome'. **Explain** what this means.
- ★ **13 Describe** two ways in which epigenetic control is achieved.
- ★ **14** Briefly **explain** how the DNA in the nucleus of a cell is believed to control the synthesis of proteins in the cytoplasm.
- ★ **15 Identify** five different environmental factors that may affect gene expression.
- ★★ **16** In multicellular organisms there are several post-transcriptional controls on gene activity. **Identify** these and **describe** the source of the controls.
- ★★ **17** Certain genes produce transcriptional factors that control the development of a foetus. **Select** one of these genes and describe the developmental feature and its control.

★★★ **18 Explain** how DNA differs from RNA in the following characteristics.

- a** Kind of sugar in the molecule
- b** Usual location in the cell
- c** Nitrogen bases present in the molecule
- d** Usual number of strands
- e** Functions in the cell

★★ **19 Describe** how the *Hox* gene can be used to explain why insects and humans have a common ancestor.

#### **Apply, analyse and interpret**

- ★ **20** A certain protein is composed of 1500 amino acids. **Determine** how many base pairs the gene responsible for its synthesis would have.
- ★ **21 Compare** structural and regulatory genes.
- ★★ **22 Hypothesise**, with reasons, the possible outcome if an organism had no homeotic genes.
- ★★★ **23** The following sequence of bases in DNA codes for the formation of a section of polypeptide containing ten amino acids:  
GTTAACCGAACGGTTAGATGTAC-  
ATTTAAG
  - a Determine** the base sequence of the mRNA responsible for transcribing this code.
  - b** Using Table 1, **determine** the sequence of amino acids in the resulting polypeptide.  
For example, GCA codes for the amino acid alanine, which is circled in the table.



**FIGURE 2** Sonogram of a developing foetus

### Investigate, evaluate and communicate

- ★★ 24 In certain situations (e.g. disturbed soil at mine sites) some individuals of a species can grow prolifically while others, with different phenotypic expressions, can only grow in the surrounding undisturbed soil. **Propose** the probable process(es) involved in this resulting difference in two closely situated populations.
- ★★★ 25 Epigenetic DNA tagging (methylation) is very important to maintain cell differentiation in multicellular organisms,

and yet it is just as significant that embryonic cells be totipotent. **Discuss** factors that could lead to DNA methylation and propose, with reasons, the formation of totipotent embryonic cells and cell differentiation.

- ★★★ 26 It has been demonstrated that some epigenetic tags can be inherited. **Discuss** the type(s) of tag that can be inherited and propose mechanisms for the inheritance.

TABLE 1 Amino acids coded for by DNA

Commonly used abbreviations for the twenty amino acids coded for by DNA		1st position	2nd position				3rd position
			T	C	A	G	
Ala Alanine	Leu Leucine	Thymine T	Phe	Ser	Tyr	Cys	T
Arg Arginine	Lys Lysine		Phe	Ser	Tyr	Cys	C
Asn Asparagine	Met Methionine		Leu	Ser	STOP	STOP	A
Asp Aspartic acid	Phe Phenylalanine		Leu	Ser	STOP	Trp	G
Cys Cysteine	Pro Proline	Cytosine C	Leu	Pro	His	Arg	T
Gln Glutamine	Ser Serine		Leu	Pro	His	Arg	C
Glu Glutamic acid	Thr Threonine		Leu	Pro	Gin	Arg	A
Gly Glycine	Trp Tryptophan		Leu	Pro	Gin	Arg	G
His Histidine	Tyr Tyrosine	Adenine A	Ile	Thr	Asn	Ser	T
Ile Isoleucine	Val Valine		Ile	Thr	Asn	Ser	C
			Ile	Thr	Lys	Arg	A
			Met/START	Thr	Lys	Arg	G
		Guanine G	Val	Ala	Asp	Gly	T
			Val	Ala	Asp	Gly	C
			Val	Ala	Glu	Gly	A
			Val	Ala	Glu	Gly	G

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» Student book questions  
Chapter 9 review

» Revision notes  
Chapter 9

» **assess quiz**  
Chapter 9 auto-correcting multiple-choice quiz

» **Flashcard glossary**  
Chapter 9 glossary



# Mutations

Mutations are caused by changes or errors in DNA replication or chromosomes that can result in changes in the phenotype of an individual. Chromosomal genetic disorders arise from non-disjunction of chromosomes during the nuclear division of meiosis for gamete production. Karyotypes show the numbers of chromosomes present in an individual and are used to predict whether there is a chromosomal genetic disorder present. Errors in DNA replications tend to result from damaging mutagens such as chemicals that are carcinogenic, radiation, heat and physical influences such as the environment. The consequences of these DNA errors will depend on the type of change caused in the DNA and therefore on the phenotype of the individual.

## OBJECTIVES

- Identify how mutations in genes and chromosomes can result from errors in:
  - DNA replication (point and frameshift mutation)
  - cell division (non-disjunction)
  - damage by mutagens (physical, including UV radiation, ionising radiation and heat and chemical).
- Explain how non-disjunction leads to aneuploidy.
- Use a human karyotype to identify ploidy changes and predict a genetic disorder from given data.
- Describe how inherited mutations can alter the variations in the genotype of offspring.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

**FIGURE 1** Mutations can come in many shapes and forms, such as this two-headed turtle.



# 10.1

## Genetic mutations

### KEY IDEAS

- ✦ Mutation in the nucleotide sequence
- ✦ Point mutation
- ✦ Substitution point mutation and change in amino acid sequences
- ✦ Frameshift mutation

Every time a cell replicates its DNA, a mistake may be made. Most mistakes are repaired by specialised proteins such as the BRCA1 and BRCA2 proteins. These proteins act as a built-in auto-correcting system. Occasionally an error in the DNA sequences is missed and is passed on during transcription to the mRNA. This is translated into an incorrect amino acid in the protein that is produced.

An example of this is a mutation in the *BRCA* genes. Most commonly, a change in a single nucleotide of the *BRCA1* gene will result in a non-functioning protein that cannot repair other DNA mutations.

#### mutation

small permanent change in the DNA of an organism

#### point mutation

a change in a single nucleotide in the DNA code that may result in translation of one different amino acid in a polypeptide sequence

#### somatic mutation

a mutation in the somatic tissue of an organism that affects the specific cell type but is not inherited

#### germ line mutation

a heritable change in the DNA that occurs in a germ cell (a cell destined to become an egg or sperm) or the zygote at the single-cell stage and so is incorporated in every cell of the body

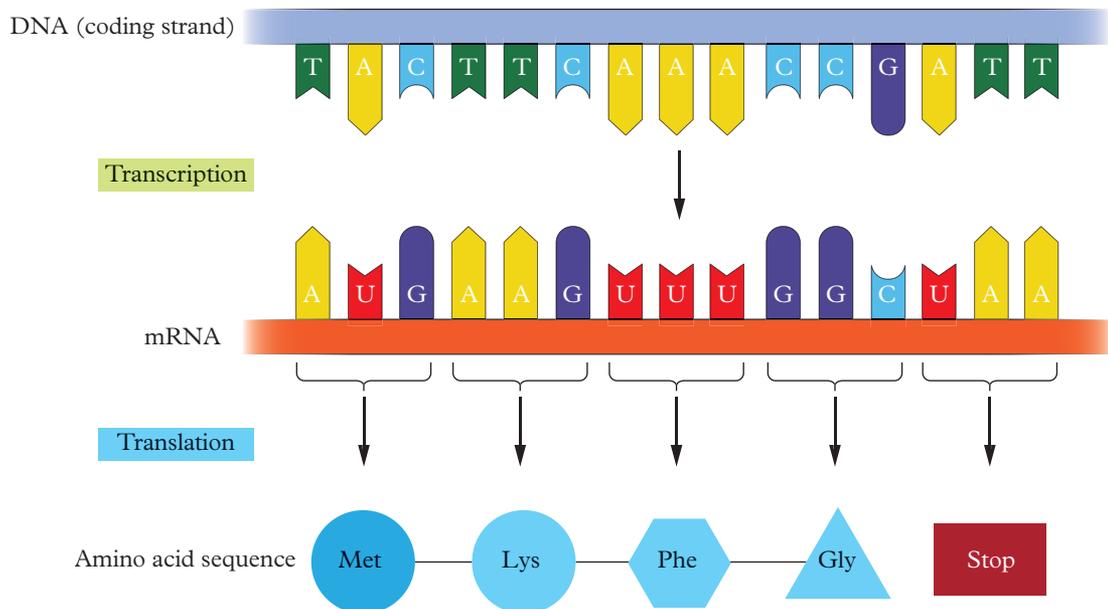


FIGURE 1 Transcription and translation of a normal DNA molecule

Such an error is called a gene **mutation** (a permanent change in the nucleotide sequence of the genetic material). Mutations that result in a change in the final transcribed protein can cause the expression of a different phenotype. Many of these mutations are a result of a change in a single nucleotide in the sequence. Such changes are called **point mutations**.

These types of errors seem to occur more regularly in older individuals and are believed to be a function of the natural ageing process or senescence. Since this type of mutation generally affects body cells as opposed to the gonad cells, it is referred to as **somatic mutation**. Only those DNA mutations that occur in the **germ line** (reproductive) cells can be passed on to future generations.

# Point mutation

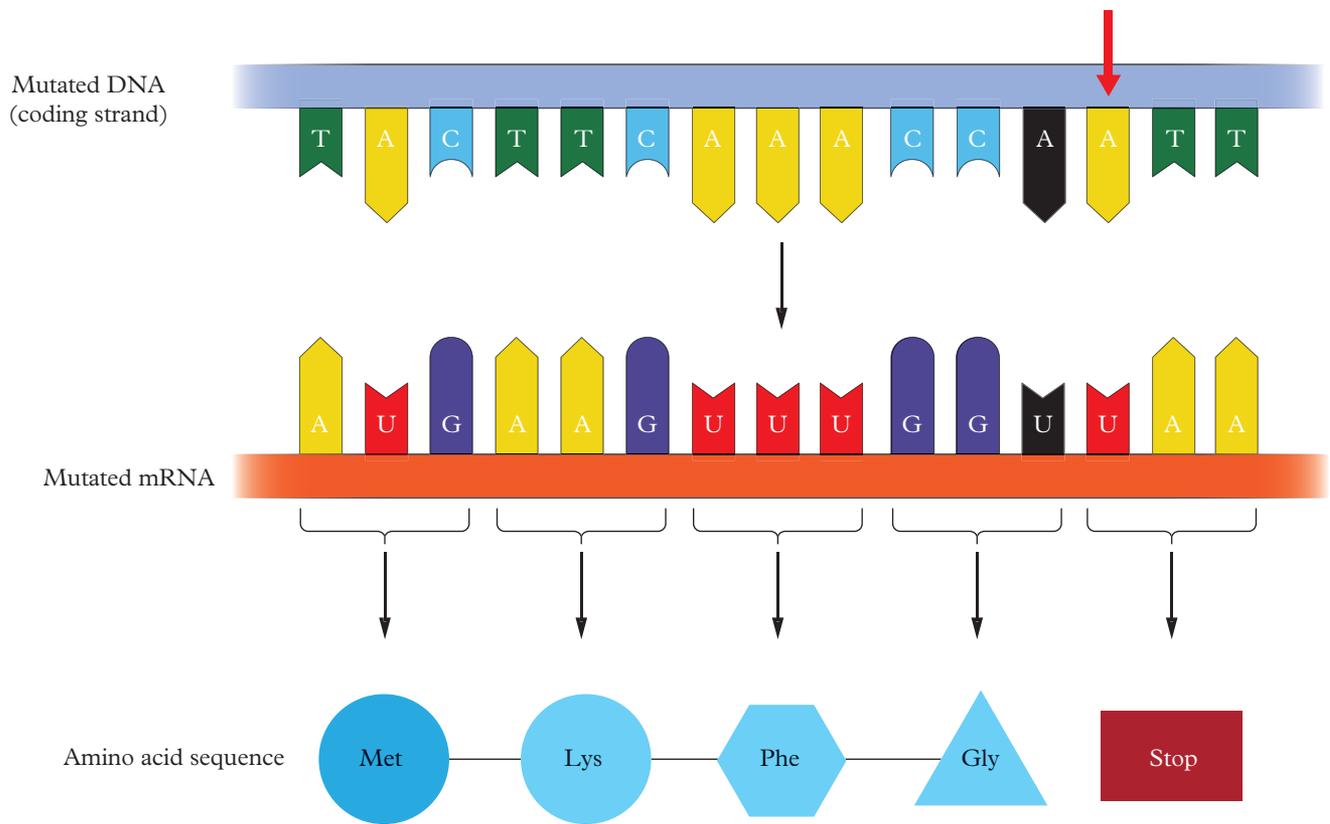
A point mutation occurs inside one DNA nucleotide triplet where there is a substitution of one nucleotide for another, or the order within the triplet may be changed. While this may cause changes in the amino acid sequence, the actual frame of the DNA strand is not altered.

There are three main types of point mutation:

- 1 silent
- 2 missense
- 3 nonsense.

## Silent point mutations

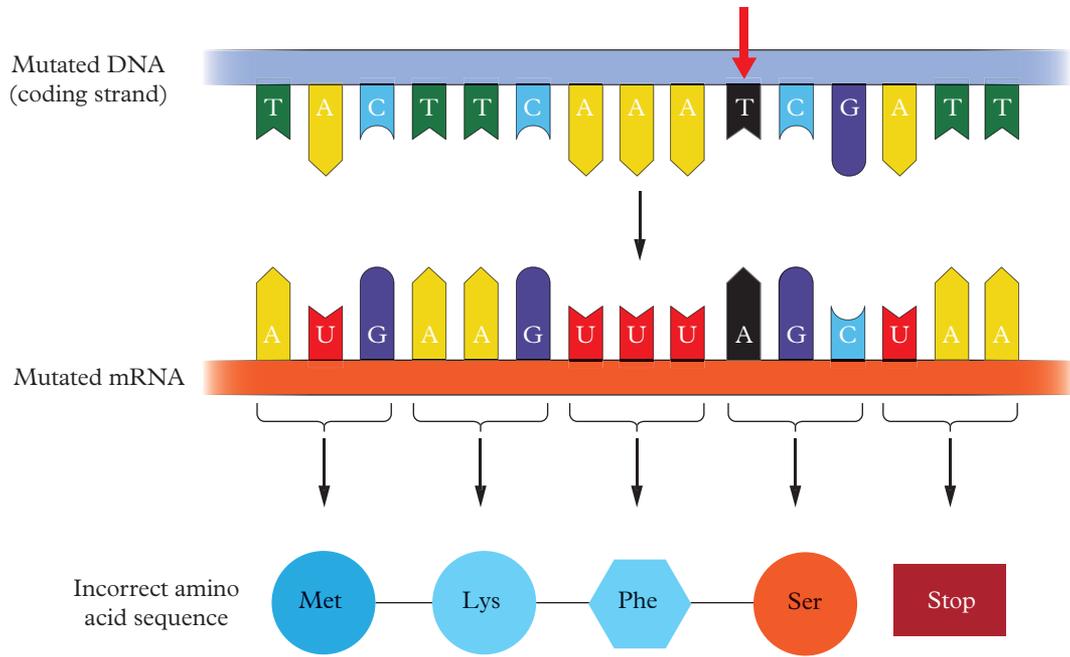
In this type of point mutation there is a substitution of one nucleotide for another, or the order may be changed within the triplet. As there are many DNA triplets that code for the same amino acid, the replacement of a single nucleotide may not result in a change in the amino acid sequence. Consequently, there may be no effect on the protein produced.



**FIGURE 2** The mutated DNA has an adenine base (error is in black and is indicated with a red arrow) instead of a guanine base in the fourth triplet. The new triplet still codes for amino acid glycine; there is no change in the amino acid sequence seen in Figure 1.

## Missense point mutation

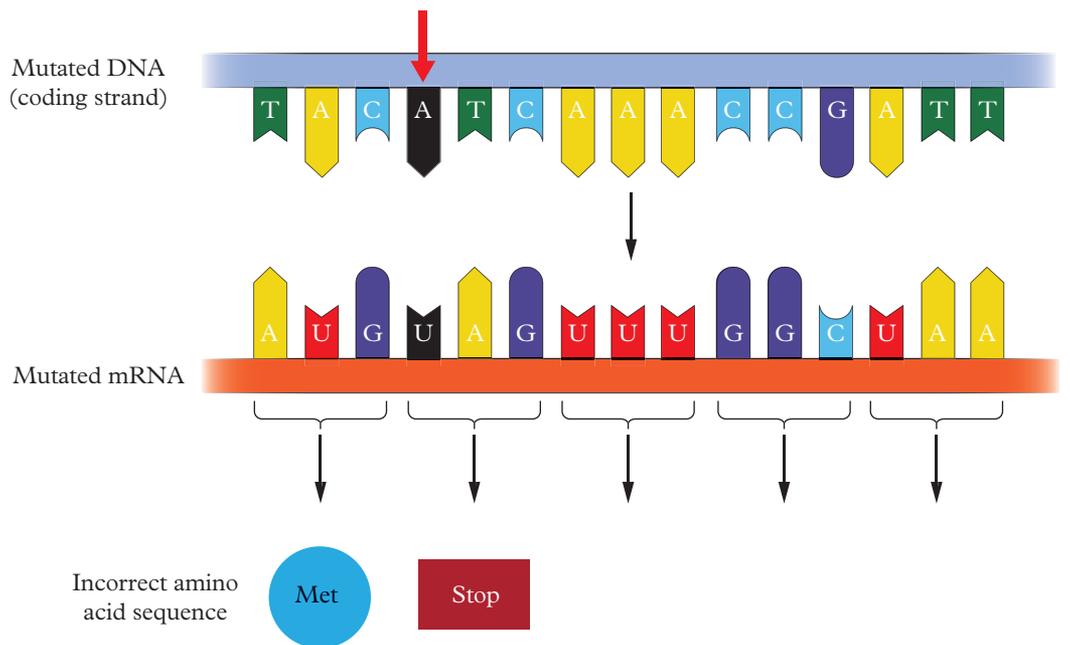
Some point mutations may result in the production of a protein in which one amino acid is substituted for another. As seen in Figure 3, there is a substitution error where the cytosine nucleotide has been replaced by thymine. This results in the coding for an incorrect amino acid. This means the resultant protein may be non-functional or possibly harmful to the organism.



**FIGURE 3** The mutated DNA has a thymine base (error is in black and is indicated with a red arrow) instead of a cytosine base in the fourth triplet. The new triplet codes for amino acid serine instead of glycine, resulting in a change in the amino acid sequence.

## Nonsense point mutations

Occasionally a point substitution will result in a stop codon, leading (through codon mutations) to premature termination of protein translation. This is illustrated in Figure 4, where there is a substitution error in the second triplet (the thymine nucleotide has been replaced by adenine). This results in the stop codon UAG so that the amino acid sequence is halted, causing a shortened polypeptide chain that may be non-functioning.



**FIGURE 4** The mutated DNA has an adenine base (error is in black and is indicated with a red arrow) instead of a thymine base in the second triplet. The new triplet UAG codes for stop and so the amino acid sequence is ended.

# Frameshift mutation

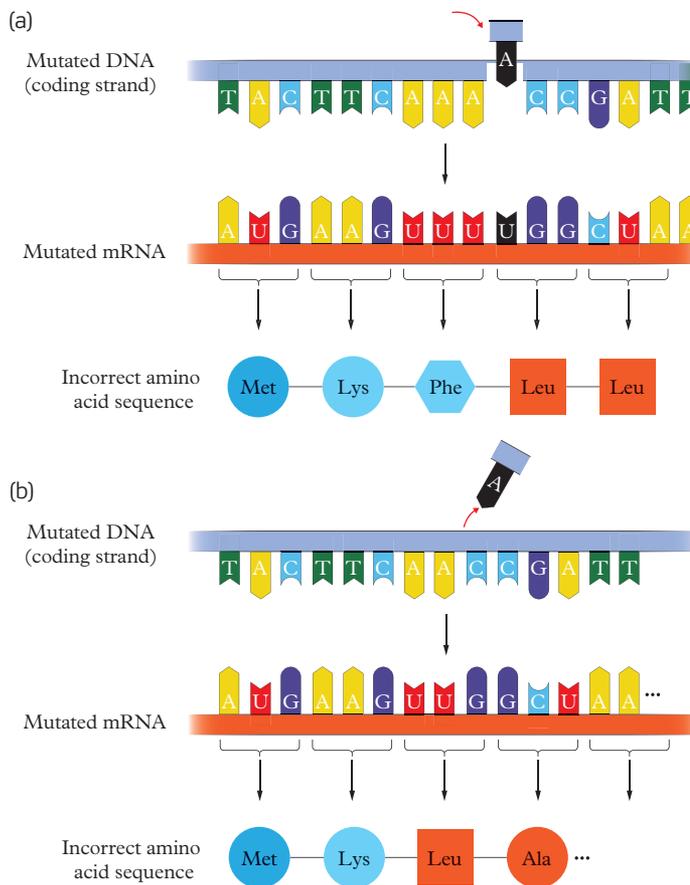
A mutation may involve nucleotides being added or removed from the DNA sequence. This may or may not be a problem if three nucleotides are added or removed as it results in the addition or removal of a whole amino acid in the protein.

If there is an addition of a single base (or the deletion of a single base) in one of these triplets, the decoding process will work perfectly until it comes to this change. From that point on, the reading frame of three nucleotides (triplets and then the mRNA codons) will have shifted, resulting in completely different proteins being produced. This is called a **frameshift mutation**.

(normal sequence)	THE CAT ATE THE RAT AND RAN FAR
(point mutation)	THE CAR ATE THE RAT AND RAN FAR
(frameshift deletion)	THE CAA TET HER ATA NDR ANF AR
(frameshift addition)	THE CAT TAT ETH ERA TAN DRA NFA R

**frameshift mutation**  
the deletion or insertion of a single or non-multiple of three nucleotides into the DNA

An insertion results in shifting of the DNA frame to the right while a deletion moves the frame to the left. In framing errors there is an increase or decrease in the number of nucleotides in the DNA strand. All triplet codes, and therefore the codons, following the frameshift will be altered. This results in the production of a very different protein that may not be functional.



**FIGURE 5** Frameshift mutations. (a) The mutated DNA has an adenine base (error in black) added in (indicated with a red arrow) after the third triplet. (b) The adenine base (error in black) in the mutated DNA has been deleted from (indicated with red arrow) the third triplet. In both cases the DNA frame has been ‘shifted’ – to the right in (a) and to the left in (b).

Deletions, insertions or substitutions can also occur during transcription of mRNA, in translation between mRNA and tRNA, or when tRNA transfers an amino acid to an amino acid sequence. These changes, however, are not permanent and only affect the protein being produced at that time.

The differences between point mutation and frameshift mutation are as follows:

- Point mutations do not change the reading frame of the DNA strand, whereas the frame of the DNA strand is shifted in one direction or the opposite direction in a frameshift mutation.
- Point mutations cause only the structure of one code of the gene to change, whereas the gene structure, through changes in the number of nucleotides, is changed in frameshift mutations.
- Point mutations are the result of a nucleotide base substitution or change of order in one triplet code during DNA replication, whereas frameshift mutations result from a nucleotide deletion or insertion.

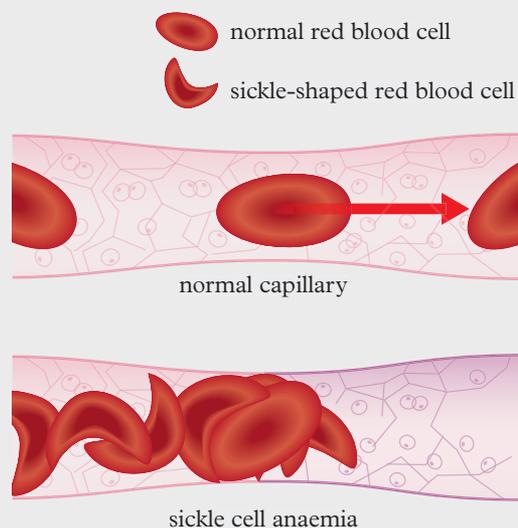
## CASE STUDY 10.1

### Sickle cell anaemia – a point mutation

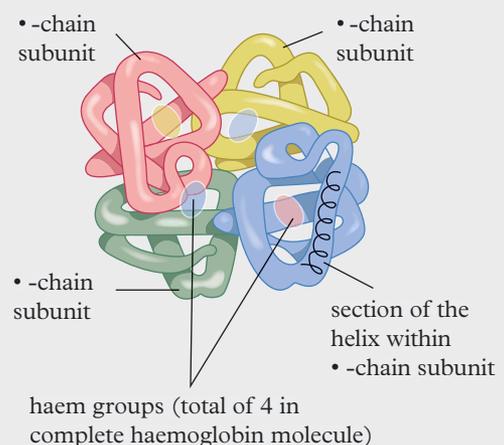
The most common form of sickle cell anaemia is caused by a point mutation in the gene that makes haemoglobin. This iron-rich compound allows red blood cells to carry oxygen from the lungs to all parts of the body. In this disease, an abnormal form of haemoglobin causes the red blood cells to sickle into a rigid shape and so clump together blocking capillaries.

Healthy humans have adult haemoglobin (haemoglobin A), which consists of two alpha ( $\alpha$ ) chain proteins and two beta ( $\beta$ ) chain proteins. These four protein chains are held tightly together by many weak hydrogen bonds or by covalent bonds between sulphur atoms in certain R groups.

The gene responsible for sickle cell anaemia is located on chromosome 11 where a point mutation in the DNA has occurred. In this case, adenine has been replaced by



**FIGURE 6** Comparison of the shapes of normal and sickle-shaped blood cells

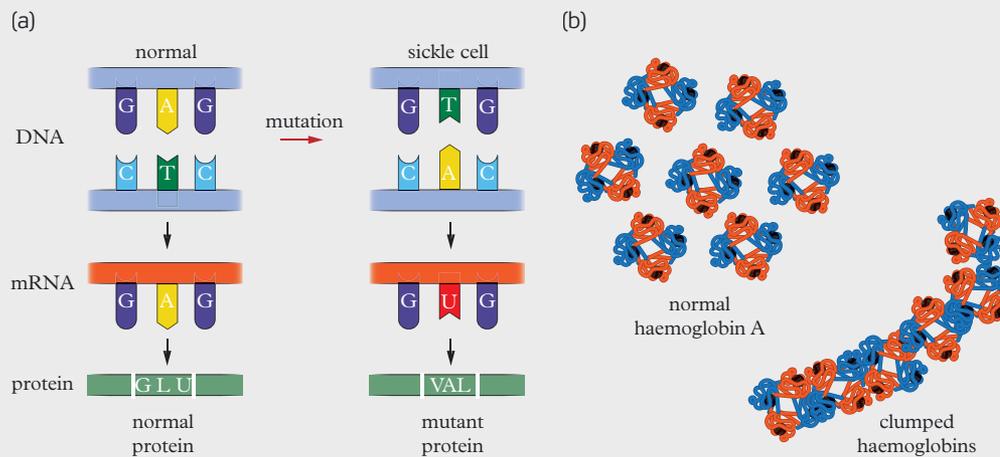


**FIGURE 7** Haemoglobin A showing the two alpha and two beta chains.

thymine, resulting in the amino acid glutamic acid of normal haemoglobin A being replaced by valine. This point substitution mutation in the DNA causes the  $\beta$ -chain subunits of haemoglobin A to become sticky (haemoglobin S), causing the red blood cells to change shape.

- (a) There are effects at the DNA level.
- (b) There are effects at the protein level.

The types of haemoglobin a person produces in the red blood cells depend on what haemoglobin alleles are inherited from the parents. For a child to have the disease both parents must pass a defective allele to their offspring. If only one parent passed the sickle cell allele to the child, that child will carry the trait and will have both normal and sickle haemoglobin. Although their blood may contain some sickle cells they tend to be symptom free. Often it only shows an effect if the person is involved in very vigorous activities, and this can lead to death.



**FIGURE 8** (a) The point mutation at the DNA level. (b) Effects at protein level. Normal haemoglobin A (left) and haemoglobin S in sickled red blood cells (right). The mutation in the DNA results in changes in the shape of the haemoglobin S molecule, which causes clumping in slightly higher oxygen demands.

## CHECK YOUR LEARNING 10.1

### Describe and explain

- 1 **Describe** where a genetic mutation can occur.
- 2 **Explain** how a genetic mutation can occur without the amino acid being changed.
- 3 **Describe** the meaning of the term frameshift.

### Apply, analyse and interpret

- 4 A student claimed that a point mutation could be described as a frameshift mutation. **Consider** their claim using examples.

### Check your obook assess for these additional resources and more:

» Student book questions  
Check your learning 10.1

» Weblink  
Sickle cell anaemia

» Weblink  
Cystic fibrosis

# 10.2

## Chromosome mutations

### KEY IDEAS

- + Block mutations
- + Non-disjunction in meiosis and gametes with more or fewer chromosomes (aneuploidy)
- + Karyotypes and aneuploidy

### chromosome mutation

a change in the chromosome structure or number, often due to an error in pairing during the crossing over stage of meiosis

A **chromosome mutation** is a change in the arrangement of blocks of genes, or the number of chromosomes, in a cell.

### Block mutations

A block mutation occurs when there is a change in a 'block' of genes located together on a single chromosome. This is due to a mistake that can occur during meiosis. During meiosis I, there is often exchange of pieces of chromatids between **homologs** (homologous chromosomes). When the homologous chromosomes pair up during prophase I, crossing over can occur. Occasionally the crossing over is incomplete.

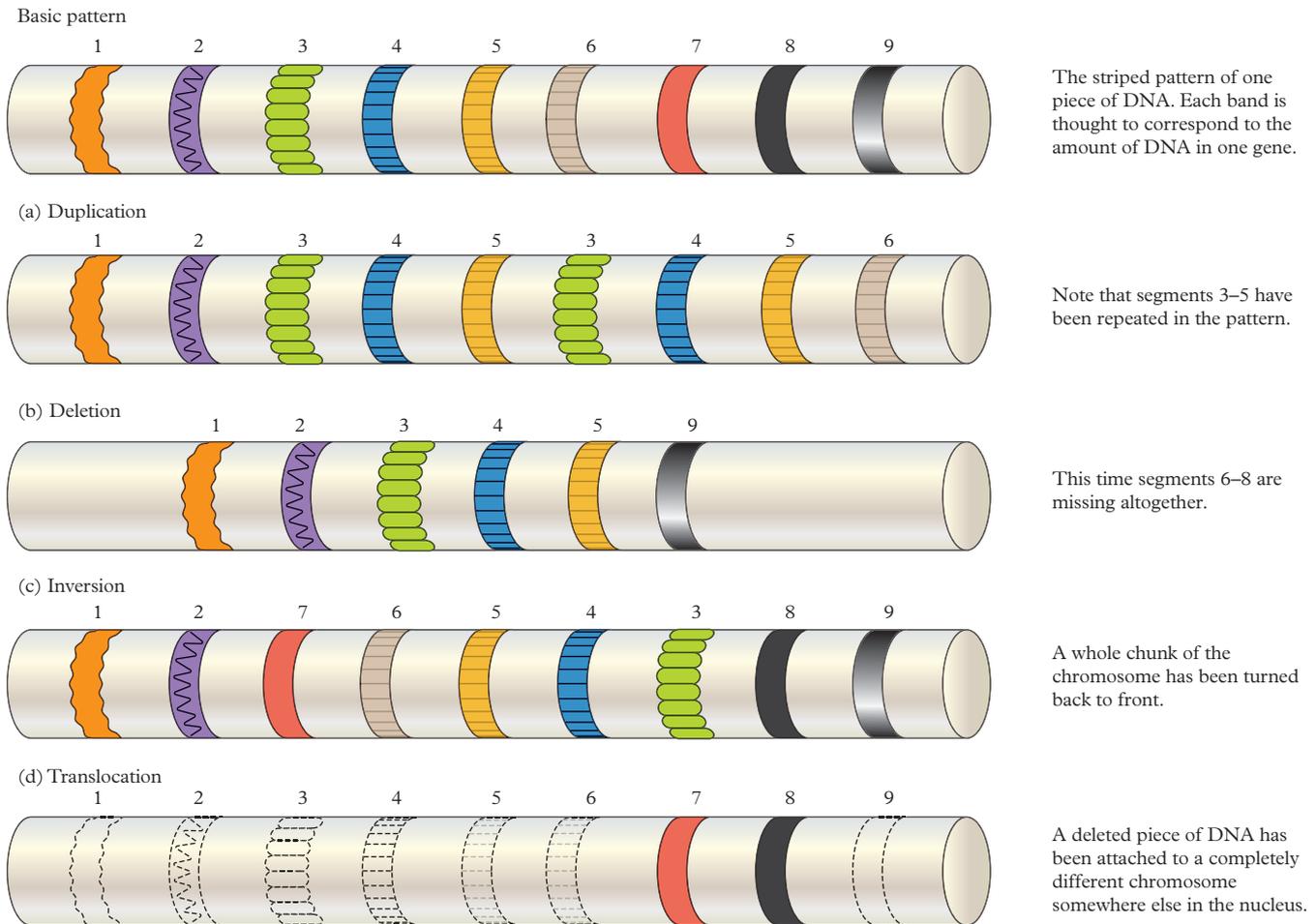


FIGURE 1 Chromosomal mutations

A **deletion** can occur when a segment that has broken off is not replaced by the corresponding segment of the homolog. The resulting chromosome will therefore not have all of the genetic information it should. Sometimes the broken-off segment becomes incorporated into the homolog, which then has two sections of that piece of information: a **duplication** has then occurred.

In other instances, the broken-off segment becomes incorporated into a completely different (non-homologous) chromosome. This is known as **translocation**.

An **inversion** occurs when the broken-off segment re-attaches 'back-to-front'. Depending on the size of the segment, and the genetic information it carries, these forms of misinformation can result in death of the developing embryo.

**homologs**  
two chromosomes that are homologous; during meiosis, the set of pairing maternal and paternal chromosomes; have the same genes at the same loci but may have different alleles

**chromosomal deletion**  
loss of a part of a chromosome during DNA replication

**duplication**  
any repetition of a region of DNA that contains one or more genes

**translocation**  
movement of a chromosomal segment from one position to another, either within the same chromosome or to another chromosome

**inversion**  
a chromosome rearrangement in which a segment of a chromosome is reversed end to end

## CASE STUDY 10.2A

### Cri-du-chat (French for 'cry of the cat')

This syndrome is caused by the deletion of the top section of the small arm of chromosome 5. Its name arises from the infant having a very high-pitched cry that sounds like the cry of a cat. About one-third of these children lose this cry by age two. Most of the cases of this syndrome are not inherited and there is no history of the disorder in the family. It appears to arise from an error during gamete formation (ova or sperm) or during early foetal development.

Children with this disorder have:

- intellectual disabilities that are severe, including delayed speech and motor ability
- delayed physical development
- a small head and jaw
- low birth weight and poor growth associated with swallowing and sucking difficulties
- weak muscle tone
- distinctive facial features, e.g. low set ears, wide nasal bridge, skin tags in front of the eyes
- general health and behavioural difficulties.



**FIGURE 2** (a) Facial features of a patient with cri-du-chat syndrome; (b) karyotype of cri-du-chat syndrome.

# Chromosomal non-disjunction mutations

## non-disjunction

the failure of homologous chromosomes or sister chromatids to separate during meiosis

## aneuploidy

presence of an abnormal number of chromosomes in a cell

## autosomal aneuploidy

presence of an abnormal number of autosomal chromosomes

## sexual aneuploidy

presence of an abnormal number of sex chromosomes in a cell

## trisomy

occurs when a diploid organism has three copies of one of its chromosomes instead of two

Occasionally, during meiosis, a pair of homologous chromosomes fails to separate. This process is termed **non-disjunction**. It results in some of the gametes having two copies of a particular chromosome, while other gametes do not have that chromosome. After fertilisation by one of these mutated gametes, the diploid zygote will have an incorrect number of chromosomes. The presence of an abnormal number of chromosomes in a cell (**aneuploidy**) will occur in every cell within the resultant individual. For example, each human cell could have 45 or 47 chromosomes instead of the usual 46.

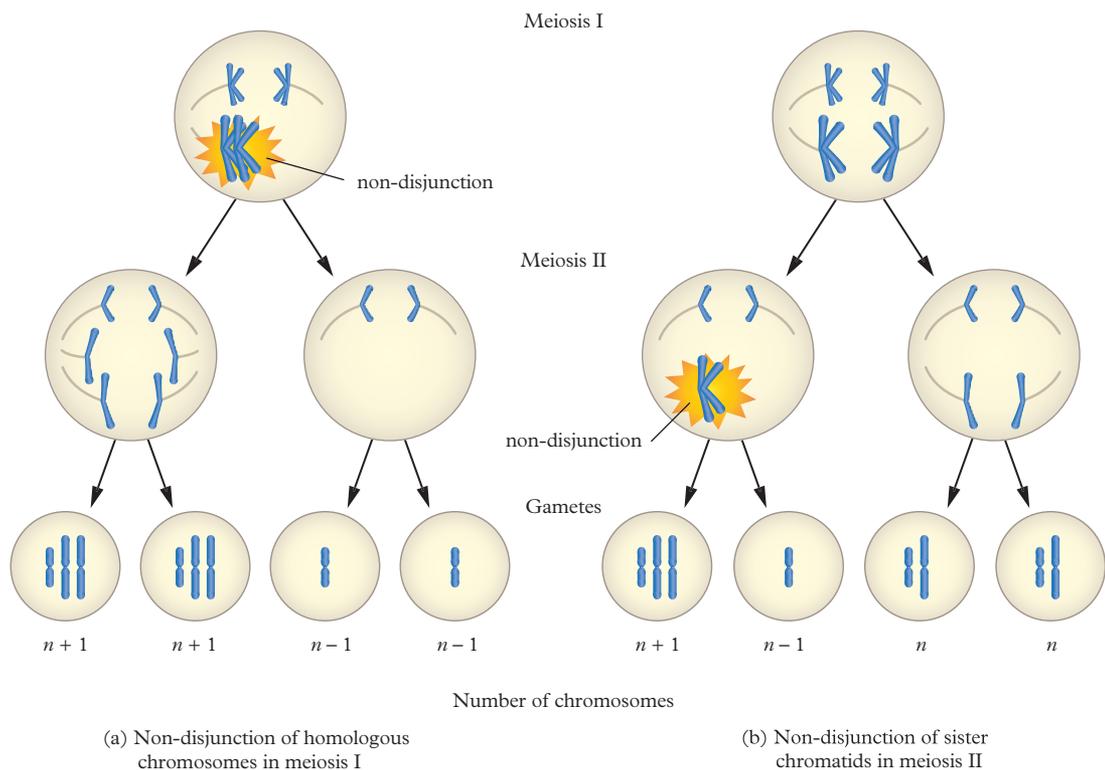
There are two main divisions of chromosomal aneuploidy errors: **autosomal aneuploidy**, which involves the 44 autosomal (body) chromosomes, and **sexual aneuploidy**, which involves the X and Y sex chromosomes.

If a male gamete with one missing autosome fertilises an ovum, the embryo will not develop. If there is an extra autosome present, the embryo may develop.

In 1959, it was discovered that the presence of an extra chromosome 21 was associated with Down syndrome in humans. This **trisomy** (three chromosomes) condition is not just limited to chromosome 21. Trisomy 18 (Edwards syndrome) and 13 (Patau syndrome) are some of the syndromes that have been identified as a result of non-disjunction.

Non-disjunction may occur during meiosis I or meiosis II. It is caused when:

- homologous chromosomes fail to separate in meiosis I
- sister chromatids fail to separate during meiosis II, resulting in an abnormal number of chromosomes in the gametes.



**FIGURE 3** (a) Non-disjunction of homologous chromosomes in meiosis I; (b) non-disjunction of sister chromatids in meiosis II

# Studying chromosomes - the karyotype

A **karyotype** is a display of the total complement of a species' chromosomes. It is prepared using mitotic metaphase chromosomes. In humans, a blood sample is usually taken, and the white blood cells separated from the other constituents. Cells in the process of dividing are interrupted by the addition of a drug (colchicine). This drug prevents anaphase from occurring by interfering with the spindle microtubules. The addition of water causes the cells to rupture. Photographs of the ruptured cells are taken. These are enlarged, and the chromosomes are cut out and arranged in pairs. The position of the centromere, and thus the length of the 'arms' of the chromatids, is used as a determinant for the pairs. Certain anomalies, such as an extra chromosome or piece of chromosome, can then be detected.

**karyotype**  
the number and visual appearance of the chromosomes in the cell nuclei of an organism or species

## CASE STUDY 10.2B

### Missing or additional sex chromosomes

Non-disjunction can produce individuals with unusual combinations of sex chromosomes. In humans, the male sex results from the presence of the Y chromosome. A normal male's sex chromosome complement is XY. Males with XXY, XXXY and XXXXY are usually sexually undeveloped and sterile.

#### 1 Klinefelter syndrome

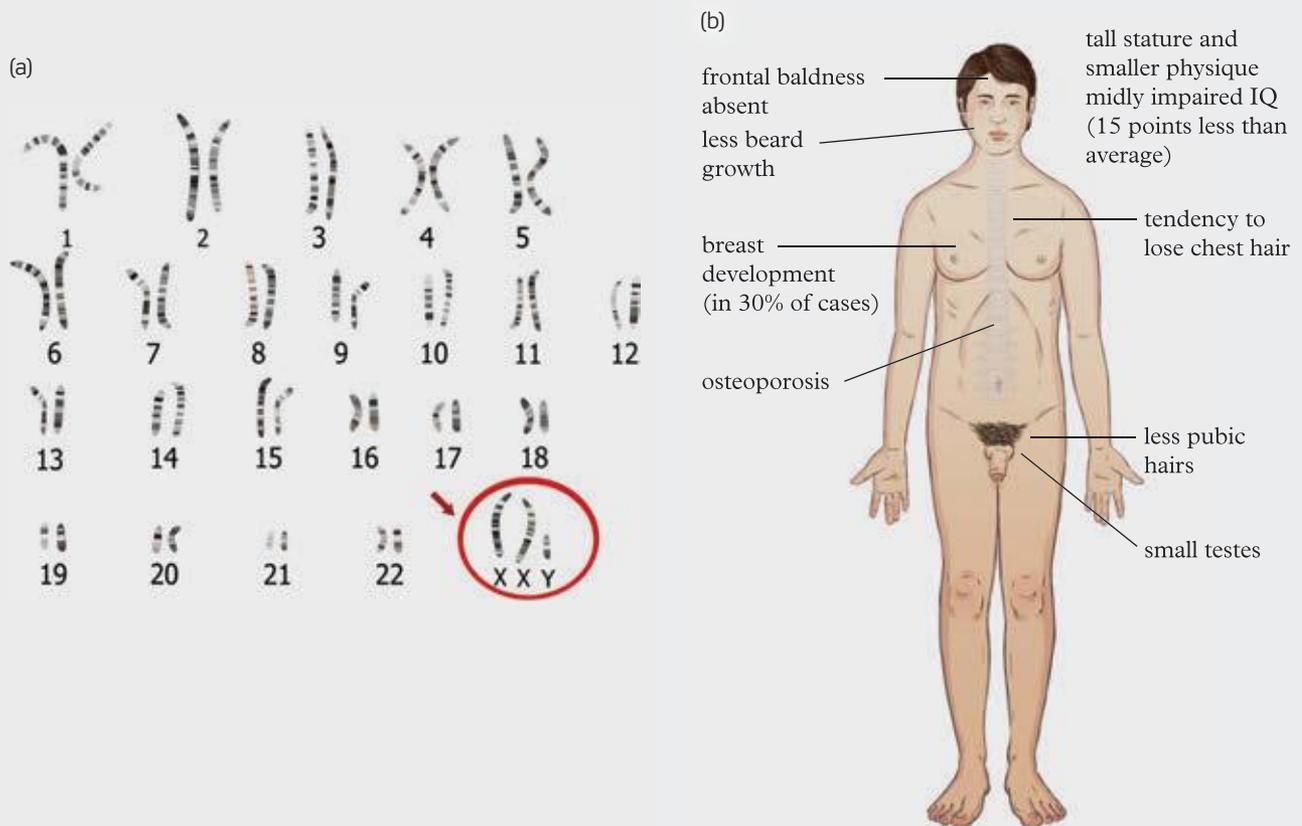


FIGURE 4 (a) The karotype and (b) the characteristics of a male with Klinefelter syndrome.

## 2 Turner syndrome

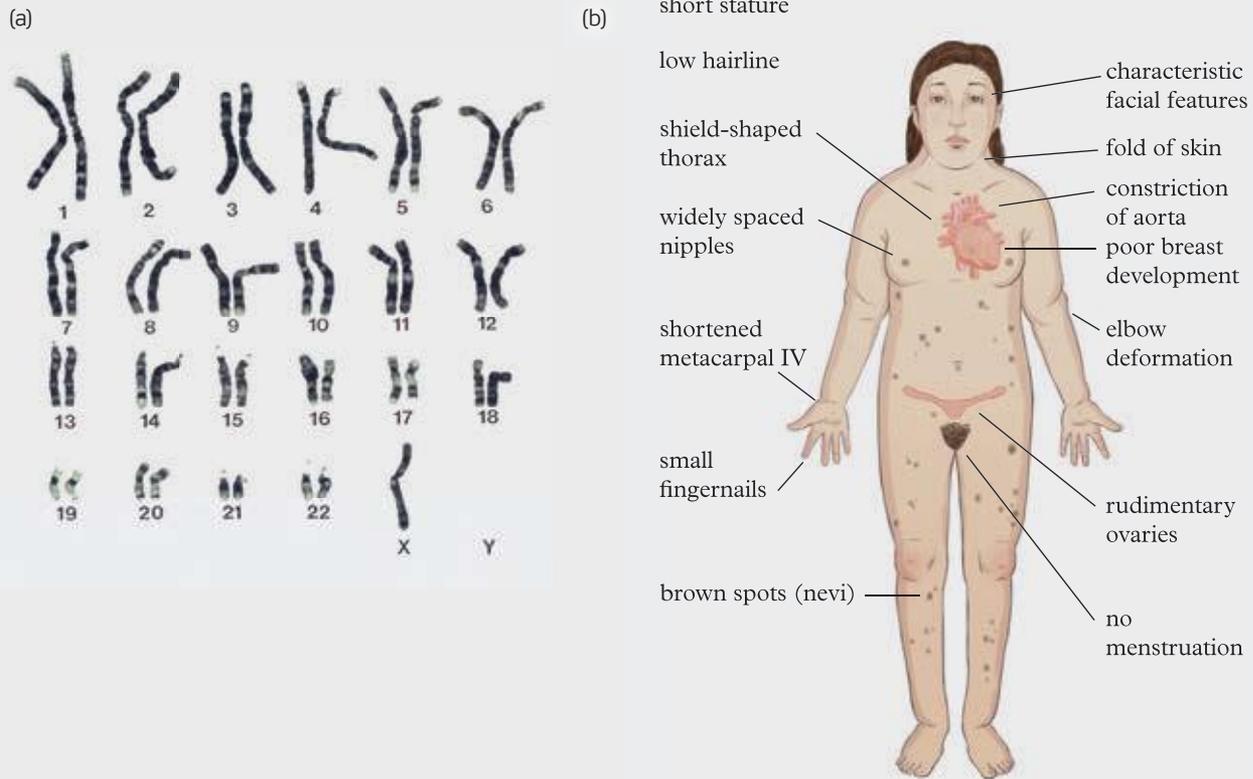


FIGURE 5 (a) The karyotype and (b) the characteristics of a female with Turner syndrome

## CASE STUDY 10.2C

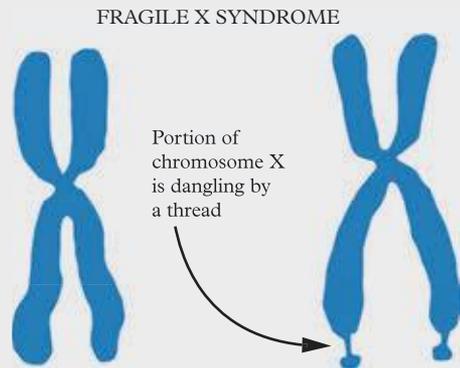
### Fragile X syndrome

Fragile X syndrome results from repeated duplication of three nucleotides of one gene (called *FMR1*) on the X chromosome. This repeated replication of three nucleotides lengthens the gene, causing it to stop the production of a protein that is essential for development and other functions. Since it is found on the X chromosome, most females will have at least one 'normal' X chromosome. Males (with only one X chromosome) are more likely than females to have the disease phenotype. During stages of cell division this section of the chromosome appears as though it is hanging from a thread, giving it the name 'fragile'.

The number of times this trinucleotide duplicates determines the extent of the symptoms. Up to 40 repeats does not appear to have any effect, but if a person has more than 200 duplications of this segment, the gene completely 'switches off' and does not attempt to make the coded protein. The exact function of the protein coded by the *FMR1* gene is not known at present, but it is thought that it is associated with communication between nerve cells in the brain.

Symptoms of this disease are varying degrees of learning, behavioural and emotional difficulties, and physical features. In children they may include:

- delayed development (e.g. sitting, walking, speaking)
- difficulties with paying attention
- hand flapping and biting associated with high levels of anxiety
- physical signs such as a long narrow face, large ears, a high arched palate, flat feet and extremely flexible joints
- seizures.



**FIGURE 6** The fragile X chromosome from fragile X syndrome

## CHECK YOUR LEARNING 10.2

### Describe and explain

- 1 Explain** the term karyotype.
- 2 Explain** what occurs in chromosomes during meiosis when a block of genes is:
  - a** deleted
  - b** duplicated
  - c** translocated.
- 3 Describe** the events during meiosis that result in the non-disjunction of chromosomes.

- 4 Define** aneuploidy and give an example of one autosomal non-disjunction and one sex chromosome non-disjunction in which the offspring survives.

### Apply, analyse and interpret

- 5 Distinguish** between an autosome and a sex chromosome.

### Check your obook assess for these additional resources and more:

» Student book questions

Check your learning 10.2

» Weblink  
Cri-du-chat

» Weblink  
Fragile X syndrome



# 10.3

## Causes and effects of mutations

### KEY IDEAS

- ✦ Mutagens and mutations in the genetic material of a cell
- ✦ Mutations and greater genetic variation in a population
- ✦ Mutation in somatic cells
- ✦ Mutation in gametes



**FIGURE 1** Blue eyes are the result of a mutation.

Mutations can have various effects on an individual. Some mutations may result in a new characteristic that will help with survival. For example, blue eyes are the result of a mutation from 10 000 years ago. Humans with this mutation who migrated from Africa to northern Europe benefited from increased vision in poor light conditions.

Over time, some mutations accumulate and can ultimately be harmful for the individual. Lethal mutations may have an immediate effect upon the cell (or the individual). This type of lethal mutation will therefore not be transmitted to offspring. Others may not exert their effect until some specific stage of development. Examples of such mutations are sickle cell anaemia and cystic fibrosis. Many mutations can become important in the future by providing variations in a population, which may benefit the population during changing environmental conditions. All alleles for any particular gene have arisen from mutation.

Once a mutation has occurred in the gametes of an individual, it becomes part of the genetic framework of the cell and with subsequent cell divisions will be perpetuated through DNA replication. If the mutation occurs in a body cell, it will not be important to the species as a whole, although it could bring about significant changes to a particular organ or tissue of the individual (e.g. tumour formation). Mutation in the sex cells may, however, affect the entire population because the mutation may be passed on to subsequent generations through the gametes.

Gene mutations can be classified in two major ways:

1. **hereditary**: inherited from a parent, present throughout life and found in virtually every cell
2. **somatic**: (acquired) may occur at some time in a person's life in non-reproductive cells and are not passed on to the next generation. These changes or mutations can be the result of environmental factors or human-made agents.

Some mutations occur naturally while others arise as a reaction to external forces.

A **mutagen** is an agent, chemical or high energy radiation that changes genetic material by directly interacting with DNA.

Examples of mutagens in everyday life (including those that are **carcinogenic** or cancer causing) include:

- 1 Physical mutagens:
  - ionising radiation:
    - X-rays – used in medicine for diagnosis of injuries to bones or the location of foreign objects

### hereditary mutation

gene change in a body's reproductive cell that can be passed from parent to offspring

### somatic

non-reproductive

### mutagen

a physical or chemical agent that changes the genetic material of an organism

### carcinogen

a substance or agent that can cause cells to become cancerous by altering their genetic structure so that they multiply continuously and become malignant

- radioactive decay – gamma rays and alpha and beta particles given off by radioactive substances, used in medicine and laboratories
- solar radiation, including infrared and ultraviolet components causing sunburn, melanomas and other skin cancers.

## 2 Chemical mutagens:

- asbestos – found in buildings, brake pads and insulation products, can cause asbestosis or malignant mesothelioma (cancer of the lung and heart lining)
- benzopyrene – formed during combustion of many organic materials; found in fireplaces, car exhaust fumes, chargrilled meat and tobacco smoke
- boric acid – used in insecticides, fungicides and for many industrial purposes
- nicotine – found in tobacco, a major cause of lung cancer in humans
- nitrous acid – a preservative for meat products
- most organic solvents, insecticides and fungicides
- sodium bisulphite – preservative in fruit juices, wine, and dried fruits.

## 3 Heavy metal mutagens:

- arsenic, chromium, cadmium, lead, nickel and their compounds are poisonous and carcinogenic. These include:
  - nickel–cadmium batteries
  - lead paint.

## 4 Biological agents:

- viruses – viral DNA can be inserted into the genome, causing DNA upsets. Viruses can cause many different diseases.

While this list looks impressive and impacts on many aspects of life, it is only an extremely small sample that cause mutation of DNA.



**FIGURE 2** X-ray machines can cause DNA mutations.



**FIGURE 3** Viruses attack DNA and cause mutations.

## CHECK YOUR LEARNING 10.3

### Describe and explain

- 1 Explain** the difference between an inherited and an acquired mutation.
- 2 Explain** why nickel–cadmium batteries must be disposed of correctly.
- Melanoma (skin cancer) can be lethal. **Describe** the mutagen that causes this.

- 4 Explain** why many chemical mutagens are still available on supermarket shelves.

### Apply, analyse and interpret

- 5 Distinguish** between a mutagen and a carcinogen. Use examples to illustrate your answer.

### Check your obook assess for these additional resources and more:

» Student book questions

Check your learning 10.3

» Weblink

Ionising radiation

» Weblink

Biological agents

# Review

## Chapter summary

- 10.1**
- A gene mutation is a permanent change in the nucleotide sequence of DNA.
  - Point mutation involves a permanent change in a single nucleotide.
  - A point mutation may or may not result in a change in the amino acid sequence.
  - A frameshift mutation (such as an addition or deletion) results in a change in the reading frame of triplets and codons that produces a non-functioning protein.
- 10.2**
- Block mutations are caused by a change in a block of genes located together on a single chromosome during crossing over of chromatids. They can cause deletions, additions, duplications, translocations and inversions.
  - Non-disjunction in meiosis can result in gametes with more or fewer chromosomes (aneuploidy).
  - Karyotypes are used to identify aneuploidy.
- 10.3**
- A mutagen is an agent (chemical or physical) that causes a mutation in the genetic material of a cell.
  - Mutations can be beneficial and result in greater genetic variation in a population.
  - Mutation in somatic cells will only affect that individual.
  - Mutation in gametes will affect future offspring.

## Key terms

- |                        |                       |                     |                    |
|------------------------|-----------------------|---------------------|--------------------|
| • aneuploidy           | • duplication         | • inversion         | • somatic mutation |
| • autosomal aneuploidy | • frameshift mutation | • karyotype         | • translocation    |
| • carcinogen           | • germ line mutation  | • mutagen           | • trisomy          |
| • chromosomal deletion | • hereditary mutation | • mutation          |                    |
| • chromosome mutation  | • homologs            | • non-disjunction   |                    |
|                        |                       | • point mutation    |                    |
|                        |                       | • sexual aneuploidy |                    |

## Revision questions

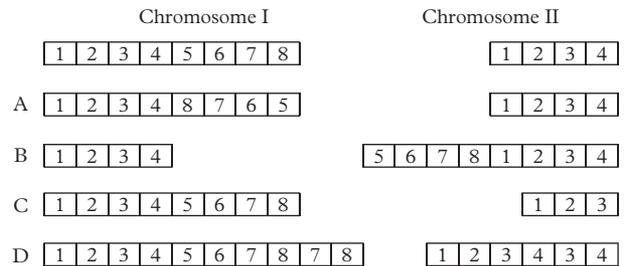
The relative difficulty of these questions is indicated by the number of stars beside each question number:

\* = low; \*\* = medium; \*\*\* = high.

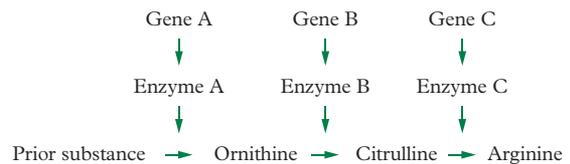
### Multiple choice

- In a point mutation:
  - there is a deletion of a group of genes from the chromosome
  - the effects are always silent because each amino acid has several codes
  - one nucleotide is substituted for another in a triplet code
  - the mutation only occurs in somatic cells
- Aneuploidy in a species always results in:
  - one extra chromosome to the species number
  - a different chromosome number to that of the species
  - one fewer chromosome to the species number
  - several extra chromosomes to the species number
- The least severe form of mutation is likely to be:
  - a substitution of a nucleotide
  - a single DNA nucleotide insertion in the middle of a sequence
  - a loss or gain of part of a chromosome
  - the loss or gain of a chromosome
- Factors in the environment that have been shown to increase the rate of mutation in an organism include all of the following **except**:
  - an increase in temperature
  - extremely large populations of other similar organisms
  - certain compounds such as some industrial and horticultural chemicals
  - high energy radiation such as ultraviolet light, X-rays and beta and gamma rays

- If a translocation occurred between chromosomes I and II shown below, which of the following would result?



Questions 6–9 refer to the following flowchart about the bread mould, *Neurospora*. The bread mould normally produces its own amino acids from raw materials through a system of enzymes.



**FIGURE 1** Mouldy bread flowchart

Use the following table to assign a response to questions 6–8.

<b>A</b>	A logical hypothesis based on the diagram
<b>B</b>	An illogical hypothesis
<b>C</b>	A hypothesis unrelated to the diagram
<b>D</b>	A restatement of the information given in the diagram

- Enzyme A catalyses the reaction in which ornithine is formed from the prior substance.

- 7 If Gene B underwent a frameshift mutation, arginine would be formed directly from ornithine.
- 8 If Gene A underwent a frameshift mutation, the mould would survive if ornithine were added to the medium.
- 9 If a nutritional mutant of *Neurospora* can only survive when provided with the amino acid citrulline, the mutation probably affected:
- A Gene A only
  - B Gene B only
  - C Gene C only
  - D either Gene A or Gene B
- 10 Mutations are caused by:
- A mutagens
  - B diseases
  - C transformation
  - D DNA
- 11 Which of the following statements is correct?
- A A neutral mutation will ultimately be beneficial to the species.
  - B Mutations provide variations in a species that can be acted upon by natural selection.
  - C Natural selection weeds out all but beneficial mutations in a species.
  - D Some alleles for particular genes have arisen by mutation.
- 12 A mutation that occurs in the body tissues of an organism but is not passed to its offspring is referred to as a:
- A homolog mutation
  - B translocation
  - C somatic mutation
  - D germ-line mutation

### Short answer questions

#### Describe and explain

- ★ 13 **Explain** the biological risks associated with any process involving regular screening with X-rays.
- ★ 14 A child has a karyotype of XYY for the sex chromosomes. In which parent did this non-disjunction occur? **Explain** your answer.

- ★★ 15 **a Define** a gene mutation.  
**b Explain** why mutations may appear:
- i immediately in somatic cells
  - ii in the first generation
  - iii not until several generations of offspring have appeared.
- ★★ 16 Suppose a gene contains the code for the synthesis of an enzyme. During replication of the gene a mutation occurs so that one of the nucleotides is left out. Is it more likely that the enzyme produced will be close to 'normal' if the deleted base occurs near the beginning or near the end of the gene? **Explain** your reasoning.
- ★★ 17 Read the following extract from 'Telomeres, Telomerase and Cancer' by Carol Greider and Elizabeth Blackburn (*Scientific American*, February 1996) and answer the questions that follow.



**FIGURE 2** The daffodil is often used as a symbol of hope for all affected by cancer.

*The tips of chromosomes are called telomeres. They are made of many short, repeated sequences of DNA nucleotides, e.g. in humans each telomere has about 70 repeats of the sequence TTAGGG.*

*During each cell division a number of these repeats are lost – they are not copied while the rest of the chromosome is. When the telomeres are too short (i.e. too many repeats have been lost and only 1–2 are present) then all cells (except those in testes and ovaries) die.*

*The enzyme telomerase is present in the cells of testes and ovaries and can rebuild the telomeres. Thus, telomerase can make a cell able to live forever. It is usually present in cancer cells after uncontrolled mitosis has started.*

Cancer is ‘uncontrolled mitosis’ of a cell. Using the information from the extract and your knowledge of how errors can occur during cell division, **explain** how cancer is caused and **identify** why many cancer cells do not die.

### Apply, analyse and interpret

- ★ **18 Contrast** a point and frameshift mutation.
- ★★ **19 Distinguish** between a somatic and germ line mutation and state how these types of mutations differ in their effect on the next generation.
- ★★★ **20** A strain of bacteria (Strain A) produced a protein that contained the following sequence of amino acids:

serine – proline – serine – leucine – asparagine

A second strain of bacteria (Strain B) produced a slightly altered protein, caused by a deletion at the start of the sequence and an insertion at the end of the sequence, resulting in the following sequence of amino acids:

valine – histidine – histidine –  
leucine – methionine

mRNA codons are translated into amino acids in the course of protein synthesis according to the genetic code shown below. Therefore, the codon for the amino acid methionine is AUG.

First position	Second position				Third position
	U	C	A	G	
U	phe	ser	tyr	cys	U
	phe	ser	tyr	cys	C
	leu	ser	STOP	STOP	A
	leu	ser	STOP	trp	G
C	leu	pro	his	arg	U
	leu	pro	his	arg	C
	leu	pro	gin	arg	A
	leu	pro	gin	arg	G

First position	Second position				Third position
	U	C	A	G	
A	ile	thr	asn	ser	U
	ile	thr	asn	ser	C
	ile	thr	lys	arg	A
	met	thr	lys	arg	G
G	val	ala	asp	gly	U
	val	ala	asp	gly	C
	val	ala	glu	gly	A
	val	ala	glu	gly	G

Note that several codons may translate into the same amino acid, while others may be punctuation messages.

- a **Apply** the genetic code to complete the grid for Strain B, showing all the possible codons for the respective amino acids, e.g. the grid for Strain A would be:

<i>ser</i>	<i>pro</i>	<i>ser</i>	<i>leu</i>	<i>asn</i>
UCU	CCU	UCU	UUA	AAU
UCC	CCC	UCC	UUG	AAC
UCA	CCA	UCA	CUU	
UCG	CCG	UCG	CUC	
AGU		AGU	CUA	
AGC		AGC	CUG	

- b Using the grids for both Strains A and B, **determine** the sequence of Strain A codons from which the mutant Strain B was derived. **Determine** the relevant Strain B codons. Underline the nucleotide that was deleted and circle the one that was inserted in the process.

### Investigate, evaluate and communicate

- ★★★ **21 Research** another syndrome that occurs in humans due to a genetic mutation. **Identify** the proportion of the population that is affected by this syndrome and what the main symptoms are.

Check your **obook assess** for these additional resources and more:

» Student book questions  
Chapter 10 review

» Revision notes  
Chapter 10

» **assess quiz**  
Chapter 10 auto-correcting multiple-choice quiz

» Flashcard glossary  
Chapter 10 glossary



# Inheritance

Traits are inherited through the combination of maternal and paternal alleles. Each gene can be expressed differently as a result of its allele combination and mode of inheritance. The frequencies of phenotypes and genotypes can be predicted from probability models and patterns of inheritance.

## OBJECTIVES

- Predict frequencies of genotypes and phenotypes using data from probability models (including frequency histograms and Punnett squares) and by taking into consideration patterns of inheritance for the following types of alleles: autosomal dominant, sex linked and multiple.
- Define *polygenic inheritance* and predict frequencies of genotypes and phenotypes for using three of the possible alleles.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority



FIGURE 1 Each generation inherits genes from the previous generation.



# 11.1

## Predicting genotypes and phenotypes

### KEY IDEAS

- ✦ Punnett squares and frequency histograms
- ✦ Monohybrid cross of two heterozygous parents
- ✦ Dihybrid cross between parents who are heterozygous
- ✦ Test crosses and the genotype of unknown individuals

### allele

one of two or more forms of a gene located in the same position on homologous chromosomes

### homozygous

describes a condition in which both alleles for the gene are the same

### pure-bred

an organism that is homozygous for a trait and thus carries the same phenotype as the parents

### heterozygous

each allele for the characteristic exhibiting a different expression

### hybrid (genetic)

heterozygote for a characteristic; plant or animal resulting from a cross between parents that are genetically unlike for that trait

### wild type

the most common phenotype for a feature in a population

### dominant trait

the particular trait of a characteristic that is expressed in the phenotype of a heterozygous individual

The way in which the gene is expressed is not always exactly the same due to slight variations in the DNA composing the gene. An **allele** is an alternative expression of a gene. Although there may be a number of different alleles for a gene, a single individual can only carry two, one on each homologous chromosome. If the two alleles for a gene in an individual are the same, the individual is said to be **homozygous** for that gene. If two homozygous individuals are bred together, the offspring can be said to be **pure-bred** for that trait. Alternatively, if the two alleles are different, they are called **heterozygous** and the individual is called a **hybrid**. The most common phenotype in any environment is called the **wild type**.

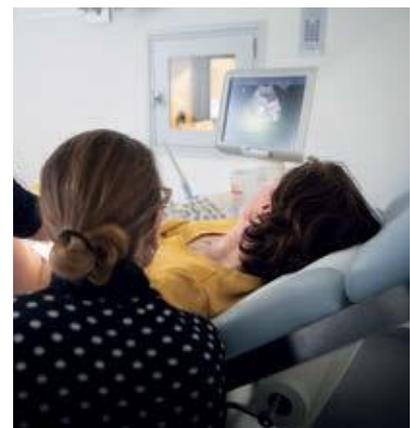
In some situations, where a single gene is responsible for a characteristic, one allele may be fully expressed while the other allele is not evident in the phenotype. In this situation, the first fully expressed allele codes are the **dominant trait**. If this allele code is found on the autosomes (not X or Y), it codes for an **autosomal dominant** trait and is represented by a capital letter (A). The allele for the **recessive trait** found on an autosome (**autosomal recessive**) is only expressed in the homozygous condition. Alleles for this recessive trait are represented by a lowercase letter (a). The **genotype** describes the alleles that are present in an individual. The **phenotype** of an individual indicates the way in which the combination of alleles is expressed. An individual that is heterozygous (Aa) will have the same phenotype as an individual that is homozygous for the dominant trait (AA). Occasionally, two alleles will both be expressed (codominant trait) or moderated by regulatory genes (intermediate dominance).

## Predicting phenotypes

When a couple is expecting a child, they may try and predict whether they are having a male or a female. All eggs contain a single X chromosome. In contrast, sperm cells contain either an X or a Y chromosome. The probability the child will be a male (XY) or a female (XX) will be 50%. Even if the parents have already delivered three females, the chance that the fourth child will be a female is 50% (or  $\frac{1}{2}$ ). The probability 'resets' with every fertilisation.

## Punnett squares

A **Punnett square** is a square diagram or tabular summary of the possible combinations of maternal alleles



**FIGURE 1** A couple finding out the sex of their child

with paternal alleles of a cross. It was devised by Reginald Punnett and is used to predict the probability of the offspring's genotype and therefore the phenotype of a particular cross. The steps involved in this process include:

- 1 Determine the possible genotype of each parental gamete.
- 2 Draw a Punnett square containing the parental gametes.
- 3 Determine the possible genotype of the offspring.
- 4 Determine the possible phenotype of the offspring.
- 5 Determine the probability of each phenotype.

The first generation of offspring is called the F1 generation. If two individuals of this F1 generation are bred with each other, the offspring are called the F2 generation.

The Punnett squares described are examples of the inheritance of alleles for a single gene (**monohybrid cross**). This method can also be used to predict the inheritance of more than one gene (e.g. **dihybrid crosses**). These genes may be on the same chromosome (linked) or on different chromosomes (unlinked). Unlinked chromosomes will sort independently, resulting in random combinations of the alleles for the two (or more) genes.

### WORKED EXAMPLE 11.1A

Use a Punnett square to determine the probability of offspring being a male or female.

Parental phenotype:	Female	Male
Parental genotype (chromosomes):	XX	XY
Gametes produced:	X or X	X or Y

### SOLUTION

- 1 Draw a Punnett square from the information provided.

		Possible female gametes	
		X	X
Possible male gametes	X	XX female	XX female
	Y	XY male	XY male

- 2 Include a prediction of the chromosomes and phenotype of the offspring and their probabilities.

Possible genotype of offspring:	XX	XY
Possible phenotype of offspring:	Female	Male
Prediction and probability:	50% or ½ the offspring of this mating will be female	50% or ½ the offspring of this mating will be male

### dominant allele (autosomal dominant)

an allele for a gene that overrides the effects of the recessive allele in the heterozygous condition; can be autosomal or sex-linked

### recessive trait

trait due to an allele that can be masked by the dominant allele in the heterozygous condition but expressed in the homozygous condition

### recessive allele (autosomal recessive)

an allele found on an autosomal chromosome that can be masked by its dominant form in the heterozygous condition; can be autosomal or sex-linked

### genotype

the genetic makeup of an individual

### phenotype

actual expression of the genotype

### Punnett square

mathematical device used to calculate probabilities of genetic crosses

### monohybrid cross

genetic cross between two individuals, both heterozygous for a specific trait

### dihybrid cross

genetic cross between two individuals, both heterozygous for two specific traits

## Study tip

A highlighter can be used to easily identify each phenotype. Use different colours to indicate each dominant phenotype (or capital letter) quickly.

### WORKED EXAMPLE 11.1B

The trait dimples (D) is dominant to no dimples (d), and tongue rolling (T) is dominant to cannot roll (t), and they are found on different chromosomes. A parent who is heterozygous for both traits (DdTt) will produce the gametes DT, Dt, dT and dt.

If both parents are heterozygous, determine the probability of one of the offspring having dimples and being able to roll their tongue.

#### SOLUTION

1 Draw a Punnett square from the information provided.

		Possible types of female gametes				
		DT	Dt	dT	dt	
Possible types of male gametes	DT	DDTT Dimples & can roll tongue	DDTt Dimples & can roll tongue	DdTT Dimples & can roll tongue	DdTt Dimples & can roll tongue	Possible offspring genotypes and phenotypes
	Dt	DDTt Dimples & can roll tongue	DDtt Dimples & cannot roll tongue	DdTt Dimples & can roll tongue	Ddtt Dimples & cannot roll tongue	
	dT	DdTT Dimples & can roll tongue	DdTt Dimples & can roll tongue	ddTT No dimples but can roll tongue	ddTt No dimples but can roll tongue	
	dt	DdTt Dimples & can roll tongue	Ddtt Dimples & cannot roll tongue	ddTt No dimples but can roll tongue	ddtt No dimples & cannot roll tongue	

2 From the Punnett square, indicate the **dihybrid ratio** for the phenotypes of the offspring.

Dimples & can roll tongue	:	Dimples & cannot roll tongue	:	No dimples but can roll tongue	:	No dimples & cannot roll tongue
9	:	3	:	3	:	1

3 Of the sixteen possible outcomes, nine of them have dimples and can roll their tongue. This means there is a 9/16 chance of the offspring having dimples and being able to roll their tongue.

#### dihybrid ratio

predicted ratio of offspring obtained from a cross between individuals simultaneously heterozygous for two characteristics

# Laws of probability

Mendel's laws are based upon mathematical principles known as the laws of probability. One of these laws is the **product rule**, which states that:

*The chance of two independent events occurring together is equal to the chance of one event occurring alone multiplied by the chance of the other event occurring alone.*

In the previous example, this means the individual probabilities of inheriting dimples and rolling the tongue could be determined independently, and then multiplied.



**product rule**  
a law of probability, stating that the chance of two independent events occurring together is equal to the chance of one event occurring alone multiplied by the chance of the other event occurring alone

**FIGURE 2** A child having dimples and rolling their tongue can be determined using the laws of probability.

## WORKED EXAMPLE 11.1C

The trait dimples (D) is dominant to no dimples (d), and tongue rolling (T) is dominant to cannot roll (t), and they are found on different chromosomes. A parent who is heterozygous for both traits (DdTt) will produce the gametes DT, Dt, dT and dt.

If both parents are heterozygous, determine the probability of one of the offspring having dimples and being able to roll their tongue.

### SOLUTION

- 1 Draw different Punnett squares from the information provided.

		Dimples	
		D	d
D	DD	Dd	
d	Dd	dd	

		Roll tongue	
		T	t
T	TT	Tt	
t	Tt	tt	

- 2 Identify the probability of dimples, then identify the probability of rolling tongue.

Chance of dimples =  $\frac{3}{4}$       Chance of rolling tongue =  $\frac{3}{4}$

- 3 Calculate the probability of both traits.

$$\begin{aligned} \text{Chance of having dimples AND rolling tongue} &= \frac{3}{4} \times \frac{3}{4} \\ &= \frac{3 \times 3}{4 \times 4} \\ &= \frac{9}{16} \end{aligned}$$

# Frequency histograms

## frequency histogram

an accurate representation of the distribution of numerical data and is an estimate of the probability frequency distribution of a continuous variable (quantitative variable)

A **frequency histogram** is a bar graph showing the frequency of particular characteristics seen in a sample. The frequency of occurrence of each single set of data is placed on the vertical *y*-axis. The name of each data type is placed on the *x*-axis. The general rules of graphing (including an appropriate title, axis labels and any units, and using a ruler and pencil) also apply.

### WORKED EXAMPLE 11.1D

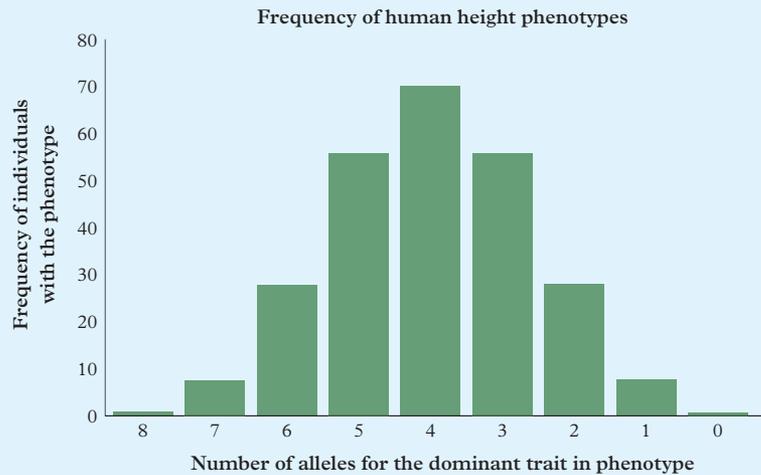
Human height is controlled by four autosomal genes (polygenic), where each allele for the dominant trait increases the height of the individual. The more alleles for the dominant height trait an individual has, the taller that person will be. If there are no environmental influences (e.g. lack of food), there are 9 possible phenotypes ranging from 8 alleles for the dominant height trait to 0 alleles for the dominant height trait (i.e. all alleles for the recessive short trait) in the genotype.

- 1 Use the data in the table below to draw a frequency histogram that shows the relative frequency of the height of offspring.
- 2 If the number of individuals in the sample have a height indicating there are 6 alleles for the dominant trait in the cross ( $AaBbCcDd \times AaBbCcDd$ ), predict the genotype combinations of alleles that will produce the same height.

Genotypes expressed as the number of alleles for the dominant trait present:								
8	7	6	5	4	3	2	1	0
Number of individuals with phenotypic heights resulting from the above allele number:								
1	8	28	56	70	56	28	8	1

### SOLUTION

- 1 Construct a histogram from the data provided.



**FIGURE 3** Graph of frequencies of human height phenotypes related to number of dominant alleles in the phenotypes.

- 2 If the parent genotype is  $AaBbCcDd \times AaBbCcDd$ , all the possible combinations that can have 6 (capital letter) alleles for the dominant trait are:  
 $AABBCCdd$ ,  $AABBccDD$ ,  $AAbbCCDD$ ,  $aaBBCCDD$ ,  $AABBCCDd$ ,  
 $AABbCCDd$ ,  $AABbCcDD$ ,  $AaBBCCDd$ ,  $AaBBCcDD$ ,  $AaBbCCDD$ .

# Test cross

It can sometimes be difficult to determine the genotype of an individual with a dominant phenotype. This is because the genotype could be heterozygous (Bb) or homozygous (BB) for the dominant trait. In animal and plant breeding, due to the short time between generations and the large number of offspring in each generation, a **test cross** can be done to determine the genotype of an individual.

Test crosses involve the individual with the unknown genotype being crossed with a homozygous individual for the recessive trait. If a large number of offspring are produced, there are two possible outcomes:

- 1 All the offspring have the dominant phenotype – the unknown parent was homozygous for the dominant trait.
- 2 There is at least one offspring with the recessive trait – the unknown parent is heterozygous.

### test cross

a cross between an organism displaying the recessive trait of a characteristic and one showing the dominant trait, to determine whether the dominant phenotype is due to a homozygous or heterozygous genotype; this only applies if a large number of offspring are produced

### WORKED EXAMPLE 11.1E

In Persian cats the long-hair trait (H) is dominant to short-hair trait (h). The owners of a cat with the dominant phenotype wanted to determine the genotype of the individual. Explain how they might achieve this.

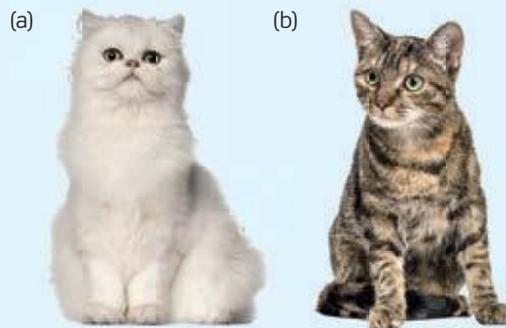
#### SOLUTION

- 1 Draw Punnett squares from the information provided.

	H	H		H	h
h	Hh	Hh	h	Hh	hh
h	Hh	Hh	h	Hh	hh

- 2 The unknown cat could be HH or Hh. It must have at least one allele for the dominant trait (H); the other is unknown. If the owner used a test cross with a cat with the alleles for the recessive short-haired trait (hh), there are two possible outcomes.

If the unknown allele is for the dominant long-haired trait, there will be no offspring with the recessive short hair phenotype. If the unknown allele is for the recessive short-haired trait, some offspring with this phenotype will be produced.



**FIGURE 4** (a) a Persian long-haired cat; (b) a domestic short-haired cat

## CHECK YOUR LEARNING 11.1

### Describe and explain

- Define** the following:
  - allele
  - gene
  - genotype
  - phenotype
  - monohybrid cross
  - dihybrid cross
  - heterozygous
  - homozygous.
- Define** the product rule.
- Explain** a Punnett square. Illustrate your answer by showing how you would determine the expected offspring of a cross between a heterozygous tall-stemmed pea plant (Tt) and a dwarf-stemmed pea plant (tt).

### Apply, analyse and interpret

- In pea plants, tallness is dominant to shortness and purple flower colour is dominant to white. If two heterozygous tall purple pea plants were crossed, **determine** what the expected ratio of the offspring will be.
- A homozygous rough black guinea pig (RRBB) is mated with a smooth white one (rrbb).
  - Describe** what the F<sub>1</sub> generation will look like.
  - Describe** the phenotypes that you would expect to see in the F<sub>2</sub> generation and predict the proportions of each type.
  - Predict** the ratios of phenotypes in the offspring of the following crosses:
    - RrBb × rrb
    - Rrbb × RrBb
    - Rrbb × rrBB.

- In guinea pigs, black (B) is dominant to white (b) and rough coat (R) is dominant to smooth coat (r). A black, rough-coated male guinea pig was crossed with a white, smooth-coated female. Several litters from the pair resulted in offspring  $\frac{1}{4}$  of which had black smooth coats,  $\frac{1}{4}$  white smooth,  $\frac{1}{4}$  white rough and  $\frac{1}{4}$  black rough. **Predict** the probable genotypes of the parents.
- Suppose you were given a pure-breeding female guinea pig with rough, black fur and a male with smooth, white fur.
  - Explain** how you could produce a strain of pure-breeding smooth, white-furred guinea pigs.
  - Consider** whether it is possible to produce a strain of pure-breeding rough, black-furred guinea pigs. **Explain** your method.

(a)



(b)



**FIGURE 5** (a) rough black coat guinea pig; (b) a white smooth coat guinea pig



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» Weblink  
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# 11.2

## Non-Mendelian genetics

### KEY IDEAS

- + Codominant traits
- + Intermediate dominance
- + Polygenic traits
- + Genes interact with each other

Each coding gene is responsible for the production of a protein; however, the expression of these genes can be modified by transcription factors or the environment (Chapter 9). This suggests that not all traits are inherited as a straightforward dominant–recessive involving two alternative expressions of a gene. For example, human eye colour was previously described as being controlled by one gene with two alleles: brown (B), which is dominant to blue (b). A heterozygote (Bb) was considered brown-eyed, while blue-eyed people were described as lacking in the melanin pigment in the front layer of the iris.

**modifier genes**  
genes that influence the expression of another gene

Eye colour, however, exhibits endless variations in hue. This is a result of other genes, **modifier genes**, influencing the amount of pigment in the iris, the tone of the pigment (which may be light yellow, dark brown, etc.) or the distribution of the pigment (e.g. even, scattered or forming a definite pattern such as a ring around the outer iris).

The expression of a simple dominant–recessive phenotype may also be greatly influenced by the environment in which the organism is reared. This means a genetically tall plant growing in a rocky, nutrient-depleted soil may not attain its full genetic potential. Hydrangeas have flowers that can be blue, pink or white. Typically blue flowers develop if the plant is grown in an acid soil, but white or pink flowers develop if the soil is alkaline.

## Codominance

**codominance**  
genetic inheritance of two or more traits of a characteristic, each of which is expressed in the phenotype

In **codominant** phenotypes, each allele expresses itself equally in the phenotype. This means each allele produces an unchanged amount of protein.

In cattle, a single point substitution in the *KIT* ligand gene can result in a change in a single amino acid in the resulting protein. This results in two alleles for hair colour, an unchanged allele that produces red-coloured hair ( $C^R$ ) and a mutated allele for white-coloured hair ( $C^W$ ). When cattle inherit both alleles (heterozygote,  $C^R C^W$ ), both alleles are expressed separately. This codominance of the alleles produces a roan-coloured coat where both white and red hairs are produced.



**FIGURE 1** Codominance between red and white cattle: (a) red-coloured, (b) roan-coloured and (c) white-coloured.

If two roan-coloured cattle are crossed ( $C^R C^W \times C^R C^W$ ):

	$C^R$	$C^W$
$C^R$	$C^R C^R$ Red hair colour	$C^R C^W$ Roan hair colour
$C^W$	$C^R C^W$ Roan hair colour	$C^W C^W$ White hair colour

the offspring will have the hair colours:

$\frac{1}{4}$  red ( $C^R C^R$ ) :  $\frac{1}{2}$  roan ( $C^R C^W$ ) :  $\frac{1}{4}$  white ( $C^W C^W$ )

Therefore the ratio is 1 red : 2 roan : 1 white.

## Intermediate dominance

Sometimes heterozygous alleles result in a phenotype in between the two traits. Some flowers, such as the snapdragon, have an allele for red flowers ( $R_1$ ) and an allele for white flowers ( $R_2$ ). In the heterozygous condition ( $R_1 R_2$ ), the flowers are pink: that is, they are intermediate between red and white.

If two pink-flowered plants are crossed ( $R_1 R_2 \times R_1 R_2$ ):

	$R_1$	$R_2$
$R_1$	$R_1 R_1$ red	$R_1 R_2$ pink
$R_2$	$R_1 R_2$ pink	$R_2 R_2$ white

the offspring will be:

$\frac{1}{4}$  red ( $R_1 R_1$ ) :  $\frac{1}{2}$  pink ( $R_1 R_2$ ) :  $\frac{1}{4}$  white ( $R_2 R_2$ )

Therefore the ratio is 1 red : 2 pink : 1 white.

### intermediate dominance (partial dominance or incomplete dominance)

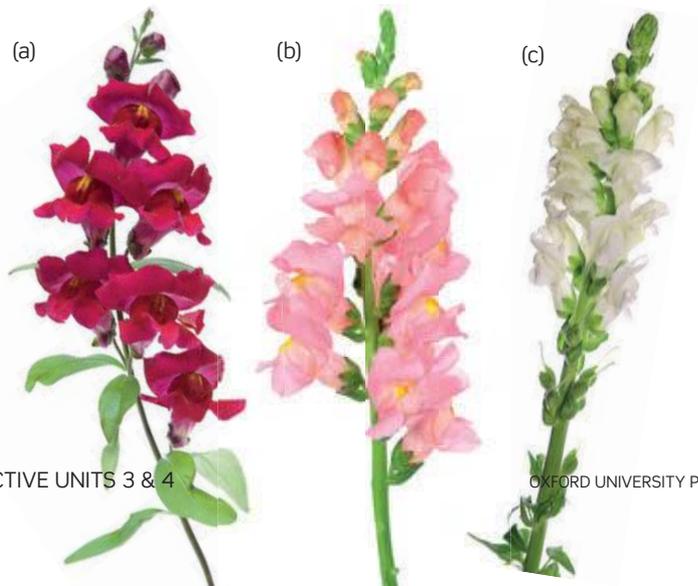
a pattern of inheritance in which neither allele for a characteristic completely masks the effects of the other; results in a blending of traits for the characteristic

Although neither trait is dominant over the other, one of the alleles has a stronger influence than the other. The phenotype is an intermediate between that of complete dominance and codominance. This situation is termed **intermediate dominance**. Other terms used to describe this type of inheritance are **partial dominance** or **incomplete dominance**. There are many blends of intermediate dominance, and thus a wide range of intermediate varieties between two extremes.

If a flower has two alleles for colour but three phenotypes, codominance or intermediate dominance may be involved.

**FIGURE 2** Intermediate dominance between red and white flowers:

- (a) red snapdragon;
- (b) pink snapdragon;
- (c) white snapdragon



## Multiple alleles

Many characteristics are governed by more than two alleles, in which case inheritance is said to be controlled by **multiple or poly alleles**. Although more than two alleles may control the characteristic, there are only ever two present in an individual, one allele on each of the pair of homologous chromosomes.

Human ABO blood groups, for example, are governed by the three alleles  $I^A$ ,  $I^B$  and  $i$ . Alleles  $I^A$  and  $I^B$  are both dominant to  $i$  but  $I^A$  and  $I^B$  are codominant. The allele  $I^A$  contains the code for an enzyme that produces molecule A (a sugar) on the membrane of red blood cells (blood type A). The allele  $I^B$  codes for an enzyme that produces molecule B (blood type B). In contrast, allele  $i$  does not produce a functional enzyme at all. This means that a heterozygous individual  $I^A I^B$  will produce both enzymes, and hence both sugars A and B on their red blood cells (blood type AB). In contrast, heterozygous individual  $ii$  will not produce either enzyme (or sugar) and will therefore be blood type O.

There are four possible phenotypic expressions of human blood types:

**TABLE 1** The different phenotypes of human blood types

Phenotype	Genotype
A	$I^A I^A$ or $I^A i$
B	$I^B I^B$ or $I^B i$
AB	$I^A I^B$
O	$ii$

The membrane sugars A and B can act as antigens if the blood is transfused into another person with a different blood type. This means red blood cells with an A sugar will activate an immune response in a person with type B blood type. The person who receives the type A blood (the recipient) will produce protein antibodies against the (donor) A sugar, causing the donated red blood cells to clump together (**agglutinate**) and potentially kill the recipient. A person with blood type O has neither A or B sugars on their red blood cells. This means their immune system will recognise the A and B sugars as foreign and produce anti-A and anti-B antibodies.

**multiple or poly alleles**  
the inheritance of a characteristic governed by more than two allelic forms, e.g. blood groups

**agglutination**  
sticking together of incompatible cells, e.g. by different 'groups' of red blood cells

### WORKED EXAMPLE 11.2A

A woman who is heterozygous for blood type A had a child with a heterozygous male with blood type B. Determine whether it is possible for the child to have a blood type that is different to either their mother or their father.

#### SOLUTION

- Identify the genotypes for the parents. The genotype of the heterozygous mother must be  $I^A i$  and the genotype of the heterozygous father must be  $I^B i$ .
- Construct a Punnett square to indicate the possible genotypes of the offspring.
- This means there is an equal chance that the phenotypes of the offspring would be A, B, (same as parents) or AB or O (different to parents).

	$I^A$	$i$
$I^B$	$I^A I^B$	$I^B i$
$i$	$I^A i$	$ii$

### Study tip

Codominant and incomplete dominant traits are always given a capital letter to represent the gene, and a superscript to indicate the allele. The  $I$  represents the gene for blood grouping and the superscript  $A$  ( $I^A$ ) represents the allele that produces the enzyme for sugar A.

**TABLE 2** Compatibility of human blood groups

Genotype	Antigens	Blood group	Antibodies	Can donate to:	Can receive from:
I <sup>A</sup> I <sup>A</sup> or I <sup>A</sup> i	A	A	anti-B	A and AB	O and A
I <sup>B</sup> I <sup>B</sup> or I <sup>B</sup> i	B	B	anti-A	B and AB	O and B
I <sup>A</sup> I <sup>B</sup>	A and B	AB	none	AB	O, A, AB, B
ii	none	O	anti-A and anti-B	A, O, AB, B	O

**universal donor**

a person with type O blood, which has no antibodies to antigens A and B; thus this blood can be donated in small quantities to individuals of all other blood groups

**universal recipient**

a person with type AB blood, which has both A and B antigens, so can receive small quantities of all other blood groups

Since type O has neither A nor B sugars on their red blood cells, they can donate to all other blood groups (**universal donor**). Although type O blood contains both antibodies A and B, when transfused into a recipient they produce very little agglutination due to their dilution by the host's blood. Since type AB will not produce either anti-A or anti-B antibodies, they can receive from all blood groups (the **universal recipient**).

Red blood cells can also have a number of Rhesus proteins on their surface. The Rhesus D protein is considered important in blood transfusions. For example, a person who does not have the Rhesus D protein (Rh<sup>-</sup>) on the surface of their red blood cells will produce anti-D antibodies if they are exposed to the D protein on transfused blood cells (Rh<sup>+</sup>). As a result, the transfused red blood cells will agglutinate, and the recipient will die.

Occasionally the Rhesus status of parents can cause problems in pregnancy. A Rhesus D negative mother is capable of producing anti-Rh antibodies if she is exposed to the Rhesus D protein. During the first pregnancy of an Rh<sup>-</sup> mother and an Rh<sup>+</sup> father, an Rh<sup>+</sup> foetus may develop. During this first pregnancy, the placenta will prevent the Rhesus D protein from mixing with the mother's blood. When the mother gives birth, some of the baby's red blood cells can pass into the mother's blood stream, resulting in the mother producing anti-Rh antibodies (and memory cells). The next time the mother is pregnant with an Rh<sup>+</sup> baby, the anti-Rh antibodies can pass from the mother into the baby, resulting in miscarriage. Most newly pregnant mothers have their blood type tested to determine whether they are Rhesus D negative and therefore whether the pregnancy is at risk. If there is a risk, immediately after delivery, the mother will be injected with anti-Rh antibodies to passively remove any of the baby's red blood cells that might trigger an immune reaction. This prevents build-up of the antibodies that might put future pregnancies at risk.

## Continuous variation

When a population is observed, a gradation of expression for many characteristics can be seen. Many people are not either tall or short; many mice are not either fat or thin. There are many variations between the two extremes. These situations are explained by **polygenic (or multiple gene) inheritance**, where two or more pairs of alleles control a single trait. Each allele pair works according to the laws of dominance and segregation. The organism's phenotype depends on the combined effect.

The cob or ear length of corn is an example of **continuous variation**. It is believed that two pairs of alleles are responsible, with a series of dominant trait alleles each contributing towards length, and the recessive trait alleles not adding any length. The shortest possible length would be represented by the double recessive condition (aa bb). Each dominant trait allele adds another length dimension so that the longest possible ear has the genotype AABB. A cross between AABB and aabb parents results in F<sub>1</sub> offspring that are AaBb and intermediate in length. If these offspring are interbred, a broad range of genotypes and phenotypes results (see Figure 3).

**polygenic (or multiple gene) inheritance**

inheritance from a set of genes that together control a quantitative character such as height

**continuous variation**

a variety of phenotypes as a result of more than one gene contributing to a characteristic

		AaBb × AaBb			
		AB	Ab	aB	ab
AB	AABB longest	AABb long	AaBB long	AaBb medium	
Ab	AABb long	AAbb medium	AaBb medium	Aabb short	
aB	AaBB long	AaBb medium	aaBB medium	aaBb short	
ab	AaBb medium	Aabb short	aaBb short	aabb shortest	

Genotypic ratio:

$\frac{1}{16}$  AABB :  $\frac{1}{8}$  AABb :  $\frac{1}{8}$  AaBB :  
 $\frac{1}{4}$  AaBb :  $\frac{1}{16}$  AAbb :  $\frac{1}{16}$  aaBB :  
 $\frac{1}{8}$  Aabb :  $\frac{1}{8}$  aaBb :  $\frac{1}{16}$  aabb.

Phenotypic ratio:

$\frac{1}{16}$  longest :  $\frac{1}{4}$  long :  $\frac{3}{8}$  medium :  
 $\frac{1}{4}$  short :  $\frac{1}{16}$  shortest.  
 or  $\frac{1}{16}$  longest :  $\frac{4}{16}$  long :  $\frac{6}{16}$  medium  
 :  $\frac{4}{16}$  short :  $\frac{1}{16}$  shortest.

This can be represented graphically, as shown in Figure 4.

FIGURE 3 Punnett square

Human height is believed to be controlled by four pairs of alleles and skin colour by up to seven pairs. Figure 5 shows the variations that can occur if two pairs of alleles determine human skin colour (i.e. production of the pigment melanin).

The colour of wheat grain is also a polygenic trait with three genes contributing to the red colour of the seed. If all six alleles for the dominant colour trait are present, the wheat seed will be a dark red. If all alleles for the recessive white trait are present, the seed will appear white. Most seeds have intermediate red colours.

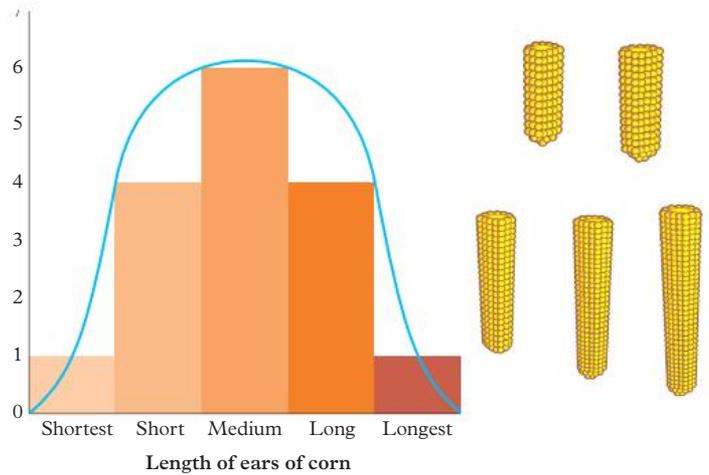


FIGURE 4 Distribution of cob lengths of corn (*Zea mays*)

FIGURE 5 Human skin pigments are controlled by two pairs of alleles. The dominant trait allele of each gene contributes to melanin production, while the recessive does not.



# Gene interactions

Sometimes two or more different genes interact in determining the phenotypic expression of a characteristic. These are termed **gene complexes**. An example of such a gene complex can be found in the coat colour of Labrador dogs where gene B controls the production of melanin in hair (allele B for black hair, allele b for brown hair). Gene D controls the dispersion and deposition of the pigment into the hair. This is an example of **epistasis**, where the phenotypic expression of one gene is masked by another gene.

Epistasis is significant in coding for enzymes in biochemical pathways. In humans, the recessive condition **phenylketonuria (PKU)** results from alleles being unable to form an enzyme (due to a homozygous recessive epistatic gene) that normally brings about the breakdown of phenylalanine to tyrosine in humans. Even though enzymes for subsequent reactions in the metabolic pathway are present, the series of reactions cannot occur. As a result, phenylalanine is converted to phenylpyruvic acid, but cannot be further processed, which causes severe intellectual disability in the individual. The phenylpyruvic acid is ultimately excreted in the urine, so tests can easily be conducted to detect PKU. Treatment involves a special diet from infancy to diminish the formation of phenylalanine.

**TABLE 3** How genes interact in dihybrid crosses with Labrador coat colours

Pigment produced but not dispersed	Brown pigment produced, dispersed and deposited	Black pigment produced, dispersed and deposited
BBdd Bbdd bbdd	bbDD bbDd	BBDD BbDD BBDd BbDd
Black or brown pigment may be formed but not dispersed. This colour ranges from almost white through yellow to a copper colour, due to other genetic influences.	The homozygous recessive form of gene B (bb) produces a brown coat. Provided there is one dominant allele D, and the pigment is dispersed to the hair, the dog is brown.	Provided there is one allele for each dominant trait (gene B and gene D) then black pigment is formed and dispersed to the hair, and the dog is black.
Yellow Labrador	Brown Labrador	Black Labrador
Phenotypic ratio: 4	Phenotypic ratio: 3	Phenotypic ratio: 9



### gene complexes

two or more genes interacting to determine the phenotypic expression of a characteristic

### epistasis

(= 'standing upon') where the phenotypic expression of one gene is masked by another gene

### phenylketonuria (PKU)

a homozygous recessive genetic disease in which one enzyme required for the normal break-down of phenylalanine is lacking

## CHECK YOUR LEARNING 11.2

### Describe and explain

- 1 **Define** the following:
  - a continuous variation
  - b partial dominance
  - c codominance
  - d modifier gene
  - e multiple alleles
  - f recipient.

### Apply, analyse and interpret

- 2 In snapdragons, tallness (T) is dominant to dwarf-ness (t) and red flower colour (R1) shows intermediate dominance to white flowers (R2). The hybrid condition results in tall plants with pink flowers. A dwarf red snapdragon is crossed with a plant pure-breeding for tallness and white flowers.
  - a **Determine** the expected proportions of genotypes and phenotypes in the offspring.
  - b **Determine** the probable genotypes of the parents.
- 3 When red shorthorn cattle are mated with white shorthorns, all of the offspring are roan (a combination of red and white). When two red cattle are mated they produce only red offspring. When two white cattle are mated they produce only white offspring. When two roans are mated, half of the offspring are roan, a quarter are red and a quarter white.
  - a **Explain** this phenomenon.
  - b **Explain** what genotypes the parents of a red calf must have.
- 4 If the litter resulting from the mating of two short-tailed cats contains three kittens without

tails, two with long tails and six with short tails, **deduce** the simplest way of explaining the inheritance of tail lengths in these cats.

**Describe** the genotypes involved.

- 5 If a man with blood type B, one of whose parents had blood type O, marries a woman with blood type AB, **determine** the theoretical percentage of their children with blood type B.
- 6 Both Mrs Middleleson and Mrs Spiros had babies the same day in the same hospital. Mrs Middleleson took home a baby girl, whom she named Jemima. Mrs Spiros took home a baby girl, whom she named Areti. Mrs Spiros began to suspect, however, that her child had been accidentally switched with the Middleleson baby in the nursery. Blood tests were made, and Mr Middleleson was found to be type A, Mrs Middleleson type B, Mr Spiros type A, Mrs Spiros type A, Jemima type O and Areti type B. **Consider** whether a mishap occurred. **Explain** your answer.



FIGURE 6 Mrs Middleleson's and Mrs Spiros' babies

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Gene interactions

# 11.3

## Sex-linked inheritance

### KEY IDEAS

- + Sex-linked genes in haemophilia and colour defective vision
- + Sex-linked traits in the phenotype of males

The sex of an individual is determined by specific sex chromosomes. All other chromosomes are termed autosomes. In humans, and in some other species, the female has two X chromosomes and the male has an X and a Y chromosome.

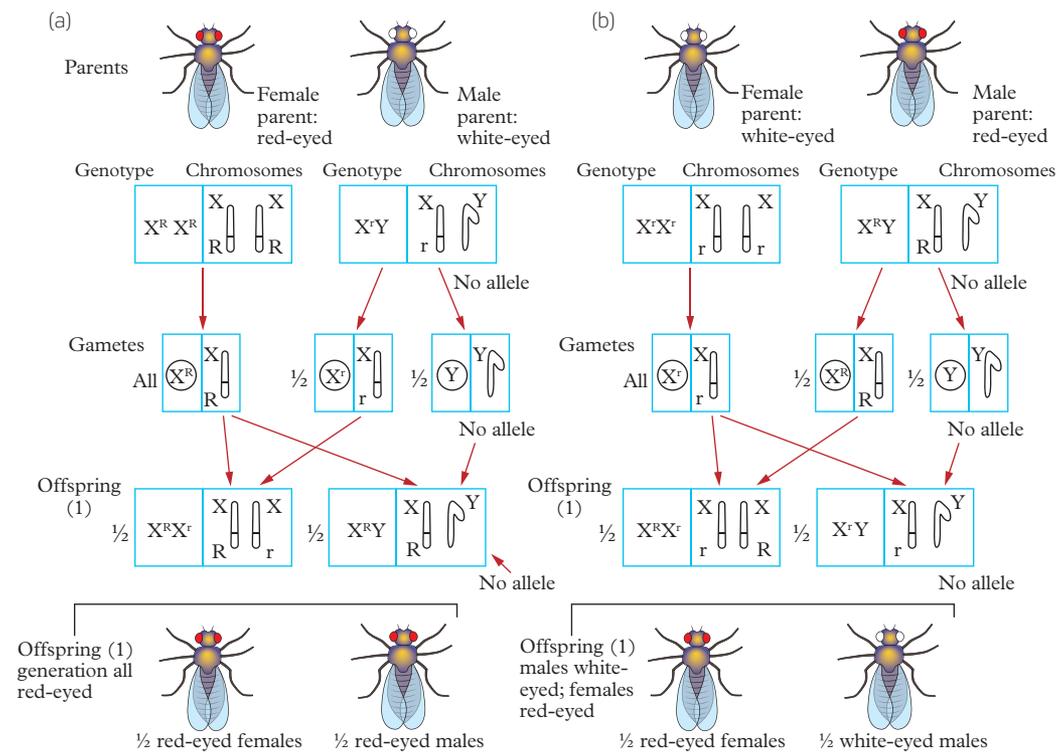
### Sex-linked genes

Genes found on the X chromosome are termed **sex-linked genes**. An equivalent allele is not carried on the Y chromosome.

In male offspring (XY), the X chromosome must come from the mother and the Y chromosome must come from the father. Since there is only one X chromosome, there is only one possible set of genes for that chromosome. If the X chromosome in a male has an allele for a recessive trait, the trait will appear in the phenotype. In contrast, females have two X chromosomes and therefore need two copies of the recessive trait allele before it is expressed in the phenotype. A heterozygous female for a sex-linked recessive gene is called a **carrier**.

**sex-linked genes**  
genes on the X chromosome

**carrier**  
an individual (female in humans) who is heterozygous for a sex-linked gene or an individual who is infected by a pathogen but does not display the symptoms

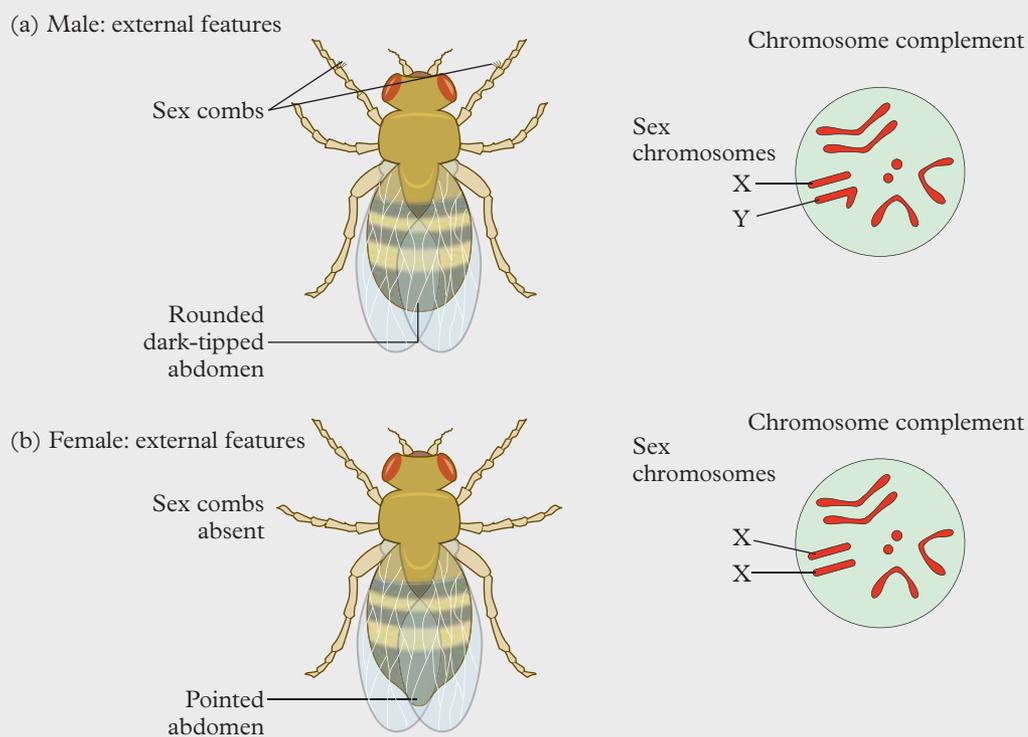


**FIGURE 1** Sex-linked genes in *Drosophila*. (a) The normal eye colour in fruit flies is red, which is dominant to white eyes. If a white-eyed individual is crossed with a pure-breeding red-eyed fly, all the offspring are red-eyed. (b) When a male and female from this cross are mated, only males exhibit the white eye trait. If this gene was autosomal, an equal number of males and females would be white-eyed.

## CASE STUDY 11.3A

### Sex determination

Studies of the inheritance of eye colour in the fruit fly, *Drosophila melanogaster*, by American geneticist T H Morgan in 1910 led to the discovery of chromosomes specifically involved in determination of the sex of the individual. Female flies were discovered to have four pairs of homologous chromosomes, but the males had three homologous pairs plus one pair of two different chromosomes. One of these chromosomes is similar to the fourth pair of the female and is called the X chromosome. The other chromosome, which has a different shape, is called the Y chromosome. In the fruit fly the fourth pair of chromosomes are the sex chromosomes. The female has two X chromosomes and the male has one X and one Y chromosome.



**FIGURE 2** Male and female *Drosophila melanogaster*

Thus, both the male and female fruit fly have three pairs of autosomes and one pair of sex chromosomes. All of the gametes of the female must have an X chromosome. Although they differ, the sex chromosomes of the male act as a homologous pair during meiosis. Therefore, half the male gametes will contain an X chromosome and half will contain a Y chromosome.

The pattern is, however, different in some organisms. In grasshoppers, for example, there is no Y chromosome. Females have two X chromosomes and males have only one X chromosome. In birds, butterflies, most reptiles and some fish, the male is XX and the female is XY. In mammals (including humans) the female is XX and the male is XY.

### colour defective vision

inability of individuals to distinguish the colours red and green

### haemophilia

a group of disorders in which the blood does not clot normally

### Barr body

inactivated X chromosome in the cells of female mammals

### X inactivation

the condensation, and thus inhibition, of one of the pairs of X chromosomes in female vertebrates

In humans, **colour defective vision** (red–green colour blindness) and haemophilia are two examples of inherited, recessive sex-linked diseases. Colour defective vision in humans is caused by a defect in the pigments in the retina of the eye that are sensitive to red and green light. These two colours, therefore, cannot be distinguished by a person with the recessive trait. Few females have colour defective vision because it is rare for females to have two alleles for the recessive trait. In contrast, 1 in 10 males have colour defective vision.

**Haemophilia** is a group of disorders in which the blood does not clot normally. Blood clotting involves a series of chemical reactions in which each reaction depends upon a specific protein factor in the blood. The most common form of haemophilia results from the absence of one of these proteins. The gene for this protein is carried on the X chromosome. Haemophiliacs may bleed to death with even minor injuries. Most people who have been diagnosed with haemophilia are now provided with the missing protein factor (produced through a genetically modified bacterium) permitting them to lead near-normal lives. This treatment does not prevent the haemophilia allele being passed on to the offspring.

A classic example of haemophilia is that of the British royal family. Neither Queen Victoria nor Prince Albert had the disease, but their descendants did, indicating that the allele on the X chromosome came from Queen Victoria (carrier). Since none of Queen Victoria's predecessors were known to exhibit the disease, it has been hypothesised that this recessive trait allele arose in her as a result of a mutation.

Although mammals carry two alleles for sex-linked genes, it has been found that in most somatic cells one of the X chromosomes condenses out into a tiny dark object called a **Barr body**. The genes on this condensed X chromosome are inactivated so that in a normally functioning female cell there is only one active X chromosome. Barr body formation is therefore a process of **X inactivation**.

Since the condensation of each X chromosome is purely random, in the total body approximately half of the cells will contain an active X chromosome from the mother and half will contain an active chromosome from the father. Females, therefore, can be considered to be genetic mosaics for sex-linked genes. It appears that for the majority of characteristics, as long as half of the cells are normal in a heterozygous female, she will show the normal phenotype. This means a woman heterozygous for colour defective vision will show normal vision.

One characteristic that does not follow this rule is that of coat colour in cats. Ginger and black hair in cats is a sex-linked and codominant trait. A ginger female mated with a black male will produce male offspring that are all ginger, and female offspring will all be tortoiseshell – a mixture of black and ginger fur colours.

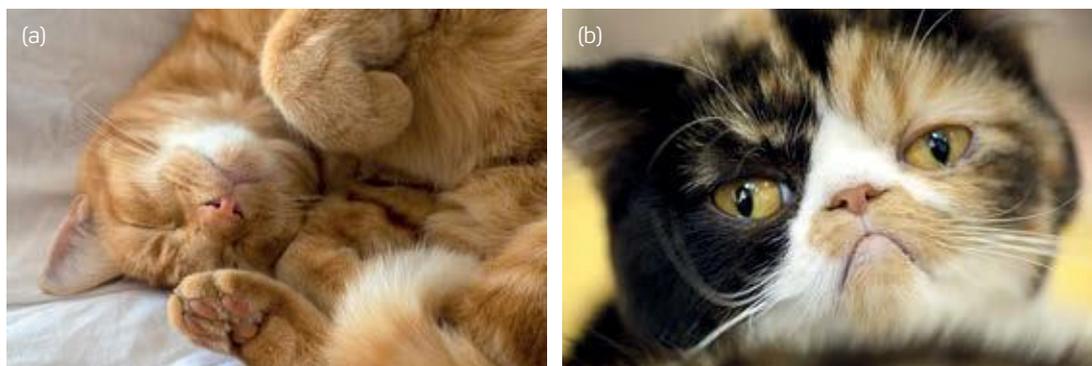


FIGURE 3 (a) male ginger cat; (b) female tortoiseshell cat

In females, those hair follicle cells with an active black X chromosome will produce black hairs, and those with an active ginger X chromosome will produce ginger hairs. The mixture of black and ginger hairs creates the tortoiseshell condition. This means tortoiseshell colouration can be found only in females as only they have two X chromosomes (with potentially different alleles for hair colour). If a tortoiseshell female is mated with a black male, the progeny will be black or tortoiseshell females and ginger or black males.

## CASE STUDY 11.3B

### Family trees

#### Family trees, or

pedigrees, are often used to determine whether an allele is dominant or recessive, or whether it is autosomal or sex-linked. In such a family tree, the female is always represented as a circle and the male as a square. The expression of the trait is indicated by shading. If only males exhibit the trait, this strongly suggests that it is sex-linked. If a son

displays the trait but not the mother, it is recessive. If both males and females show the trait in approximately equal ratios, it is most likely to be an autosomal gene.

In the family pedigree shown in Figure 5, both males and females show night blindness. Female 1, who is night blind, has sons who have normal vision. Therefore, night blindness is inherited autosomally. Since offspring 18, from a cross between two individuals with night blindness, is normal, the trait for night blindness is dominant. The possible genotypes can then be determined and are shown in Figure 5.



FIGURE 4 Three generations of a family

#### family tree

a chart showing the ancestry, descent and relationships between all members of a family or other genealogical group

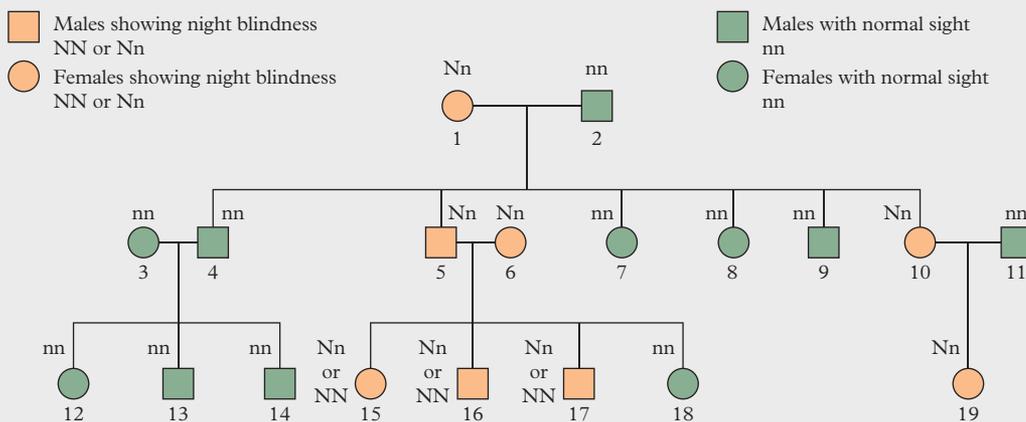


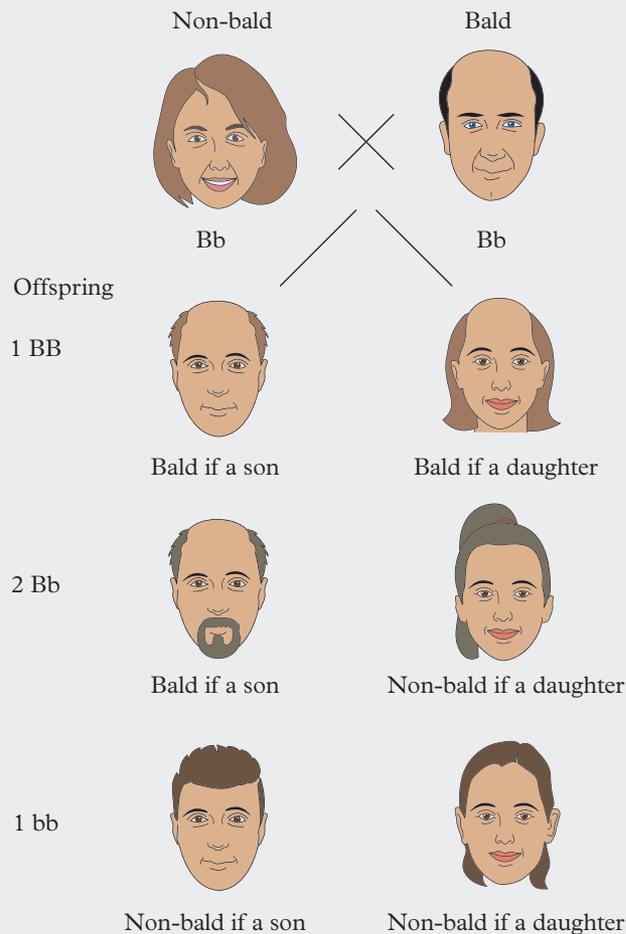
FIGURE 5 Family pedigree showing inheritance of night blindness

## CASE STUDY 11.3C

### Sex-limited and sex-influenced traits

Many traits associated with the sex of the individual are autosomal. Examples include the development of sex organs such as the penis and vagina, distribution of body hair, size of the breasts, and pitch of the voice. The sex of the individual, through hormonal action, determines whether or not the particular autosomal gene will be inhibited or activated. High levels of testosterone production in males results in the development of the male sex organs and secondary male characteristics; these are absent in females, whose testosterone production is low. These traits are said to be sex-limited since their phenotypic expression differs in the two sexes.

Pattern baldness is an autosomal trait that is also influenced by the sex of the individual. The presence of Y chromosome genes may cause this condition to be expressed, whereas absence of the Y chromosome inhibits its expression. Pattern baldness is a sex-influenced trait. It is a recessive trait in females but dominant in males.



**FIGURE 6** Inheritance of pattern baldness in humans

## Holandric genes

**Holandric genes** are those carried on the Y chromosome. Examples are the *SRY* genes that are the male sex determiners in humans. Phenotypic traits controlled by these genes are found only in males. It appears that the occurrence of human hairy pinnae, a tuft of hair sprouting from the ear rim, is probably due to a holandric gene. This condition is common in isolated parts of India. Investigations are ongoing as to the number of genes responsible for the trait, different degrees of hairiness, the different ages of onset and increase in frequency with age.



**holandric genes**  
genes found on  
a vertebrate Y  
chromosome

FIGURE 7 Examples of hairy pinnae

### CHECK YOUR LEARNING 11.3

#### Describe and explain

- 1 Define** the following terms:
  - a Barr body
  - b carrier
  - c holandric
  - d sex-linked
  - e X-inactivation.
- 2** Red–green colour defective vision is inherited as a sex-linked recessive trait. A couple was surprised to learn that one of their sons was colour blind, since neither of the parents showed this trait.
  - a **Explain** how this could have occurred.
  - b **Explain** from which of the boy's grandparents this allele could have come, if none of them showed the trait.

#### Investigate, evaluate and communicate

- 3** A tortoiseshell cat (genotype  $X^O X^B$ ) is mated with a ginger cat ( $X^O Y$ ). **Predict** the genotypes and phenotypes you would expect among the offspring.
- 4** Suppose that, in the cat crosses described in question 3, the female had long hair and the male had short hair. The gene for hair length is autosomal and shows intermediate dominance (LS giving medium-length hair). **Predict** how many different phenotypes you would expect, and in what proportions.
- 5** Haemophilia is a sex-linked recessive gene in humans. If a father and son are both haemophiliacs, but the mother is normal, **predict** with explanation the genotype of the mother.
- 6** In the family in question 5, **comment** on whether you would expect any of the daughters to be haemophiliacs.

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» Student book  
questions

Check your learning  
11.3

» Weblink  
Sex-lined genes

» Weblink  
Holandric genes



# Review

## Chapter summary

- 11.1**
  - The frequencies of genotypes and phenotypes can be determined using Punnett squares and frequency histograms.
  - A monohybrid cross of two heterozygous parents has a 1 in 4 chance of producing offspring with the recessive trait.
  - A dihybrid (unlinked genes) cross between parents who are heterozygous for both traits will produce the ratio 9:3:3:1.
  - Test crosses can be used to determine the genotype of unknown individuals.
- 11.2**
  - Codominant traits result from alleles that are expressed equally in the phenotype.
  - Intermediate dominance (including incomplete or partial dominance) results in a phenotype that is midway between that of the homozygous individuals.
  - Polygenic traits (resulting from multiple genes affecting the trait) causes continuous variation in the phenotype.
  - Genes can interact with each other to affect the phenotype.
- 11.3**
  - Sex-linked genes are found on the X sex chromosome in mammals. Examples include haemophilia and colour defective vision.
  - Sex-linked traits are more likely to appear in the phenotype of males.

## Key terms

- agglutination
- allele
- Barr body
- carrier
- codominance
- colour defective vision
- continuous variation
- dihybrid cross
- dihybrid ratio
- dominant allele (autosomal dominant)
- dominant trait
- epistasis
- family tree
- frequency histogram
- gene complexes
- genotype
- haemophilia
- heterozygous
- holandric genes
- homozygous
- hybrid (genetic)
- intermediate dominance
- modifier genes
- monohybrid cross
- multiple or poly alleles
- phenotype
- phenylketonuria (PKU)
- polygenic (or multiple gene) inheritance
- product rule
- Punnett square
- pure-bred
- recessive allele (autosomal recessive)
- recessive trait
- sex-linked genes
- test cross
- universal donor
- universal recipient
- wild type
- X inactivation

## Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number:

\* = low; \*\* = medium; \*\*\* = high.

### Multiple choice

- 1 A gene is best defined as:
  - A a portion of a chromosome responsible for several characteristics
  - B a part of a single chromosome in the nucleus
  - C a factor responsible for producing a characteristic
  - D a part of a chromosome responsible for producing one polypeptide
- 2 Chromosomes that are not sex chromosomes, are known as:
  - A autosomes
  - B phenotypes
  - C genotypes
  - D carriers
- 3 Rabbits may have long or short ears. A long-eared, homozygous dominant rabbit is mated with another long-eared, but heterozygous rabbit.  
If L represents the dominant trait allele and l represents the recessive trait allele, select the alternative below that best illustrates the genotypes of the offspring.
  - A all long-eared
  - B LL and ll
  - C LL and Ll
  - D long-eared and short-eared
- 4 The lengths of corn cobs show continuous variation as they are controlled by two pairs of alleles (A and a, B and b).  
Select the genetic combinations that would give a short ear but not the shortest ear.

- A aabb
- B AaBb
- C aaBb
- D AaBB

- 5 The coat colour of cats is a trait that is linked to the sex chromosomes. The gene for coat colour is carried on the X chromosome. Suppose that O represents ginger, B represents black and that tortoiseshell cats show both colours in their coats.  
A ginger female ( $X^O X^O$ ) is mated with a black male cat ( $X^B Y$ ).  
Identify the following litters that this mating could produce.
  - A Tortoiseshell females and ginger males
  - B Ginger females only
  - C Ginger females and tortoiseshell males
  - D Ginger females and ginger males
- 6 If a red-flowered plant when crossed with a white-flowered plant gave all offspring with pink flowers, we would assume that the alleles for red and white showed:
  - A incomplete dominance
  - B complete dominance
  - C modifier genes present
  - D complete recessiveness



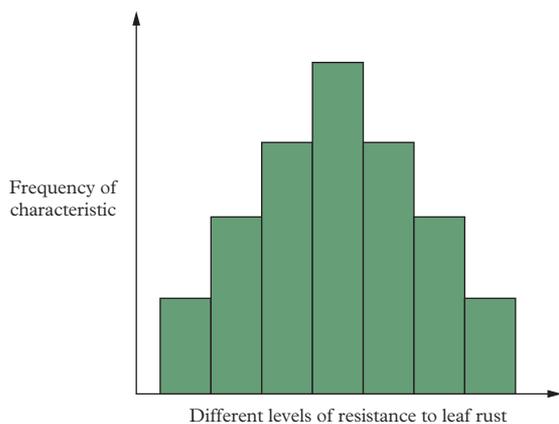
FIGURE 1 A plant with red, pink and white flowers

- 7 A man with an X-linked dominant disorder marries a woman without the disorder. Determine the proportion of their daughters that will be affected by the disorder.
- A 0%  
 B 25%  
 C 50%  
 D 100%
- 8 The term holandric gene refers to genes, in humans:
- A that are sex-linked on the X chromosome  
 B that cross over  
 C that have displayed non-disjunction  
 D carried on the Y chromosome
- 9 Members of a barley plant species show varying levels of partial resistance to the leaf rust *Puccinia hordei*.



FIGURE 2 Barley

The graph below shows the distribution of a population of barley plants with regard to this characteristic.



With respect to rust resistance, these plants show:

- A high mutation rates  
 B polygenic inheritance  
 C discontinuous variation  
 D inheritance due to a single pair of alleles
- 10 In 1910, Thomas Morgan discovered traits linked to sex chromosomes in the fruit fly. The Punnett square below shows the cross between red-eyed females and white-eyed males. Fruit flies usually have red eyes. Predict the most probable combination of offspring.

		White-eyed male	
		X <sup>r</sup>	Y
Red-eyed female	X <sup>R</sup>	X <sup>R</sup> X <sup>r</sup>	X <sup>R</sup> Y
	X <sup>R</sup>	X <sup>R</sup> X <sup>r</sup>	X <sup>R</sup> Y

- A 2 red-eyed females; 2 red-eyed males  
 B 2 red-eyed females; 1 red-eyed male; 1 white-eyed male  
 C 1 red-eyed female; 1 white-eyed female; 2 red-eyed males  
 D 2 white-eyed females; 1 white-eyed male; 1 red-eyed male

### Short answer

#### Describe and explain

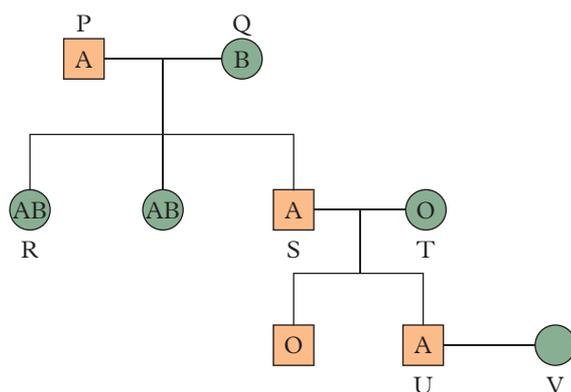
- ★ 11 **Explain** why more men than women express sex-linked recessive traits.
- ★ 12 **Explain** why some characteristics, for example skin colour, have multiple expressions.
- ★★ 13 In some breeds of dogs, a dominant autosomal trait controls the characteristic of barking while trailing (hunting or tracking game). In these dogs, another independent gene produces erect ears; it is dominant over the allele for drooping ears. Suppose a dog breeder wants to produce a pure-breeding

strain of droop-eared barkers, but he knows that the genes for silent trailing and erect ears are present in his kennels. **Describe** how he should proceed.



FIGURE 3 A droopy-eared dog

- ★★ 14 The figure below shows a diagram showing three generations of a family tree, together with the blood groups, in the ABO system, of the family members.

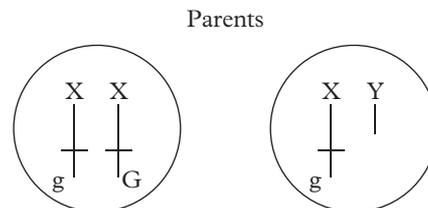


Key

	MALES	FEMALES
Blood group A	A	A
Blood group B	B	B
Blood group AB	AB	AB
Blood group O	O	O

- a **Identify** the genotypes of persons P and Q.
- b Parents U and V produce four children, each with a different blood group. **Explain** how this is possible.
- ★★ 15 Drawn below are the sex chromosomes of two parents. There are two alleles, one for normal colour vision, represented by G, and one for red–green colour defective vision,

represented by g. **Calculate** the phenotypic and genotypic ratio of their possible offspring.



### Apply, analyse and interpret

- ★ 16 **Distinguish** between an autosomal dominant and a sex-linked dominant trait.
- ★★★ 17 In peas, tall plants (T) are dominant to dwarf (t), yellow colour (Y) is dominant to green (y), and smooth seed (S) is dominant to wrinkled seed (s). **Determine** what the phenotypes of the offspring of the following matings would be.
- a  $TtYySs \times ttyyss$
- b  $TtyySs \times ttYySs$
- ★★ 18 Work has been done on the waxy and non-waxy characteristics of maize seeds. The blue–black staining reaction with iodine is given by the starch amylose. Seeds of different kinds have been analysed for their amylose content, with the following results. (Note that the endosperm of the seed develops from a triploid nucleus and so has three genes for each characteristic, not two).

Genotype of endosperm	Amylose content (%)
$WxWxWx$	22.0
$WxWxwx$	20.4
$Wxwxwx$	18.4
$wxwxwx$	0.0

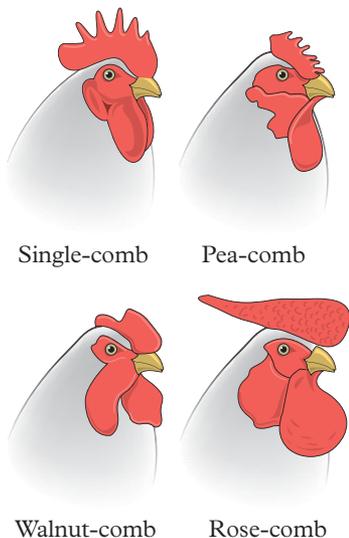
- a Attempt to account for these results. If one simply looks at the seeds, non-waxy is clearly dominant to waxy. **Determine** whether it appears to be dominant on chemical analysis.
- b In the light of your present understanding of gene action, **determine** how you would account for this inheritance.

- ★★ 19 The long hair of Persian cats is recessive to the short hair of Siamese cats, but the black coat colour of Persians is dominant to the black and tan coat of Siamese. If a pure black, long-haired Persian is mated to a pure black and tan, short-haired Siamese, **determine** what the appearance of the  $F_1$  will be. **Calculate** the probability of getting a long-haired black and tan cat if two of the  $F_1$  mate.



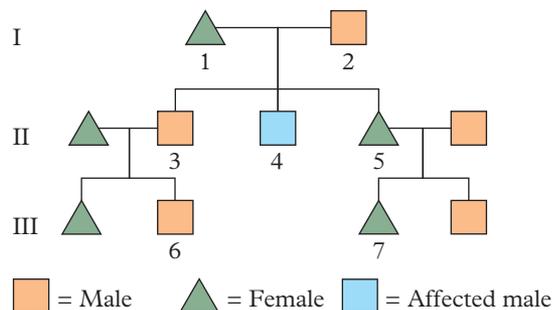
FIGURE 4 (a) Persian cat (b) Siamese cat

- ★★ 20 In domestic fowls the gene for rose comb (R) and pea-shaped comb (P) together produce the so-called 'walnut' comb shape (genotypes RRPP, RrPP, RRpp or RrPp). These are shown below:



The recessive alleles r and p produce the normal single comb shape (genotype rr pp). **Determine** what phenotypes you would expect from the following crosses, and in what proportions.

- a  $RRPp \times rrPp$
  - b  $rrPP \times RrPp$
  - c  $RrPp \times Rrpp$
- ★★ 21 Bar eye gene in *Drosophila* causes a drastic reduction in eye size. A male with narrow bar eyes crossed with a female with normal eyes produced progeny in which all females had wide bar eyes and all males had normal eyes. **Deduce** whether this cross demonstrates that the bar gene is located on the X chromosome. **Explain** your answer.
- ★★★ 22 The diagram below represents a family pedigree showing the inheritance of phenylketonuria (PKU), a fatal disease where urine is black and which is controlled by a single pair of alleles, A and a.



- a Use this pedigree to **determine** whether the allele for PKU is dominant or recessive.
- b **Identify** with reasons the genotypes of each of the individuals 1, 2 and 4.
- c **Deduce** the possible genotypes of each of the individuals 3 and 5.
- d Individual 7 married a man who is heterozygous for this condition. **Explain** the possible genotypes of their offspring. Illustrate your answer by the use of Punnett squares.

### Investigate, evaluate and communicate

★★★ 23 The frequencies per thousand births of some genetic diseases, in populations of northern European origin, are shown in the table below.

Inheritance pattern	Frequency (per 1000 births)	Pathology
<b>Autosomal dominant</b>		
Huntington's disease	0.1	Progressive dementia from mid-life
Achondroplasia	0.04	Dwarfism
Myotonic dystrophy	0.05	Progressive muscular weakness
Neurofibromatosis	0.25	Tumours of peripheral and other nerves
<b>Autosomal recessive</b>		
Phenylketonuria	0.1	Mental retardation
Cystic fibrosis	0.4	Mucoid build-up; lung congestion
Beta thalassaemia	0–10	Severe anaemia
Sickle cell anaemia	0–10	Haemolytic anaemia
Albinism	0.1	Lack pigment; abnormal vision
<b>Sex-linked</b>		
	Frequency (per 1000 males)	
Red–green colour blindness	80	Inability to distinguish red and green colours

Inheritance pattern	Frequency (per 1000 births)	Pathology
Haemophilia	0.2	Defect in blood clotting
Muscular dystrophy	0.3	Progressive muscular weakness
Fragile X syndrome	0.9	Mental retardation
Testicular feminisation	0.02	Sterile XY females; unresponsive to male sex hormones

- a Determine** the probable frequency of an individual of northern European origin simultaneously having:
- Huntington's disease and albinism
  - achondroplasia, sickle cell anaemia and cystic fibrosis.
- b** Although the traits for some disease conditions are autosomal dominant, the frequency of the disease in the population is less than that for some recessively inherited diseases. **Propose** possible reasons for this. Use examples from the table to **explain** your answer.
- c** An individual has inherited both myotonic and muscular dystrophy. From your knowledge of human physiology, explain the effects of these diseases. How could this affect the person's quality of life? **Predict** the likelihood of the individual surviving.
- d Explain** why frequencies of sex-linked diseases were recorded for males only.

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# Biotechnology

Biotechnology, the application of biological knowledge to the production of organisms, or their products useful to humankind, has been used for thousands of years. Many of the foods that are taken for granted have been produced using artificial selection and breeding of organisms with desirable characteristics. Genetic principles and techniques have been applied to commercial enterprises, such as genetic engineering of drug- and food-producing organisms, as well as manipulation of some genetic diseases and cloning.

In the twenty-first century the field of DNA technology is one of the fastest growing areas of science. Recombinant DNA technology and DNA fingerprinting and profiling are major branches of this area. Recombinant DNA (genetic engineering) involves the introduction of new genes by cutting them out of the chromosomes of one species and inserting them into the chromosomes of another species. By doing this, organisms are modified to possess new, desirable characteristics.

## OBJECTIVES

- Describe the process of making recombinant DNA:
  - isolation of DNA, cutting of DNA (restriction enzymes)
  - insertion of DNA fragment (plasmid vector)
  - joining of DNA (DNA ligase)
  - amplification of recombinant DNA (bacterial transformation).
- Recognise the applications of DNA sequencing to map species' genomes and DNA profiling to identify unique genetic information.
- Explain the purpose of polymerase chain reaction (PCR) and gel electrophoresis.
- Appraise data from an outcome of a current genetic biotechnology technique to determine its success rate.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

## PRACTICALS

	SUGGESTED PRACTICAL	<b>12.2</b> Bacterial transformations
	SUGGESTED PRACTICAL	<b>12.4</b> Gel electrophoresis

**FIGURE 1** Biotechnology is an ever-growing science with endless future possibilities.



# 12.1

## The scope of biotechnology

### KEY IDEAS

+ Biotechnology

#### biotechnology

the application of biological knowledge to the production of organisms (or their products) useful to humankind

#### artificial selection

the breeding of plants and animals to produce desirable traits

**Biotechnology** can be broadly defined as the exploitation of biological processes for human purposes. The aim of biotechnology is to improve human life and the health of the planet. Although the term conjures up images of sophisticated laboratories, and bizarre products like giant bioluminescent rabbits or human clones, biotechnology is an ancient craft. The food we eat – plant and animal – has been the result of thousands of years of choosing the most suitable organism to breed (**artificial selection**). As a result, the organism may change over time: wild mustard became broccoli, Brussels sprouts, cauliflower and cabbage. Although early farmers and manufacturers did not know the biological processes underlying their actions, they did know that certain steps were needed to attain the best results.



FIGURE 1 (a) wild mustard; (b) broccoli

## Food processing

Today a great number of food products are made using anaerobic respiration of microorganisms. The most commonly used bacteria are *Acetobacter* (vinegar from alcohol), *Lactobacillus* (butter, cheese and yoghurt from milk) and *Clostridium* (acetone and butanol from molasses). A variety of yeasts are used to produce different wines and beers. Fungi are also used to give different cheeses their distinctive flavours, such as Roquefort (*Penicillium roqueforti*) and camembert (*Penicillium camemberti*).

FIGURE 2 Modern cheese making involves highly controlled, sterile conditions for fermentation.



## Waste reduction

Many bacteria and fungi are important decomposers. They obtain their nutrients from organic matter (predominantly dead organisms) and, in doing so, release simple inorganic compounds back into the environment and make them available for use by producers.

Many decomposers (bacteria and fungi) are used as biodegradation agents; for example, to clean up oil spills and in toxic organic waste dumps.

Methanogens are utilised in a variety of processes related to domestic rubbish, sewage or agricultural waste, and for the production of methane gas. The gas is collected and used for cooking, lighting and heating. In Australia, many authorities are now using methane released from landfills to generate electricity. Bacteria and archaea are also used in the industrial treatment of sewage.

## Production of medicines

Some medicines are derived from plants and animals, from which the active ingredient is extracted and purified. In many cases, after analysis, this active ingredient (chemical compound) can be artificially synthesised.

### CASE STUDY 12.1

#### Animal cloning

##### The first mammalian clone – Dolly, the sheep

**Cloning** is the production of organisms that are genetically identical. It was not until 1997 that the first mammal, Dolly the sheep, was successfully cloned from an adult cell. She originated from an udder cell of an adult ewe. This process is called **somatic cell nuclear transfer** (SCNT), and involves transferring the nucleus of the genetic parent cell, including its DNA, into a donor egg that has had its nucleus removed.

Two types of cells are cultured in this process – recipient and donor cells. The recipient cell is an egg cell from which the chromosomes have been removed. The genetic parent cell can be any body (somatic) cell. This cell is, however, already specialised. Only some of its genes are active while other genes are inhibited. In order for all of the genes to be expressed, the cell must be returned to its non-specialised, embryonic state. An electric current is used to initiate cell division. Once the cell mass has formed, it is implanted into the uterus of a surrogate mother, where it completes development. This cloning process is simple, but the success rate is low. It took 277 trials before Dolly was produced. Dolly developed premature arthritis when only four years old and died by the time she was seven years old.



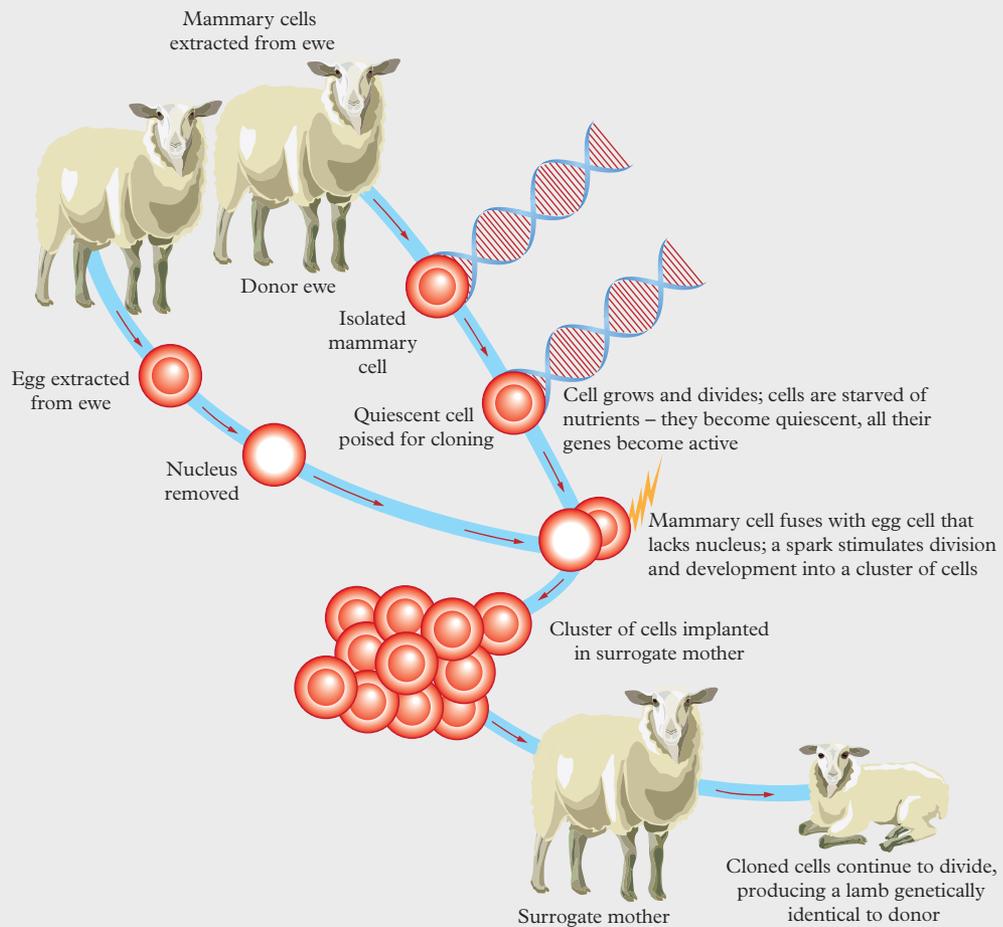
FIGURE 3 Dolly, the cloned sheep

#### cloning

the process of producing genetically identical individuals or the duplication of any kind of biological material

#### somatic cell nuclear transfer

a laboratory technique for creating an ovum with a donor nucleus from a somatic cell



**FIGURE 4** Cloning process of the first mammalian animal – Dolly the sheep

### The first primate clones

In China, a team of researchers at the Institute of Neuroscience in Shanghai, after 10 years of effort, successfully cloned two identical long-tailed macaque monkeys born in December 2017. Zhong Zhong was born two weeks before Hua Hua.

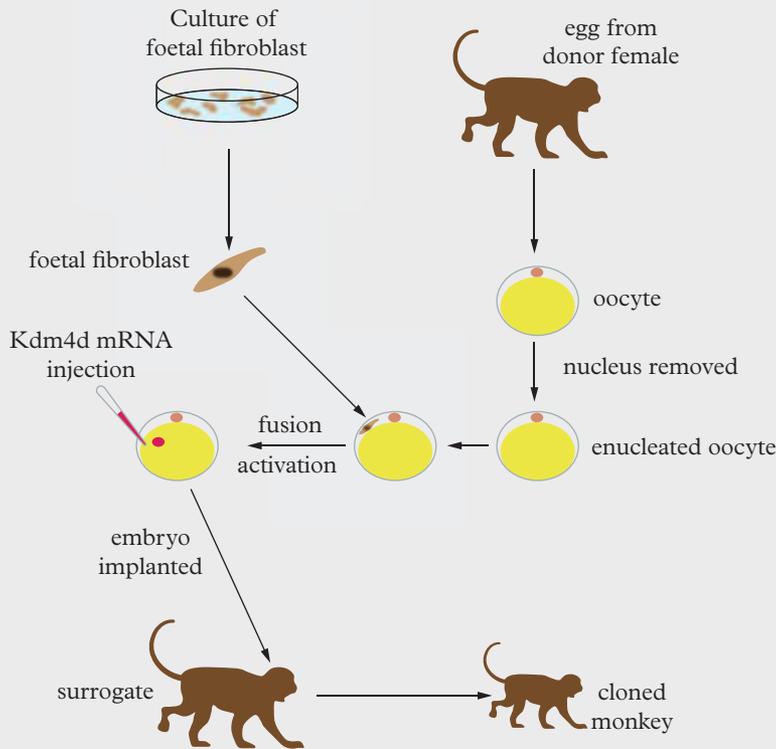
These two monkeys were cloned from a non-embryonic cell. The donor nucleus came from the connective tissue of an aborted foetus. The Chinese team succeeded, by the use of epigenetic modulators, to switch on or off certain genes in these cells that were inhibiting embryo development. The modulators also promoted embryo development and improved the pregnancy rate. It is possible to genetically modify monkey cells in a dish and then grow these cells in large numbers in cell lines. The last step required taking DNA out of these genetically modified cells and putting it into harvested monkey eggs. The researchers produced 127 eggs using this process. Of these, only 109 developed into embryos but only 79 were transferred into 21 surrogate monkey mothers. This resulted in six pregnancies and finally two live births.

The main aim of the research was to produce genetically identical animals useful in biomedical research into human genetic diseases, and for trialling of drugs. Research tests performed on cloned animals eliminates factors caused by the genetic variability

of animals not cloned. As this is an extremely expensive and time-consuming process, with extremely low results, cloning genetically identical monkeys for research is a long way in the future.



**FIGURE 5** Chinese scientists in Shanghai cloned the monkeys Zhong Zhong and Hua Hua



**FIGURE 6** Cloning macaque monkeys by somatic cell nuclear transfer using foetal monkey fibroblasts

## CHECK YOUR LEARNING 12.1

### Describe and explain

- 1 **Define** the term biotechnology.
- 2 **Describe** some biotechnologies that have been used for thousands of years.
- 3 **Explain**, with examples, why many microorganisms have played an important role in biotechnology.

### Investigate, evaluate and communicate

- 4 **Consider** the argument that 'Humans are pushing ethical boundaries too far with DNA technologies'. Select one example and **evaluate** either side of the argument.

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Cloning and ethics

» Weblink  
Gene therapy



# 12.2

## Recombinant DNA technology

### KEY IDEAS

- + Genetically modified organism (GMO)
- + Transgenic organisms
- + Recombinant DNA
- + Restriction enzymes, reverse transcriptase, DNA polymerase and DNA ligase
- + Gene cloning

**genetically modified organism (GMO)**  
an organism whose genetic material has been altered using recombinant DNA technology

**transgenic organism**  
an organism whose genome has been altered using genetic material from another species or breed

**restriction enzyme (nuclease)**  
an enzyme that cleaves DNA at or near specific recognition sites

**DNA scissors**  
restriction enzymes that cut DNA into fragments

Humans have always been curious. An understanding of the structure and function of DNA has resulted in questions about how we can modify it to improve the production of antibiotics and insulin, or to 'cure' genetic diseases.

**Genetically modified organisms (GMOs)** are any organisms that have had their DNA modified in any way. Some of these organisms may have had genes activated or inhibited, while others (**transgenic organisms**, such as bacteria) may have genes from another organism (such as a jellyfish) introduced into their DNA.

### Genetic engineering toolbox

When an engineer designs and builds a structure, they need a set of tools to cut, copy or stick together the pieces. Genetic engineering, like other forms of engineering, requires a set of molecular tools. All of these tools have been isolated from existing organisms. Since the structure of DNA is the same in all species, the enzymes associated with the DNA of one species will work effectively with the DNA of any other species. Bacterial DNA enzymes, therefore, can be used in the manipulation of plant and animal species.

### Restriction enzymes

Since the first **restriction enzyme (nuclease)** was isolated from the *Haemophilus influenzae* bacterium in 1968, more than 900 different types have been discovered from over 230 strains of bacteria. Each of these enzymes has been found to cut DNA molecules at a particular site. Each restriction enzyme is given a name that generally reflects its origin:

- The first letter (upper case) of the name comes from the genus. The next two letters (in lower case) come from the species of the bacterial cell from which it was isolated. If there is a fourth letter, it indicates the strain of that species.
- A Roman numeral following the name indicates the order in which the enzyme was isolated from a single strain of the bacterium.

This suggests that EcoRI comes from the *Escherichia coli* RY13 strain, with a target sequence of 5'G\*AATTC3'. EcoRII is derived from *E. coli* R245, with a target sequence 5'\*CCAT/GG3'. The actual cleavage of the DNA chain occurs at the point indicated at the \*. Because of their action, restriction enzymes are given the general name of **DNA scissors**. Restriction enzymes that break nucleic acid strands somewhere in the interior of the molecule are called endonucleases, while those that break the strands at the ends of the molecule are called exonucleases.

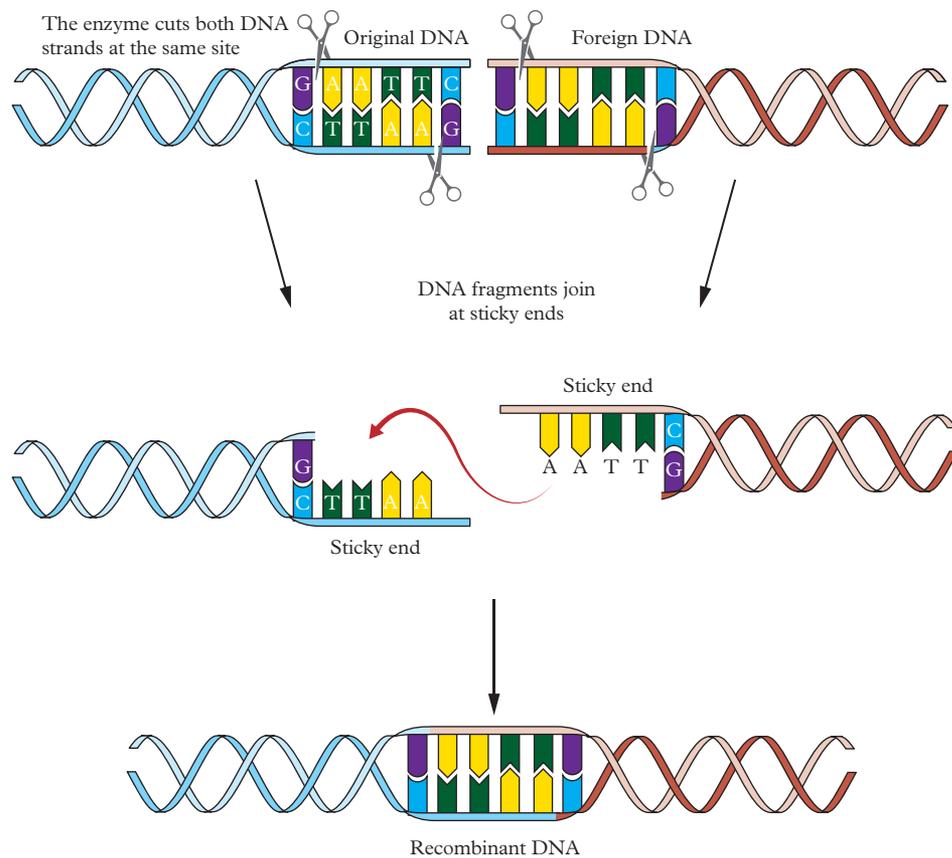


FIGURE 1 Restriction enzyme action of EcoR I

TABLE 1 Some restriction enzymes and their sources

Enzyme	Organism from which derived	Target sequence (cut at *) 5' → 3'
AvaI	<i>Anabaena variabilis</i>	C * C / T C G A / G G
BamHI	<i>Bacillus amyloliquefaciens</i>	G * G A T C C
BglII	<i>Bacillus globigii</i>	A * G A T C T
EcoRI	<i>Escherichia coli</i> RY13	G * A A T T C
EcoRII	<i>Escherichia coli</i> R245	* C C A / T G G
HaeIII	<i>Haemophilus aegyptius</i>	G G * C C
HhaI	<i>Haemophilus haemolyticus</i>	G C G * C
HindIII	<i>Haemophilus influenzae</i> RD	A * A G C T T
HpaI	<i>Haemophilus parainfluenzae</i>	G T T * A A C
KpnI	<i>Klebsiella pneumoniae</i>	G G T A C * C
MboI	<i>Moraxella bovis</i>	* G A T C
PstI	<i>Providencia stuartii</i>	C T G C A * G
SmaI	<i>Serratia marcescens</i>	C C C * G G G
SstI	<i>Streptomyces stanford</i>	G A G C T * C
SalI	<i>Streptomyces albus</i> G	G * T C G A C
TaqI	<i>Thermus aquaticus</i>	T * C G A
XmaI	<i>Xanthomonas malvacearum</i>	C * C C G G G

### Study tip

There are both DNA and RNA polymerases, and ligases. It can be important to specify which one you are talking about when answering questions. Always specify DNA ligase or RNA polymerase.

### sticky ends

fragments of unpaired DNA bases formed when particular base sequences are cut asymmetrically

### DNA ligase

a specific type of enzyme that facilitates the joining of DNA strands together

### reverse transcriptase

a DNA polymerase enzyme that catalyses the process of reverse transcription – the use of an RNA molecule as a template for the synthesis of a complementary DNA strand

### reverse transcription

the formation of DNA from an RNA template

### DNA polymerase

a type of enzyme that is responsible for assembling nucleotides to form new copies of DNA

### recombinant DNA (= genetic engineering)

the deliberate modification of the characteristics of an organism, or production of a new organism, by inserting or deleting genes into the DNA

### plasmid

a small DNA molecule that is physically separated from chromosomal DNA and can replicate independently; typically within a bacterial cell

Some enzymes, like SmaI, cut the DNA in the exact centre of the sequence, generating a blunt end with no unexposed bases.

Chain 1: 5'–CCC | GGG3'

Chain 2: 5'–GGG | CCC5'

Other enzymes like HindIII cut asymmetrically. Separation results in fragments, each of which has a protruding end composed of unpaired bases. These fragmented ends with their unpaired bases are called '**sticky ends**'.

Chain 1: 5'–A | AGCTT3'

Chain 2: 3'–TTCGA | A5'

## DNA ligase

Many cells are able to repair any mistakes made in DNA when undergoing replication. One of the enzymes involved in this repair mechanism is **DNA ligase**. Scientists have exploited this mechanism in genetic engineering. DNA that has been cut with a restriction enzyme can be recombined (in different combinations) and the phosphate–sugar bond repaired by the DNA ligase.

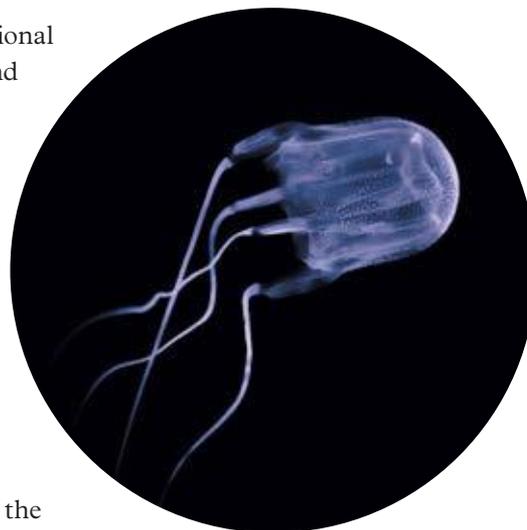
## Reverse transcriptase

There is one important difference between the functional genes found in prokaryotes (bacteria and archaea) and that of eukaryotes – prokaryotes do not have introns (small sections of DNA that are not translated into the final protein). This means that if a gene (containing introns) is transferred from a jellyfish to a bacterium, the bacteria will transcribe and translate the whole gene, including the introns. This will produce a protein that is longer than normal and, as a result, will be non-functioning.

Instead, scientists use the mature mRNA from the jellyfish that has already had its introns spliced out. A special enzyme (**reverse transcriptase**) is then used to make a complementary DNA version of the mRNA (**reverse transcription**). **DNA polymerase** is used to make the complementary DNA (cDNA) double stranded so that it can be inserted into the bacterial cells.

## Plasmids

The earliest **recombinant DNA** experiments were performed on bacteria. In addition to the circular chromosomal strand of DNA, bacteria have one or more additional small sections of DNA called **plasmids**. The genes on the plasmids give different strains of the same prokaryotic species slightly different characteristics, such as resistance to a particular antibiotic. Scientists use the plasmids to transfer genes from one organism into another (e.g. bacteria).



**FIGURE 2** The box jellyfish is a eukaryote and has genes containing introns.

Both the donor DNA and the plasmid DNA are cut with the same restriction enzyme so that it will cut both pieces of the molecule at the site of the specific recognition sequence. The donor gene is then added to the cut plasmid, and the DNA ligase can be used to splice the gene into the plasmid. The plasmid can then act as a **vector** that transfers the donor gene into a prokaryotic cell.

## Bacterial transformation

Once generated, the genetically recombined plasmid is placed with the bacterial cell into a solution of calcium chloride. This makes the bacterial membrane more porous, the plasmid moves into the cell, and the bacterium is transformed. Each time the bacterium divides, the plasmid is replicated and carried in the new bacterial cells. This production of identical copies of the gene is called **gene cloning**.

## Monitoring recombination

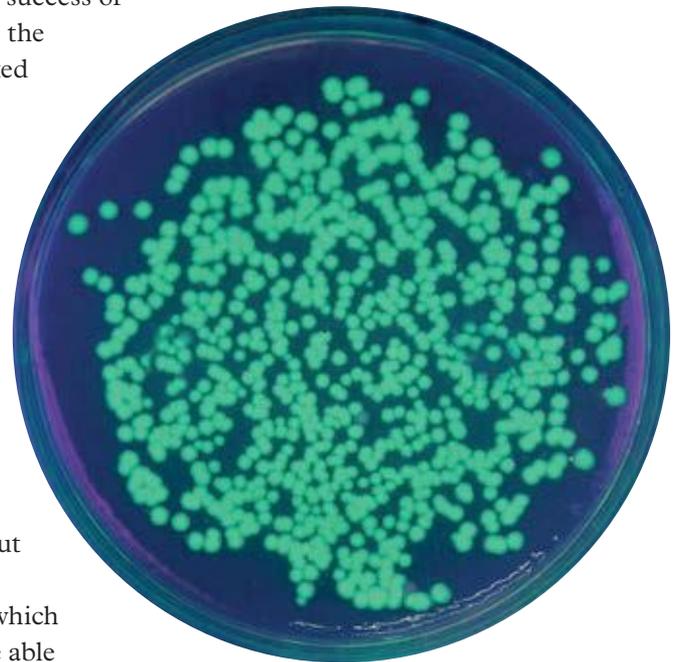
The description of recombinant DNA processes is idealistic and does not necessarily occur like this in reality. Some of the plasmids do not splice with the foreign gene. Some uncombined plasmids reinsert back into the bacterial cell and some recombined plasmids do not reinsert. To ensure that the required gene has been correctly inserted into the bacterium, scientists use other properties of plasmid genes, such as antibiotic resistance or the ability to produce a fluorescent green protein, to identify the required cells.

Choosing the right molecular tools is important for the success of bacterial transformation. Scientist must be aware of where the restriction enzyme will cut the plasmid and how the inserted gene will affect other genes that are present. For example, one commonly used plasmid contains two genes – one gene confers resistance to the antibiotic ampicillin (called *ampR*), while the other produces the lactose-digesting enzyme  $\beta$ -galactosidase (*lacZ*). The *lacZ* gene produces an enzyme that can digest the sugar X-gal to produce a blue pigment. If the restriction enzyme EcoR1 is used, it will cut the plasmid in the centre of the *lacZ* gene, interrupting this gene so that it cannot be expressed. This means the X-gal sugar cannot be digested, and therefore no blue pigment will be produced.

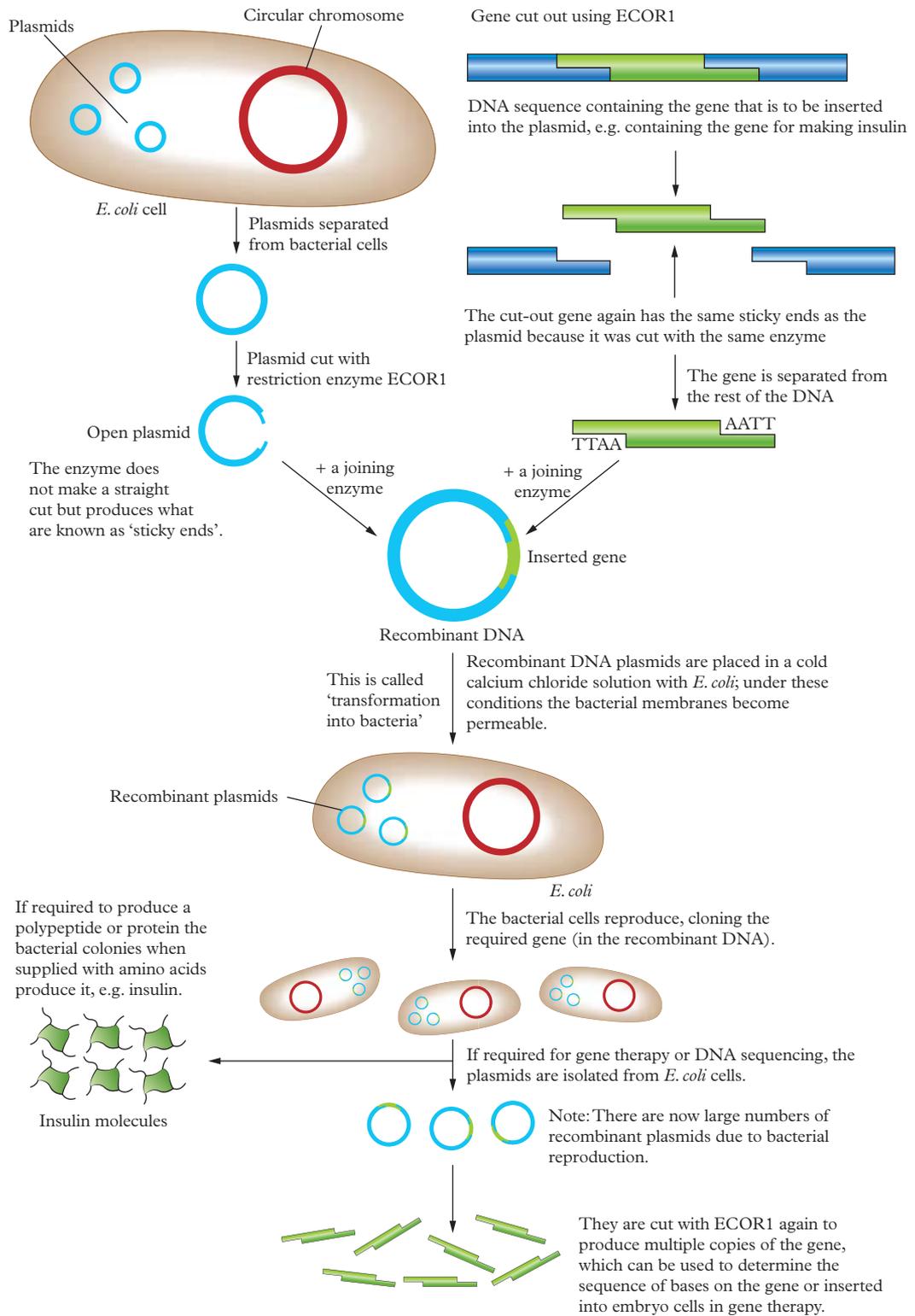
To separate the transformed bacteria from those without the recombined gene, the colonies are grown on a culture medium containing both ampicillin and the X-gal sugar, which is broken down by *lacZ*. Only transformed bacteria will be able to grow because they contain the *ampR* gene. Bacteria with un-recombined plasmids will express the *lacZ* gene. The colonies containing the recombined gene (and thus non-functional *lacZ*) will not be coloured blue. The white colonies can then be isolated and pure cultures of the recombinant bacteria grown.

**vector**  
a DNA molecule used in the transfer of foreign genetic material into another cell, where it can be replicated and/or expressed

**gene cloning**  
production of identical copies of a gene

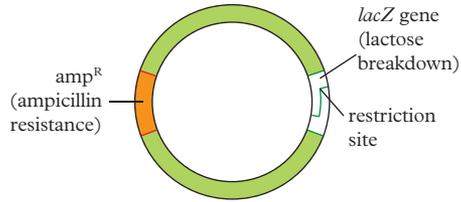


**FIGURE 3** The plasmid containing the *pGLO* gene is able to produce a green fluorescent protein when in the presence of arabinose sugar. This can make transgenic bacteria glow green in a fluorescent light.



**FIGURE 4** Recombinant DNA technology

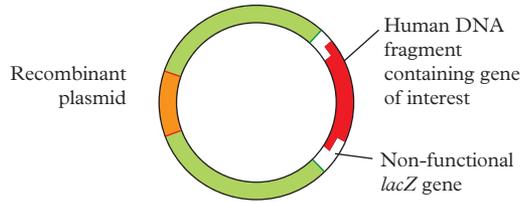
1



Bacterial plasmid before the addition of the foreign gene. Note the site at which the restriction enzyme cuts is in the middle of the *lacZ* gene; the gene for ampicillin resistance is on the opposite side of the plasmid.

2

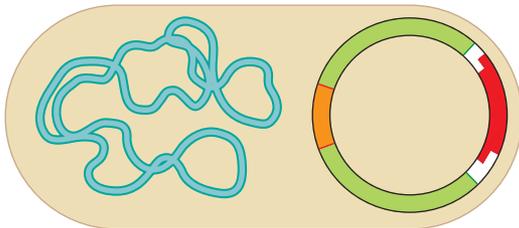
The plasmids are cut with restriction enzymes, then mixed with foreign DNA, e.g. human genes.



The human DNA has been spliced into the plasmid, making the *lacZ* gene non-functional.

3

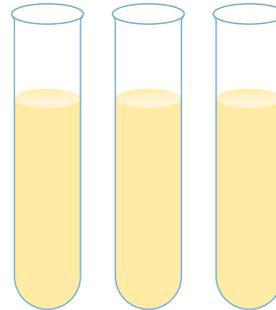
Recombinant plasmid transformed into bacterial cell.



The recombinant plasmids are transformed into the bacteria. Diagram 3 shows a recombinant plasmid in a bacterium but some plasmids will not be recombinant; in other cases, no plasmids will transform into the bacterial cells.

4

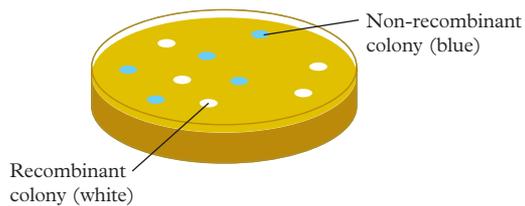
Cloned cells



The bacterial cells are grown in tubes to produce many identical cells (clones).

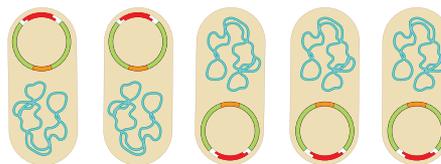
5

The cells are plated onto a growth medium containing ampicillin and X-gal; the clones of cells containing recombinant plasmids are identified by their white colour.



6

Recombinant DNA clones are grown to produce the required product, e.g. insulin.



*Note 1:* All cells within plasmids will grow because they have the ampicillin-resistant gene.

*Note 2:* The plasmids have been drawn larger (compared with the bacterial chromosome) than actual size.

**FIGURE 5** Identification of recombinant plasmids in bacteria

## Uses of recombinant bacteria

Genes that have been recombined into plasmid DNA can be used for a variety of purposes. The gene product may be required, such as human insulin. Because the human insulin gene would not normally be present in the bacterium, it is not automatically expressed when inserted into this organism. **Regulatory genes** may also need to be spliced into the plasmid to promote the expression of the desired gene.

In addition to human insulin, other substances are now produced in commercial quantities using recombinant DNA techniques. Examples include:

- vaccine antigens for diseases such as malaria and hepatitis
- interferon – used in cancer research and treatment of some viral conditions; previously extracted from infected human blood cells
- hirudin – anticoagulant used in plastic surgery; previously obtained by ‘milking’ the salivary glands of blood-sucking leeches
- human growth hormone used to treat stunted growth
- a protein that dissolves blood clots and can be used in the treatment of heart attacks and other heart conditions
- introduction of pest resistance into some plants.

Bacteria can also be used as the vectors for producing large numbers of a particular gene for other purposes such as **gene therapy**.

## Gene therapy

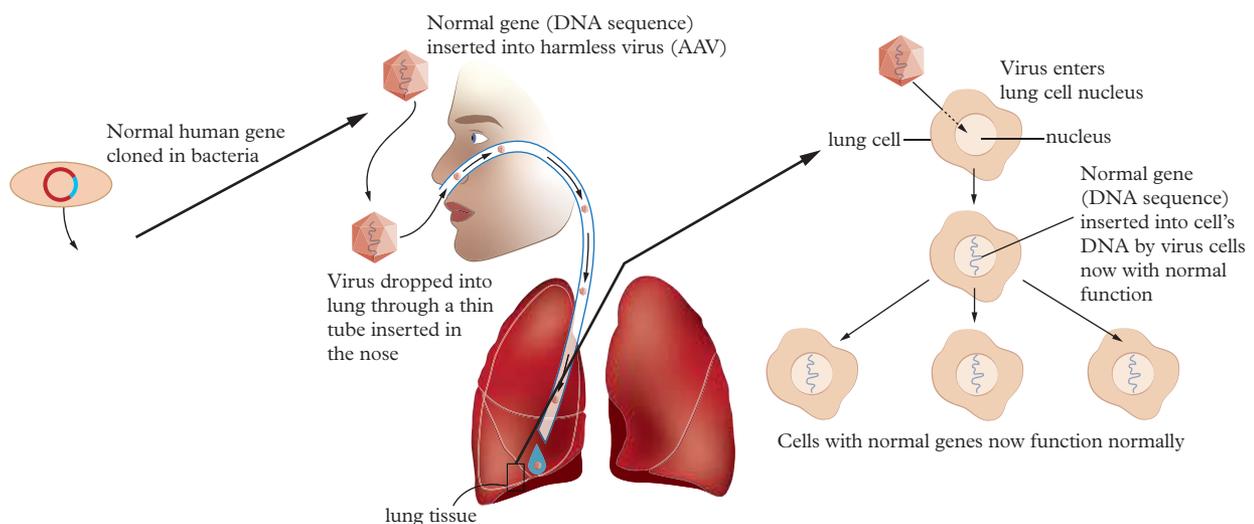
There are two types of gene therapy – **somatic gene therapy** and **germ cell gene therapy**. Somatic gene therapy involves replacing a defective gene in a somatic (body) cell with an intact gene that carries the code for the functioning protein. In this case, a virus is often used as a vector because it is able to carry the intact gene into the affected cell. In treating cystic fibrosis, for example, the correct gene is first cloned in bacterial plasmids, and then inserted into a harmless virus. This virus is sprayed into the lungs where it enters the lung cells, thereby inserting the correct gene into the cell’s DNA. Human trials of this treatment have had many setbacks as a result of the discovery that many viral genes display a preference to be

**regulator gene**  
a non-coding segment of DNA that produces transcription factors for gene expression

**gene therapy**  
the introduction of normal genes into cells in place of missing or defective ones in order to correct genetic disorders

**somatic gene therapy**  
replacement of defective genes in targeted cells that are affected by a genetic disease

**germ cell gene therapy**  
replacement of a defective gene with a normal gene in a reproductive cell (egg or sperm), allowing normal development of the embryo and preventing the disease variant from being passed down



**FIGURE 6** Somatic gene therapy treatment of cystic fibrosis

inserted into active, regulatory sections of the host cell's DNA. This has led to some instances of the gene therapy patient developing cancerous cells as a result of the treatment.

In germ cell gene therapy, a defective gene is replaced in the egg or sperm. Fertilisation of the gametes takes place in-vitro and the resulting embryo is implanted into the female. This ensures that all of the cells of the embryo will carry the normal gene, so that offspring will not have the disease, and it eliminates the defect permanently in subsequent generations of that family. This technique is controversial since there is concern about simultaneous, accidental introduction of regulatory genes that could impact on the individual (and therefore be inherited), and the possibility for 'cosmetic' gene manipulation. To date, germ cell gene therapy has not been approved for human use in most countries.

## CHECK YOUR LEARNING 12.2

### Describe and explain

- 1 **Describe** the role of 'sticky ends' in recombinant DNA technology and how they are produced.
- 2 Read the following passage and **identify** the most appropriate word or words to fill in the blank spaces.

The isolation of specific genes during a genetic engineering process involves forming eukaryotic DNA fragments. These fragments are formed using ... (a) ... enzymes, which make staggered cuts in the DNA within specific base sequences. This leaves single-stranded 'sticky ends' at each end. The same enzyme is used to open up a circular loop of bacterial DNA, which acts as a ... (b) ... for the eukaryotic DNA. The complementary sticky ends of the bacterial DNA are joined to the DNA fragment using another enzyme called ... (c) ... . DNA fragments can also be made from ... (d) ...

templates. Reverse transcriptase is used to produce a single strand of complementary DNA and the enzyme DNA polymerase catalyses the formation of a double helix. Finally, new DNA is introduced into host ... (e) ... cells. These can then be cloned on an industrial scale and large amounts of protein harvested. An example of a protein currently manufactured using this technique is ... (f) ... .

- 3 **Explain** why regulator genes often have to be inserted with a functional human gene into the transformed plasmid of a bacterium in order to form the gene product.

### Apply, analyse and interpret

- 4 **Distinguish** between DNA polymerases, restriction enzymes and DNA ligase.
- 5 **Distinguish** between genetically modified organisms and transgenic organisms.
- 6 **Identify** some concerns about genetically modified food. For each state, with reasons, whether or not the concern is scientifically valid.

### Check your obook assess for these additional resources and more:

- |                          |  |                               |
|--------------------------|--|-------------------------------|
| » Student book questions | » Suggested practical 12.2 Bacterial transformations | » Weblink Restriction enzymes |
| Check your learning 12.2 |  |                               |



## 12.3

## Transgenic organisms

## KEY IDEAS

- + Biotechnology – production of pharmaceuticals and use in agriculture

In the description of recombinant DNA, the bacteria carrying the inserted genes are called transgenic, i.e. they contain DNA from another species. Plants and animals can also be transgenic. There are many different types of vectors that can be used to introduce new genes into organisms: plasmids, viruses or gene guns.

Gene guns are used to microinject new genes directly into the fertilised egg cells of animals. So far this has been achieved in mice and farm animals, although the survival rate of the changed eggs is low. If the new genes are injected at an early stage, all the animal's cells will contain the added genes. If the foreign DNA is not taken up until after fertilisation and early cleavage, a mosaic of altered and normal cells results.

Transgenic sheep have been developed, carrying the gene for a human blood clotting factor that is missing in haemophiliacs. This factor is expressed in the ewe's milk when lactating. Australian scientists are working on introducing a gene from *Escherichia coli* into sheep to synthesise cysteine, an amino acid that cannot be naturally produced by sheep and which promotes wool growth.

Because of their tough cellulose walls, it is more difficult to insert foreign genes into plant cells than animal cells. Plant callus tissue (aggregates of cells grown as a tissue culture) can be treated to remove the wall and therefore make plasmid insertion easier.

Many transgenic plants are being trialled in Australia. The soil bacterium *Bacillus thuringiensis* has a gene that produces a toxin to kill budworm. Budworm normally attacks cotton plant buds, preventing the formation of the cotton ball. The transgenic Bt cotton has a copy of this gene for the toxin inserted in its nuclear material, enabling it to control budworm infestation without growers having to resort to chemical pesticides.



**FIGURE 1** Genetically modified cauliflower and broccoli has produced the broccoflower.

Canola plants are grown primarily for the oil that is extracted from their seeds. These plants are susceptible to fungal infestation. When transformed by certain genes from grapes and legumes, these plants are resistant to fungal attack. Other plants are genetically modified to produce higher proteins, different types of proteins or useful chemical products.

## Advantages and disadvantages

Genetically modified (GM) crops are currently grown in 26 nations around the world. Some countries ban farmers from planting crops of genetically modified organisms (GMOs). Countries that ban GM crops received considerable attention in 2015, when the majority of European Union nations decided to block the cultivation of new GM crops within their borders. Regulations in Australia are in place requiring GM food to be labelled – not as a warning but as advice. So far tests suggest that food modified to produce higher quality or different types of proteins (often in the form of enzymes) is safe to eat.

There are fears that the new proteins could cause a toxic or allergic response. Some people already display allergic responses to particular chemicals in certain food plants. They have been able to isolate the foods that contain these chemicals and therefore avoid eating them. If other plants have been genetically engineered to produce these compounds, these foods could inadvertently trigger a severe allergic response in sensitive people. Simply labelling the food as GM may not be an adequate safeguard. The long-term effect of GM plants on the health of consumers has not been ascertained.

Other ethical concerns are related to the source of the transgene. Is it right for vegans to eat plants that have been modified with animal genes? How would religious strictures apply to people of Islamic or Jewish faiths who eat sheep with a pig transgene, or people who practice Hinduism eating chicken with an inserted cow gene?

Contamination of natural crops by GM counterparts may be of greater concern. Small farmers in Mexico grow a large number of different strains of maize (selectively bred over 6500 years). They also keep some of each season's crop to grow in the next planting. In order to prevent contamination, Mexico imposed a ban on growing GM maize in 1998. In spite of this, transgenic Bt maize was found growing among some crops. It was imported from the USA as food and was either deliberately or accidentally planted. Bt maize contains a gene for a bacterial toxin that kills some pests. Because of this attribute it could be competitively superior among the contaminated crops and this could lead to loss of genetic diversity.

While this contamination does not affect the quality of the food source, contamination of food crops by 'pharmed' crops could be dangerous. These are GM crops specifically modified to produce particular substances such as vaccines, human therapeutic proteins and industrial chemicals. In late 2002, for example, it was disclosed that fields of soybeans were contaminated by GM corn in two different locations, probably by seed left over from a previous growing season. Since the pharmaceutical companies will not disclose the exact nature of the transgenic genes to avoid competition with other companies, this type of contamination is very serious. In these cases, the contaminated soybean crop was detected in time and destroyed at an estimated financial loss of nearly US\$3 million. Growing 'pharmed' crops anywhere near food crops is also a potential hazard due to the possibility of cross-pollination.

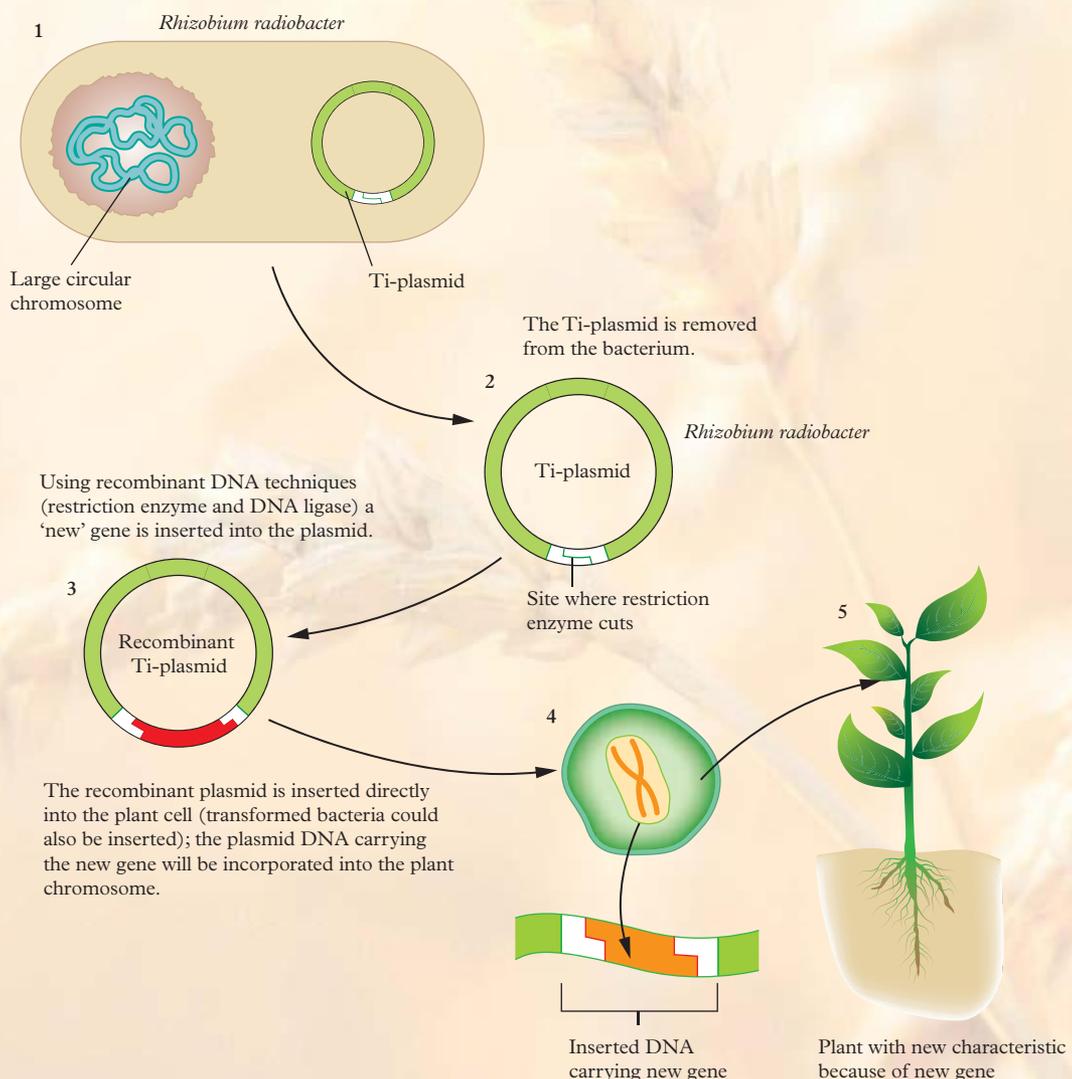
There are ways in which contamination can be prevented. The best method is to only



**FIGURE 2** The pGLO gene was added to these mice when they were undeveloped zygotes.

allow genetic modification for pharmaceutical purposes in non-food plants. Other proposals include that ‘pharmed’ crops be separated in time (to prevent cross-pollination since fertile periods will not coincide) and space (an adequate distance apart) from food crops. This distance, however, is highly speculative. In Australia, for example, it was found that pollen from GM oilseed rape had contaminated fields up to 3 km away. More stringent safeguards also need to be placed on the separation of harvested products.

More recently, scientists have been examining the role of gene drives in eradicating whole populations. Gene drives are an introduced sequence of genes that are continually copied onto new chromosomes so that they are preferentially inherited. This means each new generation will have a much higher percentage of offspring with the new set of genes. Over time, the large number of these genes in each individual will become fatal, killing off large percentages of the population. This mechanism is currently being examined in an effort to control the disease-carrying mosquito population.



**FIGURE 3** Development of a transgenic plant using the Ti-plasmid as a gene vector



**FIGURE 4** The DNA gene gun. DNA-coated pellets are shot under pressure through the wall and membranes and into the nucleus of plant cells.

### CHECK YOUR LEARNING 12.3

#### Describe and explain

- 1 **Describe** a transgenic plant and animal.
- 2 **Compare** the advantages and disadvantages of transgenic organisms.

#### Apply, analyse and interpret

- 3 **Construct** a research question for genetically modified food.

- 4 **Construct** a research question for the development of a transgenic plant.

#### Investigate, evaluate and communicate

- 5 **Research** transgenic animals and **identify** a credible and non-credible resource on this topic.

#### Check your obook assess for these additional resources and more:

» Student book questions  
Check your learning 12.3

» Weblink  
Gene guns

» Weblink  
Genetically modified food



# 12.4

## Polymerase chain reaction (PCR)

### KEY IDEAS

- ✦ Polymerase chain reactions: repeated cycling of denaturation, annealing and elongation
- ✦ Restriction fragment length polymorphisms
- ✦ Gel electrophoresis
- ✦ Comparison of the restriction fragment length polymorphisms

### polymerase chain reaction (PCR)

technique that permits the amplification of any short sequence of DNA

The idea of the **polymerase chain reaction (PCR)** for rapidly making multiple copies of segments of DNA was first conceived in 1983 and was a well-established procedure by 1993, thereby enabling the Human Genome Project.

## Polymerase chain reaction

The reaction exploits the naturally occurring DNA polymerases that are able to copy genetic material. There are three key steps in this process that must be repeated many times.

- 1. Denaturation:** the two strands of DNA are separated by heating to 90–96°C to produce single strands of nucleotide sequences. DNA is synthesised from the 3' end to the 5' end.
- 2. Annealing:** the mixture is cooled to ~52°C (depending on the primer) so that the primers can bind. Primers are short, single strands of nucleotides and must be complementary to the sequences on either side of the DNA to be replicated.
- 3. Elongation:** the mixture is heated to 75°C so that the DNA polymerase (Taq polymerase) is able to produce new strands of DNA.

Note: the temperatures used during each of the above steps are dependent on the type of Taq polymerase and primers used.

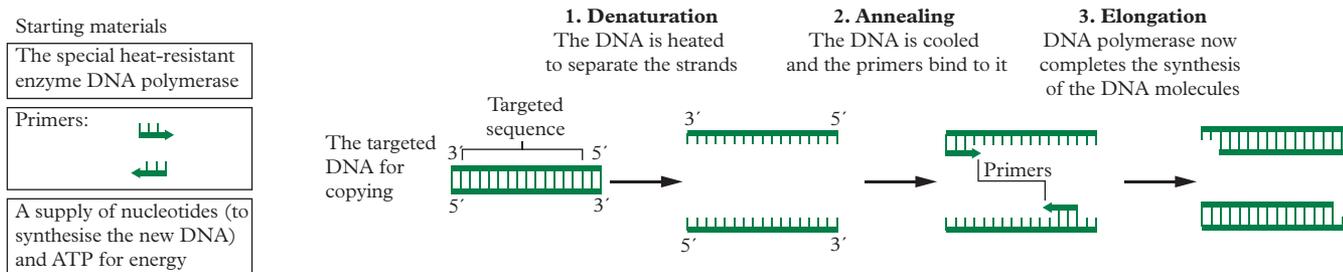


FIGURE 1 The polymerase chain reaction (PCR)

An automated cycle of rapid heating and cooling can take between 1 and 3 minutes, depending on the length of nucleic acid being copied. Each time the cycle is repeated, the amount of DNA will double. Repeating the process for 45 minutes can result in millions of copies of a specific piece of nucleic acid. Most enzymes, which are proteins, are unstable at high temperatures. The polymerase (Taq) used in this process is obtained from the bacterium *Thermus aquaticus*, a **thermophile** that lives in hot springs at temperatures lethal to other organisms. This enzyme is stable at high temperatures and thus ideal for the fluctuating temperatures of automated PCR.

### thermophile

a microorganism that can tolerate temperatures higher than 45°C

## PCR applications

PCR has a variety of applications. It is a significant tool in the detection of infectious diseases and of variations and mutations in genes. Using primers of known DNA sequences, particular types of DNA can be detected. Because a small fragment of DNA can be amplified rapidly, only a very small amount of DNA is required. This means detection of the HIV virus is more rapid after infection because the PCR is looking directly for the virus's DNA, rather than the standard test that looks for indirect evidence through antibody formation. It has been used for the detection of otitis media (a childhood middle ear infection), Lyme disease (a painful joint inflammation caused by bacteria transmitted in tick bites), the presence of the bacterium *Helicobacter pylori* that causes stomach ulcers, and three sexually transmitted diseases (herpes, papilloma viruses and chlamydia) on a single swab.

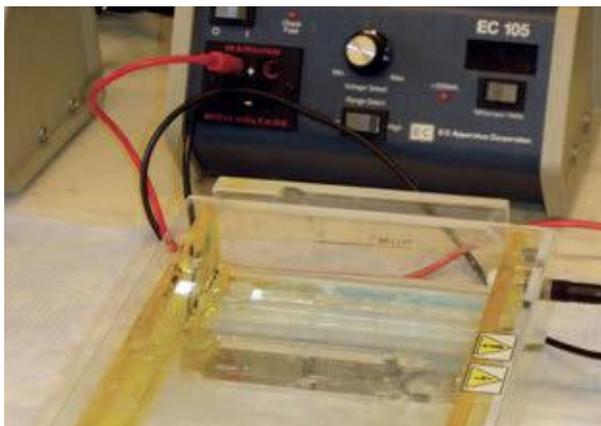
## Gel electrophoresis

The short segments of DNA that have been duplicated via PCR can be used to identify differences between individual organisms via **gel electrophoresis**.

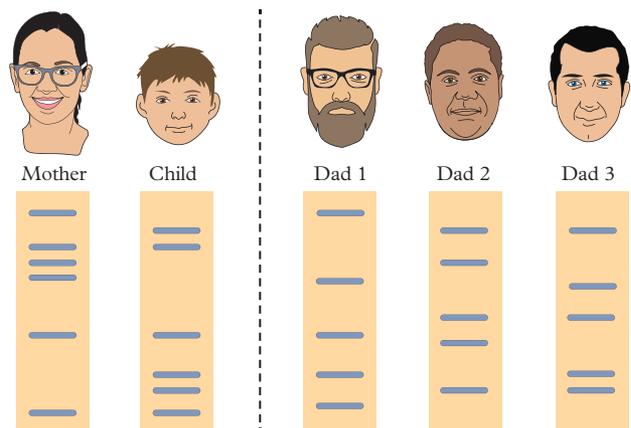
Although the functions of many alleles and genes have been identified, there are many small differences between the alleles on each individual. Many genes have non-coding areas (called introns) that can have single nucleotide repeats (SNRs). The number of repeats will vary from individual to individual and are usually passed on from parents. Therefore, the same allele in different individuals will be slightly different lengths. These differences can be picked up by first cutting the DNA from the two individuals with the same restriction enzyme. Each individual will have different **restriction fragment length polymorphisms (RFLPs)** – different length fragments that result from the single nucleotide repeats. The samples can then be loaded into a thin sheet of gelatinous material (called a gel). The gel contains many tangled fibres and can have an electric current run across it. Because DNA is negatively charged, the sample will move towards the positive terminal. Small pieces of DNA can move through the tangle of gel fibres faster than the longer lengths of DNA. This means short strands of DNA travel faster and further than the long DNA strands. Staining of the DNA enables the segments of DNA to be identified. Typically, a series of specifically measured segments of DNA (called a DNA ladder) is added to an additional well, enabling the length of the DNA strands to be measured. The different genes can be visualised, and measured against the DNA ladder, under ultraviolet (UV) light.

**gel electrophoresis**  
a laboratory method for separating mixtures of DNA, RNA or proteins according to molecular size

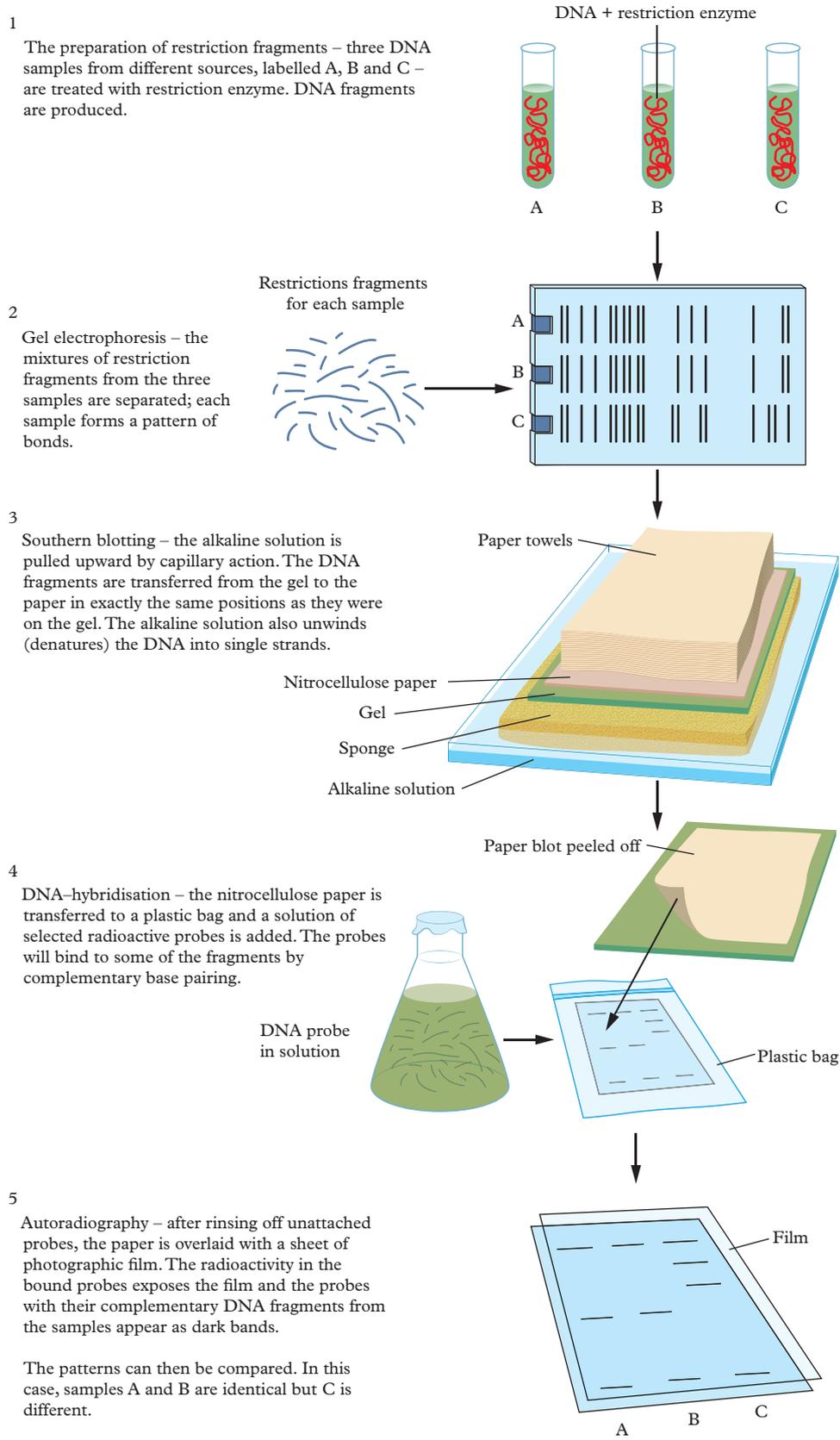
**restriction fragment length polymorphisms (RFLPs)**  
different length fragments of DNA that result from the single nucleotide repeats



**FIGURE 2** A gel electrophoresis box separates strands of DNA based on their length. The negatively-charged DNA travels towards the positive end of the gel (red electrical ports).



**FIGURE 3** Each individual inherits half their chromosomes from their mother and half from their father. In this example 'Dad 3' has provided half the genetic material of the child.



**FIGURE 4** The steps in genetic fingerprinting

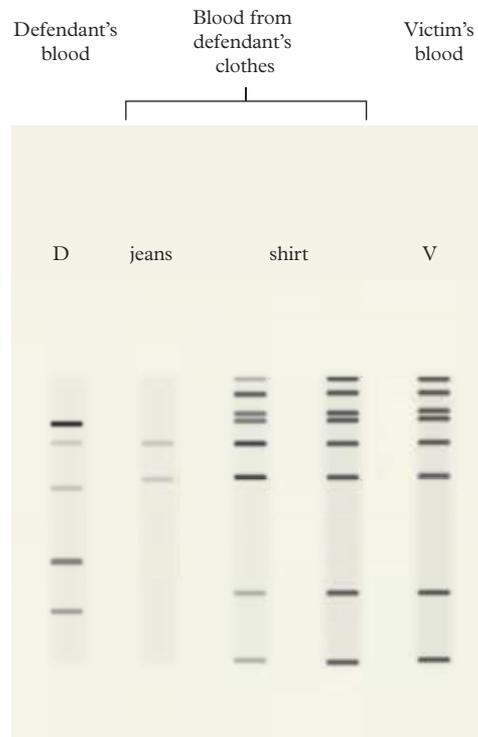
# DNA probes

DNA probes are used to identify the correct location of a gene on a chromosome (or a gel). A probe is a small section of DNA that is complementary to a sequence on the needed gene. This probe has a dye (either fluorescent or radioactive) attached. When the probe is combined with the single-stranded DNA (hybridised), the probe binds to that short section of DNA in the gene, allowing the location to be identified and isolated.

## DNA profiling

PCR and gel electrophoresis are important parts of forensic DNA typing that is commonly called **DNA profiling (fingerprinting)**.

It involves taking a DNA sample from a crime scene and using PCR to increase the size of the sample so that it can be used for gel electrophoresis. This is followed by Southern blotting, **DNA-hybridisation** and autoradiography (see Figure 4 to the left). This crime scene sample of DNA is then compared to that of a suspect. If all the restriction fragment length polymorphisms are matched, then it can act as evidence that the suspect has visited the crime location. It cannot, however, identify when the visit was made.



**FIGURE 5** A DNA profile output. This DNA profile (fingerprint) shows that the blood on the defendant's clothes is that of the victim (V) and not the defendant (D).

**DNA profiling (fingerprinting)** a technique used to identify (as for forensic purposes) the characteristics of an individual's DNA by extracting and identifying the base-pair pattern of their DNA

**DNA-hybridisation** a technique that measures the degree of genetic similarity between DNA sequences of different individuals

## CHECK YOUR LEARNING 12.4

### Describe and explain

- 1 Briefly **describe** the key steps in the polymerase chain reaction process.
- 2 **Explain** why PCR has increased the rate at which gene location and function can be determined.
- 3 **Describe** different applications of PCR.

4 **Explain** the term 'DNA profiling'.

5 **Define** the following terms:

- a restriction fragment length polymorphisms
- b gel electrophoresis
- c hybridisation
- d DNA-hybridisation.

### Check your **obook assess** for these additional resources and more:

» Student book questions

Check your learning 12.4

» Suggested practical 12.4

Gel electrophoresis

» Weblink

PCR

» Weblink

Gel electrophoresis

# 12.5

## DNA sequencing

### KEY IDEAS

- + The Sanger sequencing method
- + Bioinformatics

### genome

the complete set of nucleotide sequences encoded in the total DNA of an organism

In order for genetic engineering to be effective, the recombinant DNA must contain known genes. Since the manipulation of disease-causing alleles in humans is now a possibility, the need to identify and locate these genes on their chromosomes has become a priority. The complete 'map' of the DNA nucleotide sequencing of an organism is called its **genome**.

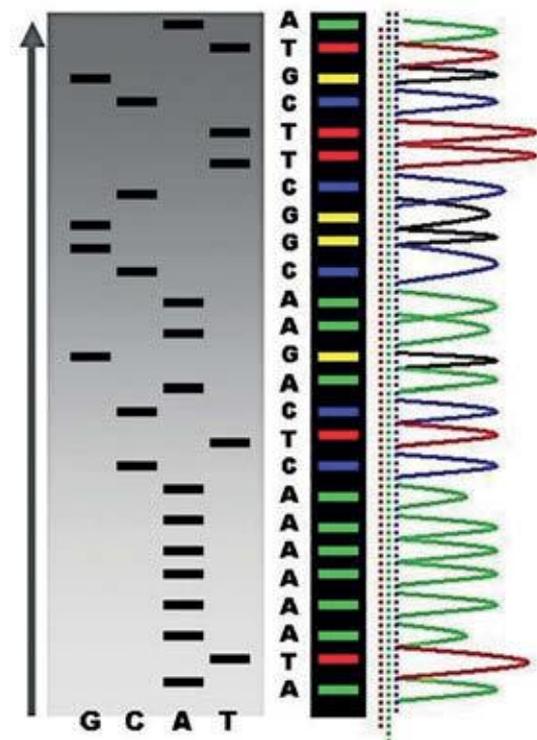
## DNA sequencing

DNA sequencing involves determining the precise sequence of the individual nucleotides of an individual. The technology behind DNA sequencing has gone through a series of changes in the last 10 years to decrease both the time and cost of the procedure.

### Sanger sequencing method

The Sanger method was the first of the DNA sequencing methods that was automated. Strands of DNA are cut by restriction enzymes to produce short sections. The DNA is placed into four tubes, each containing an appropriate DNA primer, the four different nucleotides and DNA polymerase. Each tube also contains a different di-deoxynucleotide

(dd-adenine, dd-guanine, dd-cytosine, dd-thymine). These nucleotides occasionally bind to the new strands of DNA that are generated by the template DNA. When the di-deoxynucleotides bind, it terminates the sequence. As an example, in a tube containing dd-adenine, multiple sequences of DNA terminate randomly when the dd-adenine is used, resulting in different lengths of DNA. Each strand is an indication of the location of the thymine on the original DNA strand. This is repeated in each of the other three tubes, each with sequences terminating at a different nucleotide. When the contents of each tube are separated in gel electrophoresis, the sequence of the nucleotides can be read from the bottom of the gel. Most laboratories now use computer programs to read the gel data.



**FIGURE 1** The sequencing of DNA enables random mutations associated with genetic diseases to be identified.

### bioinformatics

biological studies that use computer programming to assist with the collection, classification, storage and analysis of biochemical and biological information

### Bioinformatics

**Bioinformatics** is an interdisciplinary scientific field (biology, computer science, mathematics and engineering) that

develops methods and software tools to analyse the relationships within biological data. The development of supercomputers enabled massive sequences of nucleotides to be compared between individuals and species.

This is accomplished by comparing the new sequence with sequences that have already been reported and stored in a database. **Basic Local Alignment Search Tool (BLAST)** is a computer program that compares nucleotide or protein sequences to sequence databases and calculates the statistical significance of their matches.

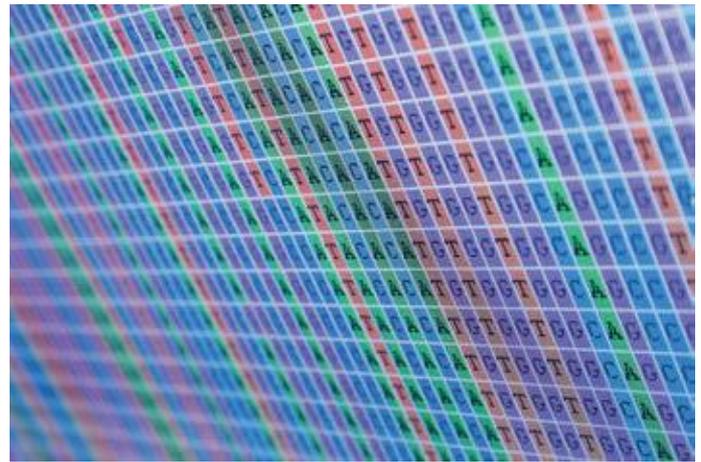
Different types of BLAST programs (QIIME, mothur, etc.) are available according to the sequences under investigation. For example, following the discovery of a previously unknown gene in a mouse, a scientist will typically perform a BLAST search of the human genome to see whether humans carry a similar gene. BLAST will identify sequences in the human genome that resemble the mouse gene based on similarity of sequence.

This powerful system can be used to:

- identify species or find homologous species, for example when working with a DNA sequence from an unknown species
- determine the domain or distinct functional and/or structural units in a protein using a protein sequence
- generate phylogenetic trees
- determine the chromosomal position of a particular DNA sequence (e.g. of an unknown species)
- compare chromosomal positions of common genes in two related species.

### BLAST (Basic Local Alignment Search Tool)

a computer program that compares unknown DNA or protein sequences with those of known sequences



**FIGURE 2** DNA bases are aligned in BLAST to identify the similarity genes have to each other.

## CHECK YOUR LEARNING 12.5

### Describe and explain

- 1 **Explain** why the sequencing of DNA nucleotides and the identification of genes is important.

### Apply, analyse and interpret

- 2 **Determine** why bioinformatics is a substantially more efficient method of analysing DNA sequences.

### Investigate, evaluate and communicate

- 3 A biologist working in the Daintree rainforest found a new species of orchid. **Discuss** techniques that could be employed to help classify this plant and place it in a phylogenetic tree.
- 4 **Discuss** why BLAST is a useful tool for all biologists.

### Check your obook assess for these additional resources and more:

» Student book questions  
Check your learning 12.5

» Weblink  
Sanger sequencing

» Weblink  
BLAST



## 12.6

# The Human Genome Project

**KEY IDEAS**

- ✦ The Human Genome Project

## The Human Genome Project

In 1985 the Human Genome Project (HGP) was conceived in the USA. The project began in 1989 and was scheduled to last for 15 years, with total funding of US\$3 billion. Its aim was to map and analyse the nucleotide sequences of each of the 100 000 human genes. In 1990 it became a collaborative international project. In 1998 a milestone was passed, with the total mapping of one human chromosome. The project also aimed to examine the social, ethical and legal implications of the research. Genomic libraries, where thousands of clones prepared from plants and animals are stored, have now been established.

The HGP was a multi-institutional project. One group, for example, studied Mormon families (which are generally large) over three generations, and focused on gene mapping using recombinants. Another group mapped gene locations with gene markers, and another used recombinant DNA techniques. Yet other groups directed their efforts towards determining the nucleotide sequencing of specific genes that have been located.

By 2000 a working draft of 90% of the human genome was published, identifying 22 000 potential genes, and screening was made available for 300 genetic diseases. These genetic diseases include the cystic fibrosis gene, adenosine deaminase deficiency, retinitis pigmentosa, severe combined immune deficiency, Duchenne muscular dystrophy, neurofibromatosis and retinoblastoma. In May 2003 the HGP was completed with 99% of gene-containing regions sequenced to 99.99% accuracy. These sequences provide a valuable reference for future medical and human biology research, comprising 3 billion nucleotide sequences.

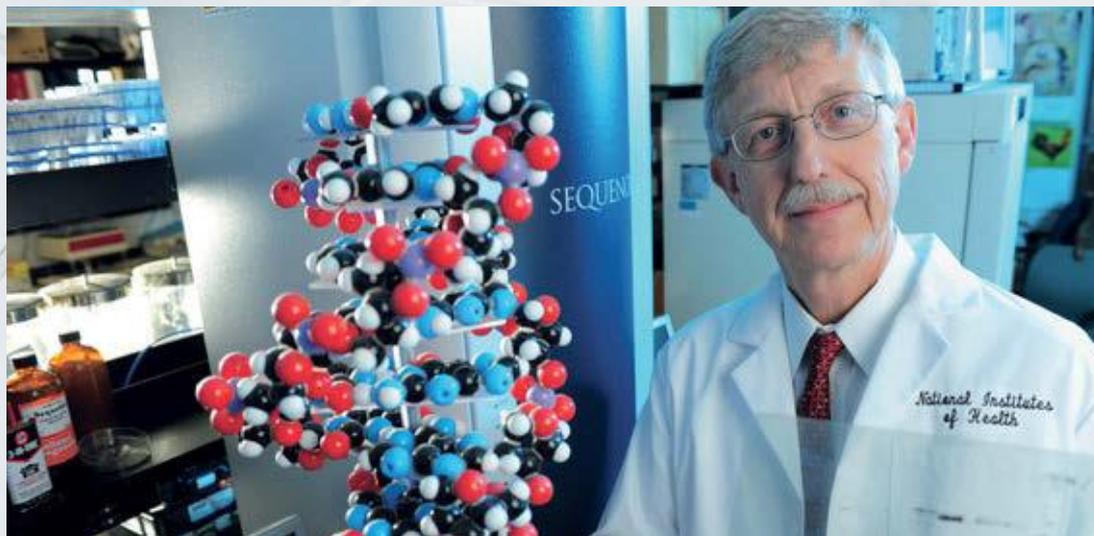


FIGURE 1 Dr Francis Collins led the Human Genome Project.

This research aimed to determine the possible allelic forms found in humans in general, as well as individual genome data. The possible determination of personal genomes raises many issues, particularly that of confidentiality. Some of the issues raised by the project include the following:

- Should employers be permitted to discriminate on the basis of predisposition for later onset of a disabling disease?
- Should this information be available to insurance companies?  
Should non-disclosure of a known possible effect be grounds for invalidation of an insurance policy?
- Who should have access to personal genome data?
- Is it beneficial to patients if a disease is diagnosed for which there is presently no known cure?
- Which genetic disorders should receive funding priorities to find effective treatments?
- Do individuals who have a family history of a genetic disease have an obligation to undergo genetic testing?
- Can courts order reluctant family members to undergo genetic testing?
- To what extent should public policy recognise intellectual property rights such as patents, copyrights and trade secrets of researchers?
- Should scientists withhold results of their work from the rest of the scientific community in order to sell their research to private companies for personal gain?
- Does an organisation, funded by public funding, have the right to patent research techniques or copyright their findings?

It is vital that questions such as these are addressed, in order to safeguard the results of this important research against misuse by individuals, groups or governments.

Since the completion of the HGP, the sequencing of the genomes of other organisms has also been undertaken on organisms used extensively in biological research, such as mice, fruit flies and flatworms. Since most organisms have many similar genes (homologous) with similar functions, the identification of the sequence or function in a research animal has the potential to explain a homologous gene in another organism.

## CHECK YOUR LEARNING 12.6

### Describe and explain

- 1 **Describe** the aims of the Human Genome Project.

### Apply, analyse and interpret

- 2 **Construct** a research question on the Human Genome Project.

Check your **obook assess** for these additional resources and more:

» Student book questions  
Check your learning 12.6

» Weblink  
The Human Genome Project

» Weblink  
Ethics



# Review

## Chapter summary

- 12.1** • Biotechnology is the exploitation of biological processes for the use of humans.
- 12.2** • Genetically modified organisms (GMOs) have had their DNA modified.
  - Transgenic organisms have a gene from another organism inserted into their DNA.
  - Recombinant DNA involves the joining together of DNA from two different sources.
  - A variety of enzymes (including restriction enzymes, reverse transcriptase, DNA polymerase and DNA ligase) are used to produce transgenic organisms.
  - Gene cloning can be used to amplify DNA.
- 12.3** • Biotechnology has the potential to advance the production of pharmaceuticals and agriculture.
- 12.4** • Polymerase chain reactions amplify the amount of DNA by repeated cycling of denaturation, annealing and elongation.
  - Different numbers of trinucleotide repeats result in restriction fragment length polymorphisms.
  - Gel electrophoresis uses an electrical current to separate strands of DNA on the basis of size.
  - Comparison of the restriction fragment length polymorphisms between two individuals allows DNA profiling to identify an individual person.
- 12.5** • The Sanger sequencing method of DNA sequencing was one of the first to be automated.
  - Bioinformatics is an interdisciplinary field that develops computerised methods to analyse the relationships in biological data.
- 12.6** • The Human Genome Project was an international collaborative project to sequence the nucleotides in the human genome.

## Key terms

- artificial selection
- bioinformatics
- biotechnology
- BLAST
- cloning
- DNA hybridisation
- DNA ligase
- DNA polymerase
- DNA profiling
- DNA scissors
- gel electrophoresis
- gene cloning
- gene therapy
- genetically modified organism (GMO)
- genome
- germ cell gene therapy
- plasmid
- polymerase chain reaction (PCR)
- recombinant DNA (= genetic engineering)
- regulator gene
- restriction enzyme (nuclease)
- restriction fragment length polymorphisms (RFLPs)
- reverse transcriptase
- reverse transcription
- somatic cell nuclear transfer
- somatic gene therapy
- sticky ends
- thermophile
- transgenic organism
- vector

## Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number:

\* = low; \*\* = medium; \*\*\* = high.

### Multiple choice

- The use or alteration of cells or biochemicals to provide a useful product is known as:  
**A** transgenesis  
**B** genetic modification technology  
**C** biotechnology  
**D** gene targeting
- Manufacturing recombinant DNA molecules involves cutting a gene from its normal location, inserting it into a circular piece of DNA from a bacterial cell, and then transferring it to cells of another species. Which of the tools below is used to cut the gene from its normal location?  
**A** restriction enzyme  
**B** plasmid  
**C** DNA ligase  
**D** vector
- Genetic engineering manipulates gene products at the level of the:  
**A** protein  
**B** amino acids  
**C** DNA  
**D** RNA
- Restriction endonucleases are most widely used in recombinant DNA technology. They are obtained from:  
**A** yeasts  
**B** bacterial cells  
**C** plasmids  
**D** all prokaryotic cells
- Which one of the following base sequences in DNA can be easily cut at about the middle by some particular restriction enzyme?  
**A** 5' CACGTA 3'; 3' CTCAGT 5'  
**B** 5' CGTTTCG 3'; 3' ATGGTA 5'  
**C** 5' GATATG 3'; 3' CTAATA 5'  
**D** 5' GAATTC 3'; 3' CTTAAG 5'
- The linking of an antibiotic resistance gene into a plasmid vector uses:  
**A** DNA ligase  
**B** exonucleases  
**C** endonucleases  
**D** DNA polymerase
- A nucleic acid segment tagged with a radioactive molecule is called a:  
**A** plasmid  
**B** probe  
**C** clone  
**D** vector
- Which of the following statements is true regarding DNA polymerase used in PCR?  
**A** It is isolated from a virus.  
**B** It remains active at high temperatures.  
**C** It is used to ligate introduced DNA in recipient cells.  
**D** It serves as a selectable marker.
- Gel electrophoresis is used for:  
**A** construction of recombinant DNA by joining cloning vectors  
**B** cutting DNA into fragments  
**C** isolation of DNA molecules  
**D** separation of DNA fragments according to their size

**Short answer**

**Describe and explain**

- ★ 10 Briefly **describe** the processes involved in producing recombinant DNA.
- ★ 11 **Explain** why gene probes are an important feature of DNA technology.
- ★ 12 **Describe** the purpose of genetic screening.
- ★★ 13 The figure below represents the DNA fingerprint of a girl (A), her parents, her sister and a number of other individuals, two of whom are brothers and are unrelated to the first family. Any band present in the DNA fingerprint of a child must also be present in at least one of the parents.

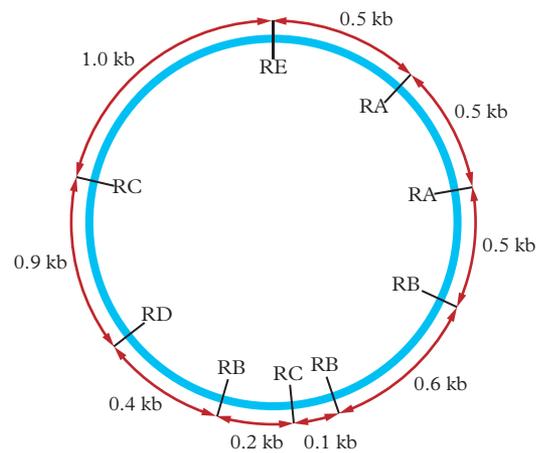


**Identify:**

- a the parents of the girl (A)
- b the girl's sister.

**Apply, analyse and interpret**

- ★★ 14 A scientist wanted to cut a bacterial plasmid into five pieces, each of a particular base length (kilobase = kb). She had five restriction nucleases available (RA, RB, RC, RD and RE). The following diagram shows how a plasmid 4.7 kb in length can be cut by these five restriction enzymes.



**Analyse** the data to determine which three enzymes she could use to obtain the five pieces of DNA of 1.5 kb, 1.2 kb, 0.9 kb, 0.6 kb and 0.5 kb in length. **Explain** your answer.

- ★★★ 15 In the following genetic profiles 1 and 2, each letter represents a gene. The upper-case and lower-case letters represent the different alleles of the gene. A slash (/) indicates the end of a chromosome. This data therefore represents genes found on three chromosomes.

Profile 1	
Paternal genes	I S C P M B h/l v b c c/Mi P P v S
Maternal genes	I S c p M B H/I V b c c/MI P P v S
Profile 2	
Paternal genes	I S c p M B h/I V B c c/MI p p V s
Maternal genes	I S c P m B h/I V B c c/ml P p V s

The potential traits exhibited by particular genotypes for these alleles are given in the following table.

Symbol	Potential trait
S	Spatial perception (2 genes, each with 2 alleles) 3–4 S = excellent, 1–2 S = good, 0 S = fair
I	Interpersonal skills (3 genes, each with 2 alleles) 4–6 I = excellent, 2–3 I = good, 0–1 I = fair

Symbol	Potential trait
M	Maths ability (2 genes, each with 2 alleles) 3–4 M = high, 1–2 M = average, 0 M = fair
V	Verbal skills (2 genes, each with 2 alleles) 3–4 V = excellent, 1–2 V = good, 0 V = fair
C	Creativity (3 genes, each with 2 alleles) 4–6 C = fair, 2–3 C = average, 0–1 C = high
B	Body build (2 genes, each with 2 alleles) 3–4 B = light, 1–2 B = average, 0 B = heavy
P	Predisposition to heart disease (3 genes, each with 2 alleles) 4–6 P = low, 2–3 P = moderate, 0–1 P = high
H	Gene for unknown trait (1 gene with 2 alleles) H/H = +, H/h = +, h/h = –

- a Determine** the genotypes and potential phenotypes for each of the two individuals.
- b Use** the potential phenotypes to suggest both a likely and an unsuitable career for each individual. Possible careers could be artist, athlete, carpenter, pilot, firefighter, scientist or teacher, but your answer is not restricted to this list. **Consider** reasons for each suggestion based on the profile.
- c Analyse** the rationale behind using the term ‘potential phenotypes’ for these genes.
- d In the future**, corporations may be tempted to base their recruitment only on genetic profiles. **Interpret** the validity of such a policy.

#### Investigate, evaluate and communicate

- ★ **16 Discuss** the advantages of modern DNA technologies in terms of increasing the speed of improvement to human life.

★★★ **17** Mammalian cloning studies have found that the recipient oocyte does not have to be the same species as the donor cell in nuclear transfer techniques. This suggests that the functional genes of the mitochondrial DNA are similar in mammalian cells. Since cow oocytes are large and easily extracted, they have been used to clone several different types of mammals and could well be used for human cloning.

**a Discuss** the ethical issues involved in using cow oocytes in human cloning.

**b Describe** how you would feel if you found out that your great-grandmother had mtDNA genes from a cow.

★★★ **18** A sheep farmer, wishing to increase the efficiency of fat lamb production, decided to develop a flock of ewes, all of whom only produced twins. Each season he culled all ewes and their offspring that had single births. A similar flock could have been produced by cloning techniques. **Hypothesise** which of the two methods (selective breeding or cloning) is most effective. **Justify** your answer.

★★★ **19** The Jack Russell terrier is a small dog that has only recently been recognised as a pure-breeding variety and thus granted pedigree status. **Investigate** the origins of this breed, the desired characteristics and the processes undertaken to achieve pedigree status.

★★★ **20 Examine** a current genetic biotechnology technique. **Analyse** the data from the published outcomes to determine the success rate. Present an argument that supports or refutes the continued expenditure of research funding on the project.

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» Revision notes  
Chapter 12

» assess quiz  
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Chapter 12 glossary



# The concept of evolution

Based on the theories of Darwin and Wallace, evolution (neo-Darwinism) uses the current understanding of genetics, molecular biology and other scientific disciplines to explain the changes in organisms over time. This evolution can be seen at the micro (selection of particular alleles in a species or population) or macro (diverging species or taxa over time) level.

A study of the geological timeline of life on Earth has shown the continuous emergence and extinction of different species. At various times, associated with climate change, there have been periods of catastrophic mass extinctions followed by a period of evolutionary radiation.

## OBJECTIVES

- Define the terms evolution, microevolution and macroevolution.
- Determine episodes of evolutionary radiation and mass extinctions from an evolutionary timescale of life on Earth (approximately 3.5 billion years).
- Interpret data (i.e. degree of DNA similarity) to reveal phylogenetic relationships with an understanding that comparative genomics involves the comparison of genomic features to provide evidence for the theory of evolution.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

**FIGURE 1** Catastrophic events, such as meteorite impacts to Earth, can cause large mass extinctions of species.



# 13.1

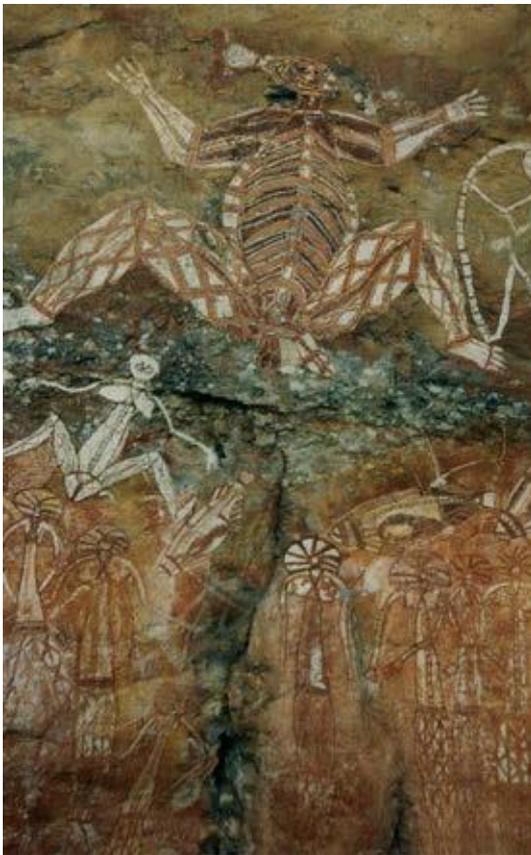
## The development of the theory of evolution

### KEY IDEAS

- ✦ The theory of evolution as a result of natural selection
- ✦ Neo-Darwinism

### Towards a theory of evolution

Over the years many attempts have been made to explain the origins of living organisms and their great diversity. Most of these explanations have been linked to a religious or philosophical doctrine, and feature some form of creator. The Dreamtime is the Aboriginal peoples' understanding of the world and its creation. In Western civilisation, the creation stories are from the Old Testament book of Genesis. It is based on the precept that all the species on Earth were created separately within six days, and the numerous descendants survived through time in their created form.



**FIGURE 1** Aboriginal art in Arnhem Land depicting a part of their creation story

Another philosophy was that of spontaneous generation: that different species of organisms spontaneously formed from non-living material. This idea originated with Aristotle. Although waning in popularity with the growth of Christianity, it was still accepted by many until Redi (1688) was able to show that life can arise only from pre-existing life (biogenesis). However, it was not until 1860, when Pasteur validated biogenesis in controlled experiments, that the theory of spontaneous generation was finally dispelled.

A number of early Greek philosophers proposed the concept of gradual changes in life forms.

- Heraclitus (480 BCE) recognised that everything is transposed into new shapes.
- Aristotle (384–322 BCE) stated that there was a natural progression from plants to plant–animals to animals, finally leading to humans.
- Thales, in 6 BCE, suggested that life began in the sea.

No scientifically sound processes for such changes, however, were proposed. The Judeo–Christian view of creation became firmly embedded in Western thought and although naturalists noted variations within closely related species, they used this as evidence that a creator had designed every species for a particular purpose. Even Linnaeus in the eighteenth century did not attribute any evolutionary kinship between taxa since he believed that species were permanent creations.

In 1809 Lamarck proposed a hypothesis to explain the mechanism of evolution based on the inheritance of acquired characteristics (**Lamarck's theory of evolution**). He suggested that parts of an organism that were used often would increase in size in the next generation whereas others would decrease in size or strength. His ideas were disproven when 20 generations of removing a mouse tail did not prevent the offspring growing tails. It was not until Darwin published *On the Origin of Species by Means of Natural Selection* in 1859 that a comprehensive theory of biological evolution was established. This was supported by evidence from an eight-year study in the Malay Archipelago by Wallace.

### Lamarck's theory of evolution

the hypothesis that an organism can pass on characteristics acquired during its lifetime to its offspring

## Natural selection

Influenced by Malthus's study of the reproductive potential of the human species (which stated that any growing population will eventually run out of resources), and observations of living organisms in various parts of the world, both Darwin and Wallace came to a similar conclusion: natural selection was the basis for evolution.

**Darwin's theory** was based on the following observations and considerable follow-up experimentation:

- Individuals within a population have a great reproductive potential.
- The numbers of individuals in a population remain approximately constant.

'Many individuals fail to reproduce. There is a 'struggle for existence' within a population.'

Charles Darwin

- Variation exists within all populations.

'In the 'struggle for existence', those individuals showing variations best adapted for their environment at that particular time have a 'reproductive advantage' and produce more offspring than less well adapted individuals.'

Charles Darwin

- Over many generations new variations gradually accumulate, possibly resulting in new species.

In this natural selection of the fittest, the variation already exists within the population. Environmental pressures 'select for' the best-suited individuals in the population. The individuals that have the phenotypes best adapted to the environment are more likely to survive and produce offspring. Individuals that have phenotypes that are poorly adapted to the environment are 'selected against' and often die. This mechanism of natural selection leads to increased vigour within the species and ensures its survival.

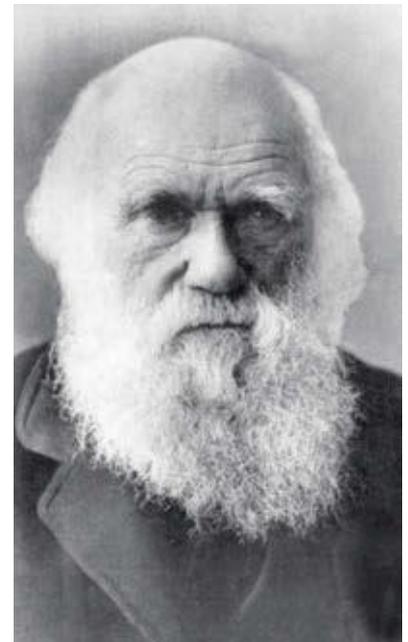


FIGURE 2 Charles Darwin

### Darwin's theory of evolution

theory that all species of organisms arise and develop through the natural selection of small, inherited variations that increase the individual's ability to compete, survive and reproduce

## Neo-Darwinism

The theory of natural selection has been extended and elaborated as a result of contemporary evidence from genetics, molecular biology, palaeontology, ecology and ethology (see Chapter 2). The theory of biological evolution is a unifying theory that attempts to provide an explanation of the changes that have occurred over time, based on scientific evidence. According to this

### neo-Darwinian theory of evolution

theory that species evolve by natural selection acting on genetic variation

### microevolution

a change in gene frequency within a population over a succession of generations

### macroevolution

major evolutionary change at or above the level of species over geological time

### punctuated evolution

theory of evolution in which a lot of evolutionary changes take place in short periods of time, often tied to speciation events such as environmental factors

theory, all organisms have developed from pre-existing organisms and so have a common origin. Over billions of years of change in many different directions, this has resulted in the immense variety of organisms that are seen in the fossil records and that presently exist.

**Neo-Darwinian** evolutionary theory is now defined as the change in the genetic composition of a population during successive generations, which may result in the development of a new species. It can refer to both the results and the process of evolution. This means:

- Organisms produce far more offspring than can possibly survive.
- Organisms have a variety of phenotypes.
- Many variations within an organism are controlled by genes.
- Natural selection keeps species adapted to their environment.
- New species may arise by isolation of populations with different selection pressures.

Evolutionary studies tend to focus on all the different variations of genes in a population (the gene pool). Thus, **microevolution** is the study of small-scale variations in gene frequency within a species or population, in which the descendent is of the same taxonomic group as the ancestor. Conversely, **macroevolution** is the study of the variation of allele frequencies at or above the level of species over geological time. These variations result in the divergence of taxonomic groups, in which the descendent is in a different taxonomic group to the ancestor.

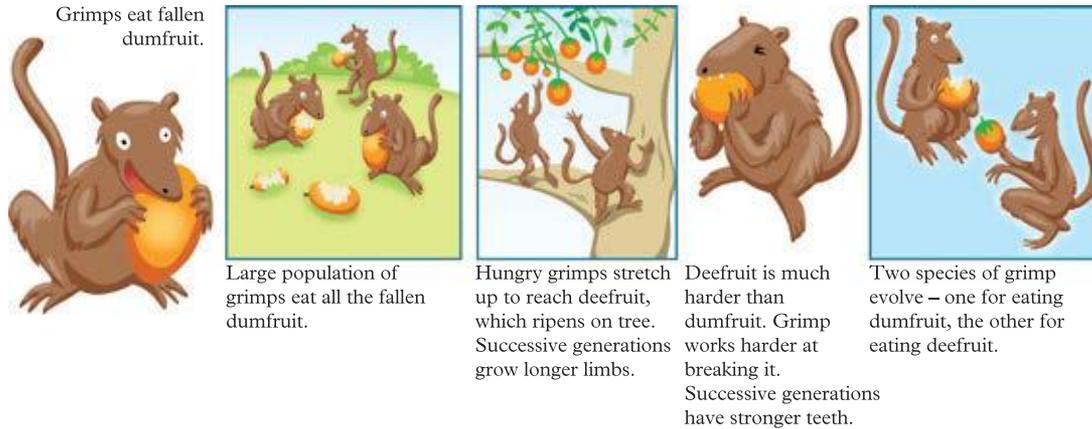
Most evolutionary studies still suggest a gradual change in populations over time, but there is some evidence that occasionally these changes may be dramatic. Such change may result from the mutation of a single gene, as seen for the axolotl. This amphibian is a descendant of a salamander, which undergoes metamorphosis from an aquatic juvenile to a terrestrial adult form. The evolution of the axolotl resulted from a single mutation that impeded the normal development of the thyroid gland. The hormone thyroxine, necessary for change from juvenile to adult form, was not produced. The axolotl remained aquatic. It is probable that this single change spread through a single population of the ancestral species.

Evolution as a result of a single gene mutation is uncommon, unless the gene is a master gene. Master genes are in control of many regulatory genes. A mutation in the master gene will change the way an organism develops. This can result in a change in the number of legs (centipede), the shape of a tail (scorpion) or the formation of pincers (spider). Natural selection may then favour this variation, selecting the organism and changing the population. This theory, known as **stepped** or **punctuated evolution**, proposes a relatively rapid change in population traits and could explain why sometimes there are no intermediate stages in the fossil records between two closely related species.



**FIGURE 3** (a) axolotl; (b) salamander

### A Lamarckian tale



Grimps eat fallen dumfruit.



Large population of grimps eat all the fallen dumfruit.



Hungry grimps stretch up to reach deefruit, which ripens on tree. Successive generations grow longer limbs.

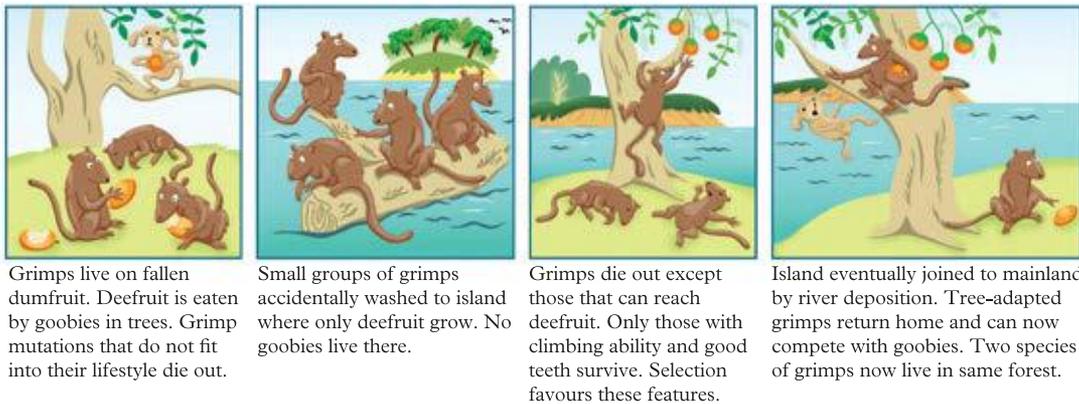


Deefruit is much harder than dumfruit. Grimp works harder at breaking it. Successive generations have stronger teeth.



Two species of grimp evolve – one for eating dumfruit, the other for eating deefruit.

### A Darwinian tale



Grimps live on fallen dumfruit. Deefruit is eaten by goobies in trees. Grimp mutations that do not fit into their lifestyle die out.

Small groups of grimps accidentally washed to island where only deefruit grow. No goobies live there.

Grimps die out except those that can reach deefruit. Only those with climbing ability and good teeth survive. Selection favours these features.

Island eventually joined to mainland by river deposition. Tree-adapted grimps return home and can now compete with goobies. Two species of grimps now live in same forest.

FIGURE 4 Two evolutionary tales

## CHECK YOUR LEARNING 13.1

### Describe and explain

- 1 **Describe** what is meant by biological evolution.
- 2 **Describe** what the theory of natural selection attempts to explain.
- 3 **Describe** the three main observations or ideas on which the theory of natural selection is based.
- 4 According to Neo-Darwinism, **explain** how the sources of variation arise.

### Apply, analyse and interpret

- 5 The largest antler span of any living animal belongs to a species of moose. The male's antlers have a span of about 300 cm.

- a **Determine** how Lamarck might have explained the enormous antlers present in this species.
  - b **Determine** how Darwin might have explained them.
- 6 Darwin recognised the existence of variation and the fact that variations are inherited. However, he knew nothing about genetics. **Determine** how the following support his theory.
    - a Knowledge of the inheritance of characteristics
    - b Events of mitosis, meiosis and fertilisation
    - c Mutation and crossing over of chromatids
    - d The role of DNA.

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Natural selection

» Weblink

Neo-Darwinism

# 13.2

## History of life on Earth

### KEY IDEAS

- + Fossil evidence supports evolution
- + Absolute dating (radiometric dating)
- + Relative dating
- + Eras, periods and epochs
- + Index fossils

There is a large body of evidence that supports the theory of evolution. This includes the patterns of geographic distribution of plants and animals (biogeographic evidence), and comparison of similar molecules or anatomy between organisms. Studies of living species, however, can only give a glimpse of shared common ancestors. Fossils (preserved traces or remains of an organism), and ageing techniques are able to provide evidence of the evolutionary timescale.

### Fossils

The term fossil is a broad umbrella term that covers the preserved remains of organisms, or traces such as footprints, coprolites (fossilised faeces) or impressions.

Since few fossils can survive the high temperatures at which igneous and metamorphic rocks form, almost all fossils are found in sedimentary rock. The structures that are most likely to form fossils are 'hard' shells, bones, teeth, woody tissues and leaves. In all cases, the formation of fossils requires quick burial, and a lack of oxygen and/or predators that might disturb the remains.

Fossils originate when organisms become encased in sand or mud sediments, usually at the bottoms of seas, lakes and marshes. New layers of sediment cover the older layers, sealing the traces or remains. Dissolved minerals wash through the fossils, precipitating minerals in the gaps between the tissues to form a rock-like structure. At a much later time, these sedimentary rocks may become exposed and affected by erosion.

### Principle of rock succession

The fossil record shows that there has been a succession of different life forms on Earth. Over time, new fossils form on top of previous fossils. This means that the deeper the fossils are found in the Earth, the older the fossil is thought to be. In this way, the **relative age** of the fossils can be determined.

Fossils that are found in the more ancient, deep strata tend to be less complex in structure than the younger, upper strata fossils. Each strata of rocks has quite unique fossil assemblages. Fossils from the lower, older strata from different parts of the world contain similar types of organisms.

#### relative age

an expression of the geologic age of a fossil organism, rock, geologic feature or event, relative to other organisms, rocks, features or events without expressing absolute age



**FIGURE 1** Fossilised starfish from Australia dated to the Silurian period.

Occasionally some fossilised species completely disappear from the upper levels or rock. As a result, palaeontologists devised methods of identifying systems of rocks that contain similar fossil forms (**index fossils**). A segment of an exposed stratified rock face that is characterised by particular species of index fossils is termed a zone, the lower boundary is the level at which the fossils first appear and the upper boundary is the level at which they disappear. In this way the order of geological events is able to be determined.

**index fossil**  
a distinctive, abundant fossil with a wide geographic distribution over a relatively short geological period of time



**FIGURE 2** This *Tyrannosaurus rex* fossil is well-preserved with the teeth and bones remaining.

## Absolute age

The atmosphere surrounding the Earth is constantly being bombarded by cosmic rays. This causes some atoms to form **isotopes** (variations of an element that differ in their number of neutrons within their nuclei). Although they have the same atomic number (number of protons), their atomic masses differ (protons + neutrons). Some isotopes are radioactive (e.g. carbon 14) whereas others are stable (e.g. carbon 12). While an organism is alive, the number of radioactive isotopes present in their body remains constant. However, once an organism dies, the mass of isotopes will start to decrease. The radioactive isotopes start to spontaneously change into a more stable form (decay). How fast this happens is called the rate of decay. The length of time it takes for half the remaining isotope to become stable is called its **half-life**. For example, 1 kg of carbon 14 will take 5730 years for half (0.5 kg) to become stable. After another 5730 years, half the remaining mass of carbon 14 (0.25 kg) becomes stable. This means after 11 460 years, only  $\frac{1}{4}$  of the original radioactive carbon 14 will remain.

**isotopes**  
variations of an element that differ in the number of neutrons within their nuclei; many isotopes are radioactive forms of an element

**half-life**  
the time taken for a quantity, for example the radioactivity of an isotope or a chemical, to break down to half its original value

Table 1 shows the half-life of some of the elements used to date rocks.

**TABLE 1** Approximate half-life of some isotopes used to date rocks. The atomic weight is shown after the name of the isotope.

Radioactive element	Approximate half-life (years)	Product of decay
Thorium 232	14.0 billion	Lead 208
Potassium 40	1.3 billion	Argon 40
Uranium 238	4.5 billion	Lead 206
Uranium 235	0.7 billion	Lead 207
Carbon 14	5730	Nitrogen 14

**radioactive element**

an element that emits radiation as a result of the spontaneous degeneration of its nucleus

Some **radioactive elements** have such a long half-life that they are not useful in dating very young rocks as their products of decay are too small to measure accurately. Similarly, elements like carbon 14 decay so rapidly that their quantities in very old rocks and fossils (>50 000 years old) are too small to measure. The age of fossils >50 000 years can be determined by the comparative decay rates of different radioactive elements in the rocks surrounding the fossil. By using the decay of other radioactive elements, geologists have been able to determine the age of the Earth (4.6 billion years).

It has been estimated that the first life forms (prokaryotes) originated by abiogenesis about 4 billion years ago. Each population of prokaryotes would have become specialised to the conditions through natural selection. Evidence of changes in populations over time can be seen in fossils found in rocks of various ages. The earliest fossils, stromatolites (sediment-trapping cyanobacteria) from Western Australia (Figure 3) have been aged as existing 3.5 billion years ago.

Figure 4 to the right shows a diagrammatic summary of the history of life on Earth. The timescale is divided into eras, from the Precambrian (prokaryotes and some jellyfish) to the Cenozoic (which includes present life). Each era is subdivided into periods, and epochs are subdivisions of periods. Each of these divisions is characterised by specific index fossils (distinctive, abundant fossils with a wide geographic distribution over a relatively short geological period of time).

**FIGURE 3** The Shark Bay stromatolites in Western Australia are thought to be some of the earliest fossils on Earth.



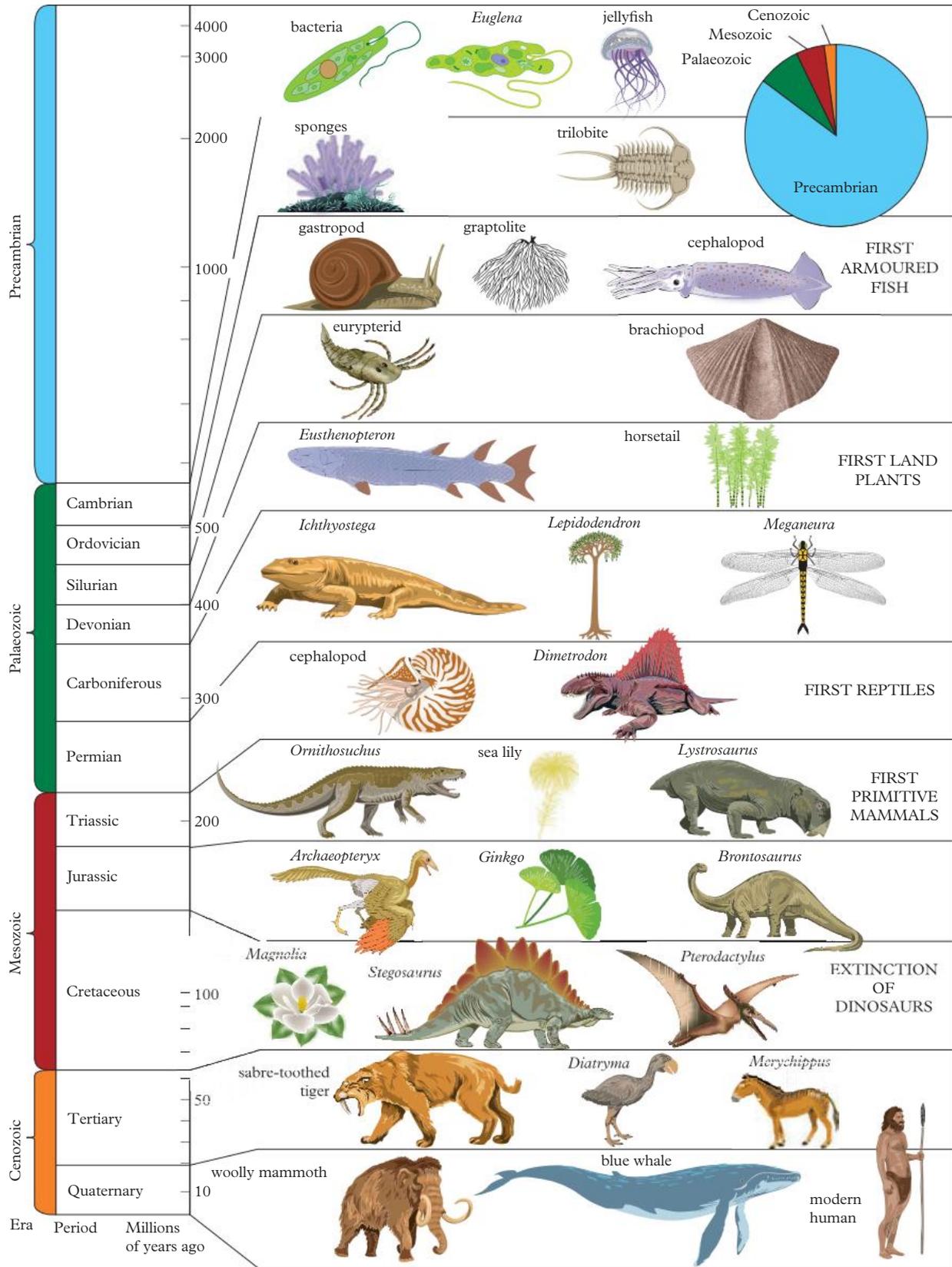


FIGURE 4 Possible history of life on Earth, illustrating key species' emergence in different periods of geological time

**TABLE 2** Possible time frame for major events in the Earth's history

Time (billions of years ago)	Event
0.5	Oldest known animal fossils
1.0	Origin of eukaryotes
1.5	
2.0	
2.5	Oxygen from photosynthetic bacteria accumulates in the atmosphere
3.0	Diversification of autotrophic bacteria
3.5	Oldest known fossils (anaerobic prokaryotes)
4.0	
4.5	Formation of Earth

### CHECK YOUR LEARNING 13.2

#### Describe and explain

- Describe** the techniques used to determine the age of rock strata.
- Explain** why different radioisotopes are needed to age different strata.
- Define** an index species.

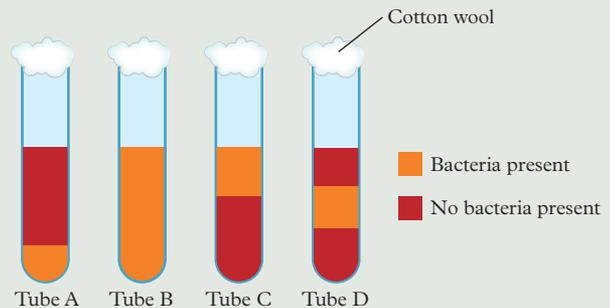
#### Investigate, evaluate and communicate

- This table shows the levels of dependence on oxygen of four types of bacteria.

1	Live only in the presence of oxygen
2	Are killed by the presence of oxygen
3	Are killed by normal oxygen levels but need a small amount of oxygen to live
4	Live with or without oxygen

The diagram below shows the growth of four types of bacteria in a nutrient broth. Some oxygen from the air dissolves in the nutrient broth. The amount of dissolved oxygen decreases as the

distance from the surface increases.



In what order would you arrange the tubes of bacteria so that the first tube was representative of the earliest form of bacteria that evolved in an anoxic environment and the fourth the most recently evolved form.

Fully **justify** your answer from the data given and your knowledge.



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# 13.3

## Episodes of mass extinction

### KEY IDEAS

- ✦ Selection pressures
- ✦ Extinct species
- ✦ Five mass extinction events in Earth's history
- ✦ Enhanced global warming

### endangered species

a species of animal or plant that is seriously at risk of extinction

### extinct species

a particular animal or plant species which has no more individuals of that species alive anywhere in the world

### mass extinction

the rapid and widespread extinction of a large number of species, due to a catastrophic global event or rapid, widespread environmental change

The concept of time for humans is very different to that involved in evolution. The average life span of humans (approximately 82 years) is insignificant when compared to the millions of years it takes for species to evolve.

At any point in time, planet Earth appears to be a relatively solid, stable entity; however, this is deceptive. The crustal plates that make up the surface of the Earth are constantly moving. The magnetic poles of the Earth undergo periodic reversals. Changes in climate have occurred periodically throughout this planet's history, resulting from moving tectonic plates, changes in the tilt of the Earth's axis of rotation, and the shape of Earth's orbit around the sun.

## Periodic mass extinctions

Conservationists often classify species on the basis of its likelihood of surviving. An **endangered species** (a rare species that occurs in low numbers) is likely to become extinct if the selection factors causing its decline continue. Other species become extinct if the selection pressures change quickly. This is especially evident in species with a limited number of variations present in their population. An **extinct species** is defined as one that has not been sighted in the wild for 50 years.

The fossil record shows that many organisms have become extinct throughout the history of life on Earth. Natural and physical changes on Earth bring about movement of the continents and variations in climate. These changes impact environmental selection pressures.

Scientists have identified five major extinction events, in which over 75% of the existing species died out. These events are referred to as **mass extinctions**. Most of these extinctions appear to be related to periods of rapid climate change brought on by a variety of factors.

## The next mass extinction?

Over the past 100 years the level of carbon dioxide in the atmosphere has increased dramatically. Humans have increasingly cut down forests (carbon stores) and replaced them with crops or grazing plants that do not absorb as much atmospheric carbon dioxide. Much of the timber from these forests is used for combustion, which releases carbon dioxide to the atmosphere. Fossil fuels such as coal and oil are increasingly burnt for energy, emitting carbon dioxide as well as other greenhouse gases. Simultaneously, there has been an increasing demand for meat.

Much land that was previously forested is now used for cattle grazing, causing the release of large quantities of methane gas. The movement of the tectonic plates as a result of an active volcanic belt causes further release of greenhouse gases.



FIGURE 1 Mass clearance of forest for farming

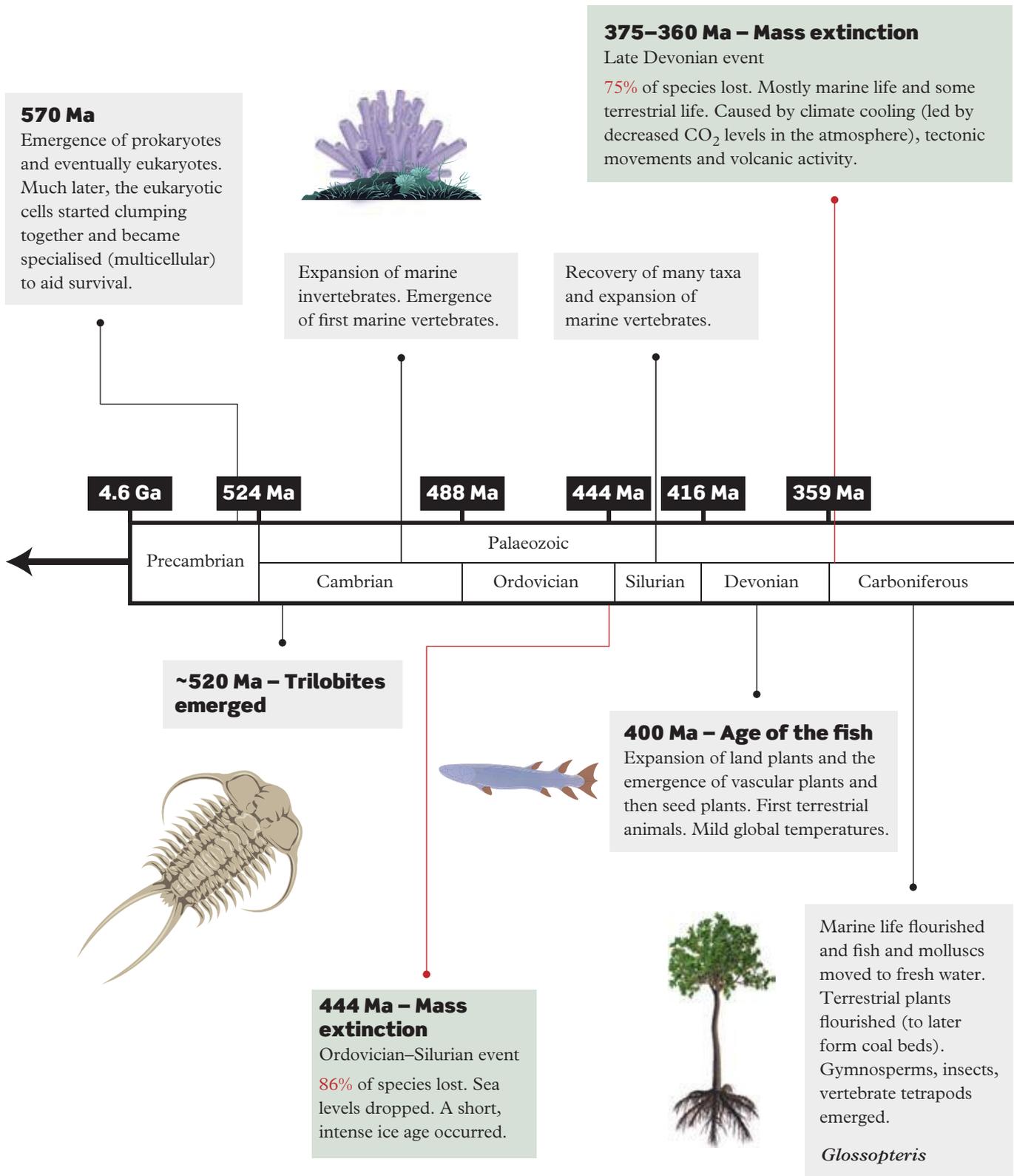


FIGURE 2 Timeline of mass extinction events

Reef-building corals evolved. Large fish and reptiles became the main predators. Gymnosperms dominated on land. Small mammals evolved from therapsids. Mass radiation of dinosaurs and first flying reptiles. Frogs established.

### 65 Ma – Mass extinction

K–T (Cretaceous–Tertiary) event

76% of species lost. Caused by meteorite shower and volcanic activity producing enough dust and ash to block out the sun and drive a global winter. Poisonous sulphur gases were released into the atmosphere.

Reptiles diversified, jaw structures changed, creating more efficient predators. Mammal-like reptiles emerged.

Therapsids

Rapid diversity of dinosaurs. First bird *Archaeopteryx*.



Modern life with dominance of flowering plants, insects and mammals on land. New array of marine life.

299 Ma

251 Ma

199 Ma

145 Ma

65 Ma

Mesozoic

Cenozoic

Permian

Triassic

Jurassic

Cretaceous

### 251 Ma – Mass extinction

Permian–Triassic event

95% of species lost extreme global warming from volcanic eruptions near Siberia. Huge release of green house gases. Ocean became acidic and stagnant, and released toxic H<sub>2</sub>S.

Explosion of marine plankton. Seagrasses covered the sea floor. Conifers replaced cycads on land. Flowering plants appeared. Salamanders, turtles, lizards, snakes and crocodiles evolved. The largest reptiles, *Albertosaurus* and *Tyrannosaurus*, evolved. Mammals split into marsupials and placentals. Wading birds and shorebirds evolved.

### 199–214 Ma – Mass extinction

Triassic–Jurassic event

20% of marine animals and many predatory land reptiles caused by Pangaea split into Laurasia and Gondwana, volcanic activity and asteroid collisions driving climate change.



Separation of South America, Africa and India from Antarctica–Australia drove changes to ocean distribution and rain-bearing winds.

90 Ma – many marine species and large dinosaurs became extinct.

Whilst Earth's orbit should be placing it in a period of glaciation, carbon dioxide levels are maintaining it as a warm period. The question then, is which of these opposing factors will predominate over the oncoming years?

As it currently stands, global temperatures on Earth are continuing to increase. This is leading to melting of the polar ice caps and a rise in sea level. Furthermore, an increase in ocean temperatures and dissolved CO<sub>2</sub> are dramatically changing the environmental conditions of our oceans.



Although it has been estimated that only a small fraction (possible as few as 0.001%) of the species that have ever lived are presently in existence, species extinction of both plants and animals has increased up to 100 times faster than has been calculated from the past. This is attributed to habitat destruction and other human activities. The *Living Planet Report 2018*, published by the World Wildlife Fund (WWF), stated that populations of animals in the wild has dropped by 60% in the last few decades. The Earth may be facing its sixth mass extinction.

**FIGURE 3** *Taudactylus acutirostris* – the sharp-snouted day frog from Queensland – was listed as critically endangered until 2006 when it was deemed extinct.

### CHECK YOUR LEARNING 13.3

#### Describe and explain

- 1 Explain** why the first mass extinction only affected marine animals.
- 2 Describe** how a shower of meteorites landing on Earth over a relatively short time span could bring about mass extinctions.
- 3 Explain** why Earth is not currently entering an ice age.

#### Apply, analyse and interpret

- 4 Determine** the major contributing factor to past mass extinctions.
- 5 Determine** why mammals remained small and were a relatively insignificant group during the age of the dinosaurs, yet survived the mass extinction of the dinosaurs.

#### Investigate, evaluate and communicate

- 6** The cyclic activities of the revolution of Earth around the Sun place Earth in position for a global cooling every 21 000 years. **Calculate** the number of years between each mass extinction event. **Investigate** whether they tally with the Earth's cyclic activities. **Explain** how other factors can override this cycle.
- 7 Hypothesise** how a global temperature rise or drop of 1–2°C could bring about mass extinction. **Justify** your response from your knowledge of ecosystems and ecosystem change.



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*Taudactylus acutirostris*

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The next mass extinction

# 13.4

## Evolutionary radiation

### KEY IDEAS

- + Evolutionary radiation
- + Identifying recent common ancestors of different species
- + Phylogenetic trees
- + A clade

### evolutionary radiation

diversification of species

Just as there have been mass extinctions, there have also been rapid expansions in the number and diversity of taxa. Random mutations in each population provide new variations that can fill available niches in the environment. If organisms have the characteristics to survive in the changing environment, they will be reproductively successful and pass the mutations to future generations. This process is called **evolutionary radiation**.

## Evolutionary radiation

Evolutionary radiation brings about diverse changes in the morphology of organisms. It may occur as a result of a mutation in an allele providing a new trait that opens up new opportunities for subgroups within the species (and eventually the formation of new species), or as a result of mass extinctions opening up previously occupied niches. This radiation may affect one taxonomic group or many. It may be either rapid or gradual. The most common form of evolutionary radiation is that of adaptive radiation.

## Adaptive radiation

### adaptive radiation

an evolutionary process in which organisms diversify rapidly from an ancestral species into several divergent forms

**Adaptive radiation** is driven by a single lineage's adaptation to the environment. It is a form of divergent evolution where groups with a common ancestor accumulate mutations over time, resulting in a new species. For this to occur, the common ancestor must have a **key adaptation** or novel phenotypic trait that allows the organism to evolve to exploit a new niche or resource. Although the variation(s) may have been present for some time, it is not until an environmental pressure acts upon the population that these variations will be selected.

### key adaptation

a novel phenotypic trait that allows an organism to evolve and exploit a new niche or resource, resulting in the subsequent radiation and success of a taxonomic group

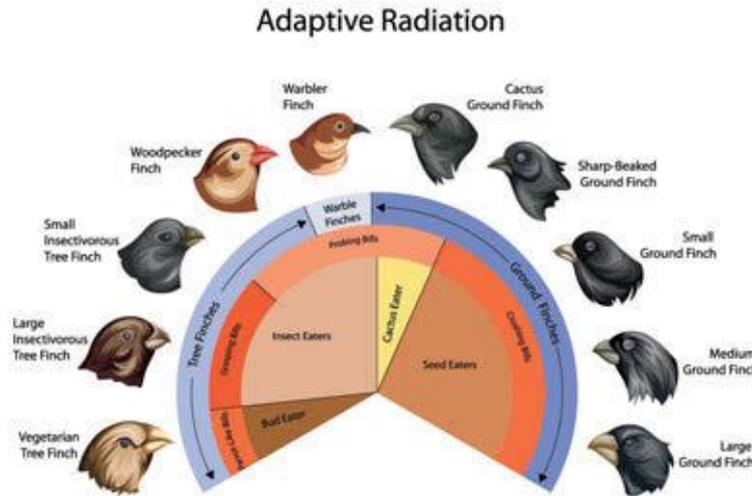
One of the most spectacular evolutionary radiations in the animal kingdom, in terms of both species richness and diversity of body form, is seen in the Crustacea. These animals range in size from giant crabs, immobile barnacles, and amorphous (no distinct body shape) parasites to microscopic plankton. The planktonic copepods of the open ocean are the most abundant multicellular animals (with differentiated tissues) on Earth. Crustacea also occupy most habitats on Earth and are found in such diverse places as deep open trenches, mountain tops and deserts.

Adaptive radiation may result from release from competition. One theory of the origin of the different finches Darwin observed on the Galapagos Islands



**FIGURE 1** Zooplankton seen through a microscope

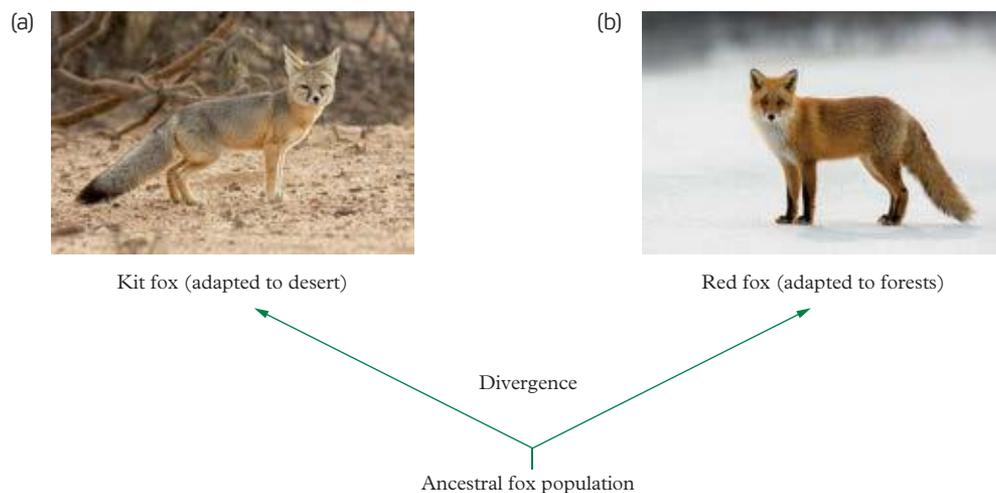
was adaptive radiation of ancestral finches that arrived from the mainland. These birds are thought to have flown in by chance to one island from the mainland and then spread to nearby islands. As each of these birds arrived at a new island, the lack of competition from other species of birds allowed them to survive. Slight variations in beak size and shape (key adaptations) allowed different groups of the original populations to evolve in response to available niches, competition for food and other resources. Another theory for the emergence of the different Galapagos Island finches is considered in Section 15.3 (Character displacement).



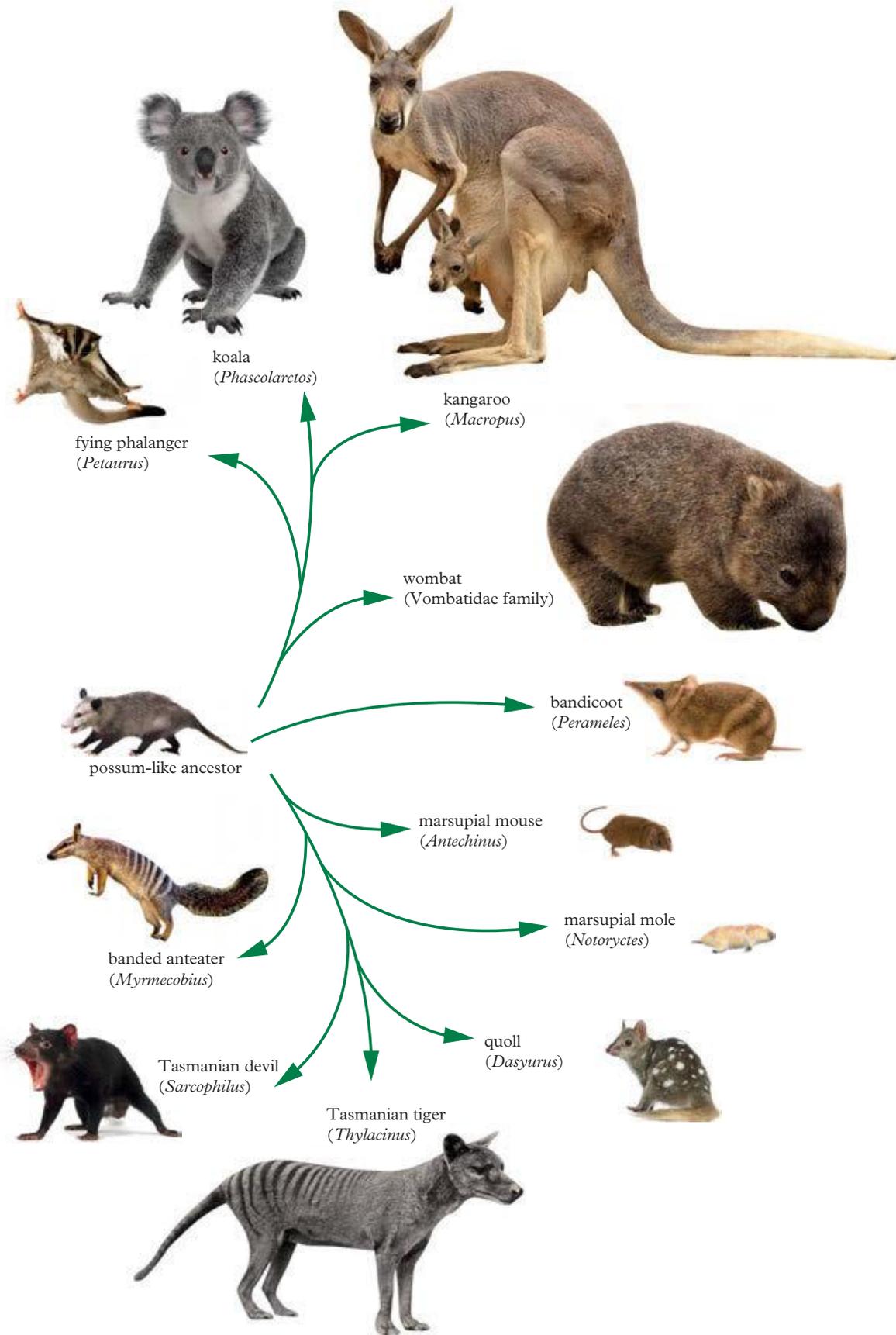
**FIGURE 2** Adaptive radiation in size and beak structure shown in Darwin’s finches on the Galapagos Islands

In other situations, such as after a mass extinction, previously occupied niches may become vacant. Those members of a population with variations that allow them to exploit a new niche have an advantage. Over time, as a result of exploiting existing and new mutations, these groups of individuals become new species. An example of this is the adaptive radiation of Australian marsupials.

Like many other mammals, Australian marsupials often have parasites such as the platyhelminth parasites. As marsupials evolved from their original carnivorous diets to omnivorous diets, there were changes in their intestinal tracts that opened up new niches for the parasitic worms.



**FIGURE 3** Adaptive radiation between the (a) kit fox and the (b) red fox due to different environmental selection pressures



**FIGURE 4** Adaptive radiation of Australian marsupials

## Molecular clock

Divergent evolution occurs when two populations of organisms share a common ancestor. Over time, the two populations are exposed to new selection pressures and differences accumulate. Some of these differences are molecular, where mutations in the DNA sequences accumulate over time. Differences in the DNA sequence may cause corresponding differences in the amino acid sequences, and eventually in the phenotype of the organism. The number of differences in a molecule between two species is an indication of the amount of time that has passed since they shared a common ancestor. If the mutation rate of a particular gene is known, this is called a **molecular clock**.

Each gene will accumulate mutations at different rates.

## Conserved genes

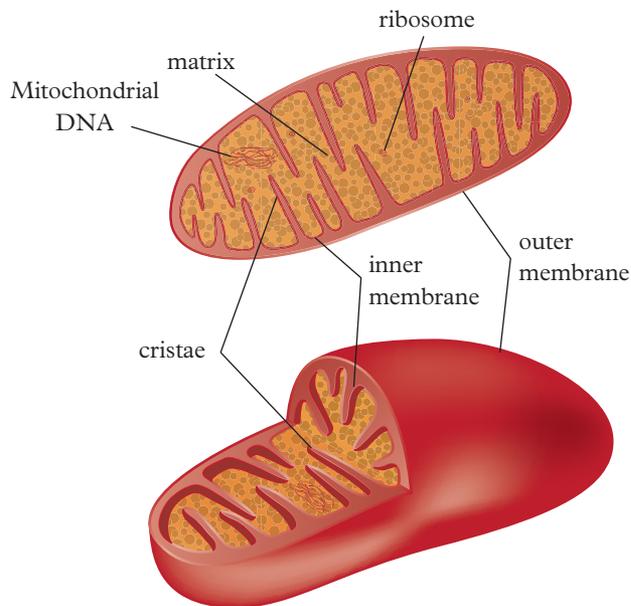
Some genes are less likely to accumulate mutations than other genes. These **conserved genes** are often involved in key roles in the survival of the organism. As a result, any mutations may cause the organism to die, preventing the mutation from being passed on to the next generation. Some examples of these types of genes are:

- regulatory genes that, for example, code for protein-based hormones
- genes that code for the formation of tRNA
- genes involved in ATP production (e.g. those coding for the proteins involved in the electron transport system).

The molecular clock of these genes can therefore appear to move slowly, taking millions of years for mutations to accumulate.

## Mitochondrial DNA

All living cells need mitochondria to produce the ATP necessary for transporting usable energy around the cell. As a result, each cell contains multiple copies of mitochondria, each with its own copy of DNA. The mitochondrial DNA (mtDNA) is inherited directly through the maternal line (from mother to offspring), with no recombination. This means any variation is a result of an accumulation of regular mutations, producing a reliable molecular clock.



**FIGURE 5** The structure of the mitochondria.

**molecular clock**  
a technique that uses the mutation rate to deduce when two or more life forms diverged

**conserved gene**  
a gene that has remained essentially unchanged throughout evolution

## Using the molecular clock

It has been found that mutations occur more readily in non-coding sequences of DNA. The degree of evolutionary divergence of different organisms can be estimated by the number of differences between their comparable base sequences. Using a similar technique, the rate of mutation for any particular gene might be determined. Some genes, for example, have been found to accumulate mutations at a relatively constant rate (e.g. a 1% change per million years). These genes can then be used as molecular clocks to show where divergence of species occurred.

The use of molecular clocks is, however, limited since:

- the rate of change in different organisms (e.g. animals and plants) may not be the same
- the rate of change can vary between different genes and proteins
- earlier changes may be reversed by later changes over long periods of time.

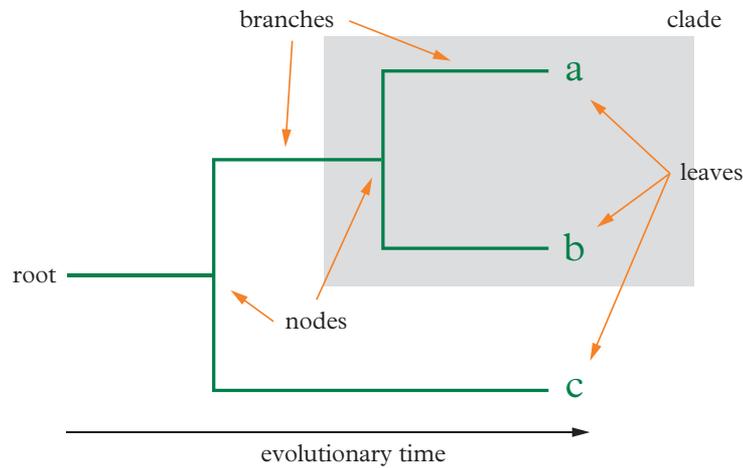
	10	20	30	40	50
Human	AAAGAAGACC	ACGGAGGCC	TGCTGGAGCT	GAAGGCCGTG	CTGGAGGCC
Chimpanzee	AAAGAAGACC	ACGGAGGCC	TGCTGGAGCT	GAAGGCCATG	CTGGAGGCC
Rat	GAGAAGACC	AAGGAGGCC	TACTGGAGCT	AAAGGCCATG	CTGGAGGCC
Guinea pig	AGAGAAGACC	AAGGAGGCC	TGCTGGAGCT	GAAGAGCATG	CTGGAAGCTC
Cow	AGAGAAGACC	AAAGAGGCC	TGCTGGAGCT	GAAGGCCATG	CTGGAGGCCA
Dog	AGAGAAGACC	AAGGAGGCC	TGCTGGAAC	GAAAGCCATG	CTGGAGGCC
	60	70	80	90	100
Human	ACCCTGAGGT	GGTGTCCCAC	TACCTGGTGG	GGGTACGCTT	CACCTG-GAG
Chimpanzee	ACCCGAGGT	GGTGTCCCAC	TACCTGGTGG	GGGTACGCTT	CACCTG-GAG
Rat	ACCCCAAAGT	GGTAGCCCAC	TACCCCGTAG	AGGTGCGCTT	CACCCGAGGC
Guinea pig	ACCCCAAAGT	GGCAGCCCAC	TACCCTGTGG	GGGTGCGCTT	CACCCGGGGG
Cow	GCCCAAAGGT	AGTGGCCCAC	TACCCCGTGG	AGGTACGCTT	CACTCGCGGG
Dog	ACCCCAAAGT	GGTGGCCCAC	TTCCCTGTGG	AGGTCCGCTT	CACCCGCGGG
	110	120	130	140	
Human	GATGACATCC	TACTGAGCCC	CTGCTTCCAG	TGGGACAGCCG	
Chimpanzee	GATGACATCC	TACTGAGCCC	CTGCTTCCAG	CGGGACAGCCG	
Rat	GATGACATTC	TGCTGAGCCC	CTGCTTCCAG	AGGGACAGCTG	
Guinea pig	GACGACATCC	TGCTGAGCCC	CTCCTTCCAG	AGGGACAGCTG	
Cow	GACGACATCC	TGCTGAGCCC	CTGCTTCCAG	CGAGACAGCTG	
Dog	GATGACATCC	TGCTGAGCCC	CTGCTTCCAG	AGGGACAGCTG	

**FIGURE 6** Differences in the sequence of 140 nucleotides in the same small DNA segment from six different mammals shows 100% similarity between the human and chimpanzee, but six differences between the human and rat, and at least one difference between the human and guinea pig, cow or dog.

Taken together, information from protein similarity, DNA hybridisation, comparisons of conserved genes, nuclear DNA sequencing and mitochondrial DNA studies provide strong evidence for both divergent evolution and the relative time period during which this took place.

## Phylogenetic trees

The evolutionary relationship between two or more organisms can be shown using a phylogenetic tree. These diagrams use the similarities between organisms (homologous structures or molecular sequences) to represent the length of time that has passed since the species shared a recent common ancestor. The individual taxa group is placed on a 'leaf', and the ancestral line is represented by a branch (Figure 7). Each common ancestor is represented by a node (the point at which two branches combine). Each group of taxa that evolve from a common ancestor is called a clade. The beginning of the tree is the 'root' and represents the last common ancestor. The last common ancestor is typically unidentified on a phylogenetic tree. For all life on Earth, the last common ancestor is still unknown, but is postulated to be an archaea.



**FIGURE 7** The ancestral line of each taxa is represented by a branch, with the taxa named on the leaves. The nodes represent a common ancestor.

### Study tip

All organisms share a common ancestor if you go back far enough in time. For this reason, it is better to describe the most recent common ancestor when examining evolutionary relationships between organisms.

### WORKED EXAMPLE 13.4

Use the characteristics of the organisms below to construct a phylogenetic tree.

	Cells	Legs	Antenna	Wings
Worm	Yes	0	0	0
Spider	Yes	8	0	0
Carpenter ant	Yes	6	2	4
House fly	Yes	6	2	2
Dragonfly	Yes	6	2	4

### SOLUTION

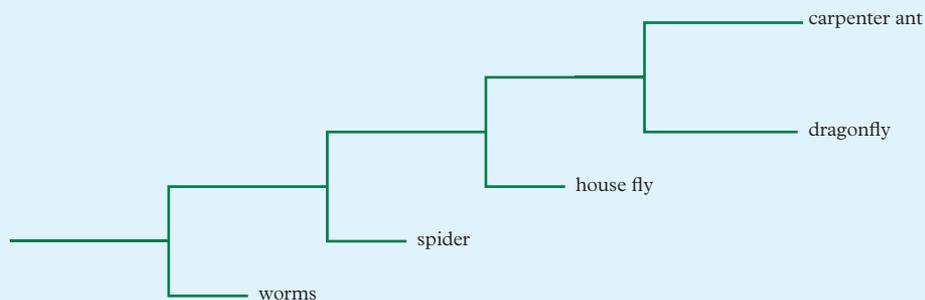
1 The organisms need to be grouped according to their characteristics.

Key observations include:

- all organisms are multicellular → common ancestor
- all organisms except for worm have legs → common ancestor
- carpenter ant, housefly and dragonfly have antenna → common ancestor
- carpenter ant and dragonfly have 4 wings → common ancestor

2 Construct the phylogenetic tree by starting with the root and drawing branches for each organism.

The phylogenetic tree would therefore be:

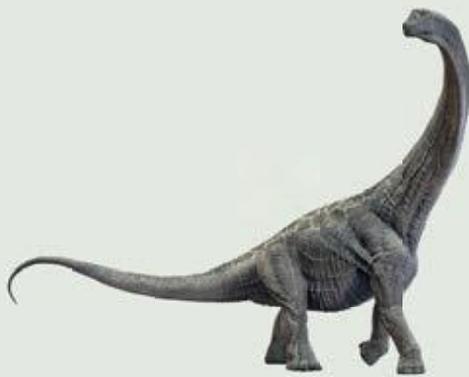


**FIGURE 8** Phylogenetic tree of different multicellular organisms

## CHECK YOUR LEARNING 13.4

### Describe and explain

- 1 **Identify** two causes of evolutionary radiation of species.
- 2 **Explain** why the presence of key adaptations are important before adaptive radiation can occur.
- 3 **Explain** what biologists mean by a conserved gene.
- 4 mtDNA has been significant in tracing evolutionary events such as the length of time since divergence of an ancestor into new species. **Describe** the advantages of using mtDNA rather than nuclear DNA in these studies.
- 5 **Define** a molecular clock. What are the limitations of molecular clocks?
- 6 **Explain** how the emergence of mammals, after the extinction of the dinosaurs, is an example of adaptive radiation.



**FIGURE 9** After the extinction of the dinosaurs, mammals were able to flourish.

- 7 **Describe** how phylogenetic trees are used to illustrate the relationship of different organisms.

### Apply, analyse and interpret

- 8 Studies of nuclear DNA from three closely related species were examined. The similarity in genes between species was identified as follows:

- between A and B was 92%.
- between A and C was 96%.
- between B and C was 99%.

In a particular segment of DNA, consisting of 1000 nucleotides, the number of substitution differences in the bases was:

- 6 between A and B
- 4 between A and C
- 2 between B and C.

Both B and C exhibited a deletion at the same position when the segments of all three species were analysed.

Mitochondrial DNA marker segments were virtually the same, with no differences between species B and C and one difference shown in species A. This difference was found in a non-conserved gene that has a known mutation rate of 1 mutation per thousand years.

- a Using this information, **sketch** a phylogenetic tree showing the divergence of these species from a common ancestor.
- b **Determine** what time frame the second species diverged after the appearance of the first. **Justify** your answer.

### Investigate, evaluate and communicate

- 9 **Research** a phylogenetic tree of your favourite animal. **Reflect on** the different relations. Were these what you expected?
- 10 **Compare** phylogenetic trees to ancestral trees. What are the main differences?
- 11 **Research** the Last Universal Common Ancestor (LUCA) of all life on Earth. **Identify** one current hypothesis for what the LUCA was. Be sure to use credible sources when researching. What do you think the LUCA was?

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Molecular clock

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Phylogenetic trees



# Review

## Chapter summary

- 13.1 • The theory of evolution as a result of natural selection is supported by evidence from Charles Darwin and Alfred Wallace.
  - Neo-Darwinism uses the modern understanding of genetics to explain evolution by natural selection.
- 13.2 • Fossils provide evidence that supports evolution.
  - Index fossils are distinctive, abundant fossils found in a wide distribution for only a relatively short period of geologic time.
  - Relative dating uses index fossils and the position of the fossil in the Earth to determine whether the fossil is older or younger than the other fossils. Older fossils are always found in lower rock strata.
  - Absolute dating (radiometric dating) measures the number of radioactive isotopes left in rock, compared with recently formed rock of the same type, to determine the age.
  - The timescale is divided into eras. Each era is divided into periods, and periods are divided into epochs.
- 13.3 • Selection pressures on Earth are constantly changing.
  - An extinct species has not been sighted in the wild for 50 years.
  - There have been five mass extinction events in Earth's history. These have been caused by global climate change from volcanic activity, tectonic plate shifts or meteors hitting the Earth.
- 13.4 • Evolutionary radiation (due to a diverse range of mutations in surviving organisms) occurs when there are available niches in the ecosystem.
  - Phenotypes and molecular (DNA, RNA or proteins) variations can be used to identify recent common ancestors of different species.
  - A phylogenetic tree is a diagrammatic representation of the evolutionary relationship between organisms.
  - A clade is a group of organisms that share a recent common ancestor.

## Key terms

- adaptive radiation
- conserved gene
- Darwin's theory of evolution
- endangered species
- evolutionary radiation
- extinct species
- half-life
- index fossil
- isotopes
- key adaptation
- Lamarck's theory of evolution
- macroevolution
- mass extinction
- microevolution
- molecular clock
- neo-Darwinian theory of evolution
- punctuated evolution
- radioactive element
- relative age

## Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: \* = low; \*\* = medium; \*\*\* = high.

### Multiple choice

- 1 Darwin was able to explain many observations with his theory of evolution by natural selection. Which of the following could this theory **not** explain?
  - A Adaptation to the environment
  - B The origin of variations
  - C Effects of selective breeding
  - D Change in a species
- 2 Natural selection is sometimes described as 'survival of the fittest'. In this context, the 'fittest' describes those animals in a population which:
  - A produce the largest number of healthy offspring
  - B are able to change to better suit the environment
  - C pass on acquired characteristics to their offspring
  - D are bigger and stronger than others
- 3 The fossils shown in the rock stratum in Figure 1 have been identified as coming from the early Ordovician period. Without access to rock data (and using the information in the geological timeline on page 339), how did the scientists make this claim?



FIGURE 1 Fossils in rock stratum

- A The presence of cockle shells (bivalves)
- B A large number of different types of algae
- C The absence of fish
- D The range of different invertebrates

- 4 Which of the following would be the most valuable fossil species for confirming that two rocks from different areas were the same age?
  - A A species of mollusc unique to the particular area
  - B A species of terrestrial organism with known climatic requirements
  - C A species that left fossils over much of the Earth's surface although it existed for only a short period of geological time
  - D A species of marine organism that is known to have lived only where specific environmental conditions existed
- 5 Each core sample in Figure 2 shows the types of rock below the surface at the drill site. The youngest rocks are at the top of each core sample, and any fossils in the core are shown.

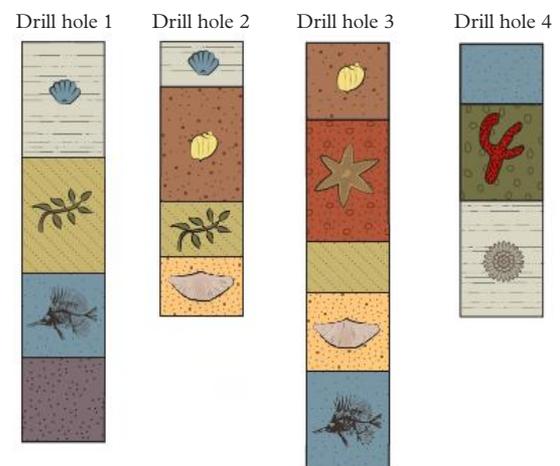


FIGURE 2 Core samples from four drill holes

What is the order of these fossils from youngest to oldest?

- A
- B
- C
- D

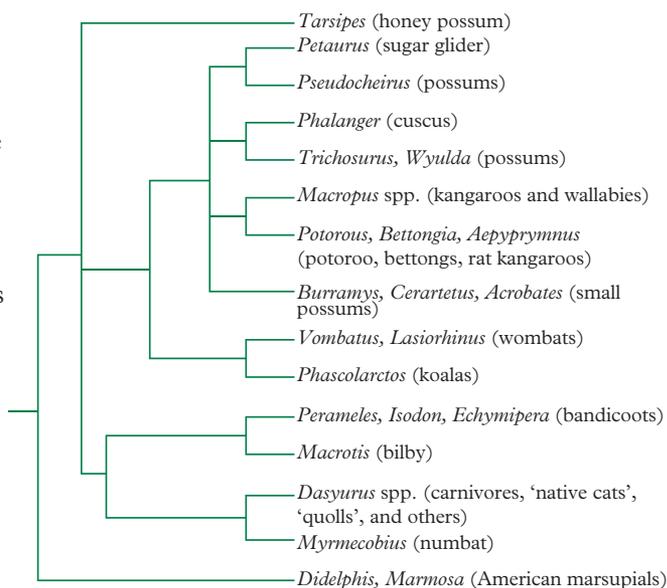
## Short answer

### Describe and explain

- ★ 6 **Define** biological evolution.
- ★ 7 Would radioactive carbon be used to estimate the age of rocks older than 1 000 000 years old? **Explain** your answer.
- ★ 8 **Define** the term 'geological timescale'.
- ★ 9 Does a geological timescale give absolute ages of fossils? **Explain** its use.
- ★ 10 **Explain** how the absolute age of a fossil is measured.
- ★ 11 **Describe** possible causes for adaptive radiation.
- ★ 12 **Describe** how DNA analyses have been significant in tracing evolutionary pathways.
- ★ 13 Fossil evidence supports a theory of progressive increase in complexity of organisms.
  - a **Define** a fossil.
  - b Giving two examples, **explain** why the fossil record is incomplete.

### Apply, analyse and interpret

- ★★ 14 **Infer** why some organisms survived more or less unchanged for millions of years, while others were evolving or becoming extinct.
- ★★ 15 Biologists often use 'dentition' (the pattern of teeth) to decide relationships between vertebrates. Using this criterion, the koala is a 'fat possum'. Most other characteristics suggest that the koala is a 'wombat up a tree'. In order to clarify this, blood proteins of all the marsupials were analysed. The data from this analysis was used to produce a phylogenetic tree of the marsupials.
  - a **Determine** which of the above suggested relationships is supported by the data from the blood protein analysis.
  - b Giving reasons to support your choice, **infer** the most likely relationship.



### Investigate, evaluate and communicate

- ★★★ 16 Populations of pigeons contain both pale grey and dark grey individuals. The difference in colour is genetically determined. There is a higher proportion of dark individuals in city populations and a higher proportion of pale individuals in country populations. All pigeons normally breed in summer. Some characteristics of city and country environments are shown in the table below:

	City	Country
Winter temperatures	Warmer	Colder
Winter food supply	Good	Poor
Risk of predation	Similar	Similar

- a **Hypothesise**, based on evolutionary theory, what could theoretically account for the observed distribution of colour forms.
- b A scientist set out to test the hypothesis that the observed distribution of colour forms existed because dark pigeons, unlike pale ones, are able to breed in winter provided there is adequate food. He proposed carrying out four different tests:

- 1 counting the numbers of different coloured pigeons breeding at different times of the year in both city and country populations
- 2 measuring the numbers of deaths caused by predators in both city and country populations
- 3 artificially improving the food supply to a country population
- 4 removing all eggs from the winter nests in a city population.

Propose which of these tests would best provide evidence to support the hypothesis. Give justified reasons why this test is better than the other three.

★★★ 17 Current evidence suggests that the:

- first organisms (prokaryotes) appeared on Earth over ~3.5 billion years ago
- the first eukaryotes evolved ~2 billion years ago
- the first multicellular animals evolved ~600,000 years ago.

During that time period, all organisms were marine. Over the last 600 000 years the increase of eukaryotic marine species and terrestrial plants and animals has expanded enormously despite periods of mass extinctions.

**Predict** possible reasons for the very slow start in the evolution of life on Earth. **Justify** your response.

★★★ 18 In 2015 a massive volcanic eruption in Iceland resulted in huge ash clouds over the northern regions of the world that lasted for several weeks. It was so severe that all aircraft in Europe were grounded for that time period. A visitor to Iceland shortly after this event noted that large banks (about a metre high) of ash were lined up on either side of all of the roads when the roads had been cleared. She also observed the local people clearing their fields of ash to allow the sparse grasses to grow so their ponies and caribou could graze. Along with seal meat, these are the main food sources for the people of Iceland. Taking into account the characteristics of this ecozone, discuss the short-term and long-term consequences for the ecosystem without this human intervention.

★★★ 19 A comparison of the base sequences of the same section of DNA that codes for ribosomal RNA was made of four Australian plant genera: *Eucalyptus*, *Vigna*, *Glycine* (flowering plants, the latter two belonging to the bean family) and *Pinus* (a non-flowering plant). The results are shown below for the first 11 bases in this sequence.

Using this data, construct an evolutionary tree showing the relationships between these four plants. **Justify** your response.

	1	2	3	4	5	6	7	8	9	10	11
<i>Eucalyptus</i>	C	C	C	–	T	C	T	T	T	T	T
<i>Vigna</i>	C	T	C	T	T	T	T	T	T	C	A
<i>Glycine</i>	C	T	C	T	T	T	T	A	A	C	G
<i>Pinus</i>	C	C	T	–	C	C	C	C	C	C	C

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# Natural selection and microevolution

Variations in genotypes in the gene pool (due to mutation and recombination) result in large variations in the phenotypic expression in members of a population.

Natural selection of individuals occurs from the interaction between the phenotype of the organism and its environment, resulting in an increased ability to survive (viability) and to produce offspring (fecundity). These processes can affect the frequencies of alleles in the population's gene pool, leading to microevolution.

The genetic equilibrium of populations is maintained when the environmental conditions are constant. Changes in the environment can result in progressive or disruptive selection.

Variations in allele frequency in a population are caused by mutations, gene flow between populations, genetic drift (resulting from non-random mating in a small population, bottlenecks and founder events) and natural selection of specific phenotypes.



**FIGURE 1** Natural selection occurs more frequently with a large number of offspring.

## OBJECTIVES

- Recognise natural selection occurs when the pressures of the environmental selection confer a selective advantage on a specific phenotype to enhance its survival (viability) and reproduction (fecundity).
- Identify that the selection of allele frequency in a gene pool can be positive or negative.
- Interpret data and describe the three main types of phenotypic selection: stabilising, directional and disruptive.
- Explain how populations with reduced genetic diversity (i.e. those affected by population bottlenecks) face an increased rate of extinction.
- Explain microevolutionary change through the main processes of mutation, gene flow and genetic drift.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority



MANDATORY  
PRACTICAL

### 14.3 Changes in the gene pool due to selection pressure



# 14.1

## Microevolution through natural selection

### KEY IDEAS

- + Natural selection
- + Microevolution

### Natural selection

Two concepts are basic to the modern theory of evolution:

- Mutations cause variability in the phenotype of a population.
- Natural selection acts on the phenotypic variability of a population.

Natural selection – the differential reproduction of genotypes resulting from interactions between individual organisms and their environment – is the process through which evolution occurs. Natural selection cannot occur if there is no variation in the phenotype of a population. It is the process whereby organisms that have characteristics suited to the environment are more likely to survive – they are more viable. This viability may be expressed as a physical trait, metabolic reactions, behaviour or a combination of these. The more **viable** an organism, the greater chance it has to survive and produce offspring. The viable parent will produce offspring with the same viable characteristics that enhance their own survival in the environmental conditions. This means an organism that is ‘fit’ for the environment is able to produce a greater number of viable offspring. They have greater **fecundity** (enhanced reproduction).

**viable**  
able to survive and reproduce

**fecundity**  
the natural capability to produce offspring

**FIGURE 1** Some individuals have high fecundity – they produce a large number of viable offspring.



# Microevolution

**Microevolution** describes the change in the allelic frequency in a population over a succession of generations.

Through natural selection, individuals with phenotypes better suited to the environment at that time survive and reproduce, while individuals with less suited phenotypes are less likely to reproduce. Since the number of individuals with viable phenotypes are likely to increase, the beneficial alleles they carry will also increase in the population. By acting on the phenotypes of individuals, natural selection inadvertently increases favourable alleles and decreases non-beneficial alleles in the gene pool. This change in allelic frequency results in microevolution of the population.

Although natural selection acts on the phenotypes of the members of a population that best suit the environment at a particular time, this can lead to the population losing alleles that may be useful in different environmental conditions. This can result in the population being at a disadvantage should the environmental conditions change. Over a long period natural selection can have both positive and negative effects.

**microevolution**  
a change in gene frequency within a population over successive generations



**FIGURE 2** Death adders have evolved to have different colourings based on their environment: (a) the desert death adder camouflages with sand whereas (b) the common death adder camouflages with leaf litter on the forest floor.

## CHECK YOUR LEARNING 14.1

### Describe and explain

- 1 **Define** the terms viability and fecundity.
- 2 **Explain** how the fecundity of one generation affects the viability of the next.
- 3 **Define** microevolution.
- 4 If natural selection acts on individuals, **describe** how this results in changes to the allelic frequencies of a population.
- 5 **Explain** how natural selection could have a negative effect on a population.

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| » Student book questions | » Weblink<br>Natural selection | » Weblink<br>Microevolution |
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- Check your learning 14.1



# 14.2

## Variation in a population

### KEY IDEAS

- ✦ The gene pool
- ✦ Natural selection on all phenotypes
- ✦ Stable allelic frequency in a gene pool
- ✦ Changing selection pressures
- ✦ Disruptive selection

### gene pool

total aggregate of genes in a population at any one time

A population is an interbreeding group of organisms of the same species, living in the same place at the same time. It is unified and is defined by its **gene pool** – the total sum of all the alleles of all the genes of all the individuals in the population. The variation of alleles for a gene and recombination during meiosis I results in the different phenotypes in the individuals of the population.

It is the phenotypes on which natural selection acts. Any individual in the population has only a sample of the gene pool (two alleles for each gene). If the population is large, the relative proportion of alleles from the total gene pool that an individual carries is small. Conversely, if the population is small, the relative proportion of alleles from the total gene pool that an individual carries is large.

As seen in Chapter 10, mutation of genes is a random event. Most mutations are spontaneous. Which gene mutates is independent of the environment; however, the rate of mutation may be influenced by environmental factors. These factors include exposure to radiation (X-rays, ultraviolet rays), radioactive substances and a number of different chemicals.

All genes, including structural or regulatory genes, are capable of mutating to produce a new allele. The new allele(s) may be:

- neutral (have no impact on the survival of individuals, e.g. whether hair is curly or straight)
- harmful to the individual (decreasing the individual's viability or fecundity)
- advantageous (increasing the individual's viability or fecundity).

The variety of alleles can be recombined through sexual reproduction, producing variation in the genotypes in the population. The genotypic variation must be expressed in the phenotype before natural selection can have an effect. Mutations in the somatic cells will only affect the viability of an individual. If the mutation is not present in the individual's gametes, it will not be passed on to the next generation of the population. This means a mutation in somatic cells will not affect the evolution of a population.

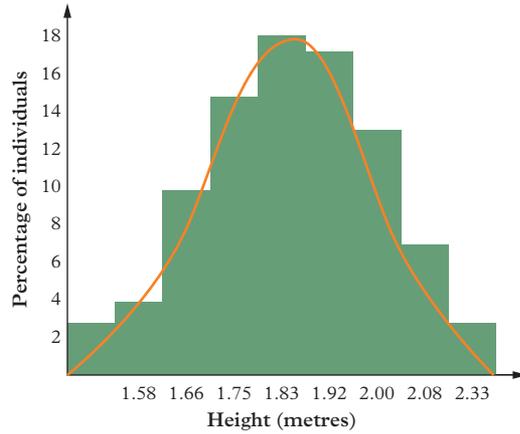
Each organism has an enormous number of genes (humans have approximately 22 000 structural genes) and each of these may have two or more alleles. The viability of an organism relies on the integration of the total genotype of an individual. It may be an advantage for a tree to have alleles that enhance the growth rate of the trunk and limbs. This characteristic would be a disadvantage if the tree grew rapidly above the ground without a strong root structure. This means the viability of a tree relies on the entire genetic context in which it operates.

**FIGURE 1** The colour and banding patterns on the shells of the bivalve mollusc *Donax variabilis* show diverse phenotypes.





**FIGURE 2** Genotype variations are responsible for the different colours in tigers.



**FIGURE 3** Histogram of the heights in an adult human population. The curve derived from this approximates a curve of normal distribution.

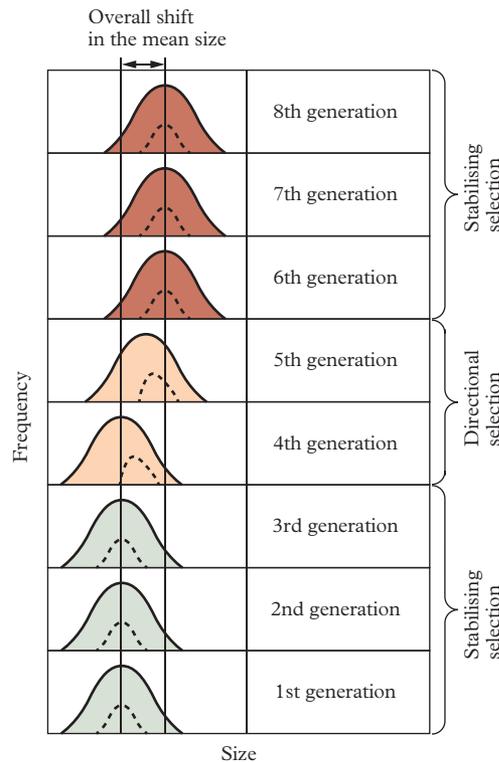
Natural selection, therefore, acts on the entire phenotype (combination of alleles) most suited to the environment at the time. The individuals with a matched combination of alleles have a higher fecundity than individuals with a mismatched combination of alleles.

## Stable environmental conditions

Most populations contain individuals with a variety of anatomical and physiological characteristics as well as distinctive abilities and behavioural traits. These characteristics are determined by the genotype.

Some of these phenotypic variations will be more common than others. If they are plotted on a histogram it usually results in a normal distribution curve that is symmetrical about a mode (the most frequent measurement).

If either environmental or heredity characteristics are plotted separately, they tend to give a normal distribution curve. In nature, however, both operate together and it is not possible to distinguish genetic from environmental influences. Plants grown in nutrient-deficient soils, for example, will tend to be stunted whereas the same plants grown in soils rich in nutrients will grow to their full genetic potential. The environment, in this case, has brought about changes in the phenotype.



**FIGURE 4** Stabilising and directional evolution. The broken curve represents the breeding population.

Variation in a population is important for the species to survive new selection pressures. If the selection pressures in an environment have not changed for thousands of years, the same phenotypes will be selected. This means some allelic combinations have a high selection advantage. When this is plotted on a normal distribution curve, the average phenotype (the mean) will be unchanged; however, the range will be narrower than that of a changing environment.

The mean phenotype represents the characteristics that are best adapted to the environment. Any individual organism with characteristics that vary too far from the mean will not be able to survive in the unchanged environmental conditions and will therefore be unable to reproduce. This removal of any phenotypic extremes acts like a homeostatic control mechanism. This kind of selection in unchanging environmental conditions is called **stabilising selection** because it maintains constancy of the species over the generations.

However, stabilising selection does not mean that all species in a habitat remain unchanged. If a niche becomes vacant, it is very likely that some members of a population will have adaptations that will enable them to successfully fill it.

### stabilising selection

natural selection for a particular variant (mean) of a characteristic that maintains consistency of a population; occurs in times of environmental stability

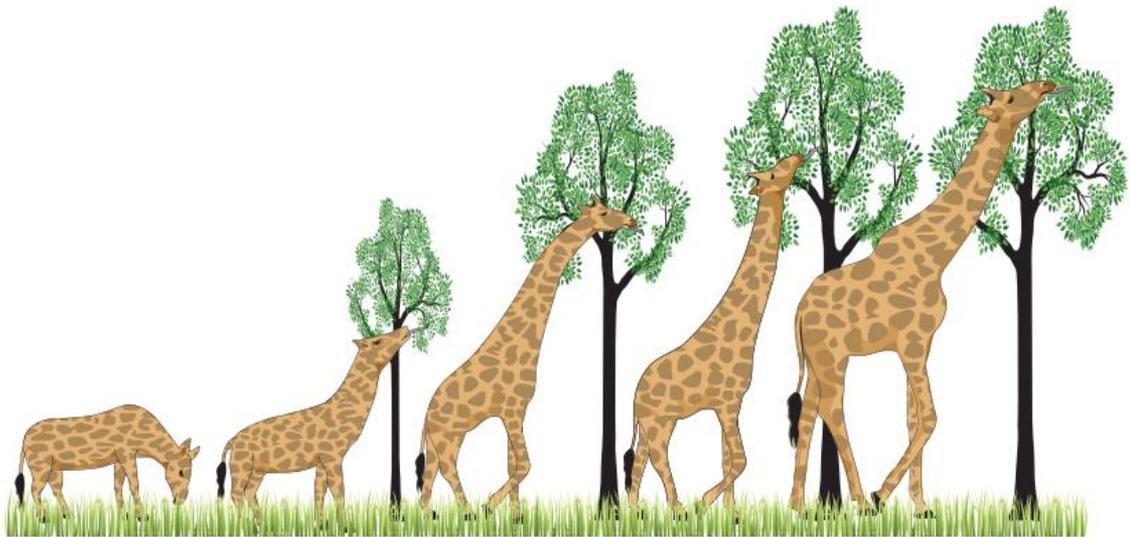
### directional selection

natural selection that favours one phenotypic extreme causing the allele frequency to shift over time in the direction of that phenotype

## Changing environmental conditions

If the environment suddenly changes, the selection pressures being exerted on individual organisms will also change. For example, an environmental change could make it an advantage to be slightly taller than in previous conditions, so taller individuals become more viable. This results in the frequency curve mean for height shifting to the right, and an overall increase in the mean height of the population. This kind of selection favours the emergence of new phenotypes and is called **directional selection**. Once the new mean has been established, it is maintained over successive generations by stabilising selection.

This type of selection could account for the evolution of the long legs and neck of the giraffe. As food sources became depleted, selection pressure favoured those individuals in the population with longer legs and necks, which enabled them to reach higher foliage.



**FIGURE 5** Possible evolution of the giraffe – those individuals with longer legs and necks were able to obtain food more readily as low foliage food became unavailable. They passed the alleles for height to their offspring.

The resistance of head lice to pyrethroid treatment is another example of directional selection. Pyrethroid is a common chemical used to disrupt the nervous system of head lice. A few head lice had a mutant allele that prevented the pyrethroid from binding to sodium channels on the nerve membranes, rendered the pyrethroid ineffective. This makes the head lice more likely to survive the treatment, allowing them to reproduce and spread to new hosts. The pyrethroid-resistant genes were found to be most common in lice in areas that had the most use of pyrethroid treatments for head lice. This meant there was directional selection in favour of pyrethroid resistance.



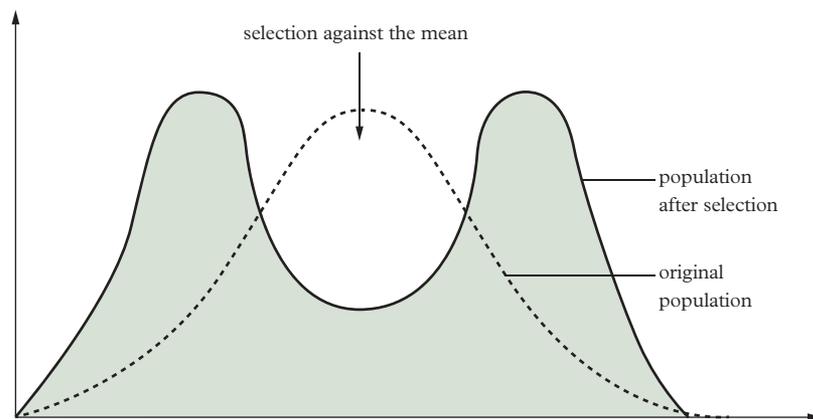
**FIGURE 6** The use of pyrethroid treatment selects for resistant head lice in a population.

Since the results of natural selection at any given moment depend upon the interaction of phenotypic and environmental variables, a situation could arise where there is an increase in the frequencies of the extreme types in a population and the intermediate (modal) types are eliminated. This is referred to as **disruptive selection**.

Plants growing on soil previously contaminated by mining operations often show disruptive selection. Examples are the grasses *Festuca ovina* and *Agrostis capillaris*. There is often a sharp boundary between contaminated and uncontaminated soil. Some of the plants have allelic variations that allow them, unlike 'normal' plants, to live on contaminated soils. While these allelic combinations allow them to survive on contaminated soils, it makes them less competitive on uncontaminated soil. This leads to intermediate phenotypes being selected against, resulting in the development of two populations with marked differences.

Natural selection perpetuates constancy, as long as the environment remains constant, but it promotes the emergence of new forms if and when the environment changes.

**disruptive selection**  
natural selection favouring individuals with extreme phenotypes



**FIGURE 7** Disruptive selection

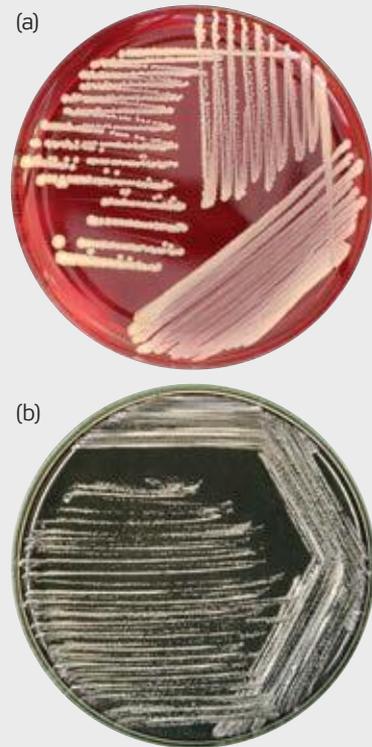


**FIGURE 8** Grass growing on contaminated soil

## CASE STUDY 14.2

### Antibiotic resistance

In 2018, Melbourne researchers uncovered a common bacterium that had developed resistance to many of the antibiotics in use in Australian hospitals. *Staphylococcus epidermidis* is commonly found on the skin of all humans and often contaminates samples taken from infected wounds. This meant it was frequently dismissed as a false positive on diagnostic tests taken of wounds that failed to heal. Genetic testing by the Peter Doherty Institute for Infection and Immunity found that three strains of this bacterium have spread globally and are resistant to nearly all antibiotic types. They found that *S. epidermidis* had developed a random mutation that led to resistance to two major antibiotics. The frequent impregnation of catheters and other implanted devices with antibiotics has led to a selection advantage for these resistant bacteria. This has resulted in an increase in the frequency of these resistant bacteria, especially in intensive care environments where strong antibiotics are often prescribed.



**FIGURE 9** (a) *Staphylococcus epidermidis* on a blood agar plate; (b) *S. epidermidis* on an agar plate

## CHECK YOUR LEARNING 14.2

### Describe and explain

- 1 **Explain** why natural selection acts on individuals but evolution occurs only in populations.
- 2 Although the frequency of alleles in a population is changed in the process, **explain** why natural selection acts only on phenotypes.
- 3 **Describe** how natural selection results in adaptation of a population.
- 4 **Describe** the conditions under which each type of selection (stabilising, directional and disruptive) is likely to be found.

### Apply, analyse and interpret

- 5 **Differentiate** between stabilising, disruptive and progressive selection.
- 6 **Describe** why ‘survival of the fittest’ is an indication of natural selection and not evolution.
- 7 **Reflect on** the following statement by writing a short response:  
‘The use of a new antibacterial drug may result in the development of new types of bacteria that are resistant to the drug.’



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Check your learning 14.2

» Weblink

Stabilising selection

» Weblink

Directional selection

# 14.3

## Gene frequencies

### KEY IDEAS

- + Allelic frequency
- + The sum of all allelic frequencies
- + Genetic equilibrium
- + Genetic drift

Many genes have more than one effect. Whether an allele for a gene increases or decreases in frequency is determined by the environmental selection pressures that are present. If a phenotype is favourably selected by environmental pressures, the frequency with which that allele occurs in a population will increase. If a phenotype is selected against, its frequency in the population will decrease.

Occasionally the advantages of a specific phenotype are greater in a heterozygous genotype than in a homozygous individual. An example of this is the allele for the recessive trait sickle cell anaemia found in Africa. When the homozygous dominant genotype is present (HH), the individuals do not have sickle cell anaemia but are vulnerable to contracting malaria. Homozygous recessive individuals (hh) suffer from sickle cell anaemia, which can result in an early death. Heterozygous individuals (Hh), although suffering mild anaemia, display a partial resistance to malaria. This means the allele for sickle cell anaemia is retained in the population and the frequency at which it occurs rarely varies.



**FIGURE 1** In humans, the ability to roll the tongue is determined by a dominant allele. Individuals who cannot tongue roll are homozygous recessive.

### Allelic frequency

Two scientists, Hardy and Weinberg, independently determined that the frequencies of the alleles of any gene in a population can be calculated from the following formula (Hardy–Weinberg equation):

$$(p + q)^2 = 1$$

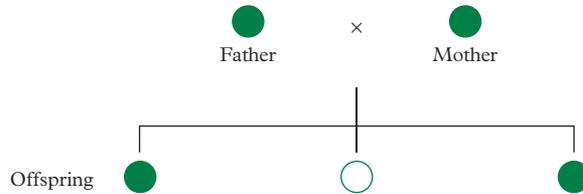
where  $p$  = frequency of the dominant allele and  $q$  = frequency of the recessive allele.

This formula can be expanded to:

$$p^2 + 2pq + q^2 = 1$$

where  $p^2$  represents the ratio of homozygous dominants,  $2pq$  the heterozygotes and  $q^2$  the homozygous recessives in a population.

Whether or not an allele for a characteristic is recessive can be determined from a family tree. If two parents show one phenotype for the characteristic (e.g. both can roll their tongues) but an offspring shows a different phenotype (e.g. cannot roll the tongue), the parents must be heterozygotes and that offspring is homozygous recessive (i.e.  $q^2$ ) for the characteristic.



**FIGURE 2** A family tree can help determine whether or not an allele for a characteristic is recessive.

The proportion of homozygous recessives in the population can then be determined using the equation below:

Proportion of homozygous recessives in a population

$$= \frac{\text{Number of individuals showing the recessive phenotype}}{\text{Total number of individuals in the population}}$$

Since:  $(p + q)^2 = 1$

Then:  $(p + q) = 1$

Since the proportion of  $q^2$  is known, the frequency of  $q$  can be determined:

$$q = \sqrt{q^2}$$

Thus, the frequency of  $p$  can be calculated from:

$$p = 1 - q$$

Using the expansion equation:

$$p^2 + 2pq + q^2 = 1$$

the proportion of homozygous dominants and heterozygotes can be determined for that characteristic. The genotype of any allele in a population can be determined using the table below.

First allele	Second allele	Frequency
T	T	$p \times p = p^2$
T	t	$p \times q = pq$
t	T	$q \times p = pq$
t	t	$q \times q = q^2$

**genetic equilibrium**

describes the condition of an allele or genotype in a population when the frequency remains stable over time

By analysing the frequencies of alleles for any particular gene in a population over a period of time, changes in the gene pool can be determined. If there are no changes, the population is said to be in **genetic equilibrium** for those alleles.

The sum of all the allelic frequencies in a population will always equal 1.

### WORKED EXAMPLE 14.3

In humans, the thickness of the lips is controlled by a single, dominant/recessive gene. In a population of 1000 individuals, 910 had thick lips and 90 had thin lips. Examination of these phenotypes in family groups show that thin-lipped parents always had offspring with thin lips, while offspring of parents with thick lips could have either thick or thin lips.

- 1 Determine, with reasons, which allele is recessive.
- 2 Calculate, using the Hardy–Weinberg equation, the frequency of homozygous dominant, heterozygous and homozygous recessive individuals in this population.
- 3 Determine the proportion of homozygous dominant, heterozygous and homozygous recessive individuals in this population.

### SOLUTION

- 1 The recessive allele results in thin lips since homozygous recessive thin-lipped parents cannot produce thick-lipped offspring, whereas two heterozygous thick-lipped parents can produce thin-lipped offspring.
- 2 The proportion of homozygous recessives ( $q^2$ ) in the population:

$$\begin{aligned}q^2 &= \frac{90}{1000} \\ &= 0.09 \\ q &= 0.3\end{aligned}$$

Using the Hardy–Weinberg equation:

$$\begin{aligned}p + q &= 1 \\ p &= 1 - 0.3 \\ p &= 0.7\end{aligned}$$

From the expansion equation:

$$p^2 + 2pq + q^2 = 1$$

Thus, the frequencies of the genotypes in the population:

$$\begin{aligned}\text{Homozygous dominant} &= p^2 \\ &= 0.7 \times 0.7 \\ &= 0.49 \\ \text{Heterozygous} &= 2pq \\ &= 2 \times 0.7 \times 0.3 \\ &= 0.42 \\ \text{Homozygous recessive} &= q^2 \\ &= 0.3 \times 0.3 \\ &= 0.09\end{aligned}$$

- 3 The proportion of genotypes in the populations:  
Homozygous dominant = 49%  
Heterozygous = 42%  
Homozygous recessive = 9%

# Genetic equilibrium

Genetic equilibrium describes the way a frequency of an allele in a gene pool does not change from generation to generation. Change in allelic frequencies (i.e. microevolution) occurs only when something upsets the genetic equilibrium. A large migration of individuals in or out of a population may change the frequencies of specific alleles. This has been summarised by the

## Hardy–Weinberg law.

In a large, randomly mating population there will be no change in allele frequency from generation to generation except where there is selection, mutation or migration.

To be in genetic equilibrium, a population must satisfy four conditions:

- 1 The population must be large enough to make it very unlikely that chance alone could significantly alter the gene frequencies.

Random environmental events, such as fire or flood, can result in the death of many individuals in a population. Both well-adapted and poorly adapted organisms will be affected by these events and this could result in loss of alleles from the gene pool.

- 2 Mutations must not occur, or there must be mutational equilibrium.

This condition is never met in any population. Mutations are always occurring, and mutational equilibrium is very rare. Mutational equilibrium occurs when the number of damaging mutations that develop in a population is equal to the number of damaging mutations that are eliminated (through the death of the individual).

More commonly there is a change in one direction, resulting in a mutational pressure changing the allelic frequencies in the population. Since mutation is a slow process, and random, mutation pressure is rarely a major factor in producing changes in allelic frequencies in a population.

- 3 There must be no immigration or emigration.

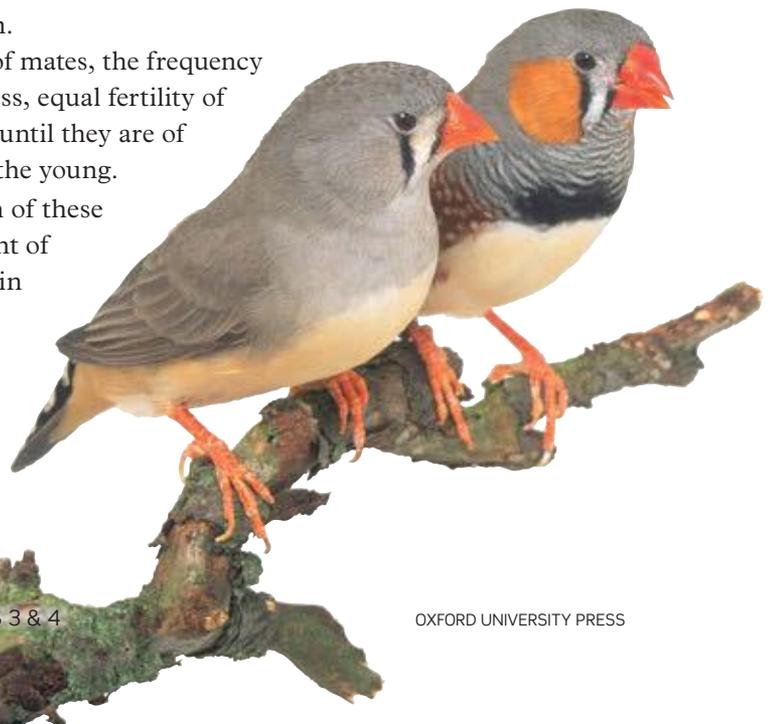
**Gene flow** refers to the movement of alleles into or out of a population. In plants, pollen can be blown, or carried by insects or birds, from population to population. The gametes of aquatic animals using external fertilisation can be carried in water currents. Immigration or emigration leads to either a gain or a loss of alleles in the population. Most natural populations probably experience at least a small amount of migration, which will enhance variation and so upset genetic equilibrium. Some populations, however, will experience either no migration or an insignificant amount, resulting in genetic equilibrium.

- 4 Reproduction must be totally random.

Reproduction refers to the selection of mates, the frequency and effectiveness of the mating process, equal fertility of all individuals, survival of the young until they are of reproductive age, and the fertility of the young.

If reproduction is random, then each of these factors must be random (i.e. independent of genotype). This condition is rarely met in any population.

Given these four conditions for genetic equilibrium, it is not surprising that evolution occurs.



## Hardy–Weinberg law

states that when there are no other evolutionary influences, the allele and genotype frequencies in a population will remain constant across generations

## gene flow

the movement and exchange of alleles between populations of a species

**FIGURE 3** Research has shown that male zebra finches (*Taeniopygia guttata*) preferentially court ‘fat’ females, whereas the female accepts a mate on the basis of his song and the ‘redness’ of his beak. Thus, mate selection in the zebra finch is not random.

## Effects of disturbing genetic equilibrium

Selection pressure will disturb genetic equilibrium. In sexually reproducing populations, selection determines the direction of change largely by altering the frequencies of alleles that arose through random mutation many generations before. New allele combinations, and allele activities that produce new phenotypes, are established. The principal role of new mutations is in replenishing the store of variability in the gene pool. This provides the potential upon which future natural selection can act. These mutations may be important to the survival of the species in a changing environment and may lead to a dramatic change in the gene pool as a result of natural selection.

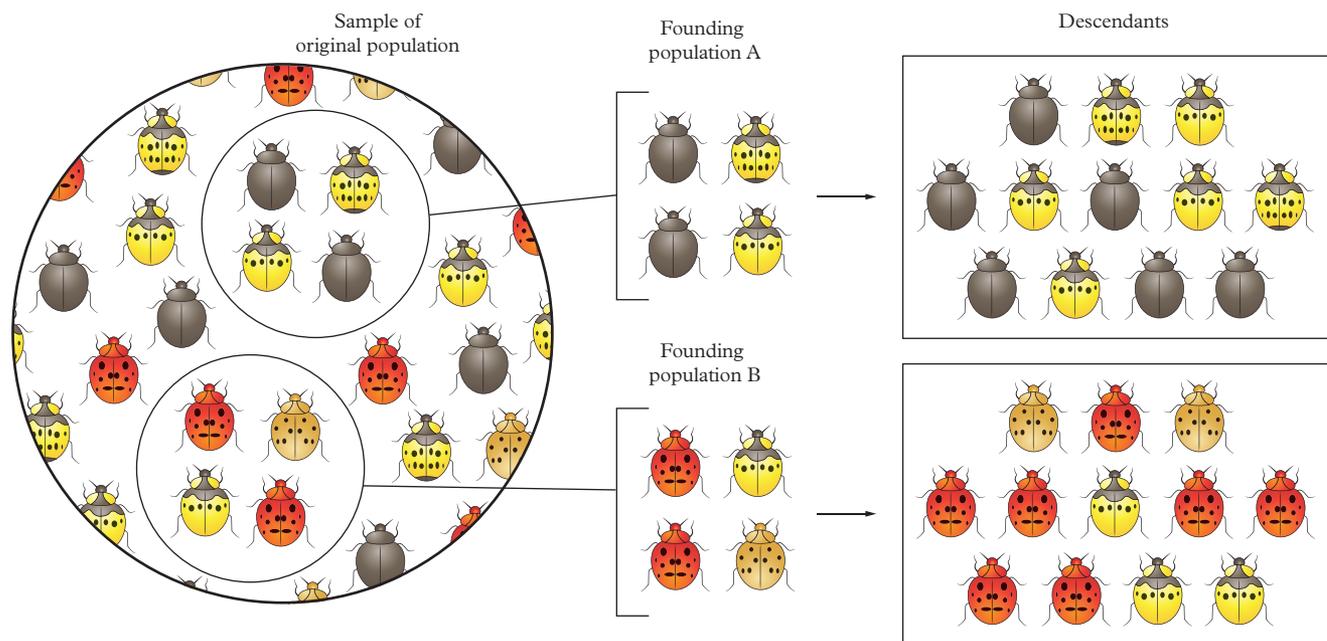
In a stable environment natural selection plays a conservative role. Each species, in the course of evolution, comes to have a combination of alleles and genes that act in very precise ways. Anything that disrupts the harmonious interaction of its genes is deleterious to the species.

### Genetic drift

In small, isolated populations there is great susceptibility to random fluctuations in the gene pool, which can easily lead to loss of an allele from the population. This can occur even when that allele is an advantage to survival. This means chance events (such as landslides or volcanic eruptions) can cause evolutionary change in small populations in a relatively short time period. This is called **genetic drift**. This **neutral evolution** has an equal chance of increasing or decreasing the survival advantage of a population.

**genetic drift** changes in the gene pool, and thus the relative frequency of different genotypes in a small population, due to chance

**neutral evolution** evolutionary changes caused by genetic drift (dominated by random processes) rather than natural selection



**FIGURE 4** Genetic drift occurs in small populations. Individuals that carry particular alleles may, by chance, produce more offspring than those with other alleles. Over time this alters the allele frequency in the gene pool. In the diagram, populations A and B represent two possible effects of genetic drift.



FIGURE 5 *Rattus fuscipes greyi*, the bush rat



FIGURE 6 The gene pool of the koala population on Magnetic Island likely has very low variability.

A research project was undertaken in South Australia to study the frequencies of alleles of a gene controlling an enzyme in the heart and kidney in thirteen populations of bush rats (*Rattus fuscipes greyi*). This research revealed that small, isolated island populations tended to be homozygous for one or the other allele, whereas the mainland populations exhibited both allelic forms. This genetic drift in the island forms could ultimately lead to their demise. A population is at risk if the environment changes when there is a low level of genetic variation.

## Founder effect

### founder effect

reduced genetic diversity as a result of a population having descended from a small number of colonising ancestors

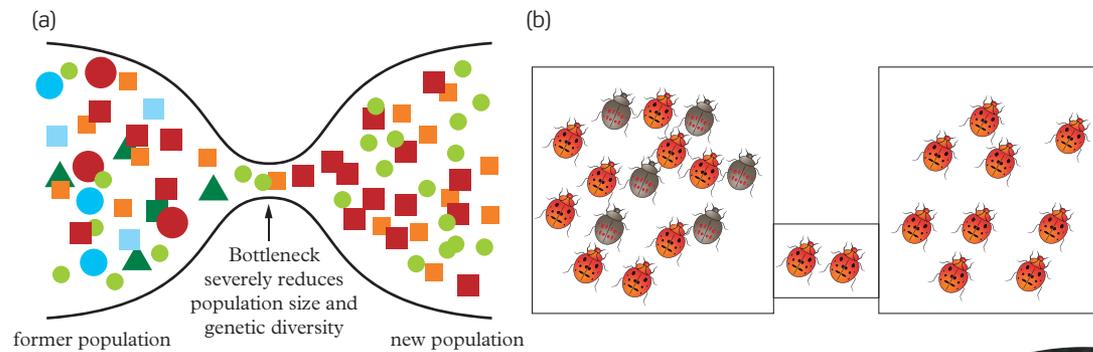
The **founder effect** is a cause of genetic drift that results from a small subgroup of a ‘parent’ population colonising a new area. Because this subgroup may not be genetically representative of the original parent population from which it was derived, it will have a limited number of different alleles in the population. As the small population increases in size, there will be continued drift that is different from that of the parent population. An example of this can be seen in the colonies of koalas that were established on several islands as a result of habitat loss on the mainland. In Queensland, eighteen koalas were taken from Bowen to Magnetic Island, off Townsville, by the District Inspector of Stock in 1932. The population size is now about 300. Although they are reported as being healthy, it is likely that the gene pool for this population has very low variability. This makes them vulnerable to possible changing environmental conditions (such as the introduction of a disease) in the future.

## Population bottleneck

### population bottleneck

an event (environmental disaster, overhunting, etc.) that drastically reduces the size of a population and thus its genetic diversity

Occasionally the size of a population will undergo a drastic reduction that is completely unrelated to natural selection. This type of genetic drift may be caused by a disease that affects a large percentage of a population or the effect of a predator (such as human hunting) that affects one or more generations. As a result, some alleles are eliminated from the population, causing an over-representation of a small number of other alleles. Following this **population bottleneck**, the population may once again increase in number, despite the overall decrease in the variation of alleles available. This makes the population vulnerable to any further changes in the environment.



**FIGURE 7** An evolutionary bottleneck: (a) showing the effect on alleles; (b) showing the effect on phenotype

It is thought that the population of Tasmanian devils underwent a population bottleneck millions of years ago. Although the size of the population was able to recover, only a limited variety of alleles remains. This means that most of the current devil population have very similar markers on the surface of their somatic cells. When a cancer cell develops in the mouth of one devil, it is able to spread to other devils by breaking off during the biting that occurs during mating. Because the markers on the body cells of all devils are very similar, the immune systems cannot recognise the foreign cancer cell, resulting in the spread of the disease (devil facial tumour disease).



**FIGURE 8** Devil facial tumour disease affects the devil's ability to eat, ultimately causing its death.

### CHECK YOUR LEARNING 14.3

#### Describe and explain

- Define** a 'gene pool'.
- The Hardy–Weinberg law states that in conditions of stability both allele frequency and genotypic ratios remain constant from generation to generation. **Identify** the conditions necessary for this genetic equilibrium.
- Explain** how genetic drift occurs. Why is it considered to be neutral evolution?

#### Apply, analyse and interpret

- Many zoos are attempting breeding programs to increase the numbers of endangered species. The aim of this venture is to release animals back into the wild once adequate numbers have been bred. **Apply** your knowledge of gene frequencies to **analyse** the inherent danger of such programs.

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|--|---|-------------------------------------|----------------------------------|

# Review

## Chapter summary

- 14.1**
  - Natural selection requires variation in a population.
  - Natural selection is the mechanism that uses environmental selection of a specific phenotype to enhance an organism's survival (viability) and reproduction (fecundity).
  - Microevolution results from the change in allelic frequency of a population over a succession of generations.
- 14.2**
  - The gene pool is the sum of all the alleles present in all the individuals in a population.
  - Natural selection acts on all the phenotypes of an organism.
  - An unchanging environment will lead to relatively stable allelic frequency in a gene pool.
  - Changing selection pressures can lead to a directional change in the frequency of alleles in the gene pool.
  - Disruptive selection occurs when a change in an environment selects against intermediate phenotypes, and selects for extreme versions of a characteristic.
- 14.3**
  - Allelic frequency can be calculated using the Hardy–Weinberg equation.
  - The sum of all allelic frequencies for a phenotype in a population equals 1.
  - Genetic equilibrium will be maintained in a large, randomly mating population with unchanging selection pressures, no mutation or migration.
  - Genetic drift (including population bottleneck and founder effect) are caused by random events that result in a change in the allelic frequencies.
  - Small populations are more vulnerable to genetic drift.
  - A limited variation in the gene pool can make a population vulnerable to changing selection pressures.

## Key terms

- directional selection
- disruptive selection
- fecundity
- founder effect
- gene flow
- gene pool
- genetic drift
- genetic equilibrium
- Hardy–Weinberg law
- microevolution
- neutral evolution
- population bottleneck
- stabilising selection
- viable

## Key formula:

Hardy–Weinberg equation	$(p + q)^2 = 1$
Expanded Hardy–Weinberg equation	$p^2 + 2pq + q^2 = 1$
Proportion of homozygous recessives in a population	$= \frac{\text{Number of individuals showing the recessive phenotype}}{\text{Total number of individuals in the population}}$

## Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: ★ = low; ★★ = medium; ★★★ = high.

### Multiple choice

- In the absence of selective forces and mutations, the frequency of a phenotype in a large population will:
  - always decrease because of replacements
  - change slowly in a predictable fashion
  - change rapidly in an unpredictable fashion
  - remain approximately the same indefinitely
- In which of the following mammalian cells would a mutation be most likely to have evolutionary significance?
  - White blood cells
  - Nerve cells
  - Sperm-producing cells
  - Muscle cells
- When a slow and progressive environmental change occurs, a particular population may continue to survive as a result of:
  - its ability to increase its reproductive rate in adverse conditions
  - its members interbreeding with members of other populations
  - no unfavourable mutations occurring within any member of the population
  - the appearance of inheritable characteristics suited to the changing environment
- In rapidly changing environments a process of succession is often observed: populations of organisms appear, flourish for a time and are then replaced by populations of other organisms.

The failure of so many populations to survive in such circumstances is most probably attributable to the fact that these organisms:

  - belong to species with low reproductive rates
  - lack the characteristics necessary to survive in the new environment
  - are unable to undergo mutations in a short time period
  - have exhausted the supply of nutrient materials
- Patterns of heredity within a population are the direct result of:
  - allele frequencies
  - environmental influences
  - mutation
  - recessive traits
- Although some alleles produce harmful effects, they are found to persist in natural populations. All of the following are possible explanations for this **except**:
  - mutated alleles are retained since they may give individuals an advantage if the environment changes
  - different alleles may give an advantage to individuals at different times or in different places
  - even if alleles are being lost by selection, new mutations can be produced
  - heterozygous individuals may be at an advantage over either kind of homozygous individual
- Population geneticists determine allele frequencies in an effort to:
  - control the characteristics of future generations
  - eliminate undesirable traits
  - understand how traits are distributed
  - identify carriers of undesirable alleles
- If a geneticist finds 25% of a population to be phenotypic for a trait known to be due to an allele for a recessive trait, it can be reasonably concluded that:
  - all individuals in the population carry the allele
  - 50% are heterozygous
  - 75% are heterozygous
  - 75% are homozygous for the dominant trait

- 9 A population's gene pool was found to have remained unaltered over a long period of time. Which of the following conditions must have existed in the population?
- A Mating had always been random.
  - B Genetic drift had often occurred.
  - C Interbreeding with other populations had been commonly practised.
  - D The population had lower mortality than other populations.

### Short answer

#### Describe and explain

- ★ 10 **Describe** the conditions under which stabilising and progressive selection act and the effects of each on a population.
- ★ 11 **Explain** how migration of individuals into or out of a population upset the genetic equilibrium of the population.
- ★★ 12 **Describe** how a 'genetic bottleneck' could occur. Could this process lead to genetic drift? Fully **explain** your answer.
- ★★ 13 **Explain** the conditions under which the 'founder effect' could occur in a population. **Describe** the possible long-term consequences of this.
- ★★★ 14 The shaded areas marked with arrows in Figure 1 show the individuals in each population that are being selected against.

a **Identify** the type of selection exhibited in each graph.

b **Explain** the consequences for future generations as a result of the type of selection shown in:

i graph B

ii graph C.

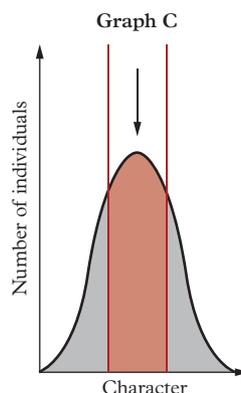
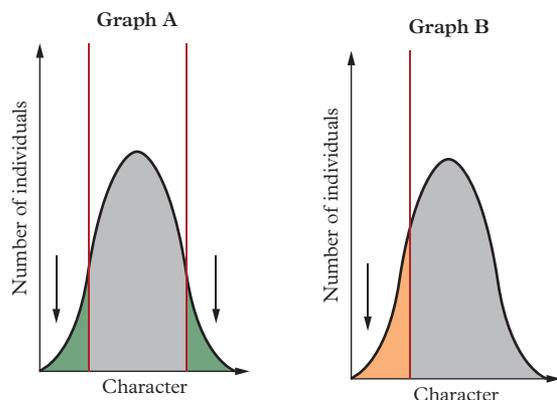


FIGURE 1 The three basic types of natural selection

#### Apply, analyse and interpret

- ★★ 15 Two populations of *Drosophila*, initially containing an equal number of wild type individuals and individuals having the gene for ebony (dark body colour), were kept in two containers under different conditions of temperature. Figure 2 shows the changes with time of the relative proportions of ebony flies. **Analyse** these results.

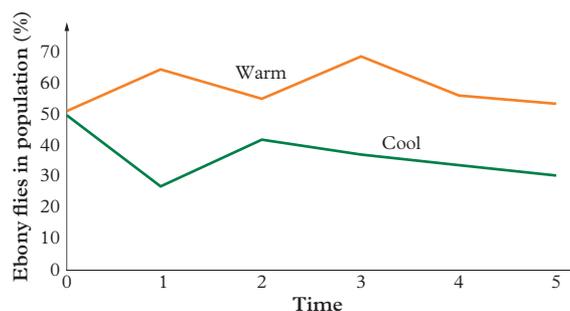


FIGURE 2 Changes in *Drosophila* colour over time due to temperature

- ★★★ 16 Tongue rolling is a dominant trait. Tongue rollers are either homozygous for this allele or heterozygous. Non-rollers are homozygous recessive.

In a survey carried out in Brisbane it was found that of 5000 people, 3200 could roll their tongues whereas 1800 could not.

- a **Determine** what percentage of people in this city sample are homozygous recessive for tongue rolling.
- b **Calculate** the frequency of the recessive allele in the population.
- c **Calculate** the frequency of the dominant allele in the population.

- d Determine** what percentage of people in this sample are homozygous dominant for tongue rolling.
- e Determine** what percentage of people are heterozygous for tongue rolling.
- f** Would you expect the same percentages (a, d, e) in the next generation? **Explain** your response.

### Investigate, evaluate and communicate

- ★★ 17 Cystic fibrosis (CF) is the most common heredity disorder among people in northern Europe caused by a recessive allele. Only 1 in 2500 actually develop the disease, but as many as 1 in 20 are carriers. Homozygous recessive individuals suffer from the incapacitating illness.

The allele for the normal dominant trait controls the amount of a protein (CFTR) found in the membranes of the cells lining the intestine and lungs. CFTR, in turn, controls the secretion of ions and fluid through those linings. CF carriers have only half the amount of normal CFTR as normal people.

In CF patients there is no secretion of chloride ions because the cell membranes have no CFTR. No fluid is secreted into the airways of the lungs, so the mucous that accumulates there becomes sticky and dehydrated, forming an ideal breeding ground for bacteria and viruses. CF patients suffer from repeated infections.

The bacterium *Vibrio cholerae*, which causes cholera, colonises the small intestine, triggering the CFTR mechanism. Patients suffer severe dehydration and electrolyte loss by diarrhoea and can die if untreated.

- a** What advantage would a CF carrier have if infected with the cholera bacterium? **Justify** your answer.
- b Propose** why the CF allele has remained so common in some parts of the world, e.g. northern Europe. **Explain** your answer.

- ★★★ 18 In populations of white clover, allele *Ac* controls the production of cyanide-forming substrate whereas allele *Li* controls the formation of an enzyme that releases the cyanide from the substrate. The alleles *ac* and *li* for the recessive traits indicate that neither substrate nor enzyme is present. Clover that contains both alleles for the dominant trait gives off cyanide when the leaves are crushed and may also release cyanide spontaneously at low temperatures. Individuals that include *Ac* but not *Li* in their genotype give off cyanide slowly when the leaves are crushed. Where *Ac* is not present in the genotype, no cyanide can be released on crushing.

From the above information **evaluate**, with reasons, the likely genotypes of plants found:

- a** in a low-altitude field grazed by cattle
- b** in a hedgerow verge seldom grazed
- c** on the highest part of a mountain where the species can survive.

**Explain** how natural selection would tend to retain a mixture of genotypes within the species as a whole.

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# Speciation and macroevolution

A species is a group of interbreeding natural populations that are reproductively isolated from other groups of organisms. They share a common gene pool, which can be exchanged between populations. Each individual within the species will only have a small subsample of the total number of possible alleles that have arisen over time by mutations. Different patterns of evolution are related to the closeness of the original lineages. A new species arises when the gene pool of a population differs so significantly from the gene pool of other populations of the same species that the populations can no longer interbreed and produce viable, fertile offspring. Different modes of speciation and reproductive isolation occur.



**FIGURE 1** Human evolution can be seen through changes in skull shape over time.

## OBJECTIVES

- Recall that speciation and macroevolutionary change result from an accumulation of microevolutionary changes over time.
- Identify that diversification between species can follow one of four patterns: divergent, convergent, parallel and coevolution.
- Describe the modes of speciation: allopatric, sympatric, parapatric.
- Understand that the differential mechanisms of isolation – geographic (including environmental disasters, habitat fragmentation), reproductive, spatial and temporal – influence gene flow.
- Explain how populations with reduced genetic diversity (i.e. those affected by population bottlenecks) face an increased risk of extinction.
- Interpret gene flow and allele frequency data from different populations in order to determine speciation.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority



# 15.1

## Diversification of species

### KEY IDEAS

- + Microevolution and macroevolution
- + Divergent evolution
- + Convergent evolution
- + Parallel evolution
- + Coevolution

Many things change over time: trees lose their leaves, mountains erode and people age. When such changes involve genetic inheritance, evolution may be involved. The central idea of biological evolution is that all life on Earth shares a common ancestor. Through the process of natural selection, the variety of life diversified to produce the range of organisms that exist today.

At different times and places, or under different circumstances, evolution may take different routes. Regardless of the pathway taken, the accumulation of mutations has resulted in a variety of phenotypes. Natural selection has acted on those characteristics that were best suited to the environment (microevolution). The accumulation of small changes in phenotypes over time can result in new species being formed (macroevolution). It is important to note that natural selection can only select from the phenotypic variations that are available. This does not mean that all adaptations are the ideal solution to an environmental pressure, just the best choice that was available at the time.

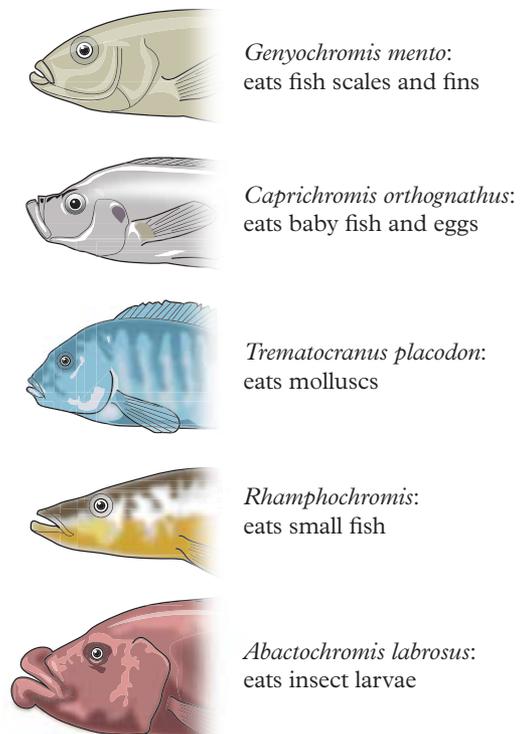
There are four key pathways that evolution can take: divergent evolution, parallel evolution, convergent evolution and coevolution.

### Divergent evolution

**Divergent evolution** occurs when a population of interbreeding organisms diverges (separates) into two or more descendent species. This may occur when there is competition for a particular resource, or when a new niche becomes available in a single environment. Any individuals that have a variation (due to mutation) that allows them to exploit a slightly different resource will therefore have an advantage. Although these variations may have been present in the population for some time, it is not until environmental pressure acts upon the population that these variations will become selected for and become increasingly dissimilar. Eventually two groups of organisms will become so different that they will no longer be able to breed together – they become reproductively isolated.

#### divergent evolution

evolution that leads to descendants becoming different in form from their common ancestor



**FIGURE 1** Divergent speciation (adaptive radiation) of cichlids taking advantage of different niches in Lake Malawi (East Africa)

Because of their recent common ancestry, different species can have some common structures that have developed slightly different purposes (homologous structures). An example of this is the leaf of a plant. Some plants have evolved different functions for their leaves. For example, some have evolved coloured leaves to attract insects (bracts or flower petals), while pitcher plants have evolved leaves shaped like a container to trap insects.

Two forces can drive divergent speciation: a mass extinction that provides new niches for surviving species, and geographic isolation.

The adaptive radiation of species is an example of divergent evolution.

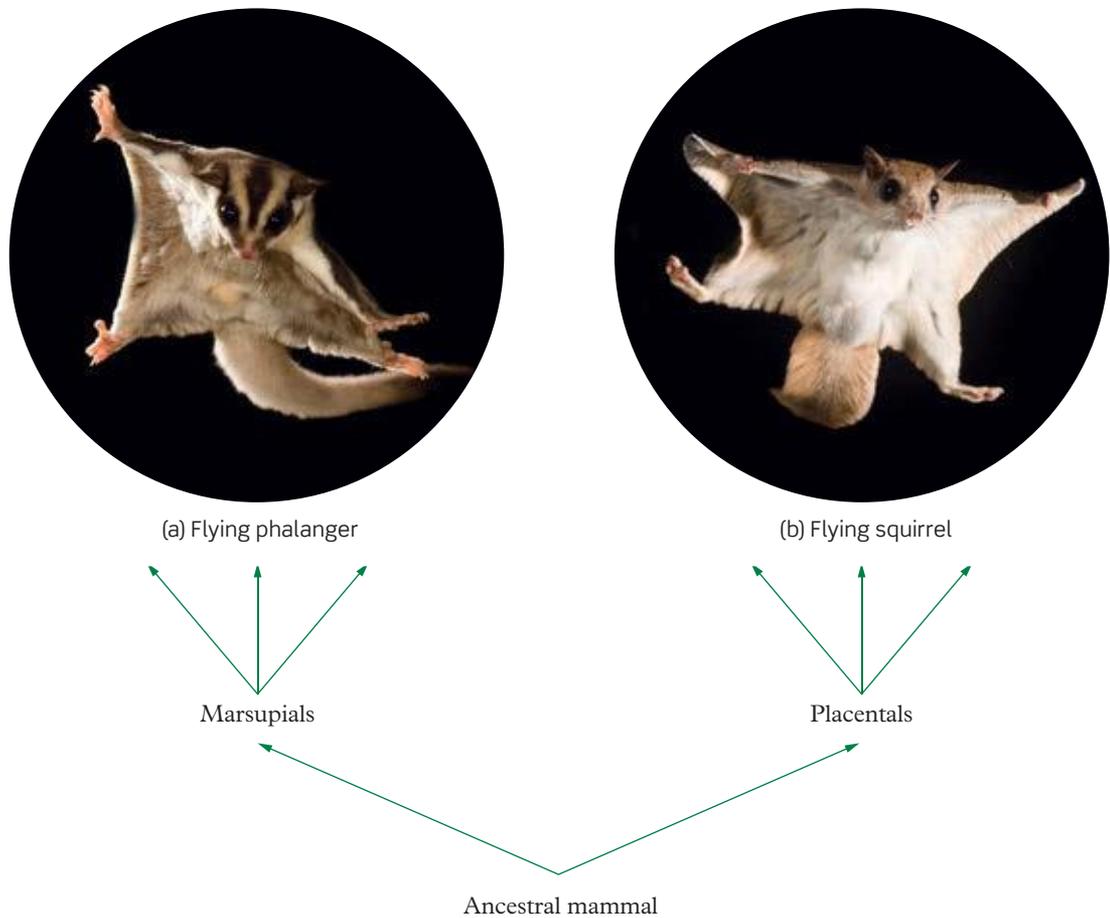


**FIGURE 2** A common ancestor leaf has diverged as a result of different selection pressures.

## Parallel evolution

**Parallel evolution** occurs when two species that once shared a common ancestor are exposed to similar environmental pressures despite their geographical isolation. As a result, similar phenotypic features are selected. An example of this is the parallel evolution of some Australian marsupials and placental mammals. These two groups shared a common mammalian ancestor when South America was joined to Australia in the large Gondwana land mass. Approximately 95 million years ago the continents separated, and different mutations began to accumulate in the two isolated groups of mammals. The majority of the mammals in South America evolved to nurture their young in the uterus via a placenta. Australia marsupials give birth to an undeveloped foetus that completes development in the mother's pouch. Despite this, similar environmental conditions existed, so that when both groups of mammals developed phenotypic variations due to random mutations, similar physical characteristics were selected. This resulted in the two groups of mammals evolving similar physical adaptations. An example of this is the similar body structures of the North American flying squirrel (placental) and the Australian flying phalanger (marsupial). Both show adaptations for their mode of feeding (fruit and insects) and locomotion (gliding from tall tree branches using membranes stretching from the fingers to toes to act as a parachute, fluffy tail and ability to climb). The fleshy membrane (patagium) in both these species evolved independently as a result of random mutations that produced a slightly greater area of skin between the limbs. When this provided a survival advantage, it was passed on to offspring. Further mutations accumulated in each group until the current phenotype of a gliding mammal evolved.

**parallel evolution**  
independent  
evolution of similar  
traits in species  
that once shared a  
common ancestor



**FIGURE 3** Parallel evolution between (a) marsupial and (b) placental mammals occupying similar niches on different continents

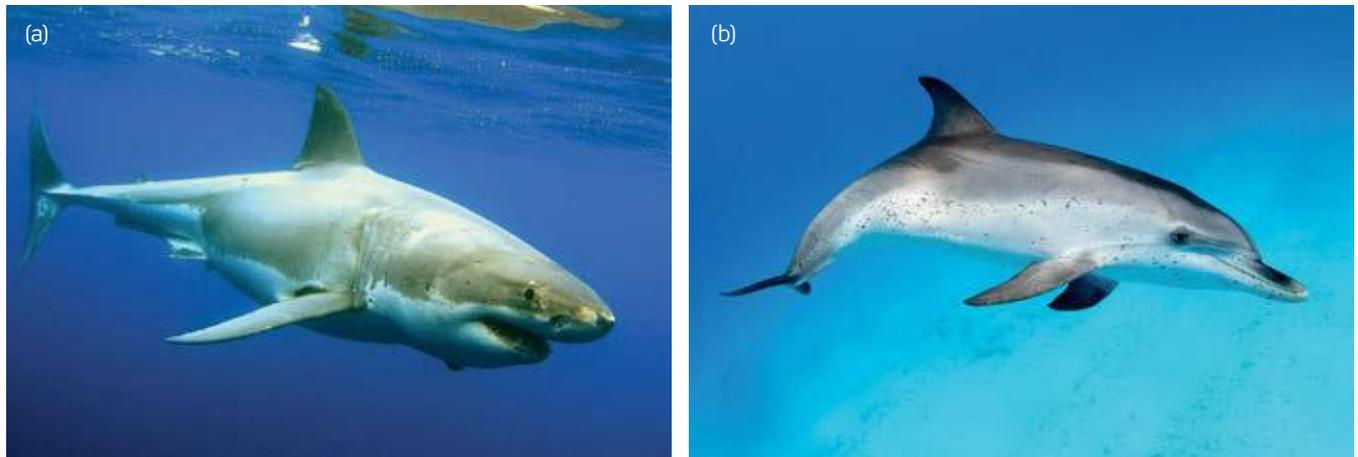
## Convergent evolution

### convergent evolution

the independent development of similarities between species as a result of them having similar ecological roles and selection pressures

In **convergent evolution**, different species demonstrate similar adaptations to similar ecological niches in different locations. The difference between parallel and convergent evolution lies in the closeness of the ancestral relationship. An example of convergent evolution would be that of the shark (fish) and the dolphin (mammal). Due to their marine environment and the need for rapid movement, they both have streamlined bodies, pectoral fins for stabilisation and flattened tail fins for locomotion. The shark swims by moving its vertical tail fin from side to side, whereas the dolphin's horizontal tail fin moves up and down. The pectoral fins of the shark have no resemblance to the tetrapod structure of the dolphin's pectoral fins. Although similar in appearance and function, key differences in internal structure make them analogous structures.

Another example of convergent evolution is the different wings of the pterosaur (extinct flying reptile), bird and bat. These homologous structures are based on the pentadactyl limb that evolved in response to selective pressures imposed by similar environmental conditions, even though they occurred at different times. These wings are similar because laws of aerodynamics govern the shape and size of a wing relative to body size and the movements required for flight.



**FIGURE 4** Convergent evolution seen between organisms in different phyla: (a) the shark and (b) the dolphin

## Coevolution

**Coevolution** results in simultaneous phenotypic adjustments between community members. When two species are very reliant on each other, each species exerts a strong selective force on the other. These interactions are mainly between predator or parasite and prey. The process usually occurs at a microevolutionary level in which small changes in particular phenotypes are selected and cause corresponding selection pressures in the associated species. As a result, the gene pool of both populations changes in a particular direction.

**coevolution** occurs when two or more species reciprocally affect each other's evolution

The first truly terrestrial animals were insects. They depended upon plants for their nutritional requirements. The evolution of insects, therefore, was intimately connected with that of plants, particularly the angiosperms. Plants responded to the selection pressure of being eaten by evolving powerful defences against animal predators. These adaptations include thorns, glass-like bristles on leaf surfaces, and bad-tasting or toxic substances in their tissues. Quinine, nicotine, caffeine, mescaline, opium and cocaine are all plant products that are believed to have evolved in response to predation.

Those plants that produced a toxin had an advantage over other members of their population without that characteristic. Instead of trying to regrow leaves that were eaten by animals, the plants could redirect their energy to reproduction. This increased the plant's representation in the next generation. In response, a chance mutation in a predator could have combated the plant toxin by deactivating it. This would allow that predator to have access to more food than other members of its species, increasing its chance of survival and reproduction. This pattern continued over time as each species (plant and predator) continued to coevolve as a result of exerting selection pressures on each other. This can result in the development of new species of both plant and predator.

Coevolution often provides positive results for all of the organisms involved in the interaction. Animal pollination provides flowering plants with a reproductive advantage over those relying on the whims of the weather. Once flowers have formed, selection pressures act to provide flowers that are increasingly attractive to pollinators. Flowers that mimic a particular insect pollinator, flowers with nectaries, or larger amounts of pollen improve the chance of cross-pollination and genetic variability in their offspring. Richer and more abundant sources of food (pollen and nectar) benefit the pollinating animal. In a similar way there has been coevolution between fruit formation and animal dispersal agents.

## CASE STUDY 15.1

### Koalas and eucalypts coevolution

It is surprising that any animal can exist on a diet of eucalypt leaves. Although the leaves have a high water content (approximately 50%), and are high in fibre (18%) and tannins (13%), the low levels of fats, carbohydrates, proteins and minerals (a total of 19%) provide very little nutritive value. In addition, the leaves produce toxic oils and other substances. For example, prussic (hydrocyanic) acid is released by young leaves of some species at certain times. The high levels of fibre (particularly lignin) make the leaves highly indigestible.

The koala is a specialist feeder on eucalypt leaves. The types of eucalypts that koalas utilise, however, are limited by their tolerance to specific plant poisons.

The coevolution of the koala with eucalypts has resulted in:

- tolerance of, or the ability to detoxify, poisonous defence chemicals produced by some species of eucalypt
- slow rate of passage of chewed and partially digested food, allowing microbial digestion of fibre
- a very enlarged caecum and proximal colon, maximising microbial digestion
- selective retention of fluids and fine particles in the proximal colon for absorption and elimination of the coarse, less digestible particles.

In spite of these adaptations the koala can still absorb only 25% of the fibre. The tannins in the leaf bind to carbohydrates and proteins, making them less available for absorption. In order to survive on this specialist diet, an adult koala must consume at least one kilogram of its preferred foliage each day.

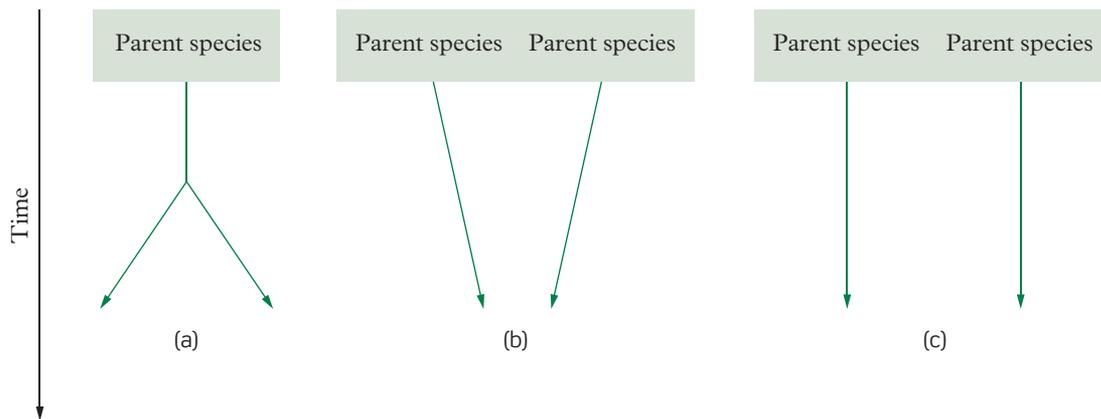
The koala's low intake of essential nutrients, and the necessity for slow digestive processes, are probably the reason for this animal's essentially sedentary nature. The brain is a highly energy-consuming organ. Another adaptation of the koala to its poor quality diet has been reduction in brain size.

**FIGURE 5** A koala is a specialist feeder on some eucalyptus leaves.



Mimicry is an example of coevolution. The white sap of the cotton bush (*Asclepias* sp.), for example, contains toxic substances (heart poisons for vertebrates) that deter predators. The monarch or wanderer butterfly (*Danaus plexippus*) has evolved enzymes that enable its caterpillar to feed on the cotton bush without being poisoned. These chemicals are stored in its body and are thus present in the adult form. Predators of these distinctively marked butterflies become very ill and rapidly learn to avoid them: the plant deterrent has now become a deterrent at the next level of the food chain.

The female of a different species, *Hypolimnas misippus*, has the same colour patterns as the wanderer butterfly but does not contain the toxic chemicals. Since these butterflies inhabit the same areas in northern Australia, predators avoid both the wanderer butterfly and the non-toxic *H. misippus*. Coevolution of the two species of butterflies has benefited the survival of *H. misippus*.



**FIGURE 6** Three of the four modes of evolution: (a) divergent evolution; (b) convergent evolution; (c) parallel evolution

### CHECK YOUR LEARNING 15.1

#### Describe and explain

- 1 Describe** the means by which divergent speciation may occur.
- 2 Define** the term ‘coevolution’.
- 3 Explain** why mimicry is described as an example of coevolution.
- 4 Identify** two specific examples of coevolution between plants and animals.

- 5 Construct** a table to compare parallel, convergent and divergent evolution.

#### Apply, analyse and interpret

- 6 Distinguish** between divergent and convergent evolution.

#### Investigate, evaluate and communicate

- 7 Discuss** the ways that coevolution differs from convergent evolution.

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» Weblink  
Parallel evolution

» Weblink  
Convergent evolution



# 15.2

## Speciation

### KEY IDEAS

- + The gradual change in a population
- + Speciation in a single population
- + A cline
- + Geographical isolates
- + Zones of hybridisation

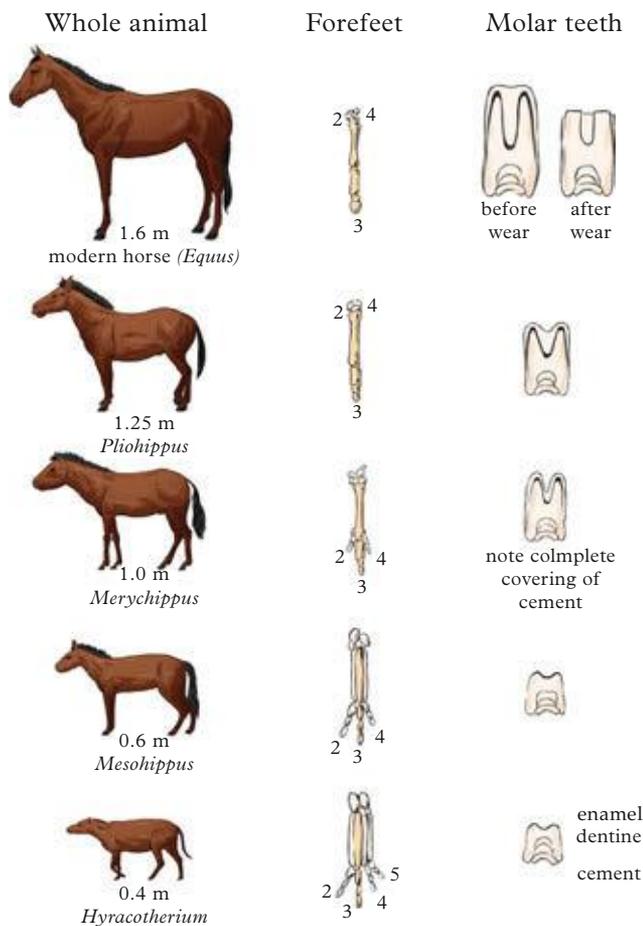
If organisms are of the same species, they are able to reproduce with each other in natural conditions to produce viable, fertile offspring. This means they share a common gene pool (all the alleles for all of the genes found in the species). A new species arises when the gene pool of a population differs significantly from the gene pool of other populations of the same species, so the populations can no longer breed with one another to produce viable, fertile offspring. This means they are reproductively isolated.

**speciation**  
the evolutionary process by which new and distinct species are formed in the course of evolution

**Speciation** – the development of new species – can take place in two general ways. As seen in Chapter 14, the number of alleles in a population’s gene pool is very large and each member of the population carries a sample of these alleles that are expressed as the

phenotype of the individual. At any time, natural selection acts on the population, choosing individuals with the overall phenotype best suited to the environment at that time. The organisms that are ‘fittest’ for the environment have a greater chance of reproducing and passing on the alleles they carry. In this way, the frequency of alleles in the population can change. Some alleles will be lost from the population, some will become less prevalent and others will become more prevalent. Over time a single species may change so much from the original form that it is considered a new species. The evolution of the horse, over a period of 50 million years, is an example of this. A small, dog-sized, forest-dwelling animal (*Hyracotherium* sp.) gradually evolved through an accumulation of mutations and natural selection. Microevolutionary changes in foot and tooth structures, accompanied by an increase in height, resulted in the macroevolution of the modern horse (*Equus* sp.) as seen in Figure 1.

More commonly, species may become split into two or more groups that no longer share the same gene pool.



**FIGURE 1** Evolution of the horse

They evolve independently of one another, each being acted upon by slightly different selection pressures until reproductive isolation occurs and they can no longer interbreed.

## Structural elements of a population

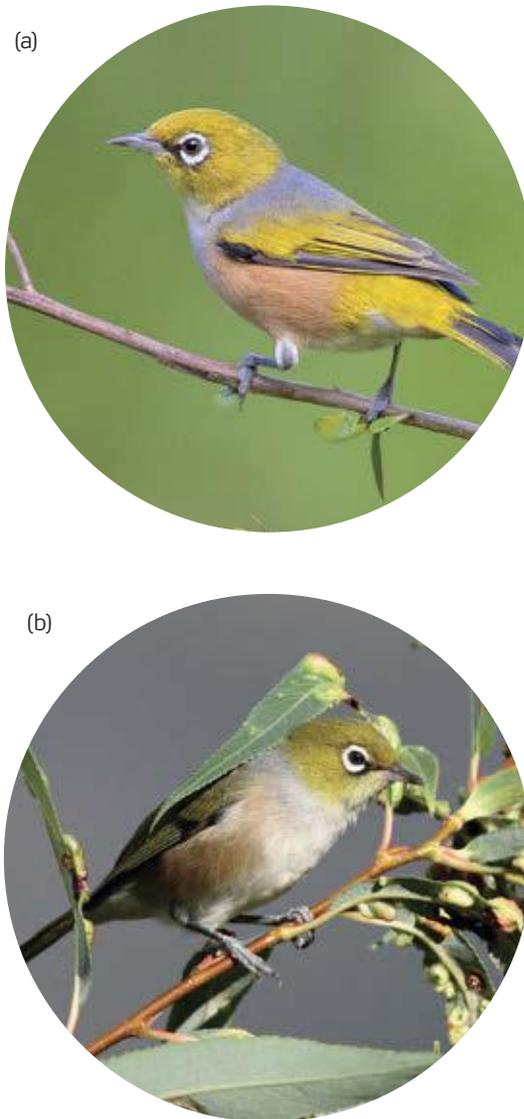
All populations (the same species in the same area during the same time period) are usually limited to a specific location by the geography of the environment or by competition for resources. These limitations result in the structural elements of a population.

### Clinal variations

Occasionally a population is spread over the side of a mountain. The climate and types of plants at the top of the mountain can be slightly different to those found at the base of the mountain. As a result, there may be slight phenotypic differences between members of a species that can survive at the top of the mountain and those that can survive at the mountain base. All members of the population may still be able to breed with one another (gene flow occurs) despite the slightly different selection pressures. This series of gradually changing phenotypes in adjacent populations is called **clinal variation**.

Clines are ultimately the product of two conflicting forces: selection and gene flow. Selection makes every population uniquely adapted to its local environment. Gene flow, on the other hand, tends to make all populations of a species identical.

A **cline** refers to a specific characteristic such as colour or size, rather than describing the entire appearance of the species. A population may exhibit as many different clines as it has variable characteristics (features or traits). Each cline is theoretically independent of other characteristics. For example, nearly all Australian birds with size variations decrease in size from Tasmania northwards to Torres Strait along a regular cline. Intensity of colour follows a different cline, decreasing from the humid periphery of Australia to the arid interior, or from cold regions to hot regions.



**FIGURE 2** Colour cline in the silvereye (*Zosterops lateralis*) from (a) dark in Tasmania to (b) light in northern Queensland. Birds in northern Queensland are slither in build than those in Tasmania.

**clinal variation**  
gradual changes or differences in inherited characteristics of adjoining populations of a species spread across a range of environments (geographic range)

**cline**  
is a measurable gradient in a single character (or biological trait) of a species across its geographical range

## Geographical isolates

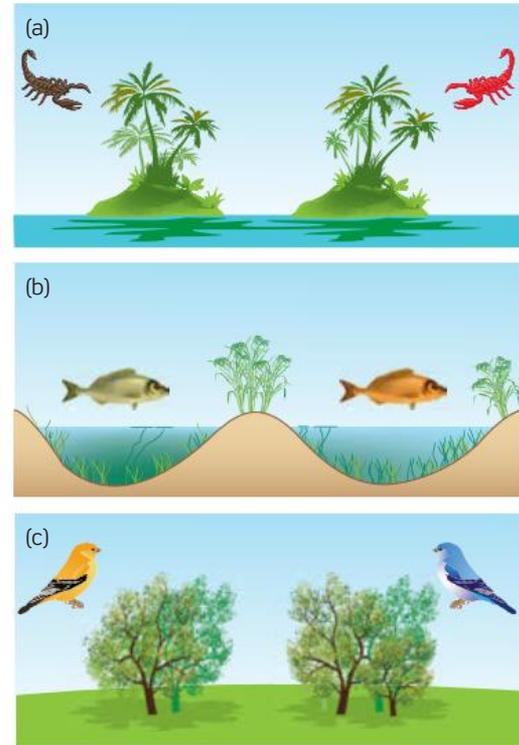
### geographic isolates

a physical barrier that prevents interbreeding between members of different populations of a species

**Geographical isolates** are different populations that are prevented from breeding with each other by a permanent physical, or extrinsic, barrier. Geographic barriers are variable, and what might be a barrier to one species might not prevent another species from breeding. For example, freshwater fish living in lakes may be isolated from other populations by land barriers between water systems, whereas birds feeding on the fish can fly from one water system to the next. Grasslands between forested areas may form barriers for bird populations. The sea is a barrier for oceanic island populations.

Geographical isolates have three possible fates. They may:

- become separate species
- die out altogether
- re-establish contact with the main body of the species.



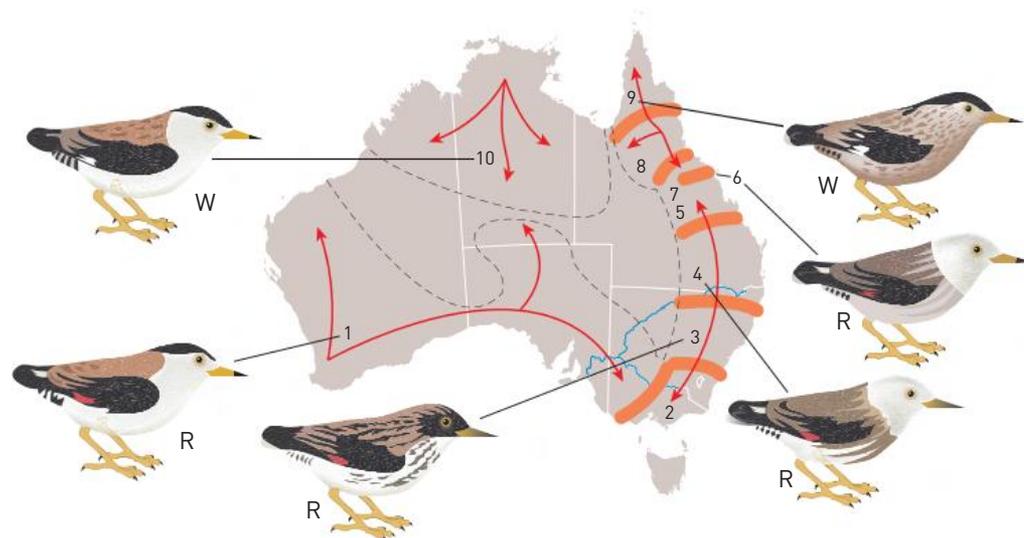
**FIGURE 3** Different examples of geographic forms that result in genetic isolation between populations of a species: (a) true islands; (b) ponds, lakes and oceans; (c) habitat fragmentation

## Zones of hybridisation

Although geographically isolated populations may evolve phenotypic differences, their gene pools may be sufficiently similar. If the populations later make contact, the individuals at the contact edge are able to produce fertile offspring. This results in a blending of the phenotypes of both populations. The majority of the two populations only interbreed with their own group. Thus, between these two groups a **zone or belt of hybridisation** arises.

### zone or belt of hybridisation

area in which two divergent subspecies may interbreed



**FIGURE 4** Varied sittella (*Daphoenositta chrysoptera*) in Australia. The arrows indicate expansion from post-Pleistocene arid refuges and the resulting belts of hybridisation (orange areas) as formerly isolated populations met along a broad front. Birds indicated with an 'R' have a red wing bar, while those indicated with a 'W' have a white wing bar.

This hybridisation occurs at a high rate after periods of climatic change: for example, the end of the Pleistocene, which was a period of glaciation. During this time many warmer temperate zone species were separated by large tracts of ice. As the Earth warmed, these small temperate zones rejoined, allowing the populations to interact.

In Australia, drought conditions prevailed between 4000 and 20 000 years ago, resulting in the isolation of forest-dwelling birds in a number of coastal refuges. The current distribution and variation of the varied sittella (*Daphoenositta chrysoptera*) reflects the existence of such refuges. With an increase in rainfall at the end of the dry period, there was expansion of the forest areas accompanied by an expansion of the range of the sittellas, resulting in a merge of the former isolated populations. Where their ranges overlap, the birds may sometimes interbreed, forming five or six zones of hybridisation.

## Subspecies and races

When an abrupt shift in genetically determined characteristics occurs in a geographically variable species, the populations on each side of the ‘step’ are termed subspecies or races. Subspecies are, therefore, groups of natural populations within a species that differ genetically and are partly isolated from each other reproductively by having different ranges. The term ‘race’ is sometimes applied to more isolated populations when the populations are recognisably different genetically but are believed to be potentially capable of interbreeding freely.



**FIGURE 5** The blue-cheeked rosella (*Platycecus elegans*) consists of three races: (a) the crimson rosella of the east coast of Australia and along the south coast of Victoria and South Australia; (b) the Adelaide rosella of the Adelaide Hills and surrounds; (c) the yellow rosella along the Murray River. The three races have a common gene pool.

### CHECK YOUR LEARNING 15.2

#### Describe and explain

- 1 **Define** a species.
- 2 Can a population have more than one cline?  
**Explain** your answer.
- 3 **Define** the term ‘cline’.

- 4 Many species can have several subspecies.  
**Explain** what this means and how it comes about.

#### Apply, analyse and interpret

- 5 **Differentiate** between clinal variation, geographical isolates and zones of hybridisation.

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» Weblink  
Clinal variations

» Weblink  
Geographical isolates

# 15.3

## Modes of speciation

### KEY IDEAS

- + Allopatric speciation
- + Parapatric speciation
- + Sympatric speciation

### Allopatric speciation

Most biologists agree that in the vast majority of cases, the initiating factor in divergent speciation is geographic separation. The causes for this separation are diverse – rivers change courses, mountains rise, continental drift occurs (e.g. the East African Rift), organisms migrate or an unfavourable habitat arises between two populations. If the organisms in the two populations cannot cross the barrier, the separated populations will no longer be able to exchange genes, and gene flow is halted. At first the only reproductive barrier will be geographic, and they will potentially be capable of interbreeding. Over time, new unique mutations may occur, and each population may be exposed to different selection pressures. Eventually they may become so genetically different that there would be no effective gene flow between them should they again come into contact. They then become reproductively isolated.

(a)



*Macropus giganteus*



*Macropus fuliginosus*

(b)



(c)



**FIGURE 1** (a) Distribution of eastern and western grey kangaroos: (b) eastern grey kangaroo (*Macropus giganteus*); (c) western grey kangaroo (*Macropus fuliginosus*).

Speciation is initiated when external barriers make the two population systems completely **allopatric** (= ‘different houses’, i.e. having different ranges). This is not completed until the populations have evolved mechanisms that will keep them allopatric, or that will keep the gene pool separate even when they are **sympatric** (= ‘same house’, i.e. having the same range).

The eastern grey kangaroo (*Macropus giganteus*) and the western species (*M. fuliginosus*) are believed to have evolved by allopatry. Evolving in isolation in the eastern and western parts of Australia, each group gradually expanded their range. Although their distribution overlaps in western Victoria and New South Wales, they do not interbreed.

There are three possible outcomes of geographic isolation of populations.

- 1 An extrinsic barrier divides a population, but the barrier breaks down before the subpopulations have evolved **reproductive isolating mechanisms**. The populations fuse together again and share a common gene pool.
- 2 Isolation is long enough for the development of incomplete intrinsic isolating mechanisms. The extrinsic barrier breaks down and hybridisation occurs. The hybrids are not as well adapted as the parental stock, and there is selection pressure to prevent mating between populations. This results in a more rapid divergence between the two populations – **character displacement** – due to the forces of natural selection.
- 3 Two populations are isolated by a geographic barrier for so long that once the barrier breaks down, they are too different to interbreed. They have become sympatric species.

**allopatric species**  
species that result when two populations of the same species become isolated from each other due to a geographic barrier

**sympatric species**  
closely related but reproductively isolated species living in the same geographic range

**reproductive isolating mechanisms**  
reproductive characteristics that prevent reproduction between populations

**character displacement**  
the evolutionary divergence of characteristics displayed by two or more species with the same niche in a particular habitat

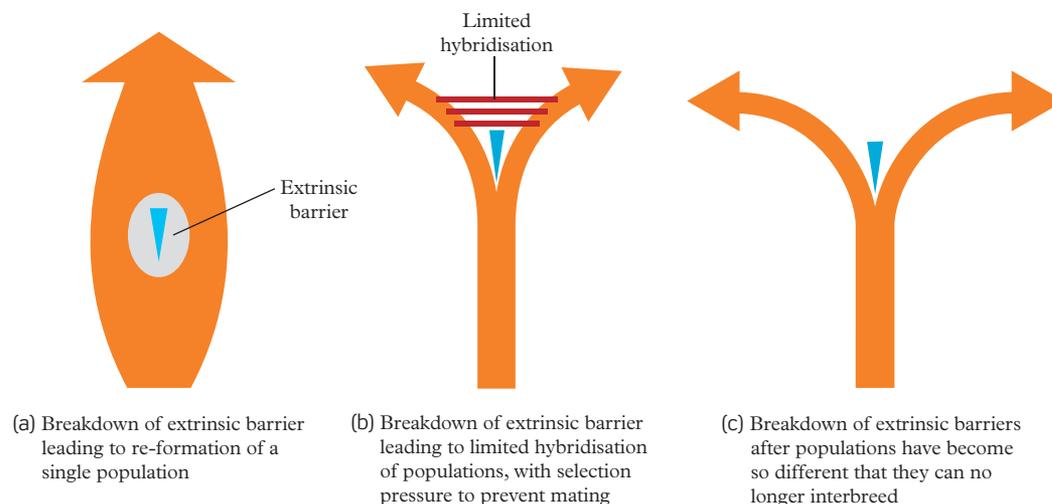


FIGURE 2 Models of geographic isolation

## Parapatric speciation

Speciation might also occur in a population with no specific extrinsic barrier to gene flow. When a population spreads over a broad geographic range, mating throughout the population is unlikely to be random. Individuals at one end of the range are unlikely to mate with those at the other end of the range. There is reduced gene flow but not total isolation. If different selective pressures exist at each end of the range, allele frequencies could alter so much that each group would have distinct characteristics and lifestyles that bring about reproductive isolation. This **parapatric speciation** is extremely rare and is more likely to occur in those species that demonstrate distinct clinal variations.

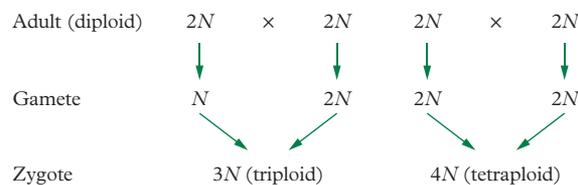
**parapatric speciation**  
when two subpopulations of a species evolve reproductive isolation from one another due to habitat differences within the population range



**FIGURE 3** Two neighbouring populations of Australian oaks became distinct while sharing a common border where limited hybridisation occurs

## Sympatric speciation

Sympatric speciation occurs when populations of a species become reproductively isolated from each other while they share the same habitat. Like parapatric speciation, this is a rare event. The reproductive isolation most commonly occurs through polyploidy, in which the offspring have more than the normal number of chromosomes for the species. This is caused by the failure of the chromosomes in the egg and/or sperm to separate during meiosis.



**FIGURE 4** Flow diagram of sympatric speciation

Sympatric speciation through polyploidy is more likely to occur in plants than in animals. Plants are more likely to self-fertilise than animals. For example, the wheat that is commonly grown today is a result of polyploidy. Durum wheat has four sets of chromosomes, while bread wheat commonly has six sets of chromosomes.

For a polyploid animal to reproduce, it must mate with another member of its species that has randomly undergone the same polyploidy. Parthenogenesis in some animals has been a result of polyploidy.

**parthenogenesis**  
reproduction from  
an ovum without  
fertilisation in animals

**Parthenogenesis** (virgin birth) is the development of a new individual from an unfertilised egg. The most common form of this results in the production of daughters only, because the females are able to either circumvent meiosis, or modify the process so that a diploid egg cell can initiate development without the trigger usually provided by sperm penetration. Elimination of the male from the reproductive process decreases genetic variability and may result in genetic drift in isolated populations. This can lead to rapid divergence of characteristics within a population, leading to speciation. This has been recorded in Bynoe's gecko (*Heteronotia binoei*), and also in the Australian morabine grasshopper (*Warramaba virgo*).

## CASE STUDY 15.3

### Parthenogenesis in an Australian gecko

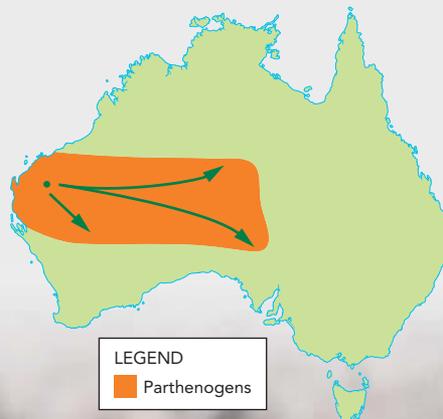
Geckos are an ancient and successful group of lizards distributed through the tropics. A study of geckos has revealed that six of the approximately 800 species are parthenogenic. They tend to have the following features:

- broad geographic range – usually larger than their sexual relatives
- common in disturbed environments, often in association with human activity. For example, the only Australian parthenogenic species, Bynoe’s gecko (*Heteronotia binoei*), is found in homestead rubbish tips in arid areas.

Chromosome studies of Bynoe’s gecko have shown that what was thought to be one species, on the basis of morphological characteristics, is in fact several, with at least four sexual species. This species is triploid; that is, it has three of each type of chromosome.

The formation of the parthenogenic triploid forms probably resulted from mutation in a female so that she produced diploid eggs, which were then fertilised by a male. From the onset of parthenogenesis there was no further mixing of genes, and they can therefore be considered as permanent hybrids. Further reproduction by parthenogenesis freezes the diversity from both of the sexual parent species.

Through chromosomal and mitochondrial DNA examinations, the site of the original hybridisation was determined as the western goldfields of the Hamersley Ranges in fairly recent evolutionary times. From there the parthenogens have spread eastward to central Australia.



**FIGURE 5** The origin and present geographic distribution of the various parthenogenic types of Bynoe’s gecko in Australia



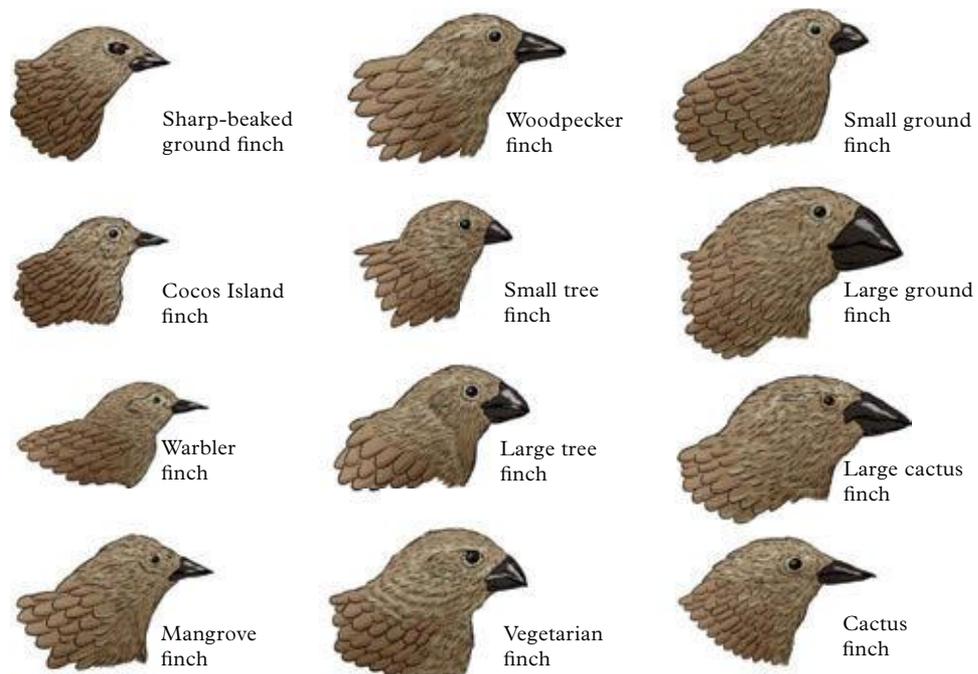
## Character displacement

Recent studies suggest that sympatric speciation may be more significant than previously thought. Within any population a vast number of characteristics can have different, alternative phenotypes. When considering all of the possible combined phenotypes, there is great variation between individuals in a population. Often the selection pressures that are present do not completely exclude any particular phenotype. Instead the homogenising gene flow maintains the group as a single species.

For a population to be stable, small changes in structure or behaviour are not favoured, and the allelic frequencies is maintained across generations. If this does not occur, and one particular combination of alleles is favoured through sexual reproduction, then natural selection occurs against less adapted combinations. The population becomes unstable. This form of population instability can occur when small, but critical changes in the common environment (e.g. food availability) favour new allele combinations over existing ones.

This does not require mutations, only different combinations of existing alleles. The species diverge because of unmanageable loss of stability.

This model of sympatric speciation, supported by mathematical models based on physical phenomena, explains, for example, the evolution of the diverse group of finches on the Galapagos Islands from one original species. As a result of natural, small random variations in a particular feature such as beak size, any slight change in the available food supply may give an advantage to birds with beak sizes either above or below the average size. For example, birds with small beaks could eat small seeds whilst those with the larger beaks were able to crack seeds that had previously been too hard to open. This meant that birds with medium-sized beaks were unable to compete with birds at either extreme. The birds will divide into two distinct types that avoid competition by utilising different food sources. Selection pressure for resource partitioning may result in different gene pools, and thus new species.



**FIGURE 6** Diverging beak sizes and shapes in the Galapagos finches

## Heat shock proteins

Research into ‘**heat shock proteins**’ (HSPs) also adds support to the idea that much evolution occurs in sympatric populations under stress. A group of proteins (called HSP90s) are known to bind to unstable proteins, preventing their breakdown in environmental disruptions (such as high temperature) by maintaining their shape.

Evidence from a variety of organisms suggests that HSP90s have a large role in maintaining species homogeneity. It is thought that they are able to prevent the expression of a number of mutations, including those of regulatory genes. This means an organism can, over many generations, accumulate many minor mutations that are hidden by the protective effect of the HSP90s.

When a population experiences environmental stress, however, it seems probable that the HSP90s are unable to deal with all of the faulty proteins that occur. This can result in the hidden mutations becoming evident in the phenotype of the organisms or species. If the mutations are in a regulatory gene and the stress occurs during the developmental stage of the organism, there will be abrupt changes in the shape and form of the adult.

Axolotls are salamanders that have not metamorphosed into the adult terrestrial form like other amphibians. They retain a sexually reproducing gilled, larval body plan due to a mutation of a regulatory gene. If experimentally given the hormone thyroxin, they will develop into an adult air-breathing form similar to other amphibians. This **developmental neoteny** can bring about rapid speciation.

This ability of HSP90s to store and release mutations helps to explain how species can make the rapid transition from one body form to another; that is, to jump dangerously maladapted intermediate forms.

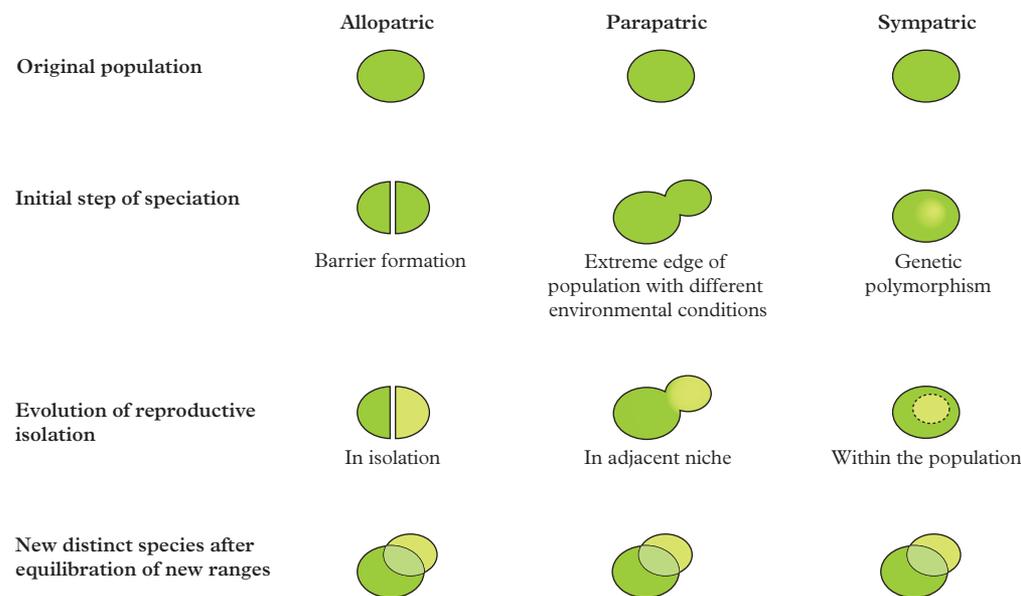
Proponents of the theory of punctuated (rapid) evolution suggest that these types of changes are the basis for evolution.



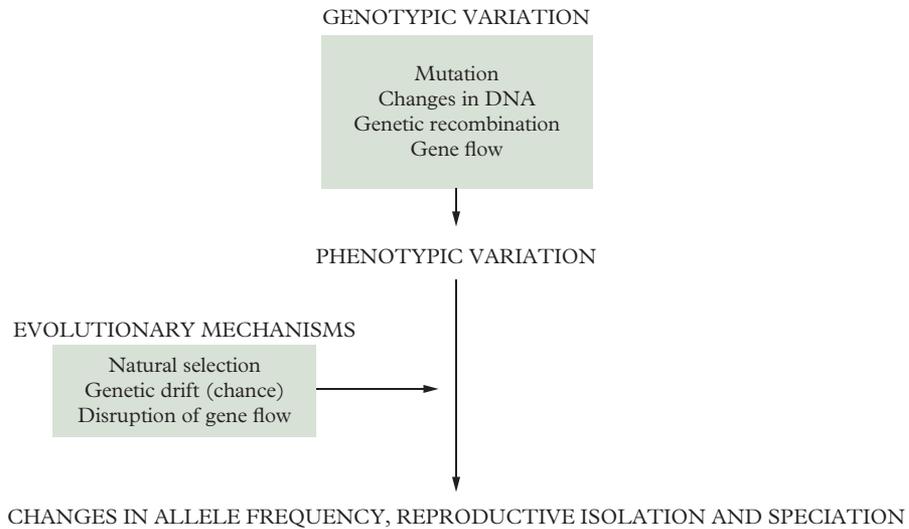
**FIGURE 7** Axolotls retain a sexually reproducing body plan due to a mutation in a regulatory gene.

**heat shock protein**  
member of a family of proteins produced by cells in response to stressful environmental, chemical or physical conditions; e.g. HSP90s assist with the activation and stabilisation of a wide variety of proteins

**developmental neoteny**  
the retention of juvenile structure or traits by adults in a species



**FIGURE 8** Comparison of allopatric, parapatric and sympatric speciation



**FIGURE 9** Steps in speciation

## Using gene flow data

In a population with a large range, gene flow may be disrupted between different ends of the range due to different environmental selective pressures. Some migration between the two populations might occur, but the influence on gene flow will depend on the migration rate (the proportion of migrants per generation). Migration can also occur between adjoining populations. The greater the migration rate, the greater the effect of gene flow. The migration of individuals does not necessarily bring about gene flow. Gene flow will only have an evolutionary effect if the migrants interbreed with the resident population and produce offspring.



**FIGURE 10** The leopard species has a large range (>20 million square kilometres) across Africa, the Middle East and Asia.

### WORKED EXAMPLE 15.3

A proportion of insects in each of two populations is resistant to a toxin produced by a plant on which the insects feed. Area 1 (where Population 1 lives) contains few of these plants. Area 2 (which contains Population 2) has a large proportion of the plants. Organisms that have allele A are able to resist the toxin. Before migration the frequency of allele A ( $f(A)$ ) was found to be:

Population 1 is 0.3

Population 2 is 0.9.

A number of insects migrate from Area 2 to Area 1. As a result, the population in Area 1 now contains 90% original residents and 10% migrants (from Area 2).

Determine the new allelic frequency for toxin resistance in Population 1.

#### SOLUTION

To calculate the new allelic frequency:

$$f(A) \text{ in Population 1 after migration} = \left(\frac{90}{100} \times 0.3\right) + \left(\frac{10}{100} \times 0.9\right) \\ = 0.36$$

This means the allelic frequency of toxin resistance has increased from 0.3 to 0.36. In this case, migration has had little impact on the allele frequency in Population 1.

In worked example 15.3, migration has had little impact on the allele frequency in Population 1. Had the proportion of immigrants from Population 2 been 30%, the impact would have been greater –  $f(A)$  and Population 1 would have increased to 0.48. If the abundance of the toxic plant increased in the range for Population 1, those insects with toxin resistance might begin to feed on those plants exclusively and the insects without the resistance might only feed on non-toxic plants. This could lead to a disruption of gene flow between the two groups of insects and ultimately speciation.

### CHECK YOUR LEARNING 15.3

#### Describe and explain

- 1 **Explain** how the development of parthenogenesis may lead to rapid evolution of a new species.
- 2 In which types of organism is polyploidy most common? **Explain** the reasons for this.
- 3 **Describe** how changes in regulatory genes can lead to rapid evolution.

- 4 **Describe** how the theory of punctuated evolution explains the rapid emergence of new species.

#### Apply, analyse and interpret

- 5 **Construct** a table to **compare** allopatric, parapatric and sympatric speciation.
- 6 **Critique**, with examples, the circumstances under which divergent speciation could occur.

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Parapatric speciation

» Weblink

Sympatric speciation

# 15.4

## Reproductive isolation

### KEY IDEAS

- + Reproductive isolation
- + Pre-mating mechanisms
- + Post-mating mechanisms

For speciation to occur, different populations must become reproductively isolated. This isolation may result from factors that prevent mating occurring or factors that occur after mating (e.g. preventing the production of a viable hybrid or affecting the hybrid reproducing).

### Pre-mating isolating mechanisms

#### Ecogeographical isolation

Two populations that are initially separated by some extrinsic barrier may, in time, become so specialised for different environmental conditions that neither can survive in the habitat of the other. This means they are unable to reproduce in natural conditions.

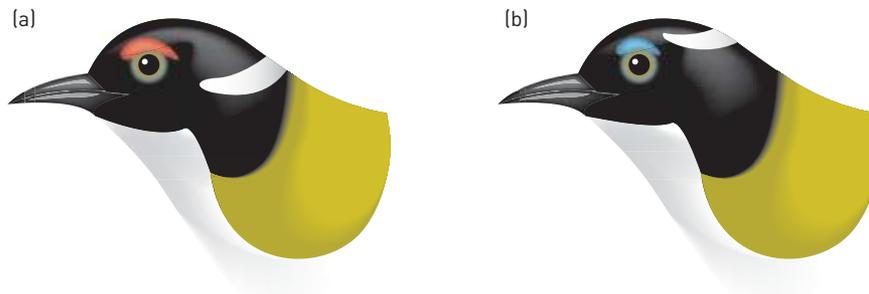
Many eucalypts of the sand plains of southern Western Australia are adapted to winter rain and will not thrive in eastern Queensland with its summer rains.

Even when the two species occupy different habitats within a common range, the individuals of each population will be more likely to encounter and mate with members of their own population than with members of the other population. Their genetically determined preference for different habitats helps keep the two gene pools separate.

The Australian white-naped honeyeater (*Melithreptus lunatus*) is found in forest areas along the east coast from Adelaide to Cairns. A similar species, the white-throated honeyeater (*Melithreptus albogularis*), lives in tropical woodland savannah from Derby in Western Australia across northern Australia to Grafton in New South Wales. In the overlap zone in north Queensland, *M. lunatus* occupies the high country and *M. albogularis* the lowlands. In central Queensland the former inhabits the hills and the latter the flat country.



**FIGURE 1**  
The mottlecah, *Eucalyptus macrocarpa*, only grows in southern Western Australia.



**FIGURE 2** Distinguishing markings of the (a) white-naped (*Melithreptus lunatus*) and (b) white-throated (*M. albogularis*) honeyeaters

## Seasonal (temporal) isolation

If two closely related species are sympatric but breed in different seasons of the year, interbreeding between them will be effectively eliminated. *Pinus radiata* and *Pinus muricata* are sympatric in parts of California. They do not form hybrids in these conditions because *P. radiata* sheds its pollen in early February, whereas *P. muricata* sheds its pollen in April. Many Australian eucalypts in mixed forests, which could potentially form hybrids, also flower at different times of the year.

## Behavioural isolation

Behaviour plays a fundamental role in species recognition among animals. Visual, auditory or olfactory signals, or combinations of them, are important in mating. Each species of firefly, for example, has its own particular flashing pattern that draws the male and female together. The duration of the flash, the interval between flashes and the intensity and colour of the light varies from species to species. Bird songs, frog calls and stridulations of many insects such as cicadas (noises made by rubbing leg parts together) are all species specific.

The black-throated finch (*Poephila cincta*) inhabits savannah woodlands from south-eastern Queensland to northern Queensland. A very closely related finch, the long-tailed finch (*Poephila acuticauda*) in dry savannah in northern Australia, is somewhat similar in appearance. They both have the same courtship pattern except that the male black-throated finch does not dance with a piece of grass in its bill, as does the long-tailed finch.



**FIGURE 3** The flashing pattern of the firefly is species-specific.



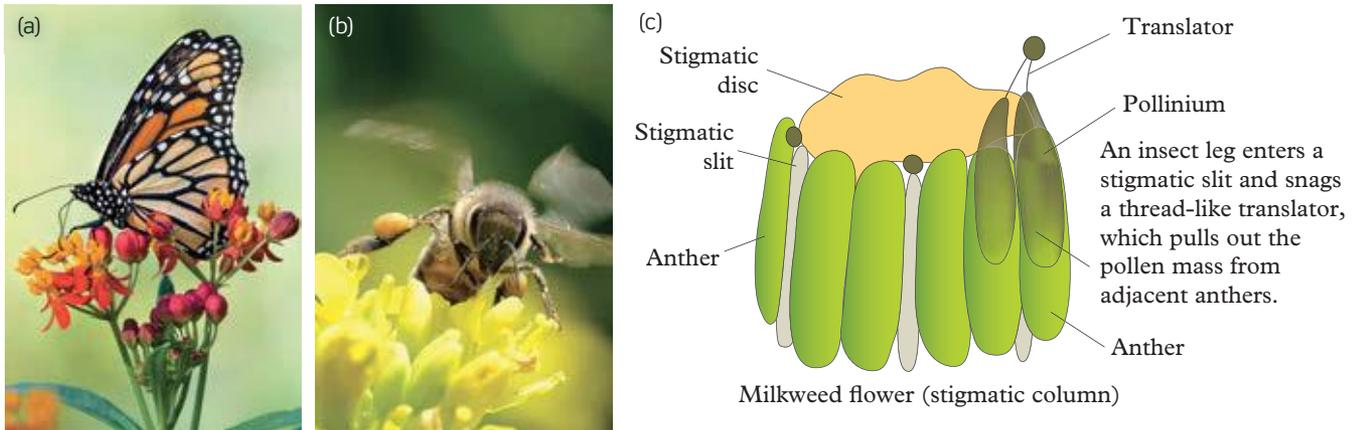
**FIGURE 4** The (a) black-throated finch has a different courtship display to that of the (b) long-tailed finch – a behavioural isolating mechanism where their ranges overlap.

## Post-mating isolating mechanisms

### Mechanical isolation

If structural differences between two closely related species make it physically impossible for mating between males of one species and females of the other, the two populations will not exchange genes.

The pollen of milkweeds/cotton bushes (*Asclepias*) is contained in small sacs (pollinia; singular, pollinium; plural) that stick to the legs of insects. The stigma of the flower has slits into which the pollen sac must be inserted. Each species of cotton bush has a distinctively shaped pollen sac with corresponding stigmal slits, making pollination between the species impossible even though the species are sympatric.



**FIGURE 5** (a) the orange milkweed with monarch butterfly; (b) bee with pollen sacs (pollinia) stuck to its legs; (c) diagrammatic representation of the milkweed reproductive structures

## Gametic isolation

Even if individuals from two different species do mate, actual fertilisation may not take place. In many species of the fruit fly, *Drosophila*, interspecific mating results in an antigenic reaction in the genital tract of the female, causing the walls of the vagina to swell and kill the sperm before they reach the egg cells.

## Developmental isolation

When cross-fertilisation occurs, the development of the embryo is often irregular and does not come to full term.

The frogs *Rana pipiens* and *Rana catesbeiana* can produce viable embryos only up to a very young stage of development. The offspring die before becoming fully developed. Crosses between goats and sheep produce embryos that usually die long before birth.

## Hybrid unviability

Hybrids are often weak and malformed, and frequently die before they reproduce.

## Hybrid sterility

Some interspecific crosses produce viable but sterile offspring. An example is that of the infertile mule – a cross between a donkey and a horse. A few fertile mules, which occurred as a result of mutation, were discovered in the USA, and a stud breeding these fertile mules has now also been established.

At one time it was thought that a particular frog species, *Crinia signifera*, was found both along the south-eastern coast and in the south-western corner of Australia. Morphologically these frogs were so similar that it was virtually impossible to distinguish between them. Experiments in breeding frogs from the east and west, however, resulted in sterile offspring. The western frog was then renamed *Crinia insignifera*. This division was further ratified with advances in audio technology, because the calls of the different frogs were found to be different.

## Selective hybrid elimination

The members of two closely related populations may be able to breed and produce fertile offspring. If these offspring and their progenies are as vigorous and well adapted as the parental forms, the two original populations will combine to form a common gene pool. If, however, they are less well adapted than the parental forms, they will soon be eliminated, and the gene flow between the two populations will decrease.

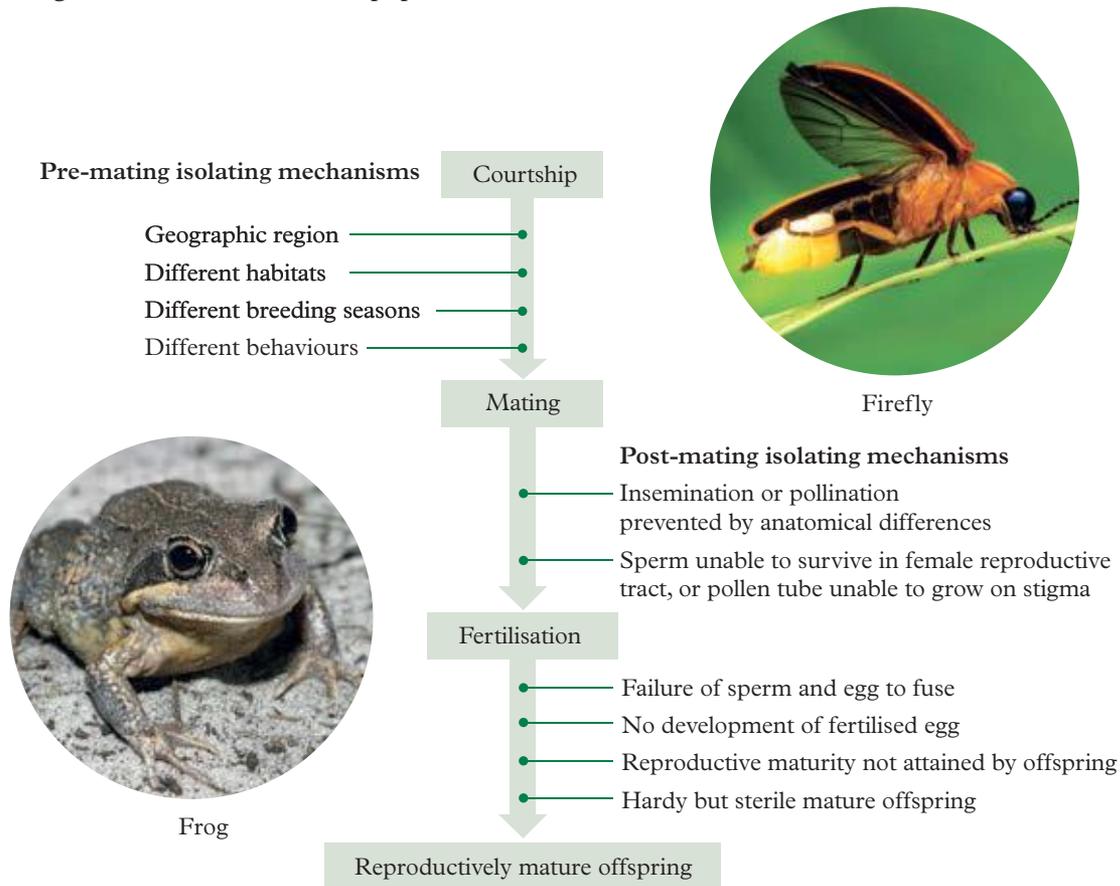


FIGURE 6 Reproductive isolating mechanisms

### CHECK YOUR LEARNING 15.4

#### Describe and explain

1 **Describe**, giving examples, four mechanisms that prevent interbreeding between different populations.

2 **Explain** the similarities and difference between a pre-mating and a post-mating isolating mechanism.

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Mechanical isolation

# 15.5

## Macroevolution

### KEY IDEAS

- ✦ Major evolutionary changes
- ✦ Macroevolutionary stasis
- ✦ Character changes in macroevolution
- ✦ Lineage splitting
- ✦ Macroevolutionary extinction

**macroevolution**  
major evolutionary change at or above the level of species over geological time

**Macroevolution** generally refers to major evolutionary changes over time – the origin of new types of organisms from previously existing, but different, ancestral types such as the radiation of the flowering plants or the origins of mammals. It is a reconstruction of the history of life based on evidence provided from palaeontology, geographical distribution and molecular biology.

The first step in understanding macroevolution is to determine what evolutionary events have occurred. This is followed by investigations of how they might have happened. For example:

- How did the adaptations for flight in birds arise?
- What accounts for the increase in brain size during human evolution?

Many large-scale patterns can be explained by the same factors that determine microevolution – mutation, migration, genetic drift and natural selection – given enough time. Mutations have been accumulating and acted upon by natural selection in organisms over the past 3.8 billion years. There has been more than enough time for the evolution of the vast array of organisms that have lived at some point on Earth.

## Patterns in macroevolution

There are four general patterns that recur throughout the history of life on Earth:

- stasis
- character changes
- lineage splitting (speciation)
- extinction.

### Stasis

**Stasis** in a group or species refers to the fact that it has not changed over long periods of time (Figure 1). Coelacanths are a fish lineage that branched off very early from the vertebrate clade. It was thought that they had become extinct 80 million years ago. In 1938, however, a coelacanth population was discovered in the waters of Indonesia. As can be seen in Figure 2, the modern coelacanth is very similar to that of the fossil. Morphological stasis in this group has been in existence for over 80 million years.

**stasis**  
a block of little or no evolutionary change in a species

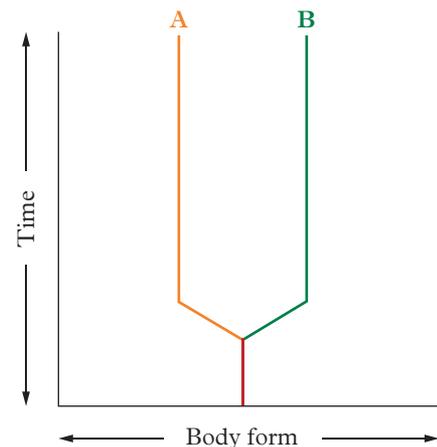


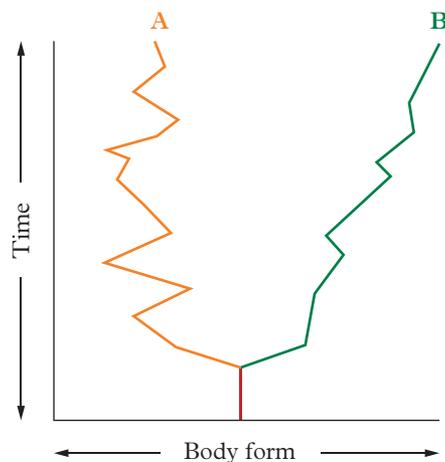
FIGURE 1 Stasis



**FIGURE 2** Coelacanth fish show stasis in form. (a) living fish in the Indian Ocean; (b) 350-million-year-old coelacanth fossil imprint

## Character changes

Different features, or characteristics, of the phenotype can change over time. These changes can occur gradually (over many millions of years) or relatively rapidly (in less than one million years). A particular feature such as the structure, physiology or behaviour of a species may show a slow, progressive change in one direction. A related lineage may show rapid changes, but in no particular direction. An example of this is shown in the fossil records of the trilobites, which lived over 300 million years ago. These records show that some trilobites, members of the clade to which modern insects and crustaceans belong, gradually increased in the number of body segments (lineage B in Figure 3). Others species of trilobites rapidly gained and lost body segments over the same time period (lineage A in Figure 3).



**FIGURE 3** Character changes



**FIGURE 4** Character change, such as number of body segments seen in fossil trilobites

**character change**  
change in phenotype  
over time

Most **character changes** in a lineage take place over a time period too long to be observed. But sometimes macroevolution doesn't take that much time. The evolution of a new species can occur in a matter of years. For example, a new finch species arose on Daphne Major in the Galapagos Islands in recent years.

When biologists Peter and Rosemary Grant first arrived on Daphne Major in 1973, there were only two species of finch present: the medium ground finch (*Geospiza fortis*) and the cactus finch (*Geospiza scandens*). In 1981, a new male finch immigrated to the island. Although similar to the medium ground finch, it had a much larger beak, an unusual hybrid genome, and a new kind of song. Somehow, he was able to find a mate that also had some hybrid chromosomes of her own. Their offspring were very different from the other birds on the island.

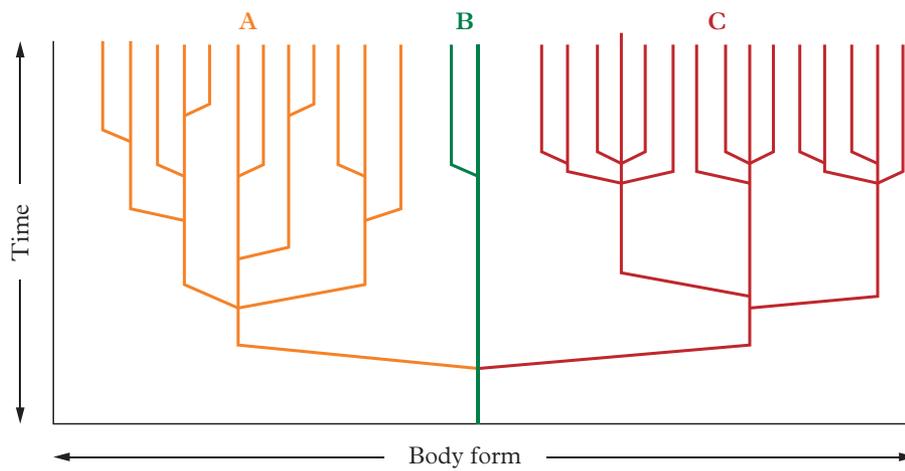
The male then mated with two females from one of the local species, *G. fortis*, the medium ground finch. After four finch generations, a drought killed off many of the birds on Daphne Major. Only a brother and sister pair of the hybrid line remained. The two family members mated with each other, producing offspring that were even more unique than their parent line. From that point on, as far as could be told, this population of finches mated only with each other. They were never seen to breed with the cactus finches or the medium ground finches on the island. A new species, *Geospiza conirostris*, had evolved.



**FIGURE 5** An example of rapid evolution on Daphne Major of the Galapagos Islands. The medium ground finch: the new species *G. conirostris* (a) and the indigenous species *G. fortis* (b).

## Lineage splitting (speciation)

Using DNA analysis, biologists have been able to identify the common ancestors of many different taxa. The sequence of species that evolved from a previous ancestor to produce the existing species is called the lineage of that organism. This rarely happens in an ordered sequence of events. Instead lineages will split to produce a range of different groups of organisms. Some of these groups will survive and continue to evolve, while others will become extinct. Construction of a phylogeny based on DNA analysis can reveal patterns. Some clades (groups of organisms with a common ancestor) will show a high rate of lineage splitting (Clade A in Figure 6) or an extremely low rate of lineage splitting (Clade B). Sometimes several lineages experience a burst divergence at the same time (Clade C).



**FIGURE 6** Lineage splitting

Some structures have evolutionary plasticity. This means they are able to provide the basis for alternative functions. This process of a structure evolving in one context and being co-opted for another function is called **exaptation**. The feathers of birds are a good example of this. It is possible that the first feathers were used by dinosaurs for insulation or display, with numerous dinosaur fossils being discovered with feathers. The feathers would have provided a selection advantage for the dinosaurs in cold environments; however, they may have been used for flight in later species.

The fact that the alleles for feathers were present in ancestors meant that they could be co-opted for a new function in the evolution of the birds. Through natural selection, features that evolved in one context are sometimes used for new functions.



**FIGURE 7** Feather imprints of a fossilised Dromaeosauridae *Microaptor zhaoianus*

**exaptation**  
the process by which an anatomical structure, physiological process or behaviour pattern of an organism acquires a new function

## Extinction

Extinction of species, and whole taxa, has occurred throughout the history of life on Earth. Both biotic and abiotic conditions can determine the success or demise of a species. A species may become extinct because its habitat has changed or because the environment has become unfavourable. Even an extremely well-adapted species will perish in a catastrophic event. For example, Mt Kilimanjaro is a volcanic mountain that has been dormant for a very long period of time. During that time, plants like the giant lobelia have become superbly adapted to the high-altitude conditions of its alpine moorlands. Should the volcano become active again, this plant and others in that zone would become obliterated at least by volcanic ash, if not by flowing magma. Loss of a species in a low trophic level of a food chain could easily result in the loss of species at higher trophic levels, especially those that are specialist feeders. Similarly, evolutionary change in one species can impact on other species in a community. Extinction is, therefore, inevitable in a changing world. Some members of a lineage survive whereas others become extinct, as shown in the cladogram in Figure 8.

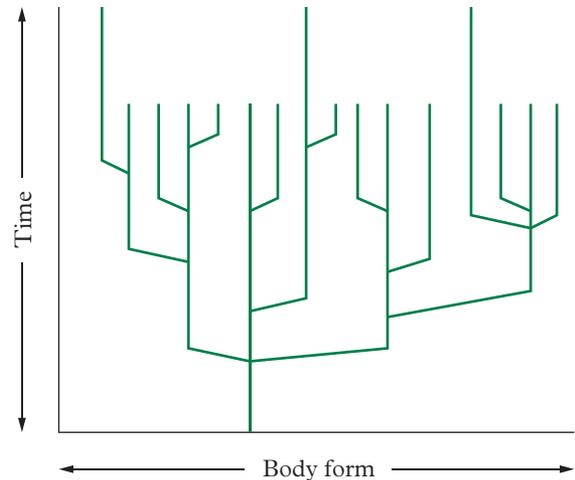


FIGURE 8 Extinction

Localised disasters such as bushfires, floods and habitat destruction by humans may reduce a population dramatically. The individuals in the population are killed randomly. The surviving members of the population are likely, therefore, to have a very reduced gene pool with some alleles being over-represented and others eliminated. Future generations will also have a limited gene pool on which to draw should they encounter changing environmental conditions. This is a form of genetic drift.

## Bottlenecks and extinction

These genetic bottlenecks are significant in the loss of particular populations. If the species is endangered, with a limited number of individuals in a single or limited populations, the chance of extinction is great. The South African cheetah (*Acinonyx jubatus*) shows more genetic uniformity (homogeneity) than inbred laboratory mice. The cheetah population was thought to be originally dramatically reduced during the last ice age (13 000 years ago) and subsequently by over-hunting in the early 20th century. The lack of genetic diversity in the cheetahs makes them more susceptible to disease and decreased production of young. Conservation efforts in South Africa have boosted the numbers of this vulnerable species from about 600 in 2007 to around 1500 in 2017.

FIGURE 9 The endangered South African cheetah is at an evolutionary bottleneck with extremely low genetic variation in its gene pool.



## Other forms of genetic drift

Genetic drift can also occur whenever a few individuals colonise a new, isolated area such as an island. The smaller the number of colonisers, the fewer alleles from the original gene pool will be present in the new population. The gene pool of subsequent populations will be limited to these founder alleles and any new mutations that appear. Again, because there is limited variation in the gene pool, the population is prone to extinction if some of those genes present are, by chance, instrumental in causing genetic disease.

## Mass extinction

Periodically Earth has experienced environmental change on a global level that has been both relatively rapid and highly destructive, resulting in a large proportion of the species living at that time becoming extinct. These mass extinction events are generally indiscriminate in relation to the types of organisms that perish, and so have a profound effect on biodiversity.

Some taxa managed to survive these events either by luck or due to adaptive features. They became the stock for massive diversification of organisms that filled the vacant niches.

### CHECK YOUR LEARNING 15.5

#### Describe and explain

- 1 **Explain** what is meant by the statement that ‘macroevolutionary changes result from an accumulation of microevolutionary changes over time’.
- 2 Two trends in macroevolution are stasis and character change. **Define** these two terms and give examples of each.
- 3 Macroevolution is generally considered to be a slow, progressive process. **Identify** at least one piece of evidence to show that this is not always the case.
- 4 **Sketch** a hypothetical clade of a lineage that undergoes, in the following order:
  - i initial multiple splitting
  - ii a period of low divergence of a few of the lineages only
  - iii an extinction of half of the lineages.
- 5 **Explain** how a genetic bottleneck could occur.

- 6 **Describe** the inherent dangers to a population exhibiting a genetic bottleneck.
- 7 **Define** exaptation. Provide one example in your response.

#### Apply, analyse and interpret

- 8 **Compare** microevolution and macroevolution.
- 9 From the fossil record, some species of trilobites showed rapid, erratic changes in the number of body segments – at one time increasing the number of segments, at another time showing a decrease followed again by an increase in segments. Other species showed a steady increase in body segments over time. Are the changes seen in the first group likely to be adaptive? **Critique** your answer.
- 10 An evolutionary novelty is the emergence of a new taxon, for example the mammals. Although sharing some characteristics with their ancestors, they have a unique set of features. **Deduce** how these ‘novelties’ may have arisen.

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Lineage splitting

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Extinction



## 15.6

## The evolution of humans

## KEY IDEAS

- ✦ Evidence of the pattern of human evolution
- ✦ Biological evolution of contemporary humans

*Homo sapiens* are classified in the class *Mammalia*, order *Primates*. Although they share many characteristics with all primates, they also have many features that are unique.

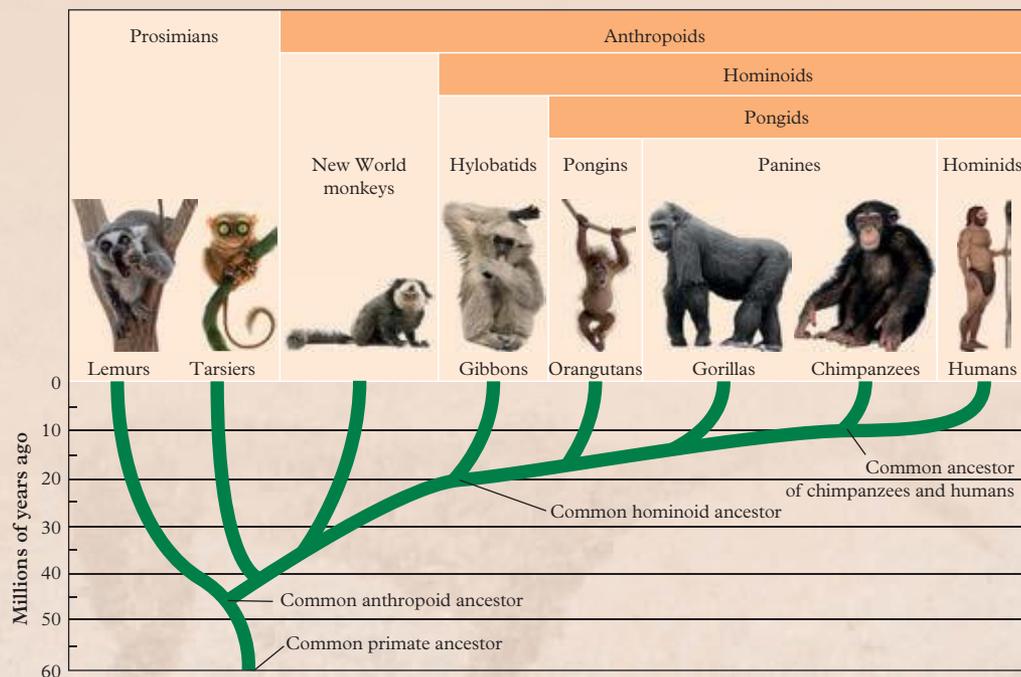


FIGURE 1 A possible evolutionary tree of the primates

## Relationships with the apes

It was found that human and chimpanzee DNA differs by only 1.1%. In other words, a strand of human DNA 3000 nucleotides long (and capable of coding for a sequence of 1000 amino acids) differs in nucleotide sequence at about thirty-three sites (eleven amino acids) from the equivalent chimpanzee strand.

These changes cannot account for the differences between the two species at the organism level. The genetic differences are thought to be in a few regulatory genes that could then bring about dramatic changes in the production of enzymes. The human and chimpanzee genes are likely so similar because the two species diverged rather recently and the large physical differences are due to a rapid evolution of regulatory genes in the human lineage.

## The fossil record

Current knowledge of human ancestry (from both increasing fossil finds and improved techniques for extracting and analysing DNA from fossils) suggests that there was not a single evolutionary pathway with simple progression from one species to another. Rather there were many diverging branches of human evolution, many of which rapidly resulted in extinction.

Proto-human, chimpanzee and gorilla groups probably evolved from a stem ancestor, possibly *Aegyptopithecus zeuxis*, which existed 30 million years ago. Fossils of *Australopithecus africanus* (from South Africa), and *Australopithecus afarensis* (from Ethiopia), aged between 3.5 and 1 million years old, were **bipedal**. The erect posture was probably an adaptation to easily view predators in savannah grasslands.

**bipedal**  
the ability to walk on two, rather than four, legs.

The first evidence of using tools was found near the bones of *Homo habilis* (= ‘handy man’), a toolmaker with a larger brain and reduced jaw, 2 million years ago.

It is believed that *Homo ergaster* (= ‘working man’) evolved from *H. habilis* and eventually resulted in *Homo erectus* (upright man). *H. erectus* was the first of our ancestors to make their way out of Africa, with fossils found as far away as China.

Between 2 and 1.4 million years ago, other species of *Homo* existed for short periods of time before becoming extinct. One of these, *Homo heidelbergensis*, also evolved in Africa and left to colonise Europe and Asia. Due to greater sophistication in tool making they were competitively superior to *H. erectus*. It is thought that the arrival of *H. heidelbergensis* led to the eventual extinction of *H. erectus*.

It is possible that adaptations of *H. heidelbergensis* due to differing environments (i.e. Africa and Europe) led to two new species – *Homo neanderthalensis* in the Middle East and Europe, and *Homo sapiens* in Africa. Neanderthals evolved between 150 000 and 200 000 years ago and only existed for around 30 000 years. The earliest modern human fossil (from Omo in Africa) is dated at about 130 000 years. Since the evolution of *H. sapiens* (with mitochondrial DNA different from all other hominids), modern humans colonised all inhabited parts of the world. Recent DNA evidence has indicated that modern *H. sapiens* also mated with other human species that existed at the time, including *H. neanderthalensis* and Denisovan hominids.

The demise of the Neanderthals was associated with the rise of modern humans, but the exact cause is not known. Early views suggest that Neanderthals succumbed to diseases, may have been less able to compete for resources or may have been systematically destroyed by *Homo sapiens*. An alternative hypothesis is that the Neanderthal population sizes were

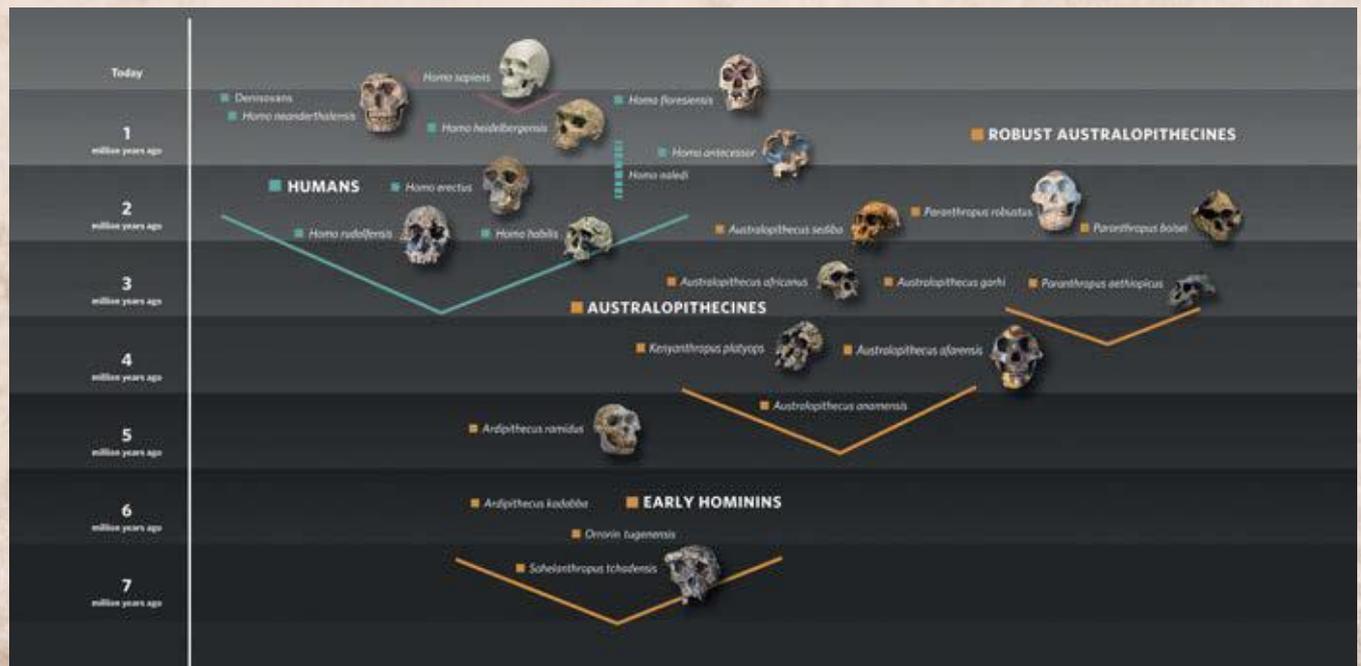


FIGURE 2 An updated evolutionary tree of hominids

so small that many deleterious gene mutations probably accumulated. The modern human population of the time was much larger so that when the two groups began interbreeding about 50 000 years ago, these deleterious variants could not persist in the human population. It is therefore possible that the Neanderthals did not become extinct in the traditional sense, but slowly became absorbed into the modern human line.

## Steps in the evolution of modern humans

The first evidence of tool use occurred with the subsequent emergence of *H. habilis*, *H. ergaster* and *H. erectus*. All three species also showed increased brain capacities, a propensity for right-handedness and the presence of one of the human speech centres (Broca's area) in the brain.

It seems likely that the ability to make tools contributed far less to increased brain size than the need for an efficient system of communication. Foresight and capacity for leadership must have been greatly enhanced by an ability to speak. Many aspects of intelligence and planning would have little survival value without a medium of communication far more efficient than that of the anthropoid apes.

The increased brain size was favoured by forward shift of the skull support in connection with upright posture. Additionally, the preparation of food was made possible by the enlarged brain. This resulted in the reduction of jaws, the teeth and the entire facial part of the skull, while simultaneously the cerebral part of the skull increased in size. It also resulted in the reduction of facial muscles and their associated bony crests and ridges.

## Biological evolution of contemporary humans

There has been an enormous expansion of humans throughout the world since the last ice age (approximately 13 000 years ago). Apart from refinements of the basic form, the evolutionary process was thought to be basically cultural. This is believed to be based on the social and technological foundations that were initiated by the species. New evidence suggests that biological evolution is also occurring at a significant rate.

## Evidence for continued human evolution

Over the past two decades, immense progress has been made in mapping the human genome, which has allowed population geneticists to examine contemporary shifts in allele frequencies. Some of these shifts have occurred over the past 2000–3000 years and others more recently.

One team counted unique single-based changes or singletons. Since they have not spread throughout the population, the scientists have deemed them to be recent mutations. The number of singletons on nearby DNA (the alleles carry neighbouring DNA with them as they are passed on during reproduction) can be used as a rough molecular clock that indicates how quickly the allele has changed in frequency. They found that the selection for height, head circumference in infants and hip size in females occurred concurrently in recent millennia.

## Examples of ongoing biological evolution

Many of the obvious changes in the human genome are associated with dietary changes over the course of human evolution. Populations in which dairying has been practised for a long time have lactase persistence, whereas those who have been farming grains (wheat, rye, oats) have additional gene duplications that produce salivary amylase to break down starches in grains.

## Lactose tolerance

In mammals, the lactase gene that produces the lactase enzyme shuts down as young are weaned. It has been found that about 3000 years ago this ‘switching off’ of the lactase gene began to cease in humans – coinciding with the domestication of cows, sheep and goats. Drinking milk has many nutritional advantages and any mutation that allowed its continued digestion would have been selected for. The genetic changes that have allowed adults to continue to digest milk over their lifetime are varied.

## Disease resistance

Over 1800 genes have been found that have only become prevalent in humans in the past 40 000 years. Many of these are associated with disease resistance. For example, in Africa more than a dozen genetic variants against malaria are rapidly spreading. Similarly, resistance to tuberculosis and leprosy (diseases normally prevalent in high-density living conditions) has been observed in city dwellers.

## Decreased brain size

Evidence suggests that brain size has decreased as population sizes have increased and become more complex. Some scientists have used this to support the notion that with decreased reliance on natural resources, and increased ability to ‘control’ our environment, the correlation between intelligence and survival is negated.

Another theory is based on the high-energy demands of the brain. By decreasing brain size, less energy is required to maintain it.

Yet another theory proposes that the modern world requires humans to work cooperatively to solve problems. A smaller brain size, according to this view, is an evolutionary advantage since it is associated with reduced aggression.



**FIGURE 3** Leprosy is caused by a mycobacterial infection. It results in skin sores, muscular weakness and nerve damage. Genetic predisposition is also a cause for leprosy.

### CHECK YOUR LEARNING 15.6

#### Describe and explain

- 1 Describe** the evidence that humans and chimpanzees have a common ancestor.
- 2 Explain** why it is considered that the development of speech was a greater selection than the use of tools in the increase in brain size in the evolution of modern humans.

- 3 Identify** three pieces of evidence for the continued biological evolution of humans.

#### Apply, analyse and interpret

- 4 Construct** a research question on a form of ongoing biological evolution in humans.

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Lucy the first bipedal fossil

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Evolution of contemporary humans



# Review

## Chapter summary

- 15.1** • Random mutations can accumulate as a result of natural selection (microevolution). The accumulation of multiple phenotypic changes over time can lead to speciation (macroevolution).
  - Divergent evolution occurs when a population of interbreeding organisms separates into two or more descendent species as a result of different selection pressures.
  - Convergent evolution occurs when two different species (with a very distant common ancestor) develop similar physical characteristics (analogous structures) as a result of similar selection pressures.
  - Parallel evolution occurs when two species with a recent common ancestor share similar selection pressures and therefore develop similar physical characteristics.
  - Coevolution occurs when two species closely interact so that when one species evolves, it exerts a selection pressure on the other species to evolve in the same direction.
- 15.2** • The gradual change in a population through changing environmental pressures can result in speciation.
  - Speciation can result when a single population separates and the two groups evolve independently so they no longer share the same gene pool.
  - A cline is a specific characteristic that can vary across a population. It is dependent on selection pressures and gene flow.
  - Geographical isolates are different populations that are separated from one another by permanent physical geographical barriers.
  - Zones of hybridisation are areas in which the habitat of two different populations meet and the different populations can interbreed at the border.
- 15.3** • Allopatric speciation occurs when a population is divided by a permanent barrier. Random mutations and different selection pressures can result in the two groups becoming reproductively isolated.
  - Parapatric speciation occurs when a population occurs over an area with different environmental conditions. Gene flow across the population slows so that a small subgroup evolves into a new species.
  - Sympatric speciation occurs when two groups that share the same habitat become reproductively isolated.
- 15.4** • Reproductive isolation can result from pre-mating mechanisms or post-mating mechanisms.
  - Pre-mating mechanisms include ecogeographical isolation, seasonal (temporal) isolation and behavioural isolation.
  - Post-mating mechanisms include mechanical isolation, gametic isolation, developmental isolation, hybrid unviability or sterility, and selective hybrid elimination.
- 15.5** • Macroevolution refers to the major evolutionary changes in different taxa groups over time.

- Macroevolutionary stasis refers to groups of organisms that are exposed to unchanging selection pressures. As a result, these organisms show little evolutionary change.
  - Character changes in macroevolution can occur at different rates. They may occur in a particular direction, only to be later reversed in different environmental conditions.
  - The pattern of lineage splitting can be determined by developing a phylogenetic tree.
  - Large-scale environmental changes can result in macroevolutionary extinction.
- 15.6**
- Evidence of the pattern of human evolution.
  - Biological evolution of modern humans.

## Key terms

- allopatric species
- bipedal
- character change
- character displacement
- clinal variation
- cline
- coevolution
- convergent evolution
- developmental neoteny
- divergent evolution
- exaptation
- geographic isolates
- heat shock protein
- macroevolution
- parallel evolution
- parapatric speciation
- parthenogenesis
- reproductive isolating mechanisms
- speciation
- stasis
- sympatric species
- zone or belt of hybridisation

## Revision questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: \* = low; \*\* = medium; \*\*\* = high.

### Multiple choice

- Allopatric species are those that do not interbreed as a result of:
  - mechanical isolating mechanisms preventing coition
  - unviability of any hybrids formed
  - specialisation for different environmental conditions and thus different ranges
  - irregular development of the hybrid embryo
- Eastern rosellas and pale-headed rosellas are thought to have descended from a bird that had a range extending over much of Australia. Now the range of the eastern rosella extends from Tasmania to southern Queensland, and the range of the pale-headed rosella extends from Cape York to northern New South Wales. There is no hybridisation where the ranges overlap. For this situation to have developed it is probable that:
  - a mutation occurred in southern Queensland
  - the pale-headed rosella migrated to the snow country
  - for a long period of time a geographic barrier isolated the northern and southern extremes
  - a cline existed in the past around the entire coast thus allowing variation to occur in the overlapping birds
- The golden marmoset of Madagascar only eats bamboo stalks. It is the only animal known to eat the entire stalk. The pith of the bamboo contains high levels cyanide.

The amount of cyanide in one meal for the marmoset would be enough to kill a much larger mammal and yet the golden marmoset experiences no ill effect on this diet.

The evolutionary relationship between the golden marmoset and bamboo would be best described as:

- A divergent evolution
  - B convergent evolution
  - C punctuated evolution
  - D coevolution
- 4 Pollen from one species of *Eucalyptus* flowering in late autumn may be deep frozen and later thawed and applied to the stigmas of a different but closely related *Eucalyptus* species that flowers in spring. If fertilisation occurs and seeds are collected and sown, interspecific hybrids may grow.
- The evolutionary consequence of the seasonal differences in flowering is:
- A the production of an adequate and continuous supply of nectar for honeyeaters
  - B giving pollen-gathering insects the chance to contribute to the formation of a new species of *Eucalyptus*
  - C the maintenance of both species of *Eucalyptus* in reproductive isolation
  - D the reduction of demand on soil nutrients for the production of large numbers of flowers
- 5 Races are sometimes described as a stage in the development of new species. Which one of the following conditions would **not** facilitate formation of two new species from two races?
- A Reproductive isolation of members of one race from the other
  - B Interbreeding between members of each race to produce fertile offspring
  - C Increasing differences between the members of each race, leading to different gene pools
  - D Each race tending to be confined to geographical areas with differing environmental conditions

6 Which of the following is **not** a reproductive barrier in speciation?

- A Non-correspondence of genital organs
- B Occurrence of polyploidy in a sterile hybrid
- C Inability of the sperm to fertilise eggs
- D Failure of insects to pollinate flowers

7 Stasis in macroevolution refers to:

- A relatively little phenotypic change in a group over a very long period of time
- B character displacement in a species as a result of competition
- C the extinction of a particular lineage
- D the retention of parental lineages after parapatric speciation has occurred

### Short answer

#### **Describe and explain**

- ★ 8 **Explain** the differences between microevolution and macroevolution.
- ★★ 9 Populations generally have at least one of the following structural features – clinal variations, geographical isolates and/or zones of hybridisation. **Define**, with an example, each of these features.
- ★★ 10 **Describe**, with examples, the circumstances under which divergent evolution could occur.
- ★★ 11 **Explain** why parapatric speciation is due to a form of geographic isolation while at the same time the parent populations are sympatric.
- ★★ 12 **Explain** why migrants must interbreed and produce offspring with residents for gene flow between populations to have an evolutionary impact.

#### **Apply, analyse and interpret**

- ★★★ 13 In Population 1 of a species the frequency of a particular allele (X) is 0.6, while in Population 2 of the same species the frequency of this allele is 0.2. A single migration occurs from Population 1 to Population 2.
  - a If migrants account for 15% of Population 2, **calculate** the frequency of this allele in Population 2 immediately

after migration. Show your working.  
Population 1 immigrants also had another allele (Y) with a frequency of 0.5 that did not occur in Population 2.

- b Determine** the frequency of allele Y in Population 2 immediately after migration.
- c** If the migrants freely interbred with the residents:
  - i calculate** the frequencies of alleles X and Y in the first generation
  - ii calculate** the frequencies of alleles X and Y in the second generation.
- d** If allele Y confers a selective advantage to Population 2 individuals in its range, but not to individuals in the Population 1 range, **deduce**:
  - i** a possible fate for members of Population 2 over a period of many generations if interbreeding between migrants and residents occurred
  - ii** a possible fate for members of Population 2 over a period of many generations if no interbreeding between migrants and residents occurred.

#### Investigate, evaluate and communicate

- ★★★ 14 Fireflies are known to be preyed upon by thrushes, jumping spiders and probably by a variety of other invertebrates such as ants. During the breeding season the female of each species emits a series of species-specific bioluminescent flashes to signal her readiness to mate and her location. Only the males of her species will respond to her signals.

One species of firefly (*Photinus*) produces a defensive steroid (lucibufagin, LBG), which they exude in droplets of blood when they are disturbed. Jumping spiders find LBG repellent. Fireflies of the genus *Photuris* are unable to synthesise LBG.

It has been found that *Photuris* females are able to mimic the sexual response flashes of *Photinus* spp. The lured *Photinus* males are promptly devoured by the jumping spiders. It has been observed that the *Photuris* females are less likely to be preyed upon by the jumping spiders after they have eaten *Photinus* males than when they hadn't partaken of such a meal.

**Decide**, with justification, a possible evolutionary pathway for the mimicry described above.



FIGURE 1 Fireflies glowing in a forest

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Chapter 15

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Chapter 15 auto-correcting multiple-choice quiz

» Flashcard glossary  
Chapter 15 glossary



## Practical manual

The QCAA Biology General Senior Syllabus outlines a number of mandatory and suggested practicals, and manipulative skills for completion in Units 3 & 4.

Suggestions for methodology and materials have been supplied in this chapter. However, the following is not prescriptive; schools may complete the mandatory or suggested practicals in any other form suited to their resources.

The experiments in this chapter have been trialed, and obvious cautions of hazards are given; however, teachers are legally obliged to carry out their own risk assessment prior to undertaking any practical activity.

### SAFETY

This chapter will highlight key safety concerns within each practical; however, there are some general safety concerns to be considered in all practicals.

- Tie long hair back.
- Do not eat or drink while in the lab.
- Always be aware of your peers in the lab and act sensibly.
- Wear a lab coat, safety glasses and closed-toed shoes.
- Familiarise yourself with the school's safety procedures and the locations of eye wash, shower, spill kits and first aid kits.
- Handle all chemicals with care and consult your teacher and risk assessments for the hazards involved with each chemical.
- Check electrical equipment before use to ensure that there is no existing damage to cables.
- Keep open flames away from flammable materials.
- Handle hot materials with the appropriate equipment (i.e. heat-resistant gloves or tongs).
- Complete fieldwork in groups and complete a full risk assessment.
- If you are unsure of any procedures in the lab or need any clarification for a practical, consult your teacher and/or lab technician.

FIGURE 1 Leaf litter holds a diverse community including decomposers who support the larger food chain.

## UNIT 3 PRACTICALS



MANDATORY PRACTICAL,  
SUGGESTED PRACTICAL  
AND MANIPULATIVE SKILLS

**3.8A** Analysing vegetation patterns using a transect line



MANDATORY PRACTICAL

**3.8B** Stratified sampling of vegetation patterns



MANDATORY PRACTICAL

**6.4** Appraisal of an ecological surveying technique



SUGGESTED PRACTICAL

**4.1A** A simplified food chain in leaf litter



SUGGESTED PRACTICAL

**4.1B** Measuring biomass



SUGGESTED PRACTICAL

**5.1** Plant distribution and abundance using quadrants



SUGGESTED PRACTICAL

**5.4A** Competitive exclusion in *Paramecium*



SUGGESTED PRACTICAL

**5.4B** Relationship between predator and prey



SUGGESTED PRACTICAL

**5.5** Population study of yeast

## UNIT 4 PRACTICALS



MANDATORY PRACTICAL

**14.3** Changes in the gene pool due to selection pressure



SUGGESTED PRACTICAL

**7.1** Extraction of DNA from strawberries



SUGGESTED PRACTICAL

**12.2** Bacterial transformations



SUGGESTED PRACTICAL

**12.4** Gel electrophoresis

## Unit 3 Mandatory practicals and manipulative skills



### 3.8A

MANDATORY PRACTICAL, SUGGESTED PRACTICAL AND MANIPULATIVE SKILLS

## Analysing vegetation patterns using a transect line



CAUTION: THE DRYING OVEN CAN CAUSE BURNS. HANDLE WITH CARE. FIELDWORK NEEDS TO BE COMPLETED IN GROUPS.

Part A – Measure abiotic factors in the field (e.g. dissolved oxygen, light, temperature, wind speed, infiltration rate) – Suggested practical

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

Part B – Measure abiotic factors in the classroom using field samples (e.g. pH, nitrogen nutrients, salinity, carbonates, turbidity) – Suggested practical

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

Part A and B – Use appropriate technology, such as data loggers, chemical tests, turbidity tubes and other equipment to measure factors. – Manipulative skill



**FIGURE 1** Ecologist has set up a transect and quadrant at Mission beach in Queensland, Australia.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

Part C – Determine species diversity of a group of organisms based on a given index. – Mandatory practical

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

### Aims

- 1 To use data collected from a transect profile to:
  - a measure a variety of abiotic factors along a transect
  - b determine the relative abundance of a species and of families of plants
  - c calculate and compare densities of plant species and families across an ecosystem
  - d calculate and compare species diversity across an ecosystem
  - e determine possible relationships between chosen plant species and abiotic conditions

### Theoretical basis

The abundance of a species is the number of individuals of a species within a given area. Density is the number of individual members of a species per unit area of an ecosystem. Since it is not always possible to count all of the individuals of a particular species in an area, some form of random sampling can be used. A transect (a measured length or strip of terrain in an environment along which individual organisms or environmental parameters are measured and recorded) is one method of randomly sampling an area. The abiotic conditions in the transect determine the vegetation present. Infiltration rate is the velocity or speed at which water enters into the soil.

## Materials

### Class requirement:

- 100 metre length of rope marked at 5 metre intervals (transect line)

### For each group in the field:

- Laboratory thermometer
- Wet-and-dry bulb thermometer
- Light meter (LUX)
- Anemometer
- Compass
- Ribbon or cloth on a stick (wind direction)
- Trowel
- Sample bottles for soil (4)
- 500 mL deionised/distilled water
- Spirit level
- Metre ruler and plastic 30 cm ruler
- Ziploc plastic bags with stick-on labels
- Pencil and marker pen
- Clipboard
- Paper to record data

### For each group in the laboratory:

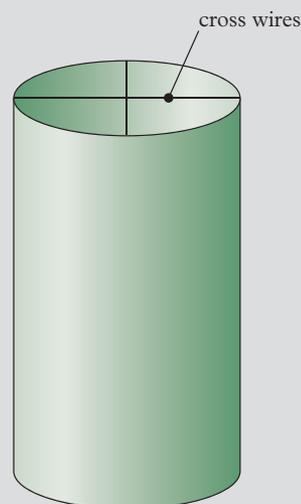
- Plant family identification key
- Universal indicator
- Talcum powder
- Evaporating dish or watch glass (small)
- Digital scales
- Drying oven (set to 100°C)
- Measuring cylinder
- Beaker
- Stopwatch
- Soil-testing kit (measures pH, salinity, nitrogen content, turbidity, carbonates, etc.)
- Petri dish
- Cross-wire projection tube
- 10 metres of builder's string (brightly coloured)
- Solid isosceles triangle

### Part A Measuring the abiotic factors in the field - Suggested practical

## Method

### 1 Temperature

Collect monthly average maximum and



**FIGURE 2** The cross-wire projection tube apparatus

minimum daily temperatures from the Bureau of Meteorology (BOM) website for the area under investigation.

Dig a narrow hole 10 cm deep. Place the thermometer in the hole and gently refill the hole. After 3 minutes, remove the thermometer and record the temperature.

Measure and record the temperature at the soil surface.

Measure and record the temperature 1 m above the soil.

### 2 Relative humidity

Use the wet-bulb and dry-bulb thermometers and the conversion chart (Figure 2 on the next page) to measure the relative humidity at both soil level and 1 m above the ground. Record the results.

### 3 Light intensity

Use the light meter to measure and record the light intensity at ground level.

### 4 Wind

Use the anemometer to measure and record the wind speed at both ground level and 1 m above the ground.

$$\begin{aligned} 1 \text{ knot} &= 1.853 \text{ km/h} \\ &= 0.514 \text{ m/s} \end{aligned}$$

Determine the direction of the wind using a cloth tied on a stick and, using the compass, record the bearings.

Wet bulb globe temperature (WBGT) from temperature and relative humidity

Relative humidity (%)	Temperature (°C)																														
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
0	15	16	16	17	18	18	19	19	20	20	21	22	22	23	23	24	24	25	25	26	27	27	28	28	29	29	30	31	31	32	32
5	16	16	17	18	18	19	19	20	21	21	22	22	23	24	24	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34	35
10	16	17	17	18	19	19	20	21	21	22	23	23	24	25	25	26	27	27	28	29	30	30	31	32	32	33	34	35	36	36	37
15	17	17	18	19	19	20	21	21	22	23	23	24	25	26	26	27	28	29	29	30	31	32	33	33	34	35	36	37	38	38	39
20	17	18	18	19	20	21	21	22	23	24	24	25	26	27	27	28	29	30	31	32	32	33	34	35	36	37	38	39			
25	18	18	19	20	20	21	22	23	24	24	25	26	27	28	28	29	30	31	32	33	34	35	36	37	38	39					
30	18	19	20	20	21	22	23	23	24	25	26	27	28	29	29	30	31	32	33	34	35	36	37	38	39						
35	18	19	20	21	22	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39								
40	19	20	21	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39									
45	19	20	21	22	23	24	25	26	27	27	28	29	30	32	33	34	35	36	37	38											
50	20	21	22	23	23	24	25	26	27	28	29	30	31	33	34	35	36	37	39												
55	20	21	22	23	24	25	26	27	28	29	30	31	32	34	35	36	37	38													
60	21	22	23	24	25	26	27	28	29	30	31	32	33	35	36	37	38														
65	21	22	23	24	25	26	27	28	29	31	32	33	34	36	37	38															
70	22	23	24	25	26	27	28	29	30	31	33	34	35	36	38	39															
75	22	23	24	25	26	27	29	30	31	32	33	35	36	37	39																
80	23	24	25	26	27	28	29	30	32	33	34	36	37	38																	
85	23	24	25	26	28	29	30	31	32	34	35	37	38	39																	
90	24	25	26	27	28	29	31	32	33	35	36	37	39																		
95	24	25	26	27	29	30	31	33	34	35	37	38																			
100	24	26	27	28	29	31	32	33	35	36	38	39																			

WBGT > 40

Note: This table is compiled from an approximate formula that only depends on temperature and humidity. The formula is valid for full sunshine and a light wind.

FIGURE 3 A table to determine the relative humidity of a soil



**FIGURE 4** A flowchart to determine the type of soil present

## 5 Soil testing in the field

- Humus

Using the trowel, dig a hole in the soil. Use the ruler to measure the depth of the topsoil (dark-coloured). Record this measurement. Measure and record the depth of leaf litter and humus (decayed plant and animal organic matter) on top of the soil.

- Texture

Place a handful of soil in your hand and moisten with water. Roll the wet soil and record features such as the ability to form a ball (indicating a high clay content), or grittiness. Use the key in Figure 3 to determine the type of soil. Record your data.

Collect samples of soil in the sample bottles and sealable plastic bag to take back to the laboratory for testing; if the selected transect is sloped, soil samples should be collected from the top and bottom sections of the transect.

## 6 Rainfall

Complete a computer search and record the average yearly rainfall for the area as well as the average for the month at the time of observation from the BOM website.

Record all the results from 1 to 6 in a table and any other observations.

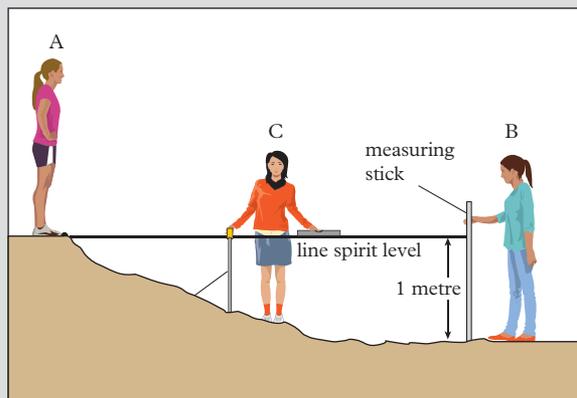
## 7 Physiography

Run a 100 m transect line through a *typical* part of the habitat.

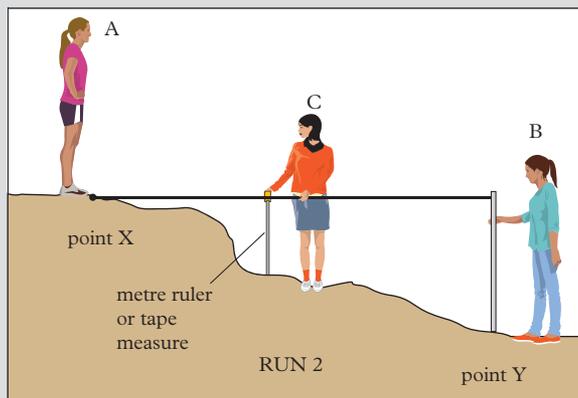
Use the compass to record the direction of the transect, and in dense vegetation ensure you maintain the compass bearing.

Using the equipment provided, measure the slope as described below. You will need four students: A, B, C and D.

- A goes to the highest point of the area to be profiled and holds one end of the string on the ground. B and C walk downhill with the other end of the string until they are 1 m below A, or 10 m away from A, whichever comes first.
- In either case, the string is held against B, at a height that keeps the string level.
- C then walks back to the middle of the interval and uses the line spirit level to check that the string is level, and B makes adjustments up or down as is necessary.
- C then walks along the line, measuring and calling out, the distance that C is along the string from A and the height of the string at that point, so that these can be recorded by D. Heights are recorded as often as is needed for an accurate profile.
- A then moves down to where B is, and B and C start all over again, remembering to add on the drop-in height from where A was to where B was.



Measuring a land surface profile:  
from the starting point



Measuring a land surface profile:  
continuing further down the slope

**FIGURE 5** Two diagrams showing how to measure land surface profiles

- f Reverse the system when you are going uphill.

Record your results in a table with distance from the start and depth in metres.

### Part B Measuring abiotic factors in the laboratory - Suggested practical

#### Method

Soil testing in the laboratory:

- pH

Place a small amount of the collected soil in a Petri dish. Sprinkle a fine layer of talcum powder over the soil. Add a few drops of universal indicator and observe the colour. Using the colour chart, determine and record the soil pH.

- Moisture

Zero an electronic balance and weigh the evaporating dish/watch glass to at least 2 decimal places. Record weight. Place approximately 10 g (using a large spatula) of soil from the sealed plastic bag onto the evaporating dish/watch glass, spread evenly across the bottom of the dish and reweigh. Record weight. (weight a) Place the dish in an oven at 100°C for 24 hours. Using heat-proof gloves remove from the oven and place in a desiccator to cool to room temperature. Reweigh dish and soil. (weight b) The difference between the two weights (weight a – weight b) provides a measure of water content. Record as grams of water per 10 grams of soil.

- Soil air content

Place a sample of soil in beaker and weigh the contents (weight of 'soil'). Slowly add water until the water is level with the top of the soil. Reweigh the beaker and its contents (weight of 'soil + water'). Determine the amount of water in the soil from ('soil + water' – 'soil'). As 1 g water is equivalent to 1 cm<sup>3</sup> and the amount of water measures the amount of air displaced, determine the soil air content in the sample.

- Soil mineral content

Using the soil mineral test kit, follow the provided instructions and record the levels of the minerals present.

### Part C Determine species diversity - Mandatory practical

#### Method

- 1 Run a transect line 100 m through the same section of vegetation used for the land profile. Consider the transect line as a strip 10 cm wide along each side of the string. Different groups of students can run adjoining parallel transect lines approximately 5 m apart. Take care not to trample plants along each transect line.
- 2 At the first 5 m interval, examine the plants directly beneath, touching or overhanging the string at the interval mark. Identify the plant(s) to family using the key provided by your teacher. Take a sample of leaves, flowers and fruit (where present) and place in the plastic bag. Label each specimen as species A, B, etc. Record on the bag label any details (herb, shrub, tree, etc.) and any distinguishing features such as height, (using the method described in Chapter 3.8, page 101) and colour of the bark. The specimens will be the reference set for the same species at different sites along the transect line and can be used for later identification of species (e.g. from plant guides, or dried plants and photos can be sent to an herbarium). Record the plants on your data sheet. For recording it is best to study each stratum (ground, shrubs, trees) separately.
- 3 Repeat step 2 at every 5 m interval along the transect line. This will give a total of 20 stations for each transect line. Add new species bags to your specimen collection as you encounter them.
- 4 At each 5 m interval, determine and record the foliage cover using the crosswire tube, at both ground level and the canopy. Take note of the tallest plant and % of foliage cover.

#### Analysing the data

- 1 In the laboratory, identify the species from plant guides. A collection of plants that cannot be identified in this way can be sent to a herbarium for identification. If plants cannot be identified give them a code name, e.g. Species A, Species B, etc. Identified species can be logged at the Atlas of Living Australia (<https://biocache.ala.org.au/explore/your-area>).

- 2 Count the total number of families and total number of different species encountered.
- 3 Use this information to calculate species Simpson's diversity index:
  - Simpson's Index of Diversity (SID):

$$SID = 1 - \frac{\sum n(n-1)}{N(N-1)}$$

where  $n$  is the total number of individuals of a particular species;  $N$  is the total number of all individuals counted (from all species);  $\sum n(n-1)$  means to calculate  $n(n-1)$  for each species surveyed, then add them all together. The closer the SID value is to 1, the more diverse the community; i.e. one species is not more prevalent than the others.

- 4 Repeat step 3 for the families.
- 5 Calculate the percentage foliage cover for both the ground cover and canopy layers cover:

$$\% \text{ foliage cover} = \frac{\text{number of foliage sites recorded}}{\text{number of observation sites}} \times 100$$

- 6 Classify the ecosystem using this calculation and Specht's structural classification of vegetation (Table 1).

**TABLE 1** Specht's structural classification of Australian vegetation

Growth form of tallest stratum	Foliage cover by the tallest stratum			
	>70%	30–70%	10–30%	<10%
Tall trees (>30 m)	Tall closed forest	Tall open forest	Tall woodland	
Medium trees (10–30 m)	Closed forest	Open forest	Woodland	Open woodland
Low trees (<10 m)	Low closed forest	Low open forest	Low woodland	Low open woodland
Tall shrubs (>2 m)	Closed scrub	Open scrub	Tall scrubland	Tall open scrubland
Low shrubs (<2 m)	Closed heath	Open heath	Low shrubland	Low open shrubland
Hummock grasses			Hummock grassland	
Tufted/tussock grasses	Closed tussock grassland	Tussock grassland	Open tussock grassland	Dense open grassland
Graminoids	Closed sedgeland	Sedgeland	Open sedgeland	
Other herbaceous species	Dense sown pasture	Sown pasture	Open herb field	Sparse open herb field

Sketching a transect is not required for this mandatory practical, but is a handy skill used by biologists. Directions for this can be found on your [gbook assess](#).

## Discussion

Write a discussion of your results including the following points:

- the level of species diversity in the two transects and possible reasons for this
- explanation of why density was not calculated and a possible means of determining density given the sampling method
- relationship between the vegetation observed and abiotic factors.

## Conclusion

Write a brief summary of your findings.



## 3.8B MANDATORY PRACTICAL

# Stratified sampling of vegetation patterns



CAUTION: THE DRYING OVEN CAN CAUSE BURNS.  
HANDLE WITH CARE. FIELDWORK NEEDS TO BE  
COMPLETED IN GROUPS.

Use the process of stratified sampling to collect and analyse primary biotic and abiotic field data to classify an ecosystem.

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

This investigation could be carried out in conjunction with Practical 3.8A as part of a full day field trip. Identify two related areas of a local ecosystem to compare the vegetation patterns. Alternatively, if time is an issue, students can use results from other groups' transects or different aspects of the same transect, in order to compare the two transects.

### Aims

- 1 To use data collected from two different transect profiles within a habitat to:
  - a measure abiotic factors along the transects

- b determine the relative abundance of species and families of plants
- c calculate relative densities of species and families
- d examine the family groups of plants present within a particular community to determine whether there is a relationship between particular types of plants
- e compare the data from the two transects and determine similarities and differences in abiotic and biotic components

### Theoretical basis

Stratified sampling is used to take into account different areas (or strata) that are identified within the main body of a habitat. Individual habitats are rarely uniform throughout their extent. There are often smaller, more identifiable areas within a habitat that are substantially different from the main part of the habitat.

For example, scrub patches within a heathland area, or areas of bracken in grassland. The different



FIGURE 1 The variable ecosystems in the grassland of Kowanyama, Queensland

abiotic conditions in habitats can impact the species that survive in that area.

## Materials

Class requirement:

- 100 metre length of rope marked at 5 metre intervals

For each group in the field:

- Laboratory thermometer
- Wet-and-dry bulb thermometer
- Light meter
- Anemometer
- Compass, ribbon or cloth on a stick (wind direction)
- Trowel
- Sample bottles for soil (4)
- 500 mL deionised/distilled water
- Spirit level
- Metre ruler and plastic 30 cm ruler
- Ziploc plastic bags with stick-on labels
- Pencil and marker pen
- Clipboard
- Paper to record data

For each group in the laboratory:

- Plant family identification key
- Universal indicator
- Talcum powder
- Evaporating dish or watch glass (small)
- Digital scales
- Drying oven (set to 100°C)
- Measuring cylinder
- Beaker
- Stopwatch
- Soil testing kit (measures pH, salinity, nitrogen content, turbidity, carbonates etc.)
- Petri dish
- Cross-wire projection tube
- 10 metres of builder's string (brightly coloured)
- Solid isosceles triangle

## Method

- 1 On arrival at the study site, scan the general habitat to determine whether any patterns can be seen, e.g.:
  - Is there a difference in aspect in different parts of the habitat?
  - If the habitat is sloped, does the vegetation appear to be different across the slope?
  - Do some areas within the general habitat appear to have different types of vegetation?
  - Do different birds occupy some habitats and not others?
  - Are there patches of die-back within the habitat?
- 2 Select two areas within the habitat with one of these differences.
- 3 For each area use the methods from Mandatory Practical 3.8A to determine:
  - a the abiotic conditions
  - b the vegetation present

## Discussion

Write a discussion of your results including the following points:

- determination of whether certain species or families occur throughout the habitat
- possible reasons for any grouping of species
- the level of species diversity in the two transects and possible reasons for this
- relationship between the vegetation observed and abiotic factors
- compare your results to the previous transect in practical 3.8A.

## Conclusion

Write a brief summary of your findings.



Select and appraise an ecological surveying technique to analyse species diversity between two spatially variant ecosystems of the same classification (e.g. disturbed or undisturbed dry sclerophyll forest).

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

### Aims

- 1 To design an experiment to survey two ecosystems of the same classification that are spatially variant, e.g. disturbed (e.g. roadside) versus undisturbed dry sclerophyll forest; grassland sprayed for weeds compared with that not sprayed; or a recently burnt area of woodland versus unburnt area
- 2 To select and appraise the technique(s) used to survey the areas
- 3 To carry out the survey
- 4 To analyse the species diversity at each site

### Theoretical basis

Different ecological techniques are appropriate for different habitats. A range of surveying techniques is described in Section 3.8.

### Method

- 1 Select the ecosystems that are going to be investigated.
- 2 Consider the factors needed to be incorporated in the survey.
- 3 Taking the ecosystem into consideration, consider the range of sampling techniques available and which would be most suitable for

the locality, e.g. quadrats, line transect, belt transect.

- 4 Appraise each technique to determine the most appropriate for the ecosystem you are testing. Include safety aspects of moving around the terrain and ways to minimise harm to the local plants and wildlife. This can be completed when you fill out your risk assessment for this practical.
- 5 Write the sequence of steps to be used in the survey. Include enough detail so that the survey could be repeated by another scientist at a later date.
- 6 Complete the survey according to your method. Note any variations that may have been necessary due to environmental conditions.
- 7 Calculate species diversity in each locality.

### Discussion

Write a discussion of your results, including the following points:

- justification for the survey technique(s)
- problems (and the solutions used) that might have arisen during the surveys related to the technique(s)
- possible improvements that could be made to the survey technique(s)
- the level of species diversity in the two localities
- suggest possible correlations (including explanations) between the environmental conditions and the relative species diversity between the two tested sites.

### Conclusion

Write a brief summary of your findings.

## Unit 4 Mandatory practical



**14.3**

MANDATORY  
PRACTICAL

### Changes in the gene pool due to selection pressure

Analyse genotypic changes for a selective pressure in a gene pool (modelling can be based on laboratory work or computer simulation).

Source: *Biology 2019 v1.2 General Senior Syllabus* © Queensland Curriculum & Assessment Authority

#### Aims

- 1 To model a gene pool through successive generations
- 2 To determine the effects on the gene pool over successive generations under varying selection pressures
- 3 To compare the effects of different selection pressures on the gene pool
- 4 To discuss limitations of evolutionary modelling

#### Theoretical basis

Evolution results from changes in the gene pool of a population in successive generations. In any population there is variation in the expression of a specific characteristic. When environmental conditions are stable, the average of these variations represents the ideal adaptations available for the population at that time. Extremes in the characteristic are selected against, that is, there is a stabilising selection. If environmental conditions change, the new selection pressure may favour one of the extremes. This results in a change in characteristics in the direction of the pressure. This is termed progressive selection. The genotypes for a particular characteristic can be represented by different coloured plastic discs. General assumptions need to be made when modelling a gene pool of a population. For the purpose of this experiment the following general assumptions concerning populations (genotype for a simple characteristic represented by a plastic disc) will be:

- all populations start with an equal number of each of the three genotypes
- breeding occurs at random with respect to the phenotype of the individuals for this characteristic
- there is an equal number of each sex in each generation
- there is only one lot of offspring in any one breeding season
- each mating results in four offspring in the ratio predicted by a Punnett square
- the parents die before the next breeding season
- there is no immigration or emigration
- there are no mutations affecting the alleles concerned.

#### Materials

- Approximately 100 plastic discs of three different colours in a black cloth bag:
  - Colour 1 = homozygous dominant
  - Colour 2 = heterozygous (one side marked with an X to indicate the allele for the dominant trait)
  - Colour 3 = homozygous recessive

#### Method

##### A Assumption 1: There is no selection pressure to change the gene pool.

- 1 Decide which disc colour represents each genotype. Record your decision.
- 2 Place four of each colour disc in the bag.
- 3 Withdraw two discs (parents) randomly. Record the parents and determine the genotype of the four possible offspring (in a Punnett square). Record your results in an appropriate table. Repeat until all 'parents' have mated, equalling six matings with 24 offspring.

- 4 From your table, count the number of each genotype of the offspring. Select the number of discs that represent these genotypes and place them in the bag (24 discs). Remember that parents die before the next mating.
- 5 Repeat steps 3 and 4 three more times.
- 6 Determine the ratio of genotypes in generation 4. Record the results. Compare this ratio with that of the original population.

### **B Assumption 2: Selection pressure acts against homozygous recessives.**

- 1 Place four of each of two colours of discs in the bag (excluding the homozygous recessive discs).
- 2 Withdraw two discs (parents) randomly. Record the parents and determine the genotype of the four possible offspring (a Punnett square). Record your results in a table. Repeat until all 'parents' have mated, equalling four matings with 16 offspring.
- 3 From your table, count the number of each genotype of the offspring. Select the number of discs that represent these genotypes and place them in the bag (remembering to exclude the homozygous recessive offspring). Remember that parents die before the next mating.
- 4 Repeat steps 2 and 3 three more times. (Record the results for each repeating step.)
- 5 Determine the ratio of genotypes in generation 4. Record the results. Compare this ratio with that of the original population.

### **C Assumption 3: Selection pressure acts for heterozygotes.**

- 1 Place eight of the heterozygote coloured discs in the bag.

- 2 Withdraw two discs (parents) randomly. Record the parents and determine the genotype of the four possible offspring (a Punnett square). Record the results in a table. Repeat until all 'parents' have mated, equalling four matings with 16 offspring.
- 3 From your table, count the number of each genotype of the offspring. Select the number of discs that represent these genotypes and place them in the bag (remembering to exclude the offspring). Remember that parents die before the next mating.
- 4 Repeat steps 2 and 3 three more times. (Record the results for each repeating step.)
- 5 Determine the ratio of genotypes in generation 4. Record the results. Compare this ratio with that of the original population.

### **Discussion**

Write a discussion of your results, including the following points:

- the validity of the assumptions in relation to a 'real' population
- the action of selection pressures in changing the gene pool for a specific species characteristic over time; give reasons for your decision
- whether, in this example, the changes would lead to clinal variation, formation of races, or speciation
- give examples from the text of where assumptions 2 and 3 have been shown to occur.

### **Conclusion**

Write a brief summary of your findings.

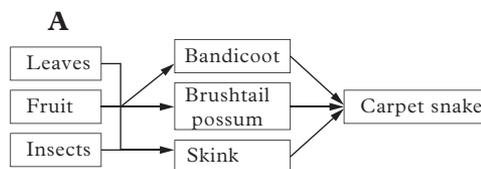
## Practice examination questions (in preparation for external assessment)

These questions are exam style questions.

### Multiple choice

Select the alternative (A, B, C or D) that best answers the question or completes the statement.

- Biodiversity:
  - only refers to the ecosystems in which particular organisms are found
  - results from the loss of some genes and gain of other genes in a range of different organisms
  - refers to the types of organisms found on Earth
  - refers to the variety of organisms, their genetic makeup and the ecosystems in which they are found
- With reference to dogs, the poodle and the sausage dog are:
  - subspecies
  - varieties
  - racés
  - hybrids
- An abiotic factor related to the climate of an area would be:
  - water currents
  - pH
  - temperature
  - topography
- Which of the following best illustrates a food chain?

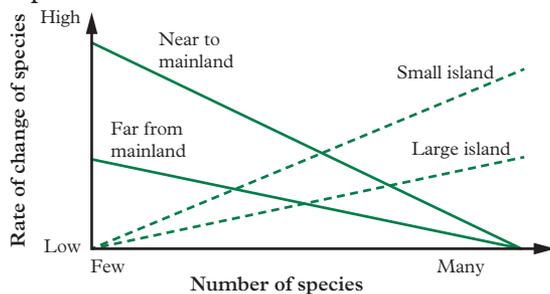


- Carpet snake → Bandicoot → Insects
- Insects → Carpet snake → Brushtail possum
- Insects → Bandicoot → Carpet snake

- Which of the following statements is correct?
  - There is greater stability in a complex food web than a single food chain.
  - Food webs exist because most animals are specialist feeders.
  - Since matter is an infinite resource it is recycled between the abiotic and biotic environment.
  - The ultimate release of mineral nutrients back into the environment is achieved by detritivores.
- In ecological pyramids:
  - as the name suggests, the shape is always a pyramid, with primary producers forming the base and higher order consumers the top
  - the base trophic level is always the largest
  - the pyramid of numbers is always the same shape as the pyramid of biomass
  - the pyramid of biomass is the same true pyramid shape as the pyramid of energy in all ecosystems
- Which of the following is correct?

	Nutrient	Reservoir pool	Cycling pool
<b>A</b>	Water	Artesian waters, glaciers	Photosynthesis – respiration
<b>B</b>	Carbon	Deep sea sediments	Respiration – photosynthesis
<b>C</b>	Nitrogen	Fossils, peat	Nitrogen fixing – denitrification
<b>D</b>	Phosphorus	Rock, deep sea sediments	Erosion – uptake – dephosphorisation

- 8 Population growth rate refers to:
- A the change in population size
  - B the speed of population changes
  - C an increase in population size due to births and immigration
  - D the number of deaths and emigrations that occur in the population
- 9 Character displacement always results:
- A when two species occupy the same niche in the same locality
  - B due to resource partitioning
  - C when the behaviour of two competing species is identical
  - D from divergence of overlapping characteristics in two species with the same niche
- 10 This graph indicates how the number of a species may change on islands being colonised from the mainland. The solid lines on the graph indicate immigration whilst the dashed lines represent extinction.



What conditions is the rate of immigration highest?

- A many species on a small island
- B a small island far from the mainland
- C an island near the mainland with few species
- D a large island far from the mainland with many species

### Short answer

- 1 The bell miner, *Manorina melanophrys*, is a bird (class *Aves*) in the order *Passeriformes* and family *Meliphagidae*. **Classify** the bell miner from kingdom to species. 3 marks
- 2 **Describe** how you could measure the height of a tree using an isosceles triangle. **Explain** why the same method cannot be used to measure the height of a hill. 4 marks
- 3 **Consider** three decisions required prior to using a transect to provide an ecological survey. 3 marks
- 4 **Compare** the composition of a plant community in a tall open forest ecosystem with frequent annual fires and one in which there has been no fires for several centuries. 4 marks
- 5 The kakapo is a flightless bird found in New Zealand. It is in danger of extinction because of introduced predators such as cats, stoats and weasels. Fifteen pairs of kakapo were placed on an island that was free of predators in 2012. The number of birds were counted every December over the next six years. The results are shown below.

TABLE 1 Population of Kakapo

	2013	2014	2015	2016	2017	2018
Breeding population	20	14	8	21	27	34
Births	9	10	13	14	19	21
Deaths	6	12	5	6	4	15
Total birds alive	23	21	29	37	52	58

- a **Determine**, with reasons, the year in which the greatest increase in population occurred. 2 marks
- b **Propose** two reasons for the low breeding population in 2015. 2 marks
- 6 **Differentiate** between a primary and a secondary forest. 1 mark
- 7 **Describe** the process of desertification. 2 marks
- 8 **Analyse** the claim that 'species evolutionary relatedness can only be inferred from molecular sequencing'. 8 marks
- 9 **Interpret** the process of determining past climate changes using core samples of polar ice. **Compare** this with the use of core samples of deep-sea sediments. 8 marks
- 10 **Analyse** the claim that 'success of ecosystem management is based on the classification of ecosystems'. 8 marks

## Practice examination questions (in preparation for external assessment)

These questions are exam style questions.

### Multiple choice

Select the alternative (A, B, C or D) that best answers the question or completes the statement.

- 1 The accompanying table shows three different mRNA molecules (each containing a base sequence) and three different protein molecules synthesised from them.

mRNA	Repeating sequence	Protein
AGAGAGAGAGAG AGAGAGAG...	AG	X
CAUCAUCAUCAU CAUCAUCAU...	CAU	Y

Which of the following shows the correct number of different types of amino acids in each protein molecule?

	X	Y	Z
A	2	1	4
B	1	3	2
C	2	1	3
D	3	1	4

- 2 In budgerigars, green (G) is dominant to blue (g). A pure breeding green budgerigar is mated with a heterozygous green budgerigar. The genotype of the offspring is most likely to be:
- A all green  
B some blue and some green  
C GG or Gg  
D GG or gg
- 3 X-linked dominance is generally less common than X-linked recessive characteristics in humans. An example of an X-linked dominant disease is muscular dystrophy, an inherited weakness and wasting of the legs and

later the hands. One would expect that:

- A women will show the trait equally as often as men  
B daughters of affected men will all be affected, but none of the sons of affected men will be affected  
C both sons and daughters of affected men will be affected  
D a man with the disease must have had a father with the disease
- 4 A transgenic organism:
- A contains genetic material from a different species or breed  
B always has some of its genes permanently inhibited  
C always has some of its genes permanently activated  
D exhibits physical characteristics of two or more organisms
- 5 Gel electrophoresis:
- A uses a thermophile to make copies of segments of DNA  
B exploits naturally occurring DNA polymerases to copy genetic material  
C is a method of extracting single nucleotide repeats from a segment of DNA  
D is a method of separating mixtures of DNA, RNA or proteins by molecular size
- 6 Darwin's theory of evolution:
- A was the first theory proposed to explain the origin of the immense biodiversity on Earth  
B proposed that an organism can pass on to its offspring characteristics acquired during its lifetime and in this way the species changes over time

- C** surported that those individuals in a population that have characteristics best adapted to the environment are more likely to survive and produce offspring
- D** demonstrated that neutral mutations that have accumulated over time in a species may, in a short period of time, become adaptive when a catastrophic event occurs
- 7 A key adaptation is a characteristic present in a population that is:
- A** essential for survival of the species under all environmental conditions
- B** selected by environmental pressure to exploit a new niche or resource
- C** selected by the population to enable radiation of the species
- D** the basis for convergent evolution of different taxonomic groups
- 8 Fecundity refers to the ability of:
- A** a population to survive a severe drought
- B** a species to produce a large number of young
- C** an individual to produce a large number of viable offspring
- D** a species to change allele frequencies over successive generations
- 9 In stable environmental conditions:
- A** all phenotypic expressions of a characteristic will be equally distributed throughout the population
- B** the phenotypic expression of a characteristic in the population will be the same
- C** directional selection favouring one expression of a characteristic occurs
- D** a distribution of the phenotypic variations in a characteristic is symmetrical about a mode
- 10 The term allopatric species refers to:
- A** two populations geographically isolated from each other so that gene flow between them is prevented
- B** members of a population that are found in slightly different habitats within a single environment

- C** the character displacement between species with the same niche requirements in a particular habitat
- D** non-random mating in a population with a broad geographic range with no specific geographic barrier to gene flow

### Short answer

- 1 **Differentiate** between DNA and RNA. 2 marks
- 2 **Contrast** mitosis and meiosis. 2 marks
- 3 **Explain** why gametogenesis involves both mitosis and meiosis. 3 marks
- 4 **Describe** post-transcription events in a eukaryotic cell. 3 marks
- 5 **Identify** the circumstances under which the law of independent assortment does not hold. 2 marks
- 6 **Define** bioinformatics. 1 mark
- 7 **Explain** giving an example why mimicry is considered an example of coevolution. 5 marks
- 8 **Explain** how gene pool bottlenecks occur and how they may result in extinction. 3 marks
- 9 Blue eye colour is dominant to brown eye colour. **Analyse** how two brown-eyed parents can produce children with eye colours that range from dark brown, mid-brown, yellow, hazel, green and a variety of shades of blue. 8 marks
- 10 It has been proposed that all speciation occurs as a result of a geographic barrier arising between two segments of a population, thus preventing gene flow between them. **Analyse**, with examples, the validity of this statement. 8 marks
- 11 Much of the DNA found in organisms does not code for a specific protein. This was once considered 'junk' DNA – redundant DNA left over during the evolutionary process. **Structure** an argument that supports the concept that this non-coding DNA has a significant impact on the life of an organism. 8 marks

# GLOSSARY

## A

### abiotic

the non-living physical factors that affect an organism's ability to survive

### abundance

number (of a species) in a specific area at any time

### abyssal zone

deep-water zone (depth 4000–6000 m)

### adaptation

a feature of an organism that enhances its ability to survive and reproduce in a particular environment

### adaptive radiation

an evolutionary process in which organisms diversify rapidly from an ancestral species into several divergent forms

### agglutination

sticking together of incompatible cells, e.g. by different 'groups' of red blood cells

### allele

one of two or more forms of a gene located in equivalent positions on homologous chromosomes

### allopatric species

species that result when two populations of the same species become isolated from each other due to a geographic barrier

### altitudinal zonation

bands of vegetation communities showing adaptations to particular environmental conditions associated with altitude

### amensalism

a relationship in which one species is inhibited by another

### amniocentesis

a surgical procedure for obtaining a sample of amniotic fluid from the amniotic sac in the uterus of a pregnant woman

### analogous structures

structures with a similar function but no structural relationship

### aneuploidy

the existence of an abnormal number of chromosomes in a cell

### anticodon

triplet of nitrogen bases found on tRNA

### antiparallel

two biopolymers that run parallel to each other but with opposite alignments, e.g. the two strands of the DNA molecule

### apomixis

asexual reproduction

### apomorphy

a specialised trait or characteristic unique to a group or species

### artificial selection

the breeding of plants and animals to produce desirable traits

### asexual reproduction

the production of genetically identical offspring from a single parent

### autosomal aneuploidy

presence of an abnormal number of autosomal chromosomes

### autosome

non-sex chromosome

## B

### Barr body

inactivated X chromosome in the cells of female mammals

### belt transect

an elongated area of known length and width through a particular environment in which specific community parameters are measured and recorded

### benthic ecosystem

the ecosystem at the lowest level of a body of water; includes the sediment surface and some subsurface layers

### Berlese-Tullgren funnel

a device used to extract small animals from leaf litter

### binomial nomenclature

method of naming species of organisms with two parts: the generic and specific names, e.g. *Eucalyptus crebra*

### biodegradable

able to be broken down by organisms

### biodiversity

the range of living organisms and their environments

### biofilm

a layer on a solid matrix composed of microscopic bacteria, algae and protozoa in a complex polymer-linked assemblage

### biogeochemical cycles

circulation of chemical elements in the biosphere

### bioinformatics

biological studies that use computer programming to assist with the collection, classification, storage and analysis of biochemical and biological information

### biological magnification

concentration of substances within the tissues of organisms as they pass along a food chain

### biological oxygen demand (BOD)

a measure of the quantity of oxygen used by microorganisms (e.g. aerobic bacteria) in the oxidation of organic matter in aquatic environments; the higher the BOD, the less oxygen is available for other organisms

### biomass

amount of organic matter in a system

### biome

the living organisms of a large area defined by its climate and dominant plant species (e.g. a desert community)

### biosphere

the part of the Earth that supports life

### biotechnology

the application of biological knowledge to the production of organisms (or their products) that are useful to humankind

### biotic

the living components in the environment

### biotic potential

number of offspring capable of being produced by individuals of a species

### bipedal

the ability to walk on two, rather than four, legs

### BLAST (Basic Local Alignment Search Tool)

a computer program that compares unknown DNA or protein sequences with known sequences

## C

### camouflage

adaptations which 'hide' the organism in its environment; any means of blending with the environment

### canopy

the upper layer or habitat zone, formed by mature tree crowns

### capping

the addition of methyl-guanine to the start of the trimmed mRNA

### capture-recapture

method of estimating population density of animals where animals are captured, marked and released; their proportion of marked animals in subsequent trapping allows estimation of population size

### carcinogen

a substance or agent that can cause cells to become cancerous by altering their genetic structure so that they multiply continuously and become malignant

### carnivore

meat-eating organism

### carrier

an individual (female in humans) who is heterozygous for a sex-linked gene, or an individual who is infected by a pathogen but does not display the symptoms

**carrying capacity**

the total population able to be supported by a particular environment

**character change**

change in phenotype over time

**character displacement**

the evolutionary divergence of characteristics displayed by two or more species with the same niche in a particular habitat

**chiasma (plural chiasmata)**

connection between non-sister chromatids of homologous chromosomes during meiosis, where interchange occurs during crossing over

**chorionic villus sampling**

a prenatal test in which a sample of chorionic villi is removed from the placenta for testing

**chromatid**

a replicated chromosome, still attached to the original at the centromere

**chromosomal deletion**

loss of a part of a chromosome during DNA replication

**chromosome mutation**

a change in the chromosome structure or number, often due to an error in pairing during the crossing over stage of meiosis

**clade**

a group of organisms that is believed to comprise a common ancestor and all of its evolutionary descendants

**cladistics**

a method of grouping organisms that uses evolutionary lines of descent rather than structural similarities

**cladogenesis**

the making of a clade by means of an ancestor species evolving into two or several new species

**cladogram**

a branching diagram showing the evolutionary relationships between a number of species

**claim**

a statement without evidence to support it

**class (taxonomy)**

one of the groups used in the classification of organisms, consisting of a number of orders; for example, animals in class Mammalia all share specific characteristics

**classification**

grouping of organisms based on similarities in morphology, anatomy and biochemistry

**climax community**

a more or less stable plant community

**clinal variation**

gradual changes or differences in inherited characteristics of adjoining populations of a species spread across a range of environments (geographic range)

**cline**

is a measurable gradient in a single character (or biological trait) of a species across its geographical range

**cloning**

the process of producing genetically identical individuals or the duplication of any kind of biological material

**clumping**

distribution where individuals are found clustered in groups in particular parts of the habitat

**codominance**

genetic inheritance of two or more traits of a characteristic, each of which is expressed in the phenotype

**codon**

triplet of nucleotides on mRNA specifying an amino acid

**coevolution**

occurs when two or more species reciprocally affect each other's evolution

**cognitive verbs**

QCAA-assigned verbs to help students answer questions correctly

**colour defective vision**

inability of individuals to distinguish the colours red and green

**commensalism**

relationship between two organisms in which one organism benefits and the other is not affected

**community**

all the species that occupy a particular place at a given time

**competition**

rivalry between individuals, of the same or different species, for a specific resource(s)

**competitive exclusion principle**

two species are unable to compete for the resources in the same niche

**condensation polymerisation**

the formation of a polymer by the reaction between two monomers, with the loss of a small molecule (e.g. water)

**conserved gene**

gene that has remained essentially unchanged throughout evolution

**consumer**

organism that eats another living organism (or part of an organism) for nutrition

**continuous variation**

a variety of phenotypes as a result of more than one gene contributing to a characteristic

**convergent evolution**

the independent development of similarities between species as a result of them having similar ecological roles and selection pressures

**cooperation**

association between (or within) species that benefits both but is not essential for the survival of either

**crossing over**

breaking and rejoining, with exchange of DNA between adjacent non-sister chromatids, of homologous chromosomes during meiosis I

**cryptic organism**

an organism that has the ability to avoid observation or detection by using camouflage, nocturnality, underground habitat, mimicry or any other method of concealment

**cycling pool**

small compartment of a biogeochemical cycle with active exchange of matter between organisms and the environment

**D****Darwin's theory of evolution**

theory that all species of organisms arise and develop through the natural selection of small, inherited variations that increase the individual's ability to compete, survive and reproduce

**decomposer**

an organism (e.g. bacteria and fungi) that utilises dead organisms or waste matter for its nutrients, releasing simple inorganic molecules

**denitrifying bacteria**

bacteria that convert nitrate to nitrite, or atmospheric nitrogen or nitrite to ammonia

**density-dependent factor**

any factor influencing population regulation that has a greater impact as the density increases

**density-independent factor**

an abiotic factor (that is independent of the density of the population) that affects the size of a population

**deoxyribonucleic acid (DNA)**

thread-like chain of nucleotides carrying the genetic instructions in a double helix of antiparallel strands

**derived characteristic**

a feature that sets members of that clade apart from other individuals

**desertification**

formation of desert conditions, usually resulting from overgrazing of susceptible areas

**detritus**

organic debris from decomposing plants and animals

**detritivore**

an organism that feeds on detritus

**developmental neoteny**

the retention of juvenile structure or traits by adults in a species

**diagnostic feature**

any feature used to separate groups in the classification of organisms

**dichotomous key**

identification key with only two alternatives at each stage

**dihybrid cross**

genetic cross between two individuals, both heterozygous for two specific traits

**dihybrid ratio**

predicted ratio of offspring obtained from a cross between individuals simultaneously heterozygous for two characteristics

**diploid**

cellular condition in which there are two of each type of chromosome present in the nucleus

**directional selection**

natural selection that favours one phenotypic extreme, causing the allele frequency to shift over time in the direction of that phenotype

**disclimax community**

final community formed after succession as a result of degrading environmental factors

**disruptive selection**

natural selection favouring individuals with extreme phenotypes

**distribution**

regions in which a species is found

**divergent evolution**

evolution that leads to descendants becoming different in form from their common ancestor

**division (taxonomy)**

major classification group of the plants, fungi and plant-like protists

**dizygotic twins**

each twin develops from a separate egg, and each egg is fertilised by a separate sperm cell

**DNA helicase**

an enzyme that breaks down the hydrogen bonds holding two DNA strands together

**DNA-hybridisation**

a technique that measures the degree of genetic similarity between the DNA sequences of different individuals

**DNA ligase**

a specific type of enzyme that facilitates the joining of DNA strands together

**DNA methylation**

the addition of a chemical tag (a methyl group) to the start of a structural gene to block transcription

**DNA polymerase**

a type of enzyme that is responsible for assembling nucleotides to form new copies of DNA

**DNA profiling (fingerprinting)**

a technique used to identify (as for forensic purposes) the characteristics of an individual's DNA by extracting and identifying the base-pair pattern of their DNA

**DNA scissors**

restriction enzymes that cut DNA into fragments

**domain (taxonomy)**

broadest taxonomic group

**dominant allele (autosomal dominant)**

an allele for a gene that overrides the effects of the recessive allele in the heterozygous condition; can be autosomal or sex-linked

**dominant species**

the most common species in a community

**dominant trait**

the particular trait of a characteristic that is expressed in the phenotype of a heterozygous individual

**duplication**

any repetition of a region of DNA that contains one or more genes

**E****ecological homeostasis**

maintenance of a population size commensurate with environmental limiting factors, mediated by feedback systems

**ecological pyramid**

a model of the relationships between different organisms in a food chain

**ecology**

the study of relationships between organisms and their environment

**ecoregion**

a subdivision of an ecozone; a geographically distinct community based on geology, soils, climate and predominant vegetation

**ecosystem**

a biological community of interacting organisms and their physical environment

**ecozone**

a large area in which organisms have been evolving in relative isolation over long periods of time

**embryology**

growth and development of a zygote until birth

**endangered species**

a species of animal or plant that is seriously at risk of extinction

**endoscope**

a lighted optical instrument that is used to look inside the body

**environment**

the conditions (biotic and abiotic) in which an organism lives

**environmental limiting factor**

any factor that limits the growth of a population

**environmental resistance**

sum total of all environmental limiting factors

**epigenetic factor**

a chemical tag that determines the degree of coiling of the DNA around the nucleosome and thus gene expression

**epigenome**

a system of gene control outside of the DNA ('above the genome')

**epistasis**

(= 'standing upon') where the phenotypic expression of one gene is masked by that of another gene

**equilibrium (set point)**

point at which a system can be maintained, e.g. population size for a specific environment

**euchromatin**

'relaxed' chromatin that contains genes that can be transcribed

**eutrophication**

build-up of nutrients in water; may result in oxygen depletion

**evenly spaced distribution**

individuals are more or less equally spaced throughout the entire area

**evolutionary radiation**

diversification of species

**exaptation**

the process by which an anatomical structure, physiological process or behaviour pattern of an organism acquires a new function

**exon**

a coding section of DNA within a split gene

**exotic**

describes organisms not naturally occurring in a particular region

**extinct species**

a particular animal or plant species which has no more individuals of that species alive anywhere in the world

**extremophiles**

organisms that live in extreme environments

**F****family (taxonomy)**

subdivision of an order in the classification of living things

**family tree**

a chart showing the ancestry, descent and relationships between members of a family or other genealogical group

**fecundity**

the natural capability to produce offspring

**5' (five-prime) end**

one end of a DNA strand in which the C<sub>5</sub> carbon atom of the sugar molecule in the DNA's sugar backbone has a 'free' phosphate group that is not linked to another chemical group

**flagship species**

a species chosen to raise support for biodiversity conservation in a chosen place or context

**foetoscopy**

technique for looking directly at the foetus within the uterus (using an endoscope)

**foliage cover**

an estimate of the area or percentage of a sample site occupied by the natural spread of plant foliage

**food chain**

simple linear arrangement of organisms showing the flow of matter and energy from one organism to another through feeding relationships

**food web**

all the possible feeding relations in an ecosystem

**founder effect**

reduced genetic diversity as a result of a population having descended from a small number of colonising ancestors

**frameshift mutation**

the deletion or insertion of a single nucleotide or non-multiple of three nucleotides into the DNA

**fraternal twins**

an alternative name for dizygotic twins

**frequency histogram**

an accurate representation of the distribution of numerical data; an estimate of the probability frequency distribution of a continuous variable (quantitative variable)

**G****gametogenesis**

formation of gametes

**gel electrophoresis**

a laboratory method for separating mixtures of DNA, RNA or proteins according to molecular size

**gene**

a region of DNA, made up of nucleotides, that encodes a molecule that has a function

**gene cloning**

production of identical copies of a gene

**gene complexes**

two or more genes interacting to determine the phenotypic expression of a characteristic

**gene expression**

the ability of a gene to be transcribed

**gene flow**

the movement and exchange of alleles between populations of a species

**gene linkage**

location of genes on the same chromosome

**gene pool**

total aggregate of genes in a population at any one time

**gene probe**

a single-stranded DNA or RNA fragment used in genetic engineering to search for a particular gene or other DNA sequence

**gene therapy**

the introduction of normal genes into cells in place of missing or defective ones in order to correct genetic disorders

**generalist feeder**

a heterotroph with a varied diet

**genetic code**

the code the body uses to convert the instructions contained in the DNA into the proteins essential for life

**genetic drift**

changes in the gene pool, and thus the relative frequency of different genotypes in a small population, due to chance

**genetic equilibrium**

describes the condition of an allele or genotype in a population when the frequency remains stable over time

**genetically modified organism (GMO)**

an organism whose genetic material has been altered using recombinant DNA technology

**genome**

the complete set of nucleotide sequences encoded in the total DNA of an organism

**genotype**

the genetic makeup of an individual

**genus**

classification category between family and species; first part of the scientific name of an organism

**geographic distribution**

the natural range of the various forms of animals and plants in the different regions and localities of the Earth

**geographic isolates**

a physical barrier that prevents interbreeding between members of different populations of a species

**geographic isolation**

a physical barrier that prevents interbreeding between members of different populations of a species

**germ cell gene therapy**

replacement of a defective gene with a normal gene in a reproductive cell (egg or sperm), allowing normal development of the embryo and preventing the disease variant from being passed down

**germ line mutation**

a heritable change in the DNA that occurs in a germ cell (a cell destined to become an egg or sperm) or the zygote at the single-cell stage and so is incorporated in every cell of the body

**gross primary production**

the total amount of organic matter in an ecosystem produced as a result of photosynthesis

**guano**

sedimentary rock, rich in phosphates, formed from the build-up of seabirds' excreta

**H****habitat**

a specific location, with a particular set of biotic and abiotic conditions; where an organism normally lives

**habitat fragmentation**

division of a habitat into smaller, isolated portions as a result of human activities in the intervening spaces

**haemophilia**

a group of disorders in which the blood does not clot normally

**half-life**

the time taken for a quantity, for example the radioactivity of an isotope or a chemical, to break down to half its original value

**haploid**

cellular condition in which there is one of each type of chromosome present in the nucleus

**Hardy-Weinberg law**

states that when there are no other evolutionary influences, the allele and genotype frequencies in a population will remain constant across generations

**heat shock protein**

member of a family of proteins produced by cells in response to stressful environmental, chemical or physical conditions; e.g. HSP90 assists with the activation and stabilisation of a wide variety of proteins

**herbivore**

plant-eating organism

**hereditary mutation**

gene change in a body's reproductive cell that can be passed from parent to offspring

**heterochromatin**

chromatin tightly coiled around histone proteins in the nucleosome

**heterotroph**

an organism that eats other living organisms

**heterozygous**

each allele for the characteristic exhibiting a different expression

**hierarchical**

relating to the graded organisation of grouping from general to very specific subgroups

**histone modification**

addition of chemical tags that vary the width between nucleosomes and so determine whether or not a gene can be transcribed

**holandric genes**

genes found on a vertebrate Y chromosome

**Holdridge life zone system**

a system of classifying areas of land, encompassing climate and ecological types

**homeobox**

DNA sequence (of about 180 base pairs) contained in a gene (e.g. the *Hox* gene) that is highly conserved and can bind to DNA to control gene expression

**homeobox (*Hox*) genes**

a subgroup of homeotic genes that control the body plan of an embryo along the head-tail axis

**homeotic gene**

any of a group of related genes that control the body plan of an embryo along the head-tail axis during early embryonic development

**homologous chromosomes**

chromosomes of the same type; usually a pair (see 'homologs')

### **homologous structures**

similar structures with slightly different functions, indicating shared ancestry

### **homologs**

two chromosomes that are homologous; during meiosis, the set of pairing maternal and paternal chromosomes; have the same genes at the same loci but may have different alleles

### **homozygous**

describes a condition in which both alleles for the gene are the same

### **Hox protein**

a transcription factor produced by a *Hox* gene

### **hybrid**

offspring resulting from a cross between parents that are genetically unlike, for example, two closely related species or varieties within a species

### **hybrid (genetic)**

heterozygote for a characteristic; plant or animal resulting from a cross between parents that are genetically unlike for that trait

### **hypothesis**

a statement that attempts to answer questions raised by observations and can be tested by experimentation

## **I**

### **immunological difference**

the degree of difference between two proteins

### **index fossil**

a distinctive, abundant fossil with a wide geographic distribution over a relatively short geological period of time

### **intermediate dominance (partial dominance or incomplete dominance)**

a pattern of inheritance in which neither allele for a characteristic completely masks the effects of the other; results in a blending of traits for the characteristic

### **interspecific**

between different species

### **intraspecific**

within a species; between individuals of the same species

### **intron**

a non-coding section of DNA within a split gene

### **inversion**

a chromosome rearrangement in which a segment of a chromosome is reversed end to end

### **in-vitro fertilisation**

a complex series of procedures used to assist with the conception of a child, where mature eggs are collected from the ovaries and fertilised by sperm in a laboratory

### **isotopes**

variations of an element that differ in the number of neutrons within their nuclei; many isotopes are radioactive forms of an element

## **J**

### **J-shaped population curve**

the graphical representation of the change in population density of an organism as it increases rapidly and then stops suddenly, due to environmental or other factors

## **K**

### **karyotype**

the number and visual appearance of the chromosomes in the cell nuclei of an organism or species

### **key adaptation**

a novel phenotypic trait that allows an organism to evolve and exploit a new niche or resource, resulting in the subsequent radiation and success of a taxonomic group

### **keystone species**

a species that has a disproportionately large effect on its environment relative to its abundance by maintaining local biodiversity within a community either by controlling populations of other species that would otherwise dominate the community or by providing critical resources

### **kingdom**

a subdivision of a domain; group of organisms with very general common features

### **K-strategist**

a species whose population fluctuates at or near the carrying capacity (*K*) of the environment in which it resides

## **L**

### **lagging strand**

DNA template from the fork to the middle of the replication bubble (point of origin)

### **Lamarck's theory of evolution**

the hypothesis that an organism can pass on characteristics acquired during its lifetime to its offspring

### **latitudinal zonation**

changes in plant community structure due to climatic conditions associated with latitude

### **law of conservation of matter and energy**

matter and energy cannot be created or destroyed but can be changed to other forms

### **law of independent assortment**

Mendelian law that states that each allele pair segregates independently during gamete formation; applies when genes for two traits are located on different pairs of homologous chromosomes

### **law of segregation**

Mendelian law that states that genes for a characteristic occur in pairs in an individual, one inherited from each parent, and are separated when the reproductive cells are formed

### **leading strand**

DNA template from the middle of the replication bubble (point of origin) to the fork

### **limiting factors**

conditions that limit the growth, abundance or distribution of an organism or a population of organisms

### **Lincoln Index (N)**

a method used to estimate the size of closed populations in which random samples of the population are captured, marked and released to mingle with the general population for a period of time before subsequent trapping

### **line intercepts**

a sampling technique used to estimate relative densities of a species by counting the number of individuals that lie on a straight line cutting through the community

### **littoral zone**

the zone between water and land, which may be affected by tidal action

## **M**

### **macroevolution**

major evolutionary change at or above the level of species over geological time

### **mangrove**

ecosystem in tropical and subtropical coastlines of quiet tidal waters

### **mass extinction**

the rapid and widespread extinction of a large number of species, due a catastrophic global event or rapid, widespread environmental change

### **meiosis**

nuclear division resulting in daughter cells having half as many chromosomes, but the same types, as the parent cell; a reduction division, from the diploid to the haploid condition

### **microclimate**

climate of a very small or restricted area, especially when this differs from the climate of the surrounding area

### **microenvironment**

an area within a general habitat with specialised environmental conditions, e.g. a hollow log

### **microevolution**

a change in gene frequency within a population over a succession of generations

### **microhabitat**

a small habitat that may be different from the surrounding larger habitat

### **mimicry**

protective adaptation in which one organism (the mimic) resembles another organism (the model)

### **mitochondrial DNA**

a double-stranded DNA found only in mitochondria; in most eukaryotes is circular and is maternally inherited

**mitosis**

nuclear division resulting in daughter cells having the same number and type of chromosomes as the parent cell

**modifier genes**

genes that influence the expression of another gene

**molecular analysis**

a branch of biochemistry where the molecular basis of biological activity of molecules such as DNA, RNA and proteins is studied

**molecular clock**

a technique that uses the mutation rate to deduce when two or more life forms diverged

**monoculture**

a system that has very low diversity; in agriculture, it describes the practice of growing a single crop type

**monohybrid cross**

genetic cross between two individuals, both heterozygous for a specific trait

**monozygotic twins**

twins that develop from one zygote, which splits and forms two embryos; since they have the same genotype, they are considered to be identical

**mRNA**

messenger RNA; RNA molecule formed during transcription

**multiple or poly alleles**

the inheritance of a characteristic governed by more than two allelic forms, e.g. blood groups

**mutagen**

a physical or chemical agent that changes the genetic material of an organism

**mutation**

small permanent change in the DNA of an organism

**mutualism**

necessary and positive association between two organisms

**N****nekton**

free-swimming organisms of surface waters

**neo-Darwinian theory of evolution**

theory that species evolve by natural selection acting on genetic variation

**neritic zone**

shallow region of the ocean overlying the continental shelves

**net primary production**

amount of energy available for herbivores in an ecosystem

**neutral evolution**

evolutionary changes caused by genetic drift (dominated by random processes) rather than natural selection

**niche**

a species' role and position in its environment; a species' interactions with the biotic and abiotic factors of its environment

**nitrifying bacteria**

bacteria that convert ammonia to nitrite and nitrate to nitrate

**nitrogen fixation**

conversion of atmospheric nitrogen to nitrate by bacteria and cyanobacteria

**non-coding DNA**

the greater part of the DNA molecule that does not contain structural genes

**non-disjunction**

the failure of homologous chromosomes or sister chromatids to separate during meiosis

**nucleosome**

a length of DNA coiled around a core of eight histone protein molecules

**nutrient cycle**

cyclung of a particular element between biotic and abiotic ecosystem components

**O****Okazaki fragments**

fragments of DNA that are formed on the lagging strand of replicating DNA

**omnivore**

an organism that can utilise a range of nutrients; both herbivorous and carnivorous

**oogenesis**

formation of ova in animals

**oogonium (plural oogonia)**

a small diploid cell in the ovary that forms a primary oocyte in a female foetus

**optimal tolerance range**

the level of an abiotic factor at which an organism will best survive

**order**

subdivision of a class in the classification of living things

**origin of replication**

a particular sequence in the DNA molecule at which replication is initiated

**ovulation**

release of the secondary oocyte that has started meiosis II from the ovary

**ovum**

haploid female gamete

**P****parallel evolution**

independent evolution of similar traits in species that once shared a common ancestor

**parapatric speciation**

when subpopulations of a species evolve reproductive isolation from one another due to habitat differences within the population range

**parasitism**

association between organisms in which one species (the parasite) is completely dependent upon the other (the host), which is usually harmed

**parthenogenesis**

reproduction from an ovum without fertilisation in animals

**persistence**

length of time a measurable chemical residue remains in the environment

**pest**

an organism that causes direct or indirect harm to humans or their resources; an organism in the 'wrong' place

**phenotype**

actual expression of the genotype

**phenylketonuria (PKU)**

a homozygous recessive genetic disease in which one enzyme required for the normal break-down of phenylalanine is lacking

**photochemical smog**

secondary pollutant produced by chemical reaction between nitrogen oxides and hydrocarbons in the presence of sunlight

**photosynthetic efficiency**

the fraction of light energy that plants and algae convert into chemical energy during photosynthesis

**phylogeny**

the evolutionary history of a kind of organism

**phylum**

major classification group of the animal kingdom

**physiological stress**

the inability of an organism to function at maximum efficiency as a result of some factor

**pioneer species**

species of plants that colonise bare ground

**pit-fall trap**

a device used to trap small animals that are active on the ground surface

**plan sketch**

an aerial view showing position and canopy cover of species

**plankton-nekton ecosystem**

the ecosystem of the ocean surface consisting of nekton (free swimmers) and plankton (microscopic organisms)

**plasmid**

a small DNA molecule that is physically separated from chromosomal DNA and can replicate independently; typically within a bacterial cell

**plesiomorphy**

an ancestral characteristic or trait that is shared by two or more taxa

**plot**

an area under investigation – generally a subset of a larger area

**point mutation**

a change in a single nucleotide in the DNA code that may result in the translation of one different amino acid in a polypeptide sequence

**polar body**

small haploid cell produced from both meiosis I and II during oogenesis as a result of uneven cell division

**polygenic (or multiple gene) inheritance**

inheritance from a set of genes that together control a quantitative character such as height

**polymerase chain reaction (PCR)**

technique that permits the amplification of any short sequence of DNA

**polysome**

chain of ribosomes that 'read' mRNA

**population**

number of individuals of a species living in a particular place at a particular time

**population bottleneck**

an event (environmental disaster, overhunting, etc.) that drastically reduces the size of a population and thus its genetic diversity

**population density**

number of an individual species living in a particular place at a particular time per unit area

**population growth**

increase in the size of a population in a particular habitat over time

**population growth rate**

the rate of change in a population over a particular range of time

**predator**

an organism that captures, kills and feeds on another animal

**pre-implantation genetic diagnosis (PGD)**

a procedure used prior to implantation to help identify genetic defects within the embryo

**pre-implantation genetic screening (PGS)**

the set of techniques for testing whether embryos (obtained through IVF) have abnormal chromosome numbers

**primary follicle**

a single-layered structure in the mammalian ovary containing the primary oocyte

**primary forest**

climax forest formed as a result of primary succession

**primary oocyte**

a diploid cell developed by an ovarian germ cell in mammals, which may later develop into an ovum

**primary pollutant**

substance that has a direct adverse effect upon the environment

**primary spermatocyte**

diploid cell formed from mitosis of a spermatogonium, which undergoes meiosis I to produce two haploid secondary spermatocytes

**primary succession**

development and change in plant communities over time, leading eventually from bare ground to a climax community

**producer**

(autotrophic) organism forming the base of all food chains; converts simple inorganic chemicals into complex organic molecules (food)

**product rule**

a law of probability, stating that the chance of two independent events occurring together is equal to the chance of one event occurring alone multiplied by the chance of the other event occurring alone

**productivity**

amount of energy fixed in organic compounds; measured by increase in biomass per unit of time

**profile**

slope of the terrain, position and height of vegetation types, and canopy cover

**punctuated evolution**

theory of evolution in which a lot of evolutionary changes take place in short periods of time, often tied to speciation events such as environmental factors

**Punnett square**

mathematical device used to calculate probabilities of genetic crosses

**pure-bred (genetics)**

an organism that is homozygous for a trait and thus carries the same phenotype as the parents

**pyramid of biomass**

a model of the amount of living matter transferred through a food chain

**pyramid of energy**

a model of the amount of energy transferred through a food chain

**pyramid of numbers**

a model of the numbers of organisms at each trophic level of a food chain

**Q****quadrant**

each of four quarters of a circle

**quadrat**

a rectangular or square plot of known dimensions

**R****race**

one group of a population that is genetically different from other groups as a result of having a different range

**radioactive element**

an element that emits radiation as a result of the spontaneous degeneration of its nucleus

**random distribution**

an unpredictable spacing of individuals; where the position of each individual of a species is independent of that of the other individuals of the species in a given environment

**random sampling**

a method of selecting a sample from a total array in such a way that every possible sample that could be selected has an equal chance of being selected

**recessive allele (autosomal recessive)**

an allele found on a chromosome that can be masked by its dominant form in the heterozygous condition; can be autosomal or sex-linked

**recessive trait**

trait due to an allele that can be masked by the dominant allele in the heterozygous condition but expressed in the homozygous condition

**recombinant DNA (= genetic engineering)**

the deliberate modification of the characteristics of an organism, or production of a new organism, by inserting or deleting genes into the DNA

**recombinant gametes**

gametes produced as a result of crossing over of the chromatids of homologous chromosomes during meiosis

**reference list**

a list of resources used in a study

**regulatory gene**

a non-coding segment of DNA that produces transcription factors for gene expression

**relative age**

an expression of the geologic age of a fossil organism, rock, geologic feature or event, relative to other organisms, rocks, features or events, without expressing absolute age

**reliable (experiment)**

the degree to which an investigation produces stable and consistent results

**replication bubble**

an unwound and open region of DNA in which DNA replication occurs, created when the enzyme DNA helicase separates the two strands of DNA

**replication fork**

structure with two branching sections that is created when DNA helicases break the hydrogen bonds holding the two DNA strands together at a certain point

**reproductive isolating mechanisms**

reproductive characteristics that prevent reproduction between populations

**reproductive isolation**

inability of different populations or species to successfully interbreed due to behavioural, structural or physiological features of the organisms

**reservoir pool**

large abiotic component of a biogeochemical cycle in which matter is slowly exchanged with organisms

**resource partitioning**

division of environmental resources by coexisting species populations to avoid competition for resources

**restriction enzyme (nuclease)**

an enzyme that cleaves DNA at or near specific recognition sites

**restriction fragment length**

polymorphisms (RFLPs)  
different length fragments of DNA that result from the single nucleotide repeats

**reverse transcriptase**

a DNA polymerase enzyme that catalyses the process of reverse transcription – the use of an RNA molecule as a template for the synthesis of a complementary DNA strand

**reverse transcription**

the formation of DNA from an RNA template

**ribonucleic acid (RNA)**

thread-like chain of nucleotides carrying the genetic instructions for forming a protein in a cell

**rRNA**

RNA component of a ribosome

**r-strategists**

a species that occupies unstable environments and uses the evolutionary strategy of maintaining high growth rates, occupying less-crowded ecological niches, and producing many offspring

**S****scientific method**

the testing of a hypothesis by controlled experimentation

**scientifically credible sources**

resources from government and institute sites, peer-reviewed scientific articles and reports, textbooks, etc.

**secondary evidence**

evidence from a secondary source (e.g. a peer-reviewed scientific article)

**secondary forest**

climax forest formed due to secondary succession

**secondary oocyte**

a large haploid cell produced during meiosis I of the primary oocyte

**secondary pollutant**

a pollutant formed as a result of the interaction between wastes and the environment

**secondary spermatocyte**

haploid cell that undergoes meiosis II to form spermatids

**secondary succession**

successive, natural changes in plant communities in an area where a previous community has been removed

**semiconservative replication**

replication of DNA resulting in two copies that each contain one of the original strands and one new strand

**sere**

an intermediate community observed during ecological succession in an ecosystem advancing towards its climax community

**Sertoli cells**

cells in the epithelium of tubules of the mammalian testis that protect and nourish the developing spermatozoa

**sex chromosomes**

chromosomes carrying information that determines the sex of the individual

**sex-linked genes**

genes on the X chromosome

**sexual aneuploidy**

presence of an abnormal number of sex chromosomes in a cell

**sexual reproduction**

the production of offspring that has genetic material from two parents

**shared characteristic**

a feature that all members of a group have in common

**Simpson's Diversity Index (SDI)**

the probability that two individuals randomly selected from a sample will belong to different species (or groups)

**Simpson's Index (D)**

the probability that two individuals randomly selected from a sample will belong to the same species (or genus or family, etc.)

**somatic**

non-reproductive

**somatic cell nuclear transfer**

a laboratory technique for creating an ovum with a donor nucleus from a somatic cell

**somatic gene therapy**

replacement of defective genes in targeted somatic cells that are affected by a genetic disease

**somatic mutation**

a mutation in the somatic tissue of an organism that affects the specific cell type but is not inherited

**specialist feeder**

a heterotroph that can thrive only on a limited diet

**speciation**

the evolutionary process by which new and distinct species are formed in the course of evolution

**species**

taxonomic group, allocated two (genus and specific) names; only members of the same species can produce fertile offspring when mating under natural conditions

**species diversity**

a measure of the number of species found in a community, compared with the number of individuals

**species richness**

a measure of the numbers of species present and the evenness of species in relation to one another

**specific name**

the descriptive name of a species

**spermatid**

immature spermatozoon

**spermatogenesis**

formation of spermatozoa in animals

**spermatogonium (plural spermatogonia)**

germ (or stem) cell in a layer lining the tubules in the testes

**spermatozoon (plural spermatozoa)**

small, motile male gamete

**split gene**

a gene that contains sections of non-coding DNA called exons (expressed as RNA and protein) interrupted by sections of DNA called introns

**SRY gene**

the gene on the Y chromosome responsible for initiating male sex determination in humans

**S-shaped population curve**

the graphical representation of the change in population density of an organism when it initially increases slowly and then rapidly as it approaches an exponential growth rate, but then decreases and levels off as the environmental carrying capacity is reached

**stabilising selection**

natural selection for a particular variant (mean) of a characteristic that maintains consistency of a population; occurs in times of environmental stability

**standing crop**

biomass of an organism at any particular moment

**stasis**

a block of little or no evolutionary change in a species

**sticky ends**

fragments of unpaired DNA bases formed when particular base sequences are cut asymmetrically

**stratification**

the division of the physical environment into smaller components for sampling

**strip census**

an estimate of the numbers of wild animals in an area by counting individuals along a typical strip and assuming a uniform population

**structural gene**

a section of DNA that carries the instructions for production of a protein

**subspecies**

a rank immediately below a species; a population that is genetically distinguishable from other populations of the same species in a particular geographic region, capable of interbreeding successfully where ranges overlap

**sugar-phosphate backbone**

the structural framework of nucleic acids, composed of alternating sugar and phosphate groups

**symbiosis**

a relationship in which two organisms live in close association over a long period of time

**sympatric species**

closely related but reproductively isolated species living in the same geographic range

**T****table**

a display of information in named rows and/or columns

**tailing**

the addition of a long tail of adenines to the end of mRNA

**taxa**

plural of taxon

**taxon**

(plural taxa) any group in a biological classification into which related organisms are classified, for example phylum, class, etc.

**taxonomy**

the science of naming and classifying living things

**temperature inversion**

trapping of a cooler layer of air in the atmosphere under a warm layer, preventing the dispersal of heat and other pollutants

**termination sequence**

a section of a nucleic acid sequence that marks the end of a gene or replication site

**test cross**

a cross between an organism displaying the recessive trait of a characteristic and one showing the dominant trait, to determine whether the dominant phenotype is due to a homozygous or heterozygous genotype; this only works if a large number of offspring are produced

**tetrad**

homologous chromosomes, each consisting of two chromatids, lying side by side

**thermophile**

a microorganism that can tolerate temperatures higher than 45°C

**3' (three-prime) end**

one end of a DNA strand in which the C<sub>3</sub> carbon atom of the sugar molecule in the DNA's sugar backbone has a 'free' OH (hydroxyl) group that is not linked to another chemical group

**tolerance range**

the range of a particular abiotic factor within which an organism can survive

**transcription**

first step of gene expression, in which a particular segment of DNA is copied into mRNA

**transcription factor**

a protein produced by regulatory genes that controls gene expression

**transect**

a measured length or strip of terrain in an environment along which individual organisms or environmental parameters are measured and recorded

**transgenic organism**

an organism whose genome has been altered using genetic material from another species or breed

**translation**

production of a polypeptide sequence from a sequence of mRNA codons

**translocation**

movement of a chromosomal segment from one position to another, either within the same chromosome or to another chromosome

**trimming**

removal of non-coding sections at the beginning and end of mRNA

**trisomy**

occurs when a diploid organism has three copies of one of its chromosomes instead of two

**tRNA**

small segments of RNA that transport specific amino acids to the mRNA attached to a ribosome during translation

**trophic level**

a feeding level in a food chain, e.g. producer, herbivore

**U****ultrasound**

a type of imaging technique that uses high-frequency sound waves

**umbrella species**

species selected when making decisions about conservation because they are representative of other species, and protecting them indirectly protects other species in the same habitat

**universal donor**

a person with type O blood, which has no antibodies to antigens A and B; thus, this blood can be donated in small quantities to individuals of all other blood groups

**universal recipient**

a person with type AB blood, which has both A and B antigens, so can receive small quantities of all other blood groups

**upwelling**

upward movement of deep, cold water to replace warm surface water

**V****valid (experiment)**

describes an experiment that provides data that relates directly to the hypothesis

**variety (taxonomy)**

a group that distinctly differs from other varieties within the species, for example a poodle and a great Dane

**vector (biotechnology)**

a DNA molecule used in the transfer of foreign genetic material into another cell, where it can be replicated and/or expressed

**vertical stratification**

the vertical arrangement of vegetation into layers (or strata), providing a variety of niches

**vestigial structure**

a structure with no apparent function, but which may have had a function in an ancestral species

**viable**

able to survive and reproduce

**W****wild type**

the most common phenotype for a feature in a population

**X****X chromosome**

female sex chromosome in vertebrates and some other animals

**X inactivation**

the condensation, and thus inhibition, of one of the pairs of X chromosomes in female vertebrates

**Y****Y chromosome**

male sex chromosome in vertebrates and some other animals

**Z****zonation**

the breaking of the biome into habitat zones

**zone or belt of hybridisation**

area in which two divergent subspecies may interbreed

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# APPENDIX

## Periodic table

1 Group													18					
1												2						
1 <b>H</b> 1.01 Hydrogen												2 <b>He</b> 4.00 Helium						
2	3	4											5	6	7	8	9	10
3	11	12	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
4	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
5	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
6	55	56	57 to 71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
7	87	88	89 to 103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118

Metals

6 — Atomic number  
**C** — Chemical symbol  
 12.01 — Atomic mass  
 Carbon — Name of element

Rare earth elements  
Lanthanoid series

57 <b>La</b> 138.91 Lanthanum	58 <b>Ce</b> 140.12 Cerium	59 <b>Pr</b> 140.91 Praseodymium	60 <b>Nd</b> 144.24 Neodymium	61 <b>Pm</b> (145) Promethium	62 <b>Sm</b> 150.4 Samarium	63 <b>Eu</b> 151.97 Europium	64 <b>Gd</b> 157.25 Gadolinium	65 <b>Tb</b> 158.93 Terbium	66 <b>Dy</b> 162.50 Dysprosium	67 <b>Ho</b> 164.93 Holmium	68 <b>Er</b> 167.26 Erbium	69 <b>Tm</b> 168.93 Thulium	70 <b>Yb</b> 173.04 Ytterbium	71 <b>Lu</b> 174.97 Lutetium
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Actinoid series

89 <b>Ac</b> 227.03 Actinium	90 <b>Th</b> 232.04 Thorium	91 <b>Pa</b> 231.04 Protactinium	92 <b>U</b> 238.03 Uranium	93 <b>Np</b> 237.05 Neptunium	94 <b>Pu</b> 244.00 Plutonium	95 <b>Am</b> 243.00 Americium	96 <b>Cm</b> 247.00 Curium	97 <b>Bk</b> 247.00 Berkelium	98 <b>Cf</b> 251.00 Californium	99 <b>Es</b> 252.00 Einsteinium	100 <b>Fm</b> 257.00 Fermium	101 <b>Md</b> 258.00 Mendelevium	102 <b>No</b> 259.00 Nobelium	103 <b>Lr</b> 260.00 Lawrencium
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- |   |   |  |
|---|---|--|
| <b>METALS</b>   | <b>NON-METALS</b>   | <b>OTHER</b>   |
| <span style="background-color: yellow; border: 1px solid black; display: inline-block; width: 10px; height: 10px;"></span> alkali metal         | <span style="background-color: lightblue; border: 1px solid black; display: inline-block; width: 10px; height: 10px;"></span> diatomic non-metals | <span style="background-color: lightgrey; border: 1px solid black; display: inline-block; width: 10px; height: 10px;"></span> metalloids             |
| <span style="background-color: orange; border: 1px solid black; display: inline-block; width: 10px; height: 10px;"></span> alkaline earth metal | <span style="background-color: purple; border: 1px solid black; display: inline-block; width: 10px; height: 10px;"></span> polyatomic non-metals  | <span style="background-color: blue; border: 1px solid black; display: inline-block; width: 10px; height: 10px;"></span> unknown chemical properties |
| <span style="background-color: red; border: 1px solid black; display: inline-block; width: 10px; height: 10px;"></span> lanthanide              | <span style="background-color: lightgreen; border: 1px solid black; display: inline-block; width: 10px; height: 10px;"></span> noble gases        |  |
| <span style="background-color: green; border: 1px solid black; display: inline-block; width: 10px; height: 10px;"></span> actinide              |   |  |
| <span style="background-color: purple; border: 1px solid black; display: inline-block; width: 10px; height: 10px;"></span> transition metals    |   |  |
| <span style="background-color: pink; border: 1px solid black; display: inline-block; width: 10px; height: 10px;"></span> post-transition metals |   |  |





The front cover shows the southern cassowary, *Casuarius casuarius*, which is found in northern Queensland as well as some parts of New Guinea. It is one of three cassowary species that originally evolved in the supercontinent Gondwana.

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