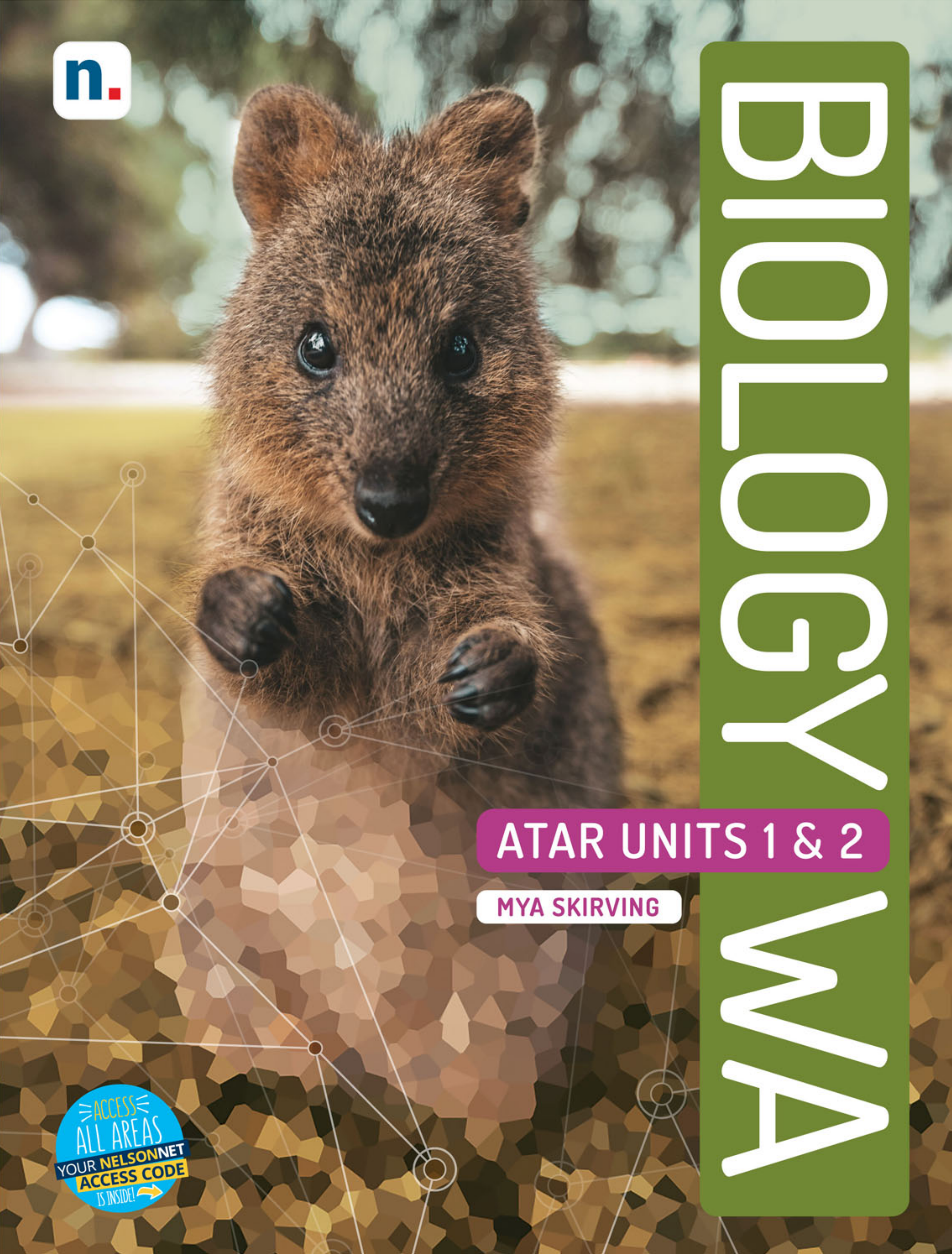
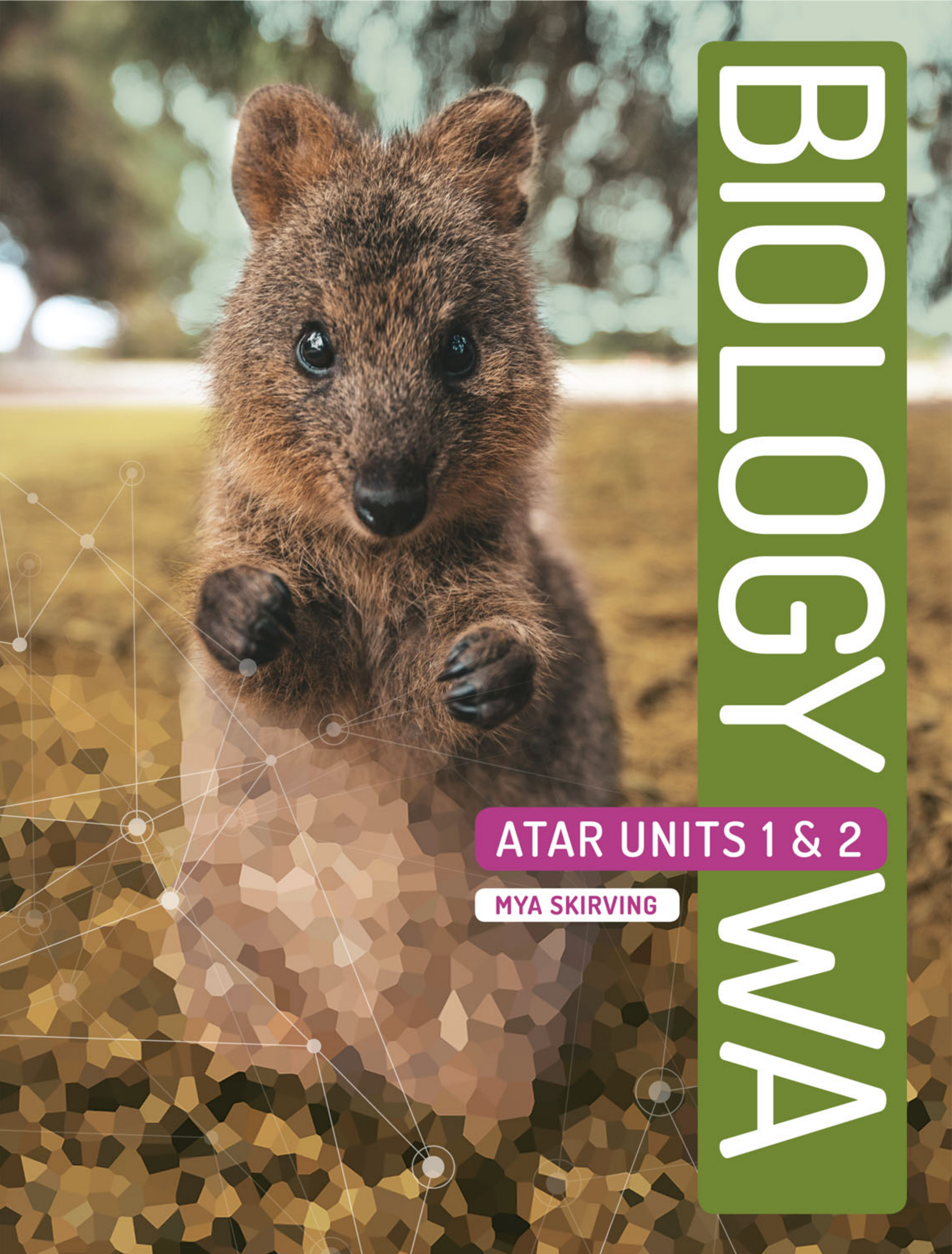


BIOLOGY WA

ATAR UNITS 1 & 2

MYA SKIRVING



BIOLOGY WA

ATAR UNITS 1 & 2

MYA SKIRVING

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FOREWORD BY LYN BEAZLEY

I am delighted and honoured to provide a preamble for this very special book.

I have been inspired by biology since my youngest days back in England, spurred on by a school visit to Charles Darwin's house and a chance to look through his microscope. I was then off to Oxford and Edinburgh to study biology, but it was only when I moved to Western Australia that I realised just how extraordinary the life forms on our planet truly are.

I came from a part of the world that has around 1500 species of flowering plants. Western Australia, a world-recognised biodiversity hotspot, has many times that number, spanning diminutive subterranean orchids to among the tallest trees in the world. Then there are our amazing land animals – aestivating frogs, marsupial moles, echidnas, honey possums (feeding exclusively on pollen and nectar), numbats and kangaroos. The creatures on our coasts and in our oceans range from elegant sea dragons and fairy penguins to mysterious whale sharks, the largest fish in the world.

Our amazing biodiversity exists across a vast land mass that varies from tropical to temperate, and is very occasionally icy. It has both lush forests and deserts, and is framed by reef-fringed coasts and deep oceans. Australia has been shaped in isolation over millions of years as it drifted north from the supercontinent Gondwanaland. It has been less impacted by the disruptive effects of glaciation and volcanic activity than many parts of our planet. Yet now we are witnessing the impact of climate change within a human lifetime.

I can think of no better way to introduce biology to our school students than through a book such as this, based on Western Australian examples of animals and plants with which they have grown up.

I hope the next generation of our students enjoy and benefit from this book, learn from it and are inspired, so they in turn can play a part in ensuring this most precious part of planet Earth is protected and can sustain generations to come.

Lyn Beazley

Lyn Beazley AO, FAA, FTSE

AUTHOR AND REVIEWER TEAM

Author

Mya Skirving

During Mya Skirving's teaching career, she has completed a Master of Science Education degree and been appointed as Science Curriculum Coordinator, Western Australian Certificate of Education (WACE) and Higher School Certificate (HSC) Biology Marker (over a 12-year period), Level 3 Classroom Teacher, and second-in-command in the science department of an academic selective school. Several of her students have been awarded a WACE Subject Exhibition. She enjoys providing useful resources for other teachers as well as students, and worked for a number of years with university students as a Teacher Advocate. Her love of the biological world, coupled with her love of education, inspired her to write this set of textbooks and NelsonNet material to fill the need for a biology resource with a particularly Western Australian flavour.

Reviewer
Jane Brandenburg
Jane fills a number of roles at a top-ranked Western Australian school, including Learning Coordinator, Creativity Activity Service Coordinator and Year Coordinator. She is also a teacher of Years 11 and 12 Biology and Human Biology, and of Science and Mathematics, including the International Baccalaureate Middle Years Programme.

Consultant
Helen Lydon
Helen Lydon is an advocate for the study of biology in Western Australia, where she has taught and examined Biology and other Sciences for over twenty years in both private and public schools, and chaired advisory committees for the School Curriculum and Standards Authority. She is delighted to collaborate with Mya on this outstanding new text.

AUTHOR'S ACKNOWLEDGEMENTS

I am sincerely appreciative of my very supportive and reassuring husband (David), our three kids (Saasha, Sophie and Justin) and our dog (Leo). Their random acts of kindness (cooking and coffees, Reabold Hill and riding), endless patience waiting for me to finish writing the various sections, and hugs eased any stress and made this experience achievable and enjoyable. Thank you – you all bring sunshine into my life.

The students, colleagues and scientists I have worked with, past and present, have all taught and inspired me, especially Ant, who had faith in my ability.

I am in awe of the beauty and resilience of our natural biological world. Nothing humans have created even comes close. I hope this book plays a part in preserving it, and I hope it will inspire passionate science students to solve big biological problems, such as infectious disease control, wise biotechnology advancement, and ecosystem rejuvenation.

Special thanks go to the following scientists, who even when busy made time for me, vastly improving the integrity of the material presented here: Lyn Beazley, extraordinary former chief scientist of WA and inspiration for many of us; Pauline Charman, Director, BioBarcode Australia and former Education Outreach Manager, Harry Perkins Institute of Medical Research, a science educator with a unique skill set and knowledge in the area of biotechnology; Stephen D. Hopper AC, Professor of Biodiversity, Centre of Excellence in Natural Resource Management, School of Agriculture and Environment, The University of Western Australia; Professor John S. Mackenzie, Emeritus Professor, Curtin University, Co-initiator and Vice-chair of One Health, world expert in Ross River virus and Australian bat lyssavirus, and Consultant for the Biosecurity Council of Western Australia and World Health Organization (WHO) (Steering Committee of the Global Outbreak Alert and Response Network); Dr Peter Mawson, Perth Zoo Science Program Leader, Department of Biodiversity, Conservation and Attractions, Western Australian Government; and Samantha Setterfield, Associate Professor, School of Biological Sciences, The University of Western Australia.

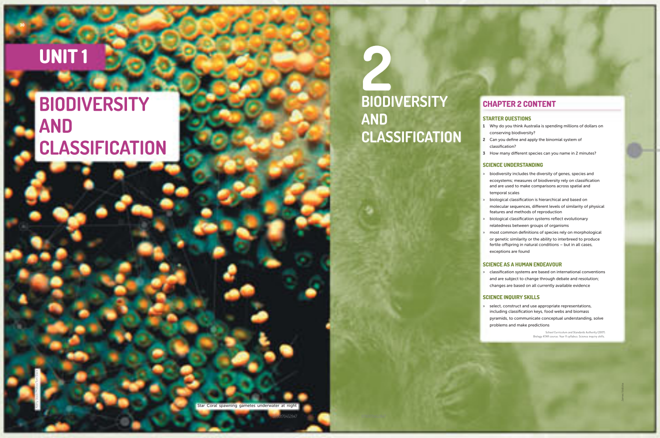
The support of the Harry Perkins Institute (a medical research facility in Perth, WA, and an educational outreach program for high school students) and Plant Energy Biology (PEB), which has so many innovative and collaborative projects happening around the globe), has been greatly appreciated.

Lastly, thank you to Jane Fitzpatrick (editor), Helen Lydon (consultant) and Jane Brandenburg (reviewer). Their queries and advice have helped shape the book into a clearer and more up-to-date and reliable resource.

USING BIOLOGY WA ATAR

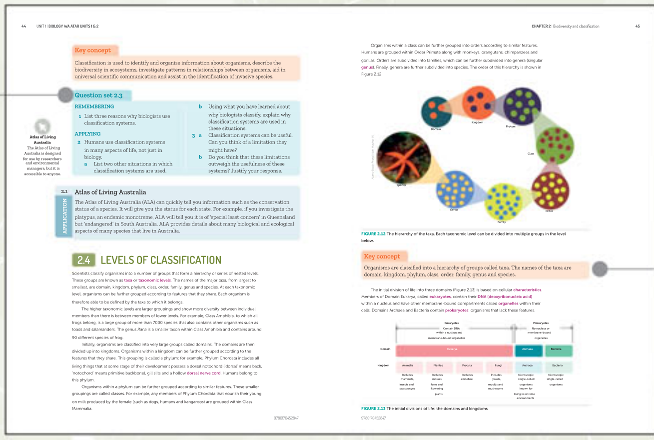
This new *Biology WA ATAR* (Units 1–4) series has been created and designed to fully meet the requirements of the Government of Western Australia, School Curriculum and Standards Authority (SCSA) Syllabus (2017). The series uses an enquiry-based approach to enhance and deepen learners' conceptual understanding and their ability to apply their knowledge. This educational package provides the resources necessary to address the Science Understanding concepts and Science as a Human Endeavour applications and Science Inquiry Skills described in the syllabus. The content is clearly illustrated, structured and presented, making it accessible to students of all levels so they can achieve maximum understanding and academic success.

Each page has been carefully planned so as to include all the information needed without appearing cluttered or overwhelming. Navigating through each chapter is easy. Activities and/or practical investigations have been included for each chapter, connecting the conceptual and the practical aspects of biology. Below is a list of the features to be found in each chapter so that students can navigate and fully utilise this resource.



Each chapter begins with a **chapter opening page** including starter questions and the learning outcomes from the SCSA Biology ATAR Syllabus that will be covered in the chapter. This gives students the opportunity to monitor their own progress and learning.

Question sets throughout each chapter enable formative assessment in bite-size chunks graded from Remembering to Creating, offering regular opportunities to recall new terms and review recent concepts.



Important ideas, concepts and theories are highlighted in **key concept boxes**, providing repetition and summary for improved assimilation of new ideas.

Development of the cell membrane model

Although cells were named and described by Robert Hooke and Antonie van Leeuwenhoek in the 17th century, it wasn't until the late 19th century, in the late 19th century before scientists began to understand the nature of the cell membrane. An important reason for this delay was that the membrane is so thin that it cannot be seen through a light microscope. This means if a typical cell of 30 micrometres (μm) was enlarged 10 000 times to the size of a watermelon (30 cm), the cell membrane would still only be equal to the thickness of a piece of paper.

Scientists had to take an indirect approach to model the structure of the cell membrane, making predictions from its physical and chemical properties decades before it could be seen. In the mid-1890s, Charles Ernest Overton demonstrated that lipid-soluble substances such as ether and chloroform readily enter cells. This suggested that the cell membrane was composed of lipid.

A series of pioneering experiments in 1925 indicated that the membrane consisted of a double layer of lipids, referred to as a lipid **bilayer**. A decade later, to account for the

SCIENTIFIC LITERACY

media item, encouraging students to use evidence to evaluate the claims and conclusions presented.

Numbat captive-breeding program at Perth Zoo CASE STUDY

Numbats (*Myrmecobius fasciatus*) once ranged across the southern third of the Australian continent west of the Great Dividing Range. Intensive agriculture and the associated fragmentation of habitat, pastoralism, altered fire regimes (which affect habitat quality and the availability of termites), and the introduction of foxes and feral cats have all contributed to the decline of numbats. Our drying climate influences the frequency and severity of fires and also reduces the availability of termites in the wild. Numbats are now restricted to two small wild populations in south-west WA, at Dryandra Woodland and the Tone-Perup Nature Reserve. The species is listed as endangered and there

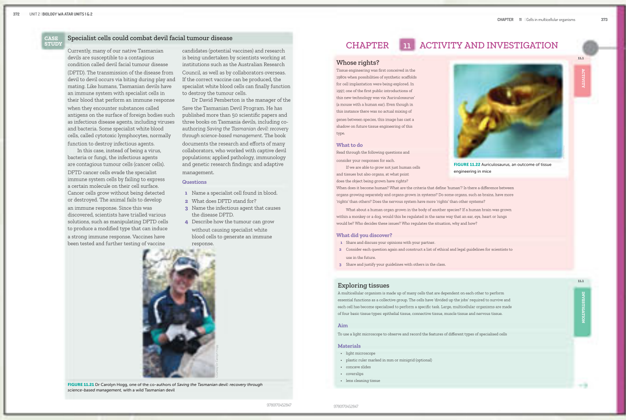
nine locations in two states, resulting in the establishment of four new self-sustaining populations: three in Western Australia and

6.2 APPLICATION **Bushfire smoke: a germination agent**

For many plant species, bushfire smoke has been found to be a germination factor. Professor Kingsley Dixon is a conservation biologist, restoration ecologist and the director of the ARC Centre for Mine Site Restoration at Curtin University. He was also the 2016 Western Australian Scientist of the Year. Based on the knowledge that cellulose is a significant substance found in plant tissue, he and his team created an artificial version of bushfire smoke using filter paper and tested for specific chemicals found in smoke. The collaborative, 11-year study identified the specific molecule in smoke responsible for germination and named it karrikinolide to honour local Noongar culture ('karrik' means smoke).

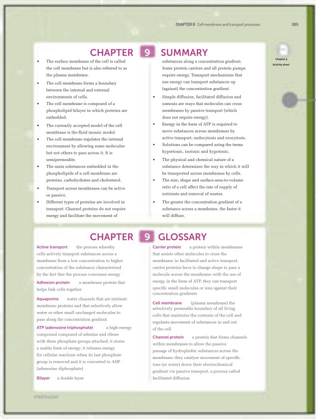
Case studies provide opportunities to see how science is applied using up-to-date, real-world and local Western Australian examples of context.

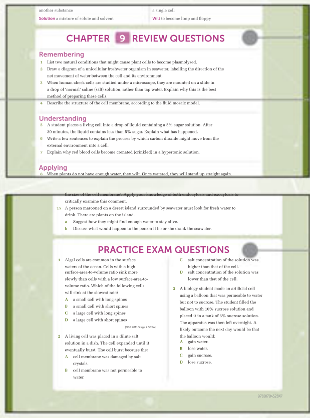
Application boxes offer opportunities for students to accurately *apply* models and scientific principles to complex systems in both familiar and unfamiliar contexts.



SOUTHERN Biological

The **activities** and **investigations** offer opportunities to develop the Science Inquiry Skills listed in the SCSA Biology ATAR Syllabus. Southern Biological and Cengage have collaborated to ensure they are effective, exciting and current. Some of the investigations written by Southern Biological are exclusive to Cengage, and all investigations have been rigorously stress-tested by Southern Biological to ensure that they will work in the classroom. Some investigations have **taking it further** ideas at the end, suggesting how to extend or adapt them for further study.





Chapter summary sections and a **glossary** of important terms introduced in the chapter support revision and self-reflection. **Chapter review questions** provide, in larger chunks, further scaffolding for summative assessment, including Creating questions. **Practice exam questions** (WACE exam questions) give practice in answering exam questions specifically related to the content students have been studying.

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WS Worksheet

Weblink

NelsonNet is your protected portal to the premium digital resources for Nelson textbooks, located at **www.nelsonnet.com.au**. Once your registration is complete, you will have access to comprehensive digital resources that supplement each chapter, including:

- worksheets
- practice exams
- useful weblinks
- answers.

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Teachers will have access to these resources plus chapter tests, answers to practice exams, practice tests, videos of laboratory investigations (provided by Southern Biological), chapter PowerPoints, syllabus mapping and teaching plan documents, and a PDF version of the student book.

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The **NelsonNetBook** is a customisable, interactive eBook that can be used online and offline. Accessible on desktops, laptops, tablets and interactive whiteboards, it reproduces the student text in digital form. Annotate your eBook with notes, highlights, weblinks and voice recordings, and access resources directly from the NelsonNet student website. Teachers can share their personalised version of the eBook with the class or particular groups. It is also possible to download an offline version of the book, and iPad and Android apps.

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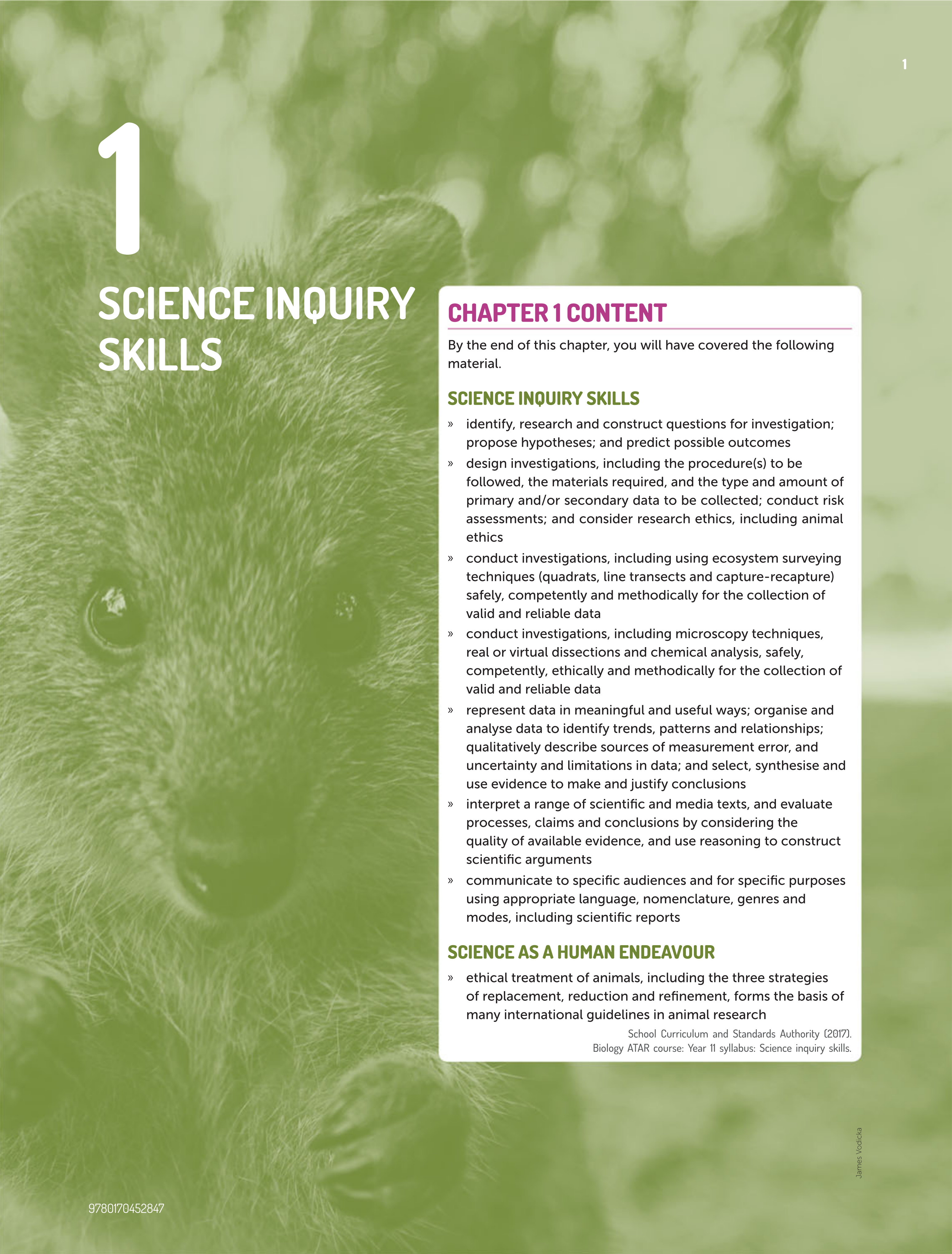


James Vodicka

1 SCIENCE INQUIRY SKILLS

CHAPTER 1 CONTENT

By the end of this chapter, you will have covered the following material.

SCIENCE INQUIRY SKILLS

» identify, research and construct questions for investigation; propose hypotheses; and predict possible outcomes
» design investigations, including the procedure(s) to be followed, the materials required, and the type and amount of primary and/or secondary data to be collected; conduct risk assessments; and consider research ethics, including animal ethics
» conduct investigations, including using ecosystem surveying techniques (quadrats, line transects and capture-recapture) safely, competently and methodically for the collection of valid and reliable data
» conduct investigations, including microscopy techniques, real or virtual dissections and chemical analysis, safely, competently, ethically and methodically for the collection of valid and reliable data
» represent data in meaningful and useful ways; organise and analyse data to identify trends, patterns and relationships; qualitatively describe sources of measurement error, and uncertainty and limitations in data; and select, synthesise and use evidence to make and justify conclusions
» interpret a range of scientific and media texts, and evaluate processes, claims and conclusions by considering the quality of available evidence, and use reasoning to construct scientific arguments
» communicate to specific audiences and for specific purposes using appropriate language, nomenclature, genres and modes, including scientific reports

SCIENCE AS A HUMAN ENDEAVOUR

» ethical treatment of animals, including the three strategies of replacement, reduction and refinement, forms the basis of many international guidelines in animal research

School Curriculum and Standards Authority (2017). Biology ATAR course: Year 11 syllabus: Science inquiry skills.

9780170452847

1.1 INVESTIGATIONS

Investigations use a scientific process to answer a question, explore an idea or solve a problem. They require activities such as planning a course of action, collecting data, interpreting data, reaching a conclusion and communicating about these activities. Investigations can include observation, data collection, research, field work, laboratory experimentation and manipulation of simulations. Investigations are central to our understanding of the biological world.

Sometimes an important advance in science begins with a lucky accident. For example, after hearing from milkmaids that people who contracted cowpox (a relatively harmless disease picked up after working with cattle) were protected from deadly smallpox, the British physician Edward Jenner effectively kickstarted the science of vaccination. Jenner used samples from open cowpox sores on a dairymaid's hands to **inoculate** (vaccinate) a young boy and protect him against smallpox. However, it would take nearly 100 years and a lot of research before scientists were able to show that micro-organisms caused infectious disease. Lucky accidental discoveries such as this may begin a new field of research, but they need to be followed up by carefully planned investigations.

Usually, advances in science come from a process of systematic observation and experimentation, inductive and deductive reasoning, and the formation and testing of **hypotheses** and theories. How these activities are carried out can vary greatly, but there are some common factors that we will explore in this chapter. The process is known as the **scientific method**.

Scientific investigations can take years to complete and may involve collaboration between many scientists. Scientists invest time in designing the investigations before they begin. When they apply for grants to carry out research, they need to show that they have carefully planned what they will do and how any money provided will be spent. Scientists then make measurements and observations and record their results. They keep records of all their experiments. Once data is collected, it needs to be analysed. There are various ways in which this is done, but in the biological and biomedical sciences it typically involves constructing graphs. Finally, the results of the investigation must be communicated, by being published.

Key concept

The scientific method contains the steps used in science and is used to observe, question and investigate the natural world.

Permission given by Samantha Setterfield, UWA Professor

FIGURE 1.1 Some scientific investigations involve field work. Here, researchers and park rangers measure aquatic plant populations on the tropical floodplains of Kakadu National Park, Northern Territory.

1.2 THE SCIENTIFIC METHOD

Investigations can vary greatly, so the generic steps for conducting an investigation will need to be adapted to the task.

The generic steps are:

1. Make an observation or observations.
2. Ask questions about the observations.
3. Form a hypothesis and make predictions based on that hypothesis.
4. Test the hypothesis using a planned procedure that is **reproducible** and uses the appropriate **models** and instruments.
5. Record results, analyse the data (usually by graphing it) and draw conclusions; accept or reject the hypothesis or modify the hypothesis if necessary.
6. Reproduce the experiment until there are no discrepancies between the observations and the **theory**. A theory is 'a set of concepts, claims and/or laws that can be used to explain and predict a wide range of related observed or observable phenomena. Theories are typically founded on clearly identified assumptions, are testable, produce reproducible results and have explanatory power'.

   (ATAR Biology Syllabus, Government of Western Australia, School Curriculum and Standards Authority)
7. Discuss and evaluate the results and the procedure.

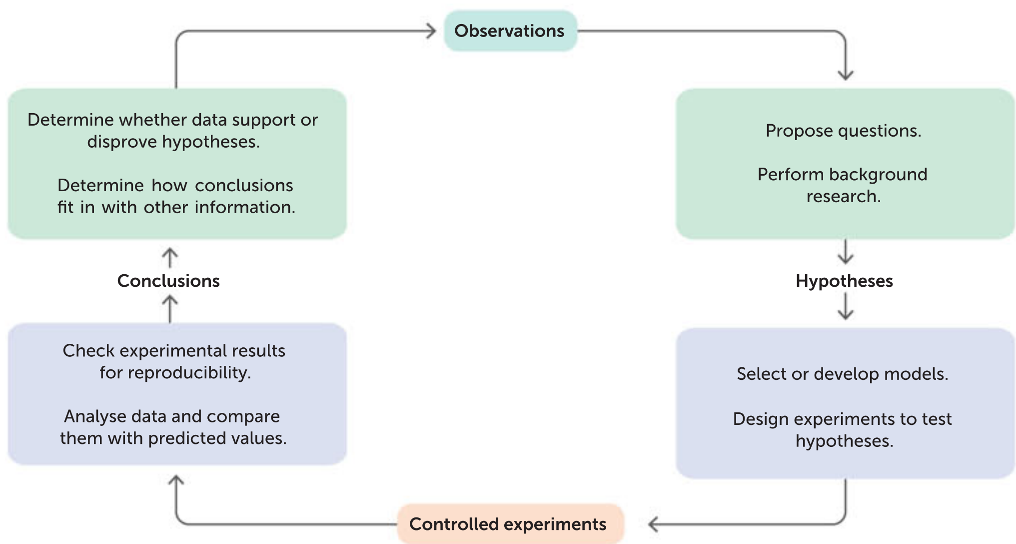


FIGURE 1.2 The scientific method

Researching and refining your question

After recording your observation(s) and formulating a question, the next step is to find out what is already known about the concepts. Use the Internet, your textbooks and the library. Make sure you keep a record of the information that you find, as well as the sources of the information. You should start a **logbook** at this stage. Your logbook will contain all of the drafts of your report and the raw data you obtain. You can also make notes from **references** in your logbook, or attach printouts. Good record keeping is important in scientific research, and it begins at this stage of the investigation.

Read a range of scientific media and texts. Published journal articles (e.g. CSIRO articles) can be helpful. Be critical of what you read. Do not assume that everything you read online or even in books is true.

Australian Academy of Science
This is a useful resource for up-to-date science news.

Australian Society for Biochemistry and Molecular Biology
This group aims to promote education and research in biology.

CSIRO (Commonwealth Scientific and Industrial Research Organisation)
This website contains useful information on all fields of scientific research, including resources for students and teachers.

You may find examples of similar investigations to the one you are thinking of conducting. It is a good idea to look at these, so you can learn from the experience of other researchers. However, in general, it is better not to try to copy someone else's investigation exactly. If you do decide to replicate someone else's investigation, then you need to acknowledge and carefully reference their work. See the section on referencing (page 15). If you do not reference the work, it is **plagiarism**. This is a very serious form of academic misconduct.

Forming a hypothesis

A hypothesis is a scientific statement, based on the available information, that can be tested by experimentation. It can be thought of as an 'educated prediction'. It should describe an expected relationship between the independent and dependent **variables** in observed phenomena. Once you have decided on your **research question**, what you are trying to find out, you need to turn it into a hypothesis.

If your research question is in the form of 'What effect does a new fertiliser have on root growth?', this can be turned into a hypothesis such as 'If a new fertiliser is applied to a plant, then the **rate** of root growth will increase'.

If the hypothesis is written correctly, the independent and dependent variables should be easy to identify. Usually, an investigation will have one **dependent variable** and one **independent variable** in each trial. A variable is a factor that can change. There may be several factors causing change in a particular variable. To conduct a trial that produces valid results, only one of these factors, the independent variable, should be manipulated (changed). The other factors, which need to be kept consistent between the **control group** and the experimental group, are called the **controlled variables**. The factor that changes as a result of the change in the independent variable is called the dependent variable. It is the set of changes in the dependent variable that is observed, measured and recorded. These are the investigation's results. The results will either support or not support the hypothesis. Results that do not support the hypothesis can be of as much value as those that do, in accumulating scientific knowledge.

Even if your hypothesis meets these criteria, do not be surprised if you change or modify it during the course of your investigation. In scientific research, the question you set out to answer is often only a starting point for more questions.

For example, for the hypothesis 'If a new fertiliser is applied to a plant, then the rate of root growth will increase', are you able to determine the independent and dependent variables? (The term 'rate' refers to change in a quantity, usually per unit time. Root growth rate is likely to be measured in millimetres per day.)

In the first half of the statement, the chosen factor to vary is the type of fertiliser. This is the independent variable. In the second half of the statement, the factor that will be observed and measured is the rate of root growth, the dependent variable. A controlled variable might be the amount of fertiliser added.

Key concept

A research question informs a hypothesis. A hypothesis describes the predicted and testable relationship between the independent and dependent variables. The independent variable is the factor that has an effect on the dependent variable. It is the changes in the dependent variable that are observed, measured and recorded.

Planning

Keep the purpose of the investigation and the hypothesis clearly in mind during the planning of the procedure. Your predictions about what you think may happen will help with your planning. It is helpful to ask yourself some questions first.

- What data will you need to collect?
- What materials and equipment will you need?
- When and where will you collect the data?
- If you are working in a group, who will collect the data?
- Who will be responsible for record keeping?
- How will the data be analysed?

The data that you collect will always include **primary data**, and will usually include **secondary data**. Primary data are data collected directly by the person conducting the investigation. Secondary data are data collected by a person or group other than the person or group using the data.

Consider how you will analyse the data. Will you need access to specific software, such as a graphing or statistics package? Keep a record of your planning. This should go in your logbook. Writing down what you plan to do, and why, will help you stay focused during the investigation. If you are working in a group, then a record of what each person agrees to do during the investigation can be very important.

When variables have a numerical value, you make **quantitative measurements**. You measure each numerical value in the appropriate units. For example, you may measure root length in centimetres, or the weight of roots in grams.

Continuous variables can take any possible value, usually within a particular range. Length, time and current are continuous variables. In the root growth example, root length is a continuous variable, because it can take any value within a range. A variable that may take only fixed values is called a **discrete variable**. Data for discrete quantitative variables (e.g. number of electrons in an atom) are usually whole numbers because the quantity cannot be broken into fractions. In the root growth example, the number of roots is a discrete variable.

In some investigations, you may have **qualitative measurements** as data. Qualitative data may include words or descriptions and can at times be subjective. For example, a chemical reaction may lead to a colour change. You would usually describe the colour in words, such as 'pink' or 'green', rather than using a number. Sometimes you use a combination of qualitative and quantitative data. For example, you may describe roots as reaching a maximum length in centimetres (quantitative), but growing in a particular direction or pattern (qualitative).

Once you have decided on the variables you will be measuring, you will be able to identify the equipment and other resources you will need.

FIGURE 1.3 These seedlings are being grown under consistent conditions to control the independent variables.

Risk assessment

You may be required to complete a risk assessment before you begin your investigation. Even if this is not a requirement, it is a good idea to think about risks. You need to consider three things.

1. What are the possible risks to you, to other people, to property and to the environment?
2. How likely is it that there will be an injury or damage?
3. If there is an injury or damage, how serious are the consequences likely to be?

A 'risk matrix', such as Table 1.1, can be used to assess the severity of a risk associated with an investigation. The consequences are listed across the top, from negligible to catastrophic, and the likelihood of each consequence occurring increases going down the rows. A negligible consequence may be getting clothes dirty or a very minor injury such as a scratch. A marginal consequence might be a bruise from falling off a bike, or a broken branch in a tree. A severe consequence could be a more substantial injury or a broken window. A catastrophic consequence would be a death or the release of a toxin into the environment. In general, you need to ensure that your investigation is low risk. You can use a risk matrix either for individual identified risks or for the investigation overall. If there are multiple experiments, then you would use a risk matrix for each one.

TABLE 1.1 A matrix for assessing severity of risk

CONSEQUENCES → LIKELIHOOD ↓	NEGLIGIBLE	MARGINAL	SEVERE	CATASTROPHIC
Rare	Low risk	Low risk	Moderate risk	High risk
Unlikely	Low risk	Low risk	High risk	Extreme risk
Possible	Low risk	Moderate risk	Extreme risk	Extreme risk
Likely	Moderate risk	High risk	Extreme risk	Extreme risk
Certain	Moderate risk	High risk	Extreme risk	Extreme risk

Once you have considered what the possible risks are, you need to think about what you will do about them: what you can do to minimise them and how you would deal with the consequences if something did happen. This may be as simple as deciding to 'Always wear a lab coat, gloves and safety glasses'. You can use a risk assessment table similar to the one shown in Table 1.2.

TABLE 1.2 A sample risk assessment

WHAT ARE THE RISKS IN DOING THIS EXPERIMENT?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
The fertiliser might be spilled on clothes or skin during application.	Wear a lab coat, gloves and safety glasses. Clean up spills immediately.

Safe use and disposal of biological material

When you are dealing with many biological materials, it is important to be aware of safe handling and disposal. For example, when growing known or unknown microbes on agar plates, it is important to use safe sterile techniques (discussed later in this chapter) and to wear a lab coat, gloves, safety glasses and, if required, face masks. Treat all microbes on agar plates as potentially pathogenic, and **autoclave** used plates before disposing of them. An autoclave is a machine that can heat an object to very high temperatures. It is sometimes used to kill pathogens.

Animal ethics

Activities that affect living organisms need to comply with the *Australian Code for the Care and Use of Animals for Scientific Purposes*.

The main thrust of ethics is treating animals, other people and the environment with care and respect. If your investigation will be using humans, then you need to make sure you do not harm them, either physically or psychologically. If you are working with animals, then there are animal ethics to consider. The welfare of animals used for the purposes of research is legislated by state and federal laws, and respect for all animals (vertebrate and invertebrate) used in research is of the utmost importance. When using animals for research, scientists must adhere to the three Rs.

Australian Code for the Care and Use of Animals for Scientific Purposes
Respect for animals must underpin all decisions and actions involving the care and use of animals for scientific purposes. Read about animal ethics here.

- **Reduction** alternatives: methods that obtain comparable levels of information from the use of fewer animals in scientific procedures or for obtaining more information from the same number of animals.
- **Refinement** alternatives: methods that alleviate or minimise potential pain and distress, and enhance animal wellbeing.
- **Replacement** alternatives: methods that permit a given purpose of an activity or project to be achieved without the use of animals or with the use of animals of a lower sentient value or non-sentient animals (those that lack a nervous system).

iStock.com/Maksym Panchuk

FIGURE 1.4 The use of animals for research purposes is governed by state and federal laws.

Animal ethics

CASE STUDY

Anyone working with animals in Australia is bound by guidelines and laws to safeguard animals. Research is conducted on animals other than humans for several reasons: some animals have lower sentience; also, the time between generations is shorter in some animals, which reduces the waiting time for results. The precise meaning of sentience is contested in science and in philosophy, but it can be defined as the ability to experience consciousness, pleasure, self-awareness and pain. Some invertebrates (such as jellyfish) do not have a central nervous system that is as sophisticated as that of humans, and they are considered to have a lower sentience than humans.

RSPCA Australia promotes ethical treatment of animals as observing what should, rather than what could, be done to animals. Scientists should have an understanding of the pain physiology of the animals used in their research. They also need to be able to recognise normal and abnormal behaviour, so they can assess an animal's welfare and make an ethical decision about whether or not to continue a trial.

A model is 'a representation that describes, simplifies, clarifies or provides an explanation of the workings, structure or relationships within an object, system or idea'.

ATAR Biology Syllabus, Government of Western Australia, School Curriculum and Standards Authority

A model can be used to test outcomes that might be expected in the real world. For example, an animal that has a similar immune response to humans can be used to test a vaccine; computer simulations can be fed real-world data to generate predicted outcomes. Animals such as mice, guinea pigs, rats, pigs and non-human primates are commonly used as models for research because, as mammals, they share a lot of genetic code with humans and have a likelihood of responding to tests in a similar way. A range of vaccines, infectious agents and chemicals have been tested on animals such as these to find out the possible effects on humans.

Since the discovery of the susceptibility of ferrets (*Mustela putorius furo*) to influenza virus in the 1930s, they remain one of the most useful animal models for studying influenza infection. They have a similar respiratory system to that of humans, their lung physiology is similar, they are susceptible to similar viruses, and (unlike guinea pigs and mice) ferrets sneeze, experience fever and produce nasal discharge.

More recently, COVID-19 coronavirus researchers have been using ferrets for the testing of infection and vaccines. The research team of Dr Rob Grenfell, Director of Health and Biosecurity, CSIRO, aims to understand how the infection progresses and how it behaves so as to be able to create an effective vaccine. However, ferrets feel pain in the same way we do, so strict ethical guidelines for the use of ferrets and other animals in Australian research laboratories must be followed. The guidelines are to be found in the *Australian Code for the Care and Use of Animals for Scientific Purposes*.

Key concept

When using animals for research, scientists must adhere to the three Rs: reduction, refinement and replacement alternatives.

Procedure

The procedure is a planned set of steps enabling you to approach your research systematically. It is important to describe clearly what you have done (noting any modifications you make) so you can review the procedure later and communicate it to others. It is written in the past tense. A fellow student should be able to follow your procedure and reproduce the results you have recorded.

Let's examine an exemplar for a given hypothesis. The first task is identifying the independent variable (the variable that you will vary), the dependent variable (the variable you will measure) and the controlled variables (those you will keep constant). (Note: fungicides are chemicals that are used to treat fungal diseases, such as rust in plants. The symptoms of rust include orange-brown patches on the leaves of affected plants.)

HYPOTHESIS	If a new brand of fungicide is applied to the plant, then symptoms of rust will disappear
INDEPENDENT VARIABLE	Type of fungicide
DEPENDENT VARIABLE	Presence/absence of symptoms (orange-brown patches)
CONTROLLED VARIABLES	Volume of water used, time of day for watering plants, plant species, ambient temperate, soil type, light conditions
PROCEDURE	**1** One hundred plants of the same species infected with the same species of rust (fungus) were obtained. All individual organisms had similar areas of orange-brown patches. **2** Fifty plants were treated with the fungicide and 50 plants were left untreated. **3** Other than the type of fungicide, the same conditions (e.g. volume of water used) were maintained for the experimental and control groups. **4** After a set time, each plant was examined for the number and size of orange-brown patches. **5** The results were recorded in an appropriate table. **6** Repeat trials were conducted and recorded. Averages of the number and size of orange-brown patches were calculated for both groups.

Once you have written a procedure, a checklist is useful to ensure your procedure has been written correctly. Check that:

- You have a relatively large sample size.
- The independent variable will be present or varied in the experimental group, but absent or kept constant in the control group.
- All other variables are to be kept constant.
- Data will be collected within the time frame you have available.
- The method for measuring the dependent variable and the units of measurement are clear.
- Multiple trials are to be conducted and an average is to be calculated.

Key concept

An investigation is designed clearly and systemically, including the materials, procedures, data collection, risk assessments and ethical considerations.

Results: recording the data

The raw data should always be recorded directly into the logbook, unless it is recorded using data loggers connected to a computer. In that case, a printout of the data should be attached to the logbook, and the file name and location recorded. Make sure that you measure and record everything you will need for your analysis. Use appropriate units (e.g. centimetres for lengths and grams for weights). Note that the **accuracy** of your measurements will often be restricted by the accuracy of the instruments you use to take them. For example, a ruler may only have markings down to 0.1 cm. Make a note of these restrictions, as they may affect the accuracy of your final results, especially if the changes measured are very small.

If you are going to be collecting multiple data points, it is a good idea to draw a table to record them in. Label the columns in the table with the name and units of the variables. Do not put the units in the table cells. The first column usually contains the measurements for the independent variable. Table 1.3 provides an example of a table of data. These data were recorded during an investigation into the use of a specific fertiliser and its impact on the yield of a species of wheat.

TABLE 1.3 The results of an investigation into soil fertiliser and wheat yield

FERTILISER APPLICATION (kg/ha)	TRIAL 1 YIELD (bushels/ha)	TRIAL 2 YIELD (bushels/ha)	AVERAGE YIELD (bushels/ha)
0	29	31	30
25	40	42	41
50	51	49	50
75	60	58	59
100	70	70	70

Results: analysing the data

Once you have collected your data, you can begin to analyse it by performing statistical calculations such as finding the **mean**, **median** and **inter-quartile range**. These calculations allow you to represent the raw data in a more meaningful and useful way.

Calculating mean, median, range and inter-quartile range

Experiments often produce a set of data that will need to be processed. The mean or average of a set of numerical data is found by:

1. adding all the data points together
2. dividing by the number of data points.

The median of a data set is the value that has half of the data points above it and half below it. The median of a data set can be found by:

1. arranging the data points in ascending order
2. selecting the middle data point; or, if there is an even number of data points, taking the mean of the two central values.

The range describes the total spread of the data. It can be calculated by:

1. ordering the data from lowest to highest
2. subtracting the lowest value from the highest value.

How to calculate the inter-quartile range
Visit Khan Academy or the Student Learning Centre at Flinders University to practise finding inter-quartile range with odd and even sets of data points.

The inter-quartile range of a data set is the middle 50% of values in a data set when they are ordered from lowest to highest. It is found by:

1 dividing the ordered data set into two halves
2 finding the median of the lower half of the set (Q1) and the median of the upper half of the set (Q3)
3 subtracting the median of the lower half from the median of the upper half (Q3 – Q1).

Constructing graphs

The most reliable way to present patterns in data, and identify the relationships between variables, is to plot a graph. Graphs show points of data for at least two variables. Because of their visual nature, graphs can reveal relationships or trends that statistics and data tables cannot.

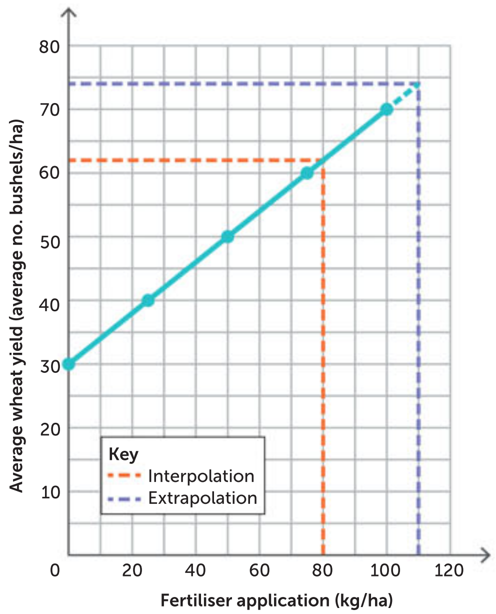
Biology for life
This website contains some helpful advice on deciding the number of data points.

Graphing with Excel
After learning the skill of hand-drawing graphs, students interested in creating graphs using Excel can use these tools.

General graphing rules

1 When presented with quantitative data, you need to decide whether they are discrete (countable) or continuous (measurable) data and select the correct type of graph to use.
2 Line graphs are used when the independent variable is continuous (can take any numerical value within the range of the data) and the dependent variable is quantitative (can be measured or counted).
3 If the independent variable provides discontinuous quantitative data or qualitative data, a column (bar) graph is usually selected. The bars in a column graph do not touch.
4 Histograms look like column graphs for continuous quantitative data, but the bars do touch. Each bar on the *x* axis represents the sum of the data for a range of values for the independent variable.
5 Pie charts are an alternative way of displaying data for a qualitative independent variable and are used when you want to show what percentage or fraction of the whole belongs in each category. The data add up to 100% or 1, respectively.
6 Column (vertical bar) and bar (horizontal bar) charts are useful for comparing two data sets where at least one data set is qualitative. Examples would be average root length varying with different types of fertiliser, or the number of endangered species in the different states or territories of Australia. The bars do not touch. However, do not use a column or bar chart to try to show a mathematical relationship between variables.
7 The independent variable measurements are read on the *x* axis and the axis is labelled. The units are included in brackets; for example, Time (years).
8 The dependent variable measurements are read on the *y* axis and the axis is labelled. Again, the units are included in brackets; for example, Length (cm).
9 Include a title to help the reader determine what the graph is showing. The title should include the independent and dependent variables involved and, when appropriate, the specific time over which the experiment was conducted (e.g. 'The effect of temperature on the amount of sugar dissolved in tea after 2 minutes').
10 The graph should take up more than 50% of the graph space provided. Therefore, the scale should be worked out to maximise the filling of the graph space, while allowing some space for extrapolation of data. The data points should *not* extend outside of the given graph space. The intervals can be worked out by dividing the range of data by the number of available intervals on the axis.

   As a guideline, use sensible interval values to make the graph easy to plot and interpret, such as 1, 2, 5, 10 or 50. Poorly spaced scales can lead to inaccurate readings. Always start from zero. To manipulate the scale to fit, you may need to 'break' the scale after zero and then indicate equal intervals after the break.
11 When drawing multiple sets of data on the same axes, a key should be used. Symbols can be, for example, Δ, × or o. The name of the data set can be written at the end of each line.



1 The heading should be specific, include the variables and, if appropriate, the time taken to conduct the experiment. Words such as 'versus' or 'against' are not to be used.

2 Add the intervals and labels to the *x* and *y* axes. The amount of fertiliser applied in Table 1.3 ranges from 0 to 100 kg/ha. The data can be shown in five equal intervals of 20 kg/ha.

3 Mark the data points showing the average yield produced for each application of fertiliser.

4 Use a ruler to join the data points.

Note: If it is not known what is happening between the points, then linearity between them is assumed. This is particularly the case in biology, where other unmeasured variables may be influencing the points, or where experimental error may produce points that are not reliable.

5 **Interpolation** involves reading points, other than data points, within the region in which you have data. It is a prediction made between two known data points.

6 **Extrapolation** is when you extend a line beyond your measured points. It is an estimation determined by extending the last line, using the gradient of the last two data points.

FIGURE 1.5 Applying general graphing rules in a biology report using data from Table 1.3

Standard deviation

Standard deviation is a measure of uncertainty that provides scientists with more information about the spread of the results. It may be shown as error bars on a graph (Figure 1.6). A high standard deviation indicates that the data points are quite varied from the average whereas a low standard deviation indicates that most points are very close to the average. For an investigation to be reliable, the data must have a low standard deviation.

Key concept

Interpolation is prediction of a data point within the range of the known data points. Extrapolation is prediction of a data point outside the range of the measured data.

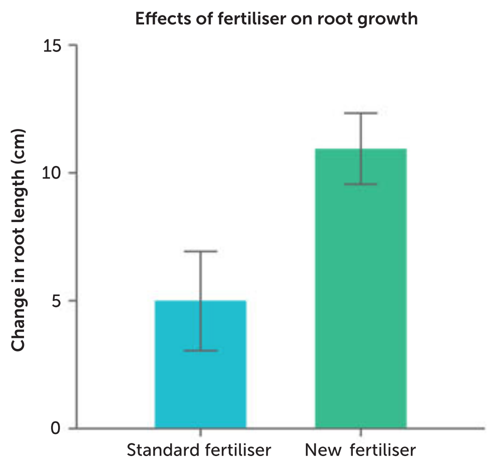


FIGURE 1.6 Bar graph of two data sets, with standard deviation (amount of uncertainty) indicated by the error bar at the top of each data set

Discussion

In a report of a scientific investigation, a discussion section includes an evaluation of the procedure and results. It can be broken into parts such as the following.

1 An evaluation of the **reliability** and **validity** of the procedure, and the accuracy of the results. You can almost always make suggestions to improve the procedure.

Reliability is the degree to which an assessment instrument or protocol consistently and repeatedly measures an attribute and achieves similar results for the same population. When you repeat an experiment and get the same results, the data are considered reliable. **Reliable data** can be achieved by repetition and replication. Repetition can be achieved through multiple trials within the same investigation or by using a large sample size. Replication can be achieved by the same investigation being conducted several times, possibly by more than one investigator. An average can be calculated from the results of both repetition and replication. If an average (mean) can be calculated, it can reduce the effects of anomalous data or **outliers**. An outlier is a data point that does not fit the pattern shown by other measured data points.

Validity is the extent to which tests measure what was intended, and the extent to which data, inferences and actions produced from tests and other processes are accurate. Valid data can be achieved by identifying the variables that should be controlled and then controlling them. It can also be gained by the use of a control group. A control refers to a standard or group that is the same as the experimental group but for which the independent variable does not vary. The purpose of the control group is to ascertain that the cause of any change in the experimental group is due to change in the one independent variable.

Accuracy is the extent to which a measurement result represents the quantity it purports to measure; an accurate measurement result includes an estimate of the true value and an estimate of the uncertainty. It is the degree of closeness of measurements of a quantity to its actual true value.

2. A discussion of the ways in which **measurement error** may have affected the data.

   Measurement error is the difference between the experimental result and its true value. Systematic error, mistakes and random error can all contribute to measurement error.

   A systematic error is an error that is due to limits in accuracy and use of instruments; for example, the failure to zero an instrument before use or using the wrong type of instrument for the investigation could cause such an error. Other examples of systematic errors include reading an instrument from a *consistent* but non-90° angle, or using a potometer that leaks water and indicates a higher rate of transpiration than is correct. If a student *consistently* reads the volume of a liquid at the same but wrong part of the meniscus, there will be systematic error. Systematic error can shift measurements in a consistent direction. This will have an impact on the reliability of the results, because if the investigation is repeated without the error, the results will not be the same.

   Mistakes, or avoidable measurement error, may arise from carelessness or incorrect use of an instrument. If a student knows to measure a water level at the bottom of the meniscus, but does not take care that their eye is level with the meniscus, avoidable measurement error can occur. Such error will also affect the results.

   Finally, random error may occur. The only way to reduce this type of error is to increase the sample size or the number of trials.

3. Future applications.

Key concept

Reliability describes how consistently a procedure measures an attribute. When you repeat an experiment on the same population and get the same results, the data is reliable. Reliable data can be achieved by repetition and replication.

Validity is the extent to which tests measure what was intended, and how accurate the data, inferences and actions produced from tests are. Valid data can be achieved by identifying and controlling variables, and by using a control group.

Accuracy is how close measurements of a quantity are to their actual true value. An accurate measurement includes an estimate of the true value and an estimate of the uncertainty.

Measurement error is the difference between the experimental result and the accepted standard result. Systematic error is due to a systematic flaw in the design or procedure and can shift measurements in a consistent direction.

Interpreting your results: conclusions

If your results support your hypothesis, then this can be stated in a conclusion, along with a statement about the relationship shown by the results.

A sample conclusion for the investigation on soil fertiliser and wheat yield could be as follows.

The results support the hypothesis. As the fertiliser application increased from 0 to 100 kg/ha, the average number of bushels per hectare rose from 30 to 70. An increase in fertiliser application caused an increase in wheat yield.

There needs to be clear evidence for any relationship claimed in the conclusion. The evidence in this case will be of a quantitative nature, because the data recorded were quantitative. If you gather qualitative results, then key qualitative data are needed as evidence for the conclusion about the hypothesis.

If the results do not support the hypothesis, this can be stated in the conclusion instead. Possible reasons for this may be suggested in the discussion.

It may be that the nature of the procedure did not take into account all of the variables. For example, in the root growth experiments, it may be that the new fertiliser works best at a particular temperature, or over a longer time, or in conjunction with certain soil conditions.

It may be that the sample size used in the experiment was simply too limited to fully test the hypothesis. Thus, you might conclude that further experiments are required to increase the total sample size being tested.

Before you decide that the hypothesis was wrong, it is a good idea to check carefully that you have not made any mistakes or ignored any variables needing to be controlled.

Key concept

The discussion and conclusion critically evaluate the procedure and results of an investigation, discussing their reliability, validity and accuracy, and, when relevant, suggest ways the investigation could be improved.

1.3 COMMUNICATING YOUR RESULTS

If research is not reported, then no-one else can learn from it. An investigation is not complete until you have communicated the results. The majority of scientific investigations are first communicated to others through the publication of written reports.

Writing reports

A report is a formal and carefully structured account of your research. It is based on the data and analysis in your logbook. However, the report is a summary. It contains only a small fraction of what appears in the logbook. Your logbook contains all your ideas, rough working and raw data. The report typically contains none of this.

A report consists of several distinct sections, each with a particular purpose. It usually includes the following:

- Introduction
- Procedure
- Results and analysis
- Discussion
- Conclusion
- Acknowledgements
- References
- Appendices.

Reports are always written in the past tense, because they describe what you have done.

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Introduction

The introduction tells the reader why you did the investigation and what your research question or hypothesis is. This is the place to explain why this research is interesting or important.

The introduction also provides any background information needed to be able to understand the rest of the report. This is the place to summarise any existing theories and models. You need to do this to put your hypothesis into context. You should also summarise any similar investigations. All of this should be correctly referenced, as described in the section on referencing (page 15).

Procedure

The procedure describes what you did. It summarises what you measured and how you measured it, step by step. Write your procedure using sentences, not dot points. There should be enough detail for another student to be able to replicate the experiment. Remember that it needs to be written in past tense. For example, you would write 'we measured the length', not 'measure the length'. Include any diagrams, such as apparatus set-ups, that are needed to make your procedure clear. The diagrams in your logbook will usually be rough sketches. The diagrams in your report should be very neat and carefully labelled. Flow charts can be useful for describing any procedures in which a series of steps has been followed. Each diagram should have a figure number, and you should refer to it within the text of your report. Position the diagram close to the relevant part of the text. Now is a good time to learn how to position figures neatly using your word processing software. When including images taken on a microscope, a scale bar and magnification must always be noted.

Results and analysis

The results section is a summary of your results. It is usually combined with the analysis section, although they may be kept separate.

When you draw a table of results, the independent variable is usually positioned in the first column and the dependent variable in the second column. If a table has more than a few rows of data, it is better to represent that data in some other way. Usually this will be a graph. Think about what sort of graph is appropriate (see pages 10–11). Do not use a column or bar chart to try to show a mathematical relationship between variables.

Discussion

The discussion section should explain what your results mean. If you began with a research question, give the scientific answer to the question here. Analyse your procedure and results to explain why the results did or did not support the hypothesis. Was your hypothesis incorrect? Or was the procedure or model used not suitable for the investigation?

If there are any implications of your work, such as implications for better agricultural processes or the design of better medicines, put them here.

Conclusion

The conclusion is a *very* brief summary of the results and their implications. Say what you found out and what it means. A conclusion should only be a few sentences long. It should include a response to your hypothesis or research question. Your conclusion should include supportive data from the results observed or measured. For example:

The mean resting breathing rate was 18 breaths per minute compared with 25 breaths per minute after 10 minutes of exercise. The results supported the hypothesis. An increase in exercise caused an increase in breathing rate.

If appropriate, include a sentence about what further research might be needed.

References

APA referencing by Murdoch University
A science bibliography usually uses APA referencing.

When writing a report that includes information from existing literature, use a citation to indicate within the report that you are using someone else's information or ideas, then include a list of references at the end. A reference list acknowledges the sources you used, which helps you to avoid plagiarism and strengthens your arguments. References can include journal articles, books, book chapters, websites, newspaper articles, conference proceedings, podcasts etc.

American Psychological Association (APA) referencing is commonly used in science reports. The APA citation style within the body of the report is an 'author–date' style: write, for example, '(Tian and Castillo, 2016)', '(Roberts et al., 2019)' or 'Tian and Castillo (2016) observed …'. The term 'et al.' means there are more than two authors.

The reference list allows readers to locate sources easily and usually follows the chosen referencing style, APA in this case. Write the surname of the author(s) followed by their initials with a comma between authors, then the year of publication within parentheses, the title, the publisher and the place of publication. For example:

Tian M, Castillo TL (2016) *Solar heating uptake in Australia: rates, causes and effects*. Energy Efficiency Reports. Report no. 10, The Department of Sustainability and Environment, Canberra.

When a website without an author is used, the listing looks like this:

ABC News. (2003) *$250 m funding boost for malaria vaccine*. Retrieved from https://www.abc.net.au/news/2003-09-22/250m-funding-boost-for-malaria-vaccine/1482220

Other ways of communicating results

You may want to present the results of your investigation in another format. Scientists communicate their findings in many ways, including posters, seminars, journal articles, reports and websites. Scientists usually use more than one means to communicate their research when it is of particular interest.

Look at examples of articles (in scientific and popular media), websites, posters and reports. This will give you an idea of how different styles are used in different contexts. Think about the purpose of your report. Is it to inform, to persuade or both? What sort of language is used? Think about your audience and use appropriate language and style. A poster is not usually as formal as a report. A website may be more or less formal, depending on the audience.

Multimedia presentations
- PowerPoint®
- Canva®

Oral presentations
- Informative
- Persuasive

Journal articles
- Research
- Case study

FIGURE 1.7 Examples of scientific presentation formats

FIGURE 1.8 A poster is a common way to present scientific findings at a conference.

1.4 ECOSYSTEM SURVEY TECHNIQUES

Maintaining **biodiversity** is essential for the conservation of the unique species that live on Earth, as well as for the preservation of the ecosystems in which they live. An ecosystem includes all of the biotic and abiotic factors in an area and their complex interactions. Scientists actively monitor, record and analyse ecosystems in order to identify species that are endangered or at risk, and work to avoid their extinction.

Australia has many endangered species, such as the Kangaroo Island dunnart, which was severely impacted by the 2019–20 bushfires. An analysis by the federal Department of Agriculture, Water and the Environment found that nearly 50 nationally threatened animal and plant species have had at least 80% of the area in which they live affected by bushfire. Once widespread across WA, the black-flanked rock-wallaby is another endangered species. Habitat clearing, changes to fire patterns and introduced predators have severely affected its population numbers. The following information describes methods scientists use to monitor the size and distribution of populations, in order to maintain biodiversity.


AAP Photo/WWF Australia

FIGURE 1.9 The Kangaroo Island dunnart is believed to be among the species worst affected by the 2019–20 bushfires.

Planning and recording in a logbook

Planning a field trip will include looking at maps and deciding which site to survey. If you have a map of your area, you can mark north and then indicate on the map where the survey is to take place. Plan for a safe investigation, taking into account the weather and any hazards you may encounter in the environment. If you are working in groups, ensure you collaborate and that everyone has a fair role to play in the process. Plan for achievable data collection for the time you have available.

A logbook is a legal document for a working scientist. If someone's work is called into question, or there are disputes over patents or ownership of data, then the logbook acts as important evidence. A logbook includes comments and ideas, thoughts about the experiments, and analysis. It also includes printouts of data, photocopies of relevant information, photos, sketches and other items. The logbook is the primary source of information when a scientist writes up their work for publication.

Some scientists keep their research records electronically, but most experimental scientists still keep a hardcopy logbook. There are several advantages to a hardcopy logbook over an electronic one. First, electronic records are easy to make changes to, and it is hard to track what was changed, when and by whom. Second, if you are working in a group, it can be hard to keep track of who has

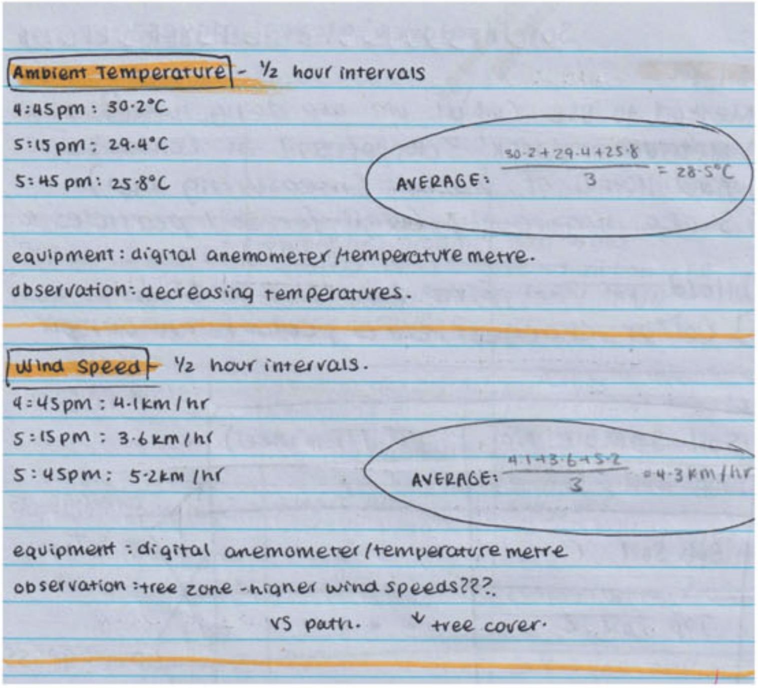

FIGURE 1.10 Exemplar of part of a logbook produced by students on a Year 11 field trip

the most recent version of the file(s). Third, files can be easily deleted or corrupted. It takes much more care and discipline to maintain a good electronic logbook than a good hardcopy. Remember that the purpose of your logbook is to record and maintain evidence of what you did. Electronic evidence is not as reliable as a signed hardcopy document.

Write down what you do as you do it. It is easy to forget what you did if you do not write it down immediately.

Include large, clear diagrams of any experimental set-up and include details of equipment used. You can also include photos of experiments.

Key concept

Your logbook is a detailed record of *what you did* and *what you found out* during your investigation. Make an entry in the logbook *every* time you work on your investigation. At the start of each session you should record the date and the names of all the people with whom you are working at the time.

Population sampling techniques

Taking reliable measurements in the field requires measuring a sufficiently large, representative sample of the population. Various standardised techniques have been developed to accurately sample populations and ecosystems. Different techniques are suitable for different types of studies, and the method of sampling a population is an important component of the experimental design (Table 1.4). It is important that any limitations of the sampling technique are considered when planning your experiment. When deciding on a sampling technique, take species distribution into consideration. If the population is clumped or low in number, then your technique needs to allow for this.

TABLE 1.4 A summary of some field techniques

TECHNIQUE	MAIN USES AND ADVANTAGES	DISADVANTAGES
Quadrats	Useful for investigating abundance, density and diversity If sufficient quadrats are used, should accurately reflect the ecosystem	Only useful for immobile species
Transects	Useful for investigating abundance and diversity along an axis Can show changes across a changing area (spatial studies)	Only useful for immobile species May not accurately reflect the whole community (species can be missed)
Electrofishing	Useful for investigating abundance and diversity of fish species	Limited application
Capture–recapture	Useful for estimating population size of mobile animals	Must be done safely (to not injure animals) and at specific times (to achieve accurate results)

Some hints for when you are in the field include:

- Use a ruler and gloves to turn over leaf litter, rocks and bark to find species living in the ecosystem.
- Look for other evidence of species living there, such as bird droppings, burrows, spider webs and nests.
- Take photographs of species instead of drawing illustrations; if you cannot find out the names of any species, then the photographs will suffice.

Abiotic factors are the non-living factors in an environment that affect organisms. They include air, water, temperature, soil composition, altitude, topography, sunlight availability, latitude and elevation. Some suggested factors that you can record are found in Table 1.5. Various measuring tools can be used, such as a pH meter for the soil or a thermometer for temperature. Digital tools such as digital thermometers, light meters, digital pH meters, GPS systems and anemometers (for measuring wind speed) are usually more accurate than human senses. Remote-controlled drones can be fitted with various sensors that detect measurements. They can feed back data to a database for quick analysis of abiotic findings or population counts. Also, you can use a table as an organised way of recording information systematically.

TABLE 1.5 Abiotic factors

ENVIRONMENTAL ABIOTIC FACTOR	MEASUREMENT	OBSERVATION AND COMMENTS
Ambient temperature		
Water temperature		
Soil temperature		
Soil texture		
Soil colour		
Soil pH		
Light intensity		
Wind speed		
pH of water		
Depth of water		
Other		

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Photographer: Michael Douglas, UWA; permission given Samantha Setterfield

FIGURE 1.11 Researcher Dr Leah Beesley from the University of Western Australia (UWA) measures river habitat and uses a GPS to locate nets as part of a study of fish populations in the Fitzroy River, WA. Researchers are trying to understand how fish populations change in response to different water levels in the river, which might result if water is used for agriculture.

Photographer: Michael Douglas, UWA

FIGURE 1.12 A drone is used to take aerial photographs to measure plant populations in Kakadu National Park, Northern Territory. Researchers and traditional owners are investigating how plant populations change in response to different patterns of burning. Photographs are taken at different times of year and compared to see how the cover of trees and shrubs changes over time.

Photographer: Michael Douglas, UWA

FIGURE 1.13 Jawoyn traditional owner Ryan Barrowei and CSIRO researcher Justin Perry control a drone to measure plant populations in Kakadu National Park. Researchers and traditional owners are investigating temporal changes (changes over time) in plant populations.

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Quadrats

A **quadrat** is a square, rectangular or circular frame of convenient size, used to mark out an area in which the vegetation is sampled. Organism size and distribution should be considered before deciding on the quadrat size. A square with sides of 50 cm would be suitable for a back yard. Squares with sides of 10 m may be used for sampling trees in a forest. Approximately 1–2 m squares would be suitable for a quadrat in a medium-sized lake area. Quadrats are helpful for assessing community diversity and composition, but their use is largely restricted to estimating numbers of plants and immobile animals. The number of quadrats used is also important: using too few will result in an incomplete or inaccurate representation of species present, and using too many will be a waste of time and effort.

In general, the steps for using quadrats in the field are as follows:

- To begin, write a list of all of the species found in the quadrats. Count the number of organisms in the selected sample of quadrats.
- Calculate the average number of each organism in one quadrat.
- Multiply this average number by the total area to calculate the abundance.
- Divide this by the area to determine density (the number of individuals per unit area).

For example, if a scientist was counting the number of shrubs in a 10 m by 10 m area, the following process could occur. The area could be divided into 100 quadrats, of which 10 could be randomly chosen for counting. A random number generator can be used to determine which sample quadrats are counted. The steps would be:

1. Randomly select the quadrats to use for counting.
2. Mark the selected quadrats and record the data in a logbook.
3. Add the total individual shrubs in the 10 quadrats.
4. Divide the total by 10 to calculate the average per quadrat.
5. Multiply this number by 100 to estimate the population in the area.
6. To calculate the population density, divide the number by 10. The answer will be the population number per unit squared.

For this example, a random number generator produced the numbers 11, 22, 35, 59, 66, 77, 78, 88, 98, 99.

The number of shrubs in each of these quadrats is recorded in Figure 1.14. The quadrat number is written first and the population for that quadrat is recorded in brackets.

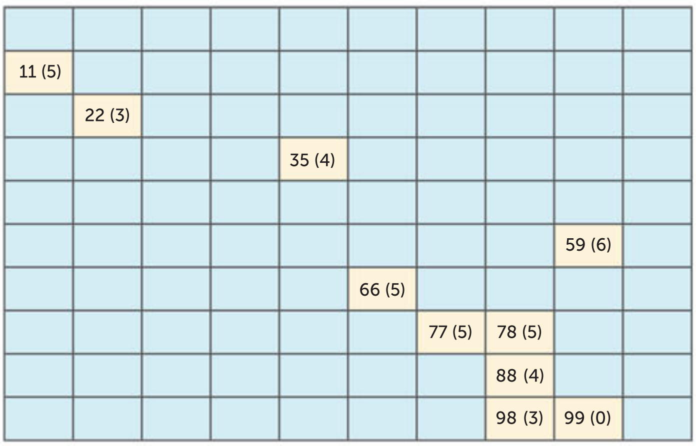

FIGURE 1.14 To investigate the distribution of shrubs in an area of 100 m^2, 10 quadrats were randomly chosen and the number of shrubs in each was counted (shown in brackets).

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Sample calculation of population density

The total number of shrubs in the 10 randomly selected quadrats is:

$5 + 3 + 4 + 6 + 5 + 5 + 5 + 4 + 3 + 0 = 40$

The average number of shrubs per quadrat is:

$40/10 = 4$ shrubs per quadrat

The total estimate for the population of shrubs is:

$4 \times 100 = 400$ shrubs in the 100 m^2 area.

The population density is:

$400/100 = 4$ shrubs m^{-2}

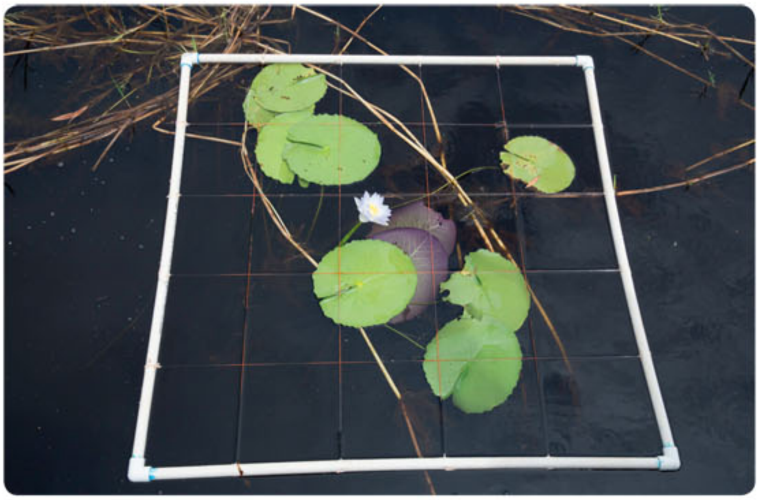


FIGURE 1.15 Researchers and park rangers use quadrats to measure aquatic plant populations on the tropical floodplains of Kakadu National Park. The researchers were measuring the impact on native plant populations of an invasive grassy weed called para grass. All measurements have to be done from airboats because normal boats cannot get through the dense vegetation and large saltwater crocodiles are very common in this area.

Key concept

A quadrat is a square, rectangular or circular frame used to mark out an area in which vegetation is sampled.

Transects

A **transect** is a line marked through an area of study (e.g. using a rope or piece of string). When choosing a transect, it is important to select a line that includes most of the plant/immobile animal groups. You can then draw a profile of the transect on graph paper using a scale. Transects are used when the area of study is too large to be able to count enough populations using quadrats. Transect surveys show changes in community composition and population abundance along an axis. The disadvantage of using a transect is that it may not give an accurate representation of the diversity and populations of species found in the area, so sometimes several transects are used. However, any organisms in low abundance in the area may still be missed when using this sampling technique.

Quadrats can be used in conjunction with transects to estimate populations. Quadrats can be placed randomly either side of the transect line.

The use of nets is helpful in conjunction with transects when surveying particular environments. Insects and other invertebrates can be collected and counted using large nets to sweep through grasses or leaves of trees in a process called sweep netting. Aquatic organisms can be collected and counted using nets held downstream of an area of riverbed that is then gently disturbed by the person doing the sampling. Nets can sweep through a designated quadrat area for counting.

FIGURE 1.16 Jawoyn traditional owner Bessie Coleman and UWA researcher Samantha Setterfield use transects to measure wattle tree populations in Kakadu National Park. Researchers and traditional owners are investigating how plant populations change in response to different patterns of burning.

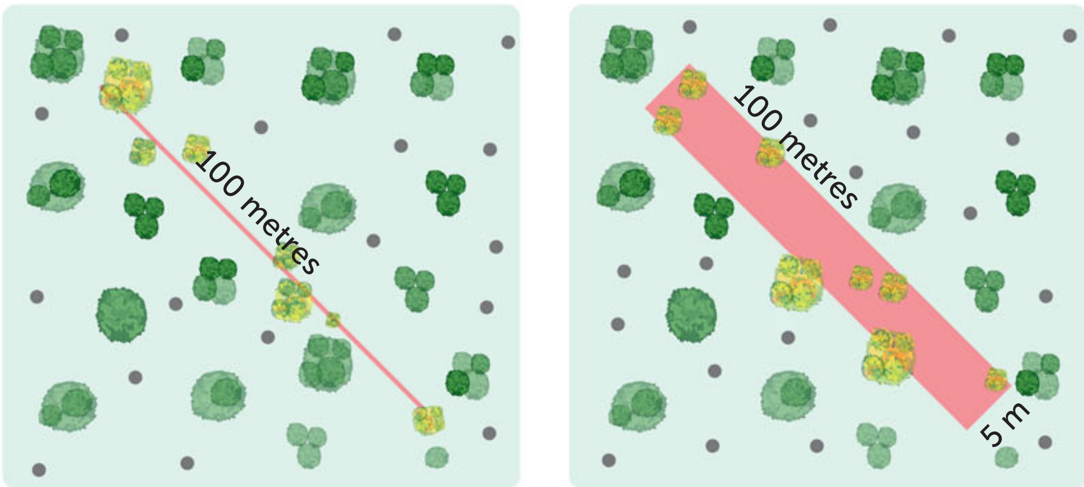


FIGURE 1.17 Examples of line and strip transect surveys, showing which trees are counted using each method (highlighted yellow).

Key concept

A transect is a line through a large area of study, selected to include most of the plant and immobile animal groups present, and used to investigate changes in community composition and population abundance along an axis.

Electrofishing

Electrofishing uses electricity to stun fish so they can be caught up in the hand net and brought to the boat for identification, weighing and measuring, before being released unharmed back into the river. Electrofishing is a good way of measuring fish populations in rivers that are habitat to large crocodiles, which could get caught in nets or harm the researchers. Researchers can use this technique to investigate how fish populations change in response to different water levels in the river. This will help them to understand how fish populations might change if water from the river is used for agriculture.

FIGURE 1.18 UWA researchers Dr Leah Beesley and Chris Keogh use electrofishing to measure fish populations in the Fitzroy River, WA.

Capture–recapture

The capture–recapture method is a powerful technique for estimating a population size. It relies on the captured sample redistributing equally throughout the population and being recaptured at the same frequency as individuals that had not been captured. Scientists need to submit comprehensive applications outlining safety and ethical handling of animals before pursuing this sampling technique. More information on the technique, including calculations, can be found in Chapter 5.

Linking WA plants to the WA curriculum
Use this document if you are trying to identify common native plants in schools.

Earth science resources for teachers and students doing field research
Explore this website.

1.5 MICROSCOPY TECHNIQUES

Cells are very small. **Microscopes** magnify objects that may not be visible to the naked eye. The use of a microscope to view cells or objects that cannot normally be seen is called **microscopy**. Most photographs of cells are taken using a microscope, and these pictures are called **micrographs**. Microscopes used in the high school laboratory are usually **monocular** (single eyepiece) **compound** (multiple lenses) light microscopes. They can magnify up to about 400 times actual size. The **resolution** of a microscope is different from the magnification. The resolution is the smallest distance by which two points can be separated and still be distinguished as separate objects. A higher resolution leads to more clarity. If two bacterial cells were very close together on a slide, they might look like a single, blurry dot on a microscope with low resolving power. Electron microscopes differ from light microscopes in that they produce an image of a specimen by using a beam of electrons rather than a beam of light. Live specimens can be examined under light microscopes, but not under electron microscopes.

Key concept

Microscopes magnify objects that may not be visible to the naked eye. The use of a microscope to view cells or objects that cannot normally be seen is called microscopy.

The resolution of a microscope is the smallest distance by which two points can be separated and still be distinguished as separate objects.

Magnification is the scaled enlargement of an object. As an object is magnified, resolution may decrease.

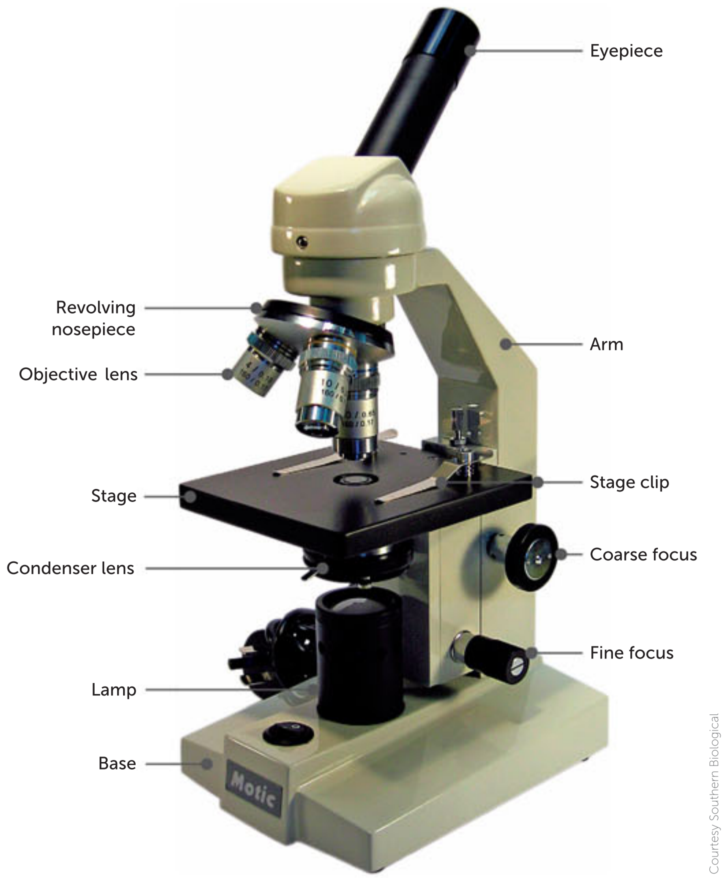


FIGURE 1.19 The parts of a light microscope

Making a temporary wet mount

You can make a **wet mount** in class. It is a glass slide holding a specimen that is suspended in a drop of liquid (such as water), for microscopic examination under a microscope. A general procedure for making a wet mount is:

1. Place a drop of water on the centre of the slide. It is also possible to first place the specimen on the slide, but small specimens usually separate more easily from the tweezers or needle if dipped into the drop of water.
2. Place the specimen, such as onion cells, into the drop of water.
3. Carefully lower the coverslip so that it touches one side of the drop of water. The coverslip should form an angle of about 45° with the slide. Touch the coverslip on the sides only to prevent leaving fingerprints. Alternatively, use tweezers to hold the coverslip.
4. Then lower the coverslip completely. Remove excess water with filter paper or paper towel. Note: a stain can be placed at one end of the coverslip and drawn through using filter paper or paper towel. Iodine and methylene blue are common stains used in the laboratory at school.

Microscope calculations can be found in Chapter 8.

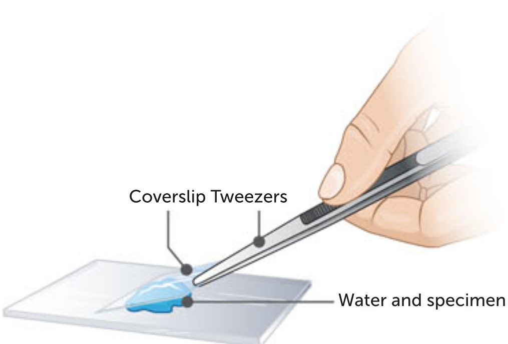


FIGURE 1.20 How to lower a coverslip to avoid the formation of air bubbles

A real heart dissection
This resource takes you step-by-step through the dissection of a sheep's heart.

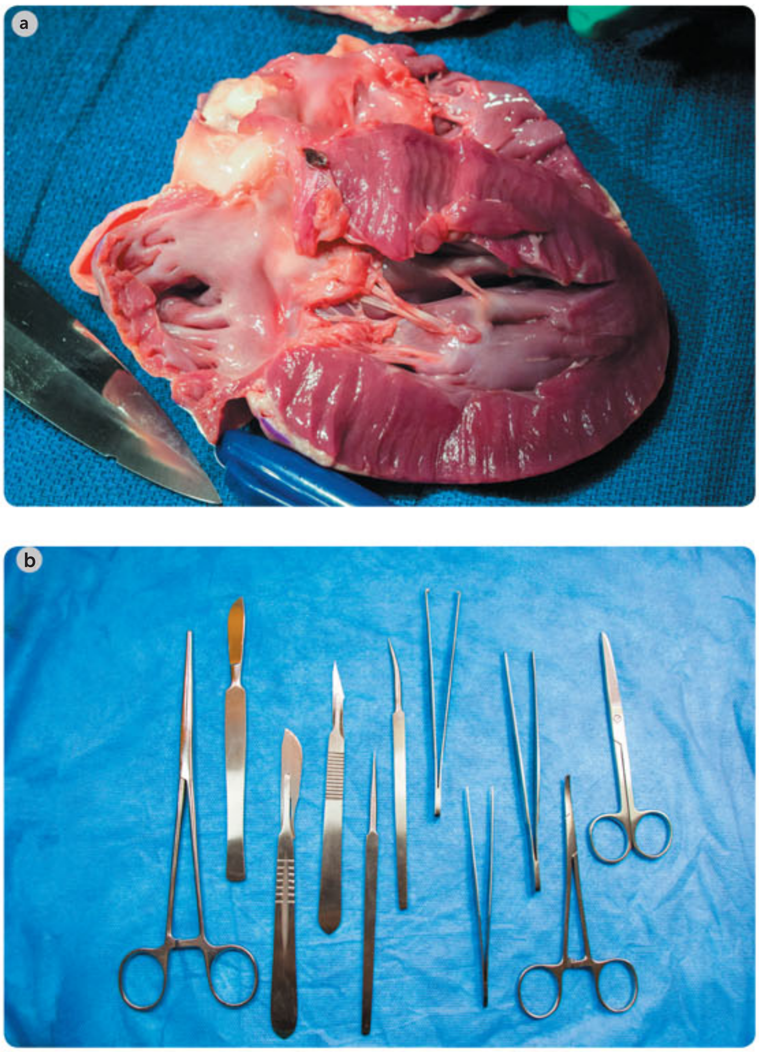
Virtual heart dissection and interactive
Watch a virtual dissection of a sheep's heart, and test your understanding of its structure.

1.6 DISSECTIONS

The process of carefully cutting open and exposing the interior parts of a plant or animal for study purposes is called **dissection**. Keep in mind that there are safety and ethical issues to consider before a real dissection. Dissections can strongly enhance your understanding of how structure and function are related in many different organisms. Hands-on learning of structure and function can transform unfamiliar and abstract concepts into more real, relevant and concrete knowledge. Typical dissection tools and their functions are summarised in Table 1.6.

TABLE 1.6 Dissection tools

TOOL	FUNCTION
Scissors	Cutting apart tissues including bone
Forceps (large tweezers)	Holding sample while cutting tissue
Mounted needle	Holding the specimen (organism being studied) in place
Scalpel (handle with a blade)	Making incisions
Dissection pins	Securing parts of a specimen to a board



Science Photo Library/Dr Barry Slaven

Shutterstock.com/Tai Dundua

FIGURE 1.21 a A dissected heart and **b** some standard dissection tools

WS Chapter 1 Activity sheet

CHAPTER 1 SUMMARY

- Science involves investigations. Prior to an investigation, scientists identify, research and construct questions; propose hypotheses; and predict possible outcomes.
- Scientists read and interpret a range of scientific and media texts. Scientists use critical thinking to evaluate claims and conclusions, which leads them to construct logical scientific arguments.
- The scientific method is used to conduct an investigation. The steps followed in an investigation may include observation, question, research, hypothesis, prediction, procedure, results, graph, discussion and conclusion.
- Prior to an investigation, a scientist should conduct risk assessments and consider research ethics.
- Any investigations that involve the use animals must consider the three Rs of animal ethics: reduction, refinement and replacement.
- During an investigation, primary and/or secondary data are collected to test a hypothesis.
- Scientists write a clear procedure to ensure the investigation collects accurate, valid and reliable data.
- A range of ecosystem survey techniques can be used to monitor populations, including estimating their size and distribution, and biotic and abiotic factors. The techniques include using quadrats, transects, capture–recapture and electrofishing.
- Written reports are often used by scientists to communicate their investigations. Posters and presentations at conferences, journal articles and press releases are also used.
- The discussion and conclusion sections of a written report evaluate any ways in which measurement error, instrumental accuracy, the nature of the procedure and the sample size can influence uncertainty in and limitations of the data.

CHAPTER 1 GLOSSARY

Abiotic factors non-living factors such as temperature, pH and wind speed

Accuracy the extent to which a measurement result represents the quantity being measured; an accurate measurement result includes an estimate of the true value and an estimate of the uncertainty

Autoclave a device used to sterilise equipment, reagents or contaminated waste; autoclaves work by subjecting contents to pressurised steam at 121°C for a set time

Biodiversity the variety of life from the genetic level through to the environment in which organisms live

Compound (of a microscope) having multiple lenses

Continuous variable a variable that is able to take any value within a range; length, time and temperature are examples of continuous variables

Control group a comparison group that is as similar as possible to the experimental group, except for the variable being tested (the ‘independent variable’); the independent variable is absent or unchanged in the control group

Controlled variable a variable that is controlled by the experimenter and kept constant during the experiment

Dependent variable a variable that changes as a result of changes to the independent variable

Discrete variable a variable that may only take certain values; number of individuals or number of legs on an animal are examples of discrete variables

Dissection the process of carefully cutting open and exposing the interior parts of a plant or animal for study

Extrapolation extension beyond the measured range of data to predict or construct new data that has not been measured

Hypothesis (plural hypotheses) a scientific statement based on the available information that can be tested by experimentation ('an educated prediction'). When appropriate, the statement expresses an expected relationship between the independent and dependent variables based on observed phenomena

Independent variable a variable intentionally varied by an experimenter to see what the outcome will be for another variable (the 'dependent variable', according to the hypothesis)

Inoculate to inject a harmless form of a disease into an organism to induce immunity without causing the disease

Interpolation predicting or constructing a new data point that has not been measured but is within the range of measured data

Inter-quartile range the middle 50% of values in a data set when they are ordered from lowest to highest; found by subtracting the median of the lower half of the values from the median of the upper half of the values

Investigation a scientific process of answering a question, exploring an idea or solving a problem that requires activities such as planning a course of action, collecting data, interpreting data, reaching a conclusion and communicating about these activities; investigations can include observation, research, field work, laboratory experimentation and manipulation of simulations

Logbook the record of an experiment or investigation kept by the scientist performing the experiment; it is a legal record of the experiments and their results

Mean the average of a set of values, found by adding all the values together and dividing by the number of values

Measurement error the difference between the measurement result and a currently accepted or standard value of a quantity

Median the central value in a data set, found by placing the values in ascending order and selecting the middle value or, if there is an even number of values, taking the average of the two central values

Micrographs photographs taken using a microscope

Microscope a piece of equipment used to magnify objects that may not be visible to the naked eye

Microscopy the use of a microscope to view cells or objects that cannot normally be seen

Model the artificial conceptual or abstract simulation of a real-world process or system, developed by simplifying key steps that produce reliable and consistent agreement as verified by field studies; a model may be mathematical equations, a computer simulation, a physical object or words, or it may take another form

Monocular having a single eyepiece (of a microscope)

Outlier a data point that does not fit the pattern shown by other measured data points

Plagiarism presenting someone else's work, including their words or ideas, as your own

Primary data data that you have measured or collected yourself

Quadrat a square, rectangle or circular frame of convenient size, used to mark out an area in which organisms are to be sampled; also a survey technique where a frame is placed on the ground and each individual of a species within it is counted, to estimate abundance and density; useful for stationary organisms

Qualitative measurement a measurement with descriptive or non-numerical results

Quantitative measurement a measurement with numerical values

Rate a measurement of change in a factor in comparison to another factor, usually per unit time; for example, a rate that can be measured is the volume of water lost from a plant per unit time

Reduction using only the minimum number of animals in research to satisfy statistical requirements

Reference the source of a specific piece of information or quotation

Refinement the modification of procedures applied to research animals in order to reduce harm

Reliability the degree to which an assessment instrument or protocol is able to consistently

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and repeatedly measure an attribute and achieve similar results for the same population

Reliable data data that have been judged to have a high level of reliability

Replacement substitution of insentient materials or animals of a lower sentience for conscious living animals

Reproducible giving the same result, within uncertainty limits, when repeated measurements are made

Research question the specific question that a particular experiment or investigation is attempting to answer

Resolution the smallest distance by which two points can be separated and still be distinguished as separate objects (of a microscope)

Scientific method a process of systematic observation and experimentation, inductive and deductive reasoning, and the formation and testing of hypotheses and theories

Secondary data data or information that have been collected by someone else

Standard deviation a measure of the dispersion of a set of data from its mean; it expresses the variability of a population or set of data

Theory a collection of models and concepts that explain specific systems or phenomena; scientific theories allow predictions to be made and hence can be proved false

Transect a method used in population sampling where a line is drawn through a community to determine the distribution of species; can be used with quadrats and is useful for stationary organisms

Validity the extent to which tests measure what was intended; the extent to which data, inferences and actions generated by tests and other processes are accurate

Variable something that can change or be changed, as distinct from a constant, which does not change

Wet mount a glass slide holding a specimen that is suspended in a drop of liquid (such as water) for examination under a microscope

CHAPTER 1 REVIEW QUESTIONS

1 Recall the difference between the resolution and the magnification of a microscope.

Use the following information to answer Questions 2–11.

A team of scientists were conducting tests on the safety of two different vaccines. Instead of using humans, they used a group of ferrets as their animal models in preclinical trials. If either vaccine proved safe (and effective), then human trials would be the next step. (In the past, some trialling vaccines have caused extreme, unsafe side effects, such as high fever.)

2 Write a hypothesis to represent what is being tested.

3 State the independent and dependent variables.

4 Explain why control groups are necessary.

5 Would the experiment generate quantitative or qualitative data?

6 List three variables that must be controlled for this experiment.

7 Describe three aspects of the experimental design that could make the data more reliable.

8 Describe two aspects of the experimental design that could make the data more valid.

9 Describe a type of graph that would be suitable to compare the results of two different vaccine groups and a control group, if results were represented by average numerical safety ratings.

10 Using the risk matrix (Table 1.1 on page 6), state a suitable term to use to rank an experiment that involves a vaccine of a highly contagious and deadly viral disease.

11 Discuss the use of the three Rs of animal ethics in an investigation.

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PRACTICE EXAM QUESTIONS

1 A gardener hypothesised that a chemical in the tap water was reducing the number of flowers on her orchids. Which of the following is a valid prediction arising from her hypothesis?

A Orchids that are not watered will grow more flowers than orchids that are watered.
B Orchids that are watered will grow more flowers than orchids that are not watered.
C Orchids watered with tap water will grow more flowers than orchids watered with rain water.
D Orchids watered with distilled (pure) water will grow more flowers than orchids watered with tap water.

[Q23 2011 SCSA/WACE]

2 Which of the following statements about the scientific method is true?

A An experiment can be valid and reliable but not ethical.
B Increasing the sample size decreases the reliability of an experiment.
C All experiments must have three independent variables.
D Controlled experiments cannot be conducted in the field.

[Q26 2011 SCSA]

3 Twenty quadrats, each measuring 1 metre by 1 metre, were placed in an area of rocky shore containing limpets (a type of marine snail that lives attached to rocks). The average number of limpets in each quadrat was 16. If the study area covered 500 square metres, what is the estimated number of limpets in the study area?

A 16
B 320
C 8000
D 320 000

[Q27 2011 SCSA]

4 During the 19th century, ships' crews often released goats on uninhabited islands. The sailors hoped that the goats would establish populations on the islands so that sailors could hunt the goats for meat when ships called in the future. The number of goats on each of two islands was monitored for several years. The results are shown in Table 1.7. (12 marks)

[Q32 2011 SCSA]

TABLE 1.7 Goat populations on two islands

NUMBER OF GOATS	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7
Island 1	4	8	15	Missing data	67	41	42
Island 2	7	4	11	28	56	49	48

a On a graph, plot a line graph of the number of goats against the year for each of islands 1 and 2; that is, plot the data separately for islands 1 and 2. (4 marks)

b i Using the graph, predict the number of goats on Island 1 in Year 4. (1 mark)

ii At the beginning of Year 8 on Island 2, there were 48 goats. During Year 8, 20 goats were born, sailors killed 10 goats and 28 goats died of other causes. What is the goats' population size on the island at the end of Year 8? Show your workings. (3 marks)

c Island 1 is 500 hectares (ha) in total area. Island 2 is 800 ha in total area.

i Calculate the population density of goats (goats/ha) on Island 1 in Year 2. Show your workings. (2 marks)

ii Which island had the greater density of goats in Year 7? Show your workings. (2 marks)

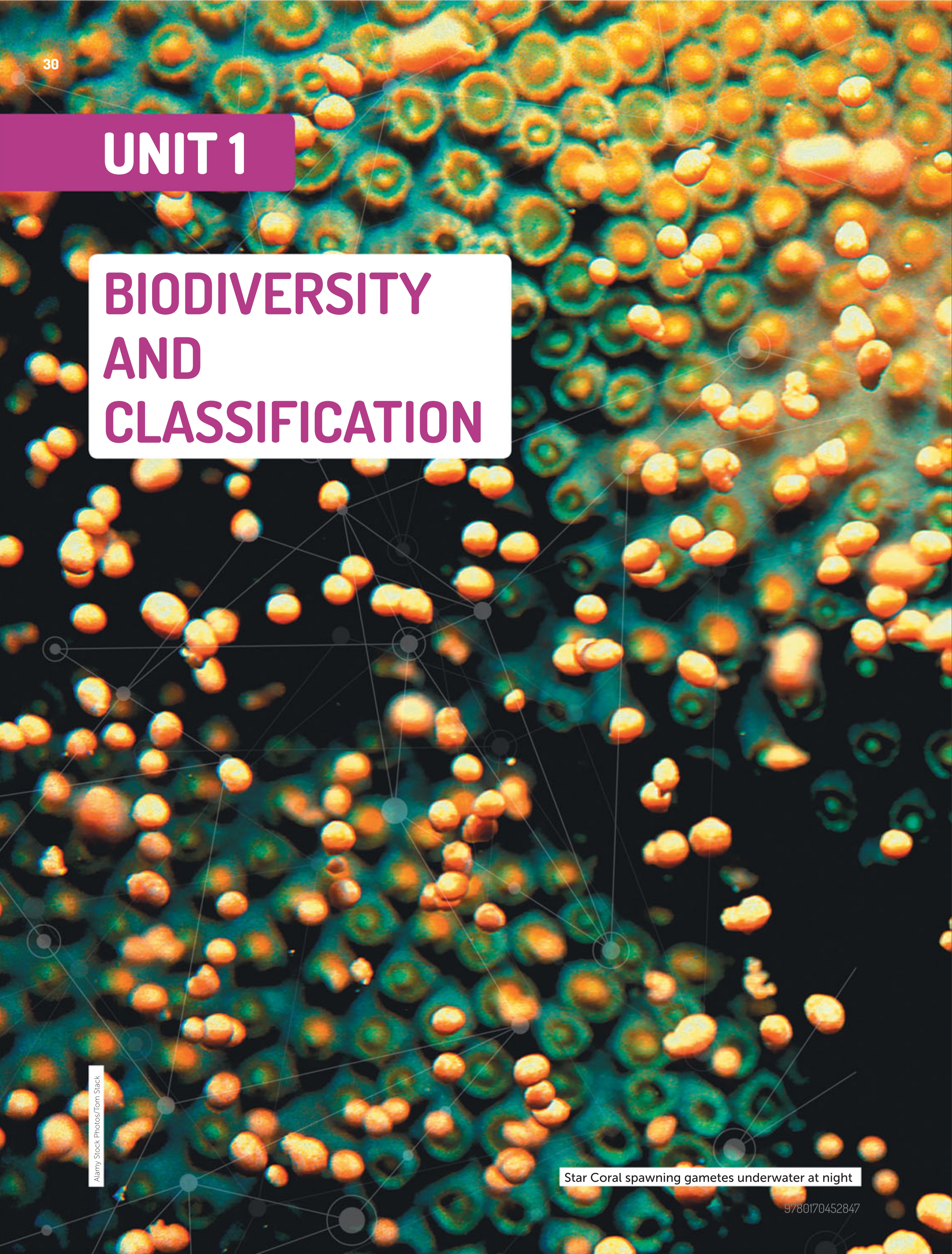
5 A scientist hypothesised that baiting decreased the number of wild dogs in the Eastern Goldfields region. (4 marks)

a What is the dependent variable for this hypothesis? Explain your answer. (2 marks)
b What is the independent variable for this hypothesis? Explain your answer. (2 marks)

[Q35d 2011 SCSA]

UNIT 1

BIODIVERSITY AND CLASSIFICATION



Alamy Stock Photos/Tom Stack

Star Coral spawning gametes underwater at night

2 BIODIVERSITY AND CLASSIFICATION

CHAPTER 2 CONTENT

STARTER QUESTIONS

1. Why do you think Australia is spending millions of dollars on conserving biodiversity?
2. Can you define and apply the binomial system of classification?
3. How many different species can you name in 2 minutes?

SCIENCE UNDERSTANDING

» biodiversity includes the diversity of genes, species and ecosystems; measures of biodiversity rely on classification and are used to make comparisons across spatial and temporal scales

» biological classification is hierarchical and based on molecular sequences, different levels of similarity of physical features and methods of reproduction

» biological classification systems reflect evolutionary relatedness between groups of organisms

» most common definitions of species rely on morphological or genetic similarity or the ability to interbreed to produce fertile offspring in natural conditions – but in all cases, exceptions are found

SCIENCE AS A HUMAN ENDEAVOUR

» classification systems are based on international conventions and are subject to change through debate and resolution; changes are based on all currently available evidence

SCIENCE INQUIRY SKILLS

» select, construct and use appropriate representations, including classification keys, food webs and biomass pyramids, to communicate conceptual understanding, solve problems and make predictions

School Curriculum and Standards Authority (2017). Biology ATAR course: Year 11 syllabus: Science inquiry skills.

James Vodicka

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Biodiversity is Us at Perth Zoo
This is an overview of global biodiversity.

2.1 BIOLOGY AND BIODIVERSITY

Biology is the study of living things. All living things, including us, interact with other living things and non-living things on our planet. Living things are **organisms** that can respire to produce energy, grow, respond to stimuli, consume nutrients, reproduce and regulate their internal environment. The study of biology is about understanding diverse living systems in all their detail, from the biodiversity of entire continents to minute cellular processes.

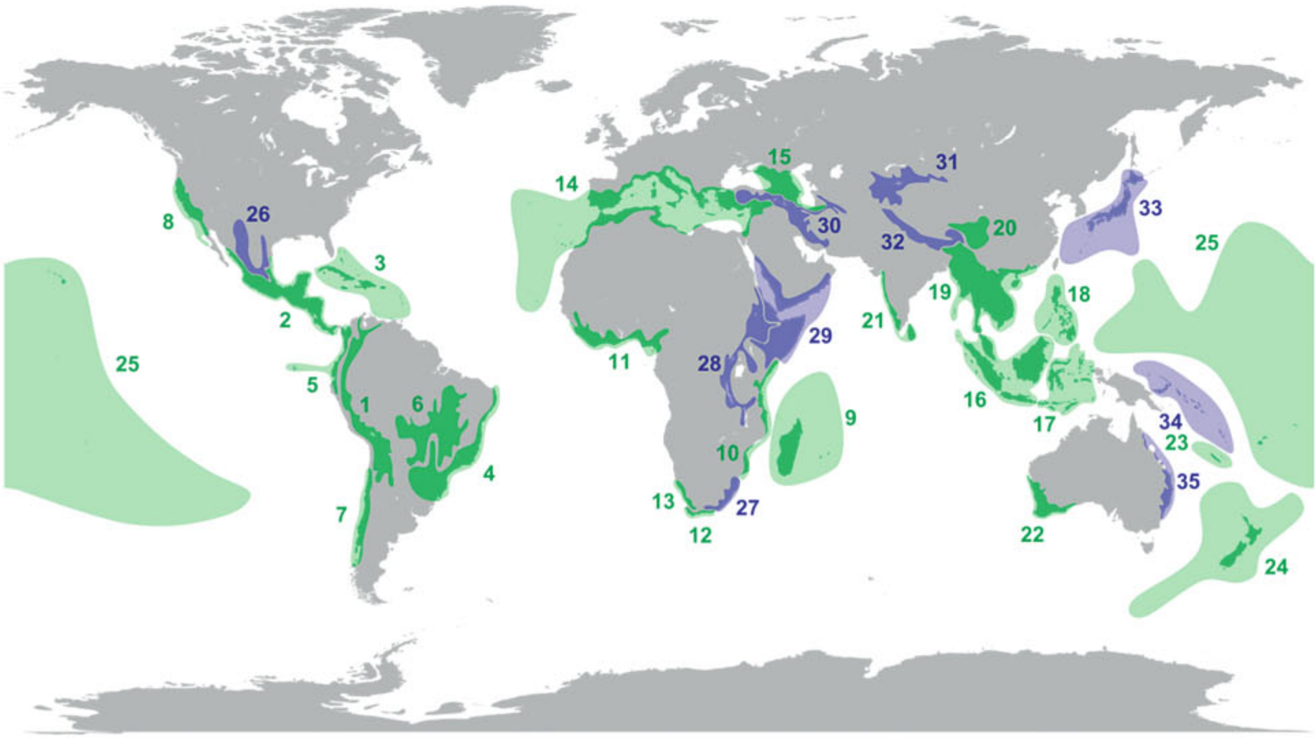
Life on Earth is extremely diverse. **Biodiversity** or biological diversity describes the great variety of life that exists in our **biosphere** (any area on Earth that living things inhabit). The biosphere includes most regions of land, most bodies of water (such as oceans), and the atmosphere up to an altitude of several kilometres. Even though scientists describe our time as a period of mass extinction, we still have a vast diversity of life on Earth to study, enjoy and protect. Scientists have named approximately 1.9 million species of organisms and there are many more that are yet to be discovered, classified and named. Biodiversity can be defined at three levels. Biodiversity includes all of the **genes** in a species' **gene pool**, all of the species in an ecosystem and all of the ecosystems in the biosphere.

Biodiversity month
In Australia, September is biodiversity month. Why is it important to study this topic?

Living in WA puts you in the same state as a 'biodiversity hotspot'. Perth Zoo runs an excursion named Brilliant Biodiversity, based on our very own hotspot in the south-west of WA. A **biodiversity hotspot** is a region with numerous **endemic** (native) species and a large number of endangered and threatened species. To qualify as one of the world's biodiversity hotspots, an area must:

1. contain at least 1500 species of endemic vascular plants found nowhere else on Earth
2. have lost at least 70% of its primary native vegetation.

To understand the levels of biodiversity, some vocabulary is needed. Table 2.1 lists some of the terms commonly used when discussing biodiversity.



Wikimedia/Ninjatacoshell

FIGURE 2.1 Biodiversity hotspots of the world, including WA's south-west coast (number 22); the first 25 hotspots are shown in green, and the 10 that have been added since 2000 are shown in blue.

Alamy Stock Photo/Suzanne Long

FIGURE 2.2 The endangered western swamp tortoise, *Pseudemydura umbrina*, is endemic to the biodiversity hotspot in WA.

TABLE 2.1 Biodiversity terms and definitions

TERM	DEFINITION AND APPLICATION TO BIODIVERSITY
Gene	A section of DNA in a chromosome that encodes an instruction, usually for a specific protein, which, when expressed, may affect a certain characteristic. Genes are inherited by offspring. Genes can come in different forms. A higher number of different forms of a gene in one species constitutes a higher genetic diversity for that species.
Gene pool	The sum of all the genes, including all of their different forms, in a given population of one species; sometimes, it is also used to refer to all the genes in a species.
Species	A group of morphologically similar organisms that share a gene pool; members of the same species are able to interbreed under natural conditions to produce viable and fertile offspring.
Ecosystem	All the organisms in a particular area, along with the non-living components of their environment, and all their interactions. It is a self-sustaining unit. Ecosystems can vary greatly, depending on biotic and abiotic factors.
Biosphere	All the environments on Earth that organisms inhabit; the combined sum of Earth's ecosystems.

Why study biodiversity?

Biodiversity has relevance and importance, not just from a scientific perspective, but also as a vital factor in the long-term survival of all life on Earth, including human societies. The following statements explain why we study biodiversity.

1 Ecosystem processes are essential to survival. We depend on processes such as **photosynthesis** for converting light energy to chemical energy that can flow through food webs and for providing oxygen to living things; nutrient cycling, which uses organic and inorganic matter from dead and decomposing organisms to support new life, and simultaneously cleans up wastes; **population** interactions such as competition and predation, which maintain the balance and diversity of organisms; and pollination, in which organisms such as insects, birds and mammals distribute the pollen of plants, thus helping them to reproduce.

2 Biodiversity delivers educational and cultural benefits. It provides clues about changes in species over time. Recreational use such as bushwalking is beneficial for human wellbeing. It is important in the spiritual life of Aboriginal and Torres Strait Islander Peoples. Biodiversity – the land, waters and all living things – forms Indigenous creation, Dreamtime stories and Songlines about how people and the world around them came to be. Aboriginal and Torres Strait Islander traditions, including family and clan totems, food and culture are inextricably tied to the Australian landscape and its biodiversity.

Aboriginal Ranger Program Round 3
Biodiversity projects generate jobs for Indigenous Peoples in WA.

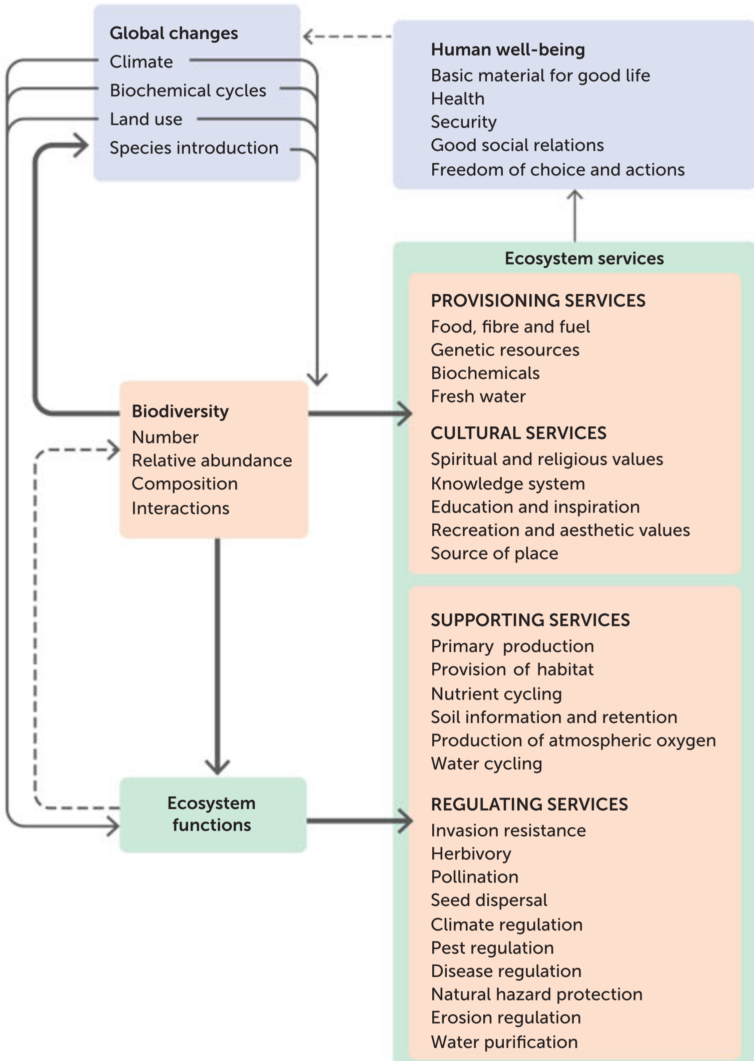
Biodiversity rationale and strategy
This video describes Victoria's plan to protect biodiversity.

3 Biodiversity contributes to the production of food, purified water and air, fibre products such as wool and cotton, fuels, climate control and pharmaceuticals.

4 Biodiversity attracts tourism and contributes to the economy. A study by Deloitte Access Economics estimated that in 2015–16, tourism, scientific research and management, recreation and commercial fishing in the Great Barrier Reef Marine Park alone contributed $6.4 billion to the Australian economy. The national economic value generated by Australia's 15 World Heritage Areas is approximately $7.25 billion annually, along with providing approximately 83 000 jobs.

Auscape/Tim Acker

FIGURE 2.3 Aboriginal and Torres Strait Islander traditions, food and culture are inextricably tied to the Australian landscape and its biodiversity.



Source: United Nations Millennium Ecosystem Assessment

FIGURE 2.4 The ecosystem goods and services provided by biodiversity

Describing biodiversity

As mentioned earlier, scientists have come to recognise biodiversity at three different levels. The first to be recognised, and still one of the most obvious to us today, is the level of species. A **species** is most often defined as a group of morphologically similar organisms that is capable of interbreeding to produce fertile offspring.

The second level of biodiversity to be recognised is ecosystems. Organisms live in complex communities and a range of different physical environments. For example, consider the differences between the communities and physical conditions present in the alpine regions of Australia and those found in the salt lakes of WA (Figure 2.6).

Dreamstime.com/Ralph Loesche

FIGURE 2.5 An Australian rainforest is an example of a very complex and diverse ecosystem.

The third, and most recently identified, level at which biodiversity is considered is genetics. Genetic diversity is now widely recognised for its biological importance.

Alamy Stock Photo/Suzanne Long

Shutterstock.com/PominPerth

FIGURE 2.6 a An alpine ecosystem in NSW; **b** a salt lake ecosystem in WA.

Key concept

Biodiversity is the variety of life that exists in the biosphere. Biodiversity includes all of the genes in a species' gene pool, all of the species in an ecosystem and all of the ecosystems in the biosphere.

Diversity of species

If you look around your classroom, you will notice diversity. Clearly, each person is a different individual. However, we also have an instinctive understanding that we all belong to the same 'kind'; that is, we share the same gene pool. We are all human and belong to the one human species, *Homo sapiens*. All of the members of the human population are more closely related to each other and more genetically similar than they are to the members of other species of mammals.

Biodiversity can refer to the existence of many different species. For example, WA's Swan coastal plain ecological community contains more than 1500 plant species, as well as approximately 130 species of fish in its rivers. This ecosystem therefore has more than 1630 different gene pools.

Traditional understandings of species

Most cultures, modern and ancient, have developed sophisticated, accurate and scientifically supportable knowledge about the species that live in their local environment. A region where traditional knowledge of species classification has been closely studied is the Amazon in South America. This is one of the most biodiverse regions on Earth, and its many Indigenous societies have had little contact with the Western world. These cultures have an encyclopedic knowledge of their local environment, combining extensive systems of classifying the organisms of importance to their lives with detailed stories describing how these organisms relate to each other and to their physical environment.

The biological species concept

In biological terms, a species is a group of organisms who are able to interbreed in nature and produce viable, fertile offspring. This definition is the **biological species concept**. It was proposed by Ernst Mayr in 1942. Most importantly, individuals within a species are reproductively isolated from individuals not belonging to that species. This definition has a very important link to the processes of evolution. Current models suggest that when populations of individuals become unable to interbreed, the evolution of new species can occur.

Limitations of the biological species model

While the biological species model is relevant to how new species evolve, there are problems in using this definition, particularly at the genetic level. For example, it is not possible to apply it to fossils of extinct organisms, because it is impossible to know which individuals could interbreed. It cannot be applied to increase our understanding of how our own species evolved. Archaeologists have found many pre-human fossils but cannot use the biological species model to classify them. Some fossils clearly represent species that are different from modern humans, but other fossils are more difficult to classify.

Often, where two identified species have populations that overlap to some extent, there are zones where **hybrid** organisms exist. A hybrid organism is the non-viable, infertile offspring that can result from the mating of two individuals from different species. The hybrid offspring carries mismatched chromosomes from both species and is difficult to classify. For example, with the loss of ice sheets in Arctic regions, polar bears have moved into more forested regions where grizzly bears live. Occasionally, the two species interbreed to produce a polar–grizzly bear hybrid. These have been called grolar bears (and some are half grizzly, half grolar; or half grolar, half polar), and seem to survive quite well in the wild in some situations. But they do not displace either of the polar bear or grizzly bear parental populations.

Other species concepts

When scientists examine and classify fossils, the **morphological species concept** is most commonly applied. This concept characterises a species by its form, or morphology. In the case of the human family tree, it is most often the skull that is best preserved and identified morphologically. However, scientists often disagree about which morphological features should be used and when the features are sufficiently different to justify the creation of a new group.

The **phylogenetic species concept** identifies a species as being the smallest group of organisms who can all trace their origins to a single **common ancestor**. **Phylogeny** (the evolutionary ancestry of a species) is an important feature of all classification systems used today.

Any group of individuals identified as being related in some way has a common ancestor. For example, all primates share a common ancestor that existed around 60 million years ago, while all mammals share a common ancestor that existed around 120 million years ago. Scientists who apply the phylogenetic species concept to **extant** (living) organisms increasingly use genetic techniques, and most phylogenetic trees produced today are based almost solely on these. A **phylogenetic tree** is a family tree of species that is based on their ancestry. The branching points on the tree show the common ancestor of all species after that point.

Biodiversity of species on the seafloor
Scientists are using computer software to model and predict biodiversity on the Antarctic seafloor. How many different species can you spot in one section of this ecosystem?

9780170452847

Key concept

A species is most often defined as a group of organisms that is capable of interbreeding under natural circumstances to produce fertile offspring.

Diversity of ecosystems

An **ecosystem** is composed of all the living organisms (**biotic factors**) in one area, together with the physical environment or non-living factors (**abiotic factors**), and their interactions. Within an ecosystem, the communities of organisms and the physical conditions tend to be fairly uniform. All the components of an ecosystem are tightly linked by the cycling of nutrients and raw materials within it. These materials include carbon dioxide, oxygen, water, nitrogen, phosphorus and many other minerals. The living components are also linked by the transfer of energy through the system. In most systems, the energy is initially transformed from light to chemical energy in food molecules, usually sugars, through photosynthesis, and then transferred between organisms via tightly linked **food webs**. As energy is transformed and transferred through the ecosystem, some is always converted to heat.

The ecosystem concept

The German explorer Alexander von Humboldt is often regarded as the father of ecology. During his voyages in the early 1800s he began studying the relationships between organisms and their environment. The term 'ecosystem' was not coined until 1935 by Arthur Tansley, a British ecologist.

The concept of ecosystems provides a powerful tool for understanding the complexity of life, but it is also a concept that scientists are continually improving and developing. One problem with the concept is that it can be difficult to determine where the dividing line is between one ecosystem and another, because all life on Earth is connected through the cycling of nutrients and the transformation of energy through food webs. It tends to be assumed that an ecosystem has some level of isolation from other ecosystems, meaning that more materials are cycled and transferred within an ecosystem than between one ecosystem and another. In reality, materials *do* cross the boundaries separating one ecosystem from another. For example, a predator such as the Australian dingo may have a range that crosses a number of different ecosystems.

Different ecosystems provide specialised habitat for different sets of species adapted to their unique combination of biotic and abiotic factors. This largest scale of biological diversity is important in maintaining species and genetic diversity.

Key concept

An ecosystem is the biotic and abiotic factors in an area, and their interactions.

Genetic diversity

Every individual carries a large number of genes that code for all of their inherited traits, and different individuals carry many different genes. Our differences arise due to genetic variation: genes come in different forms which gives rise to our differences. For example, the whole human population carries many different eye and hair colour genes. Generally, populations with higher genetic diversity (i.e. the greatest mix of different genes) are more resilient and can better survive sudden changes in the environment, compared to populations with low genetic diversity.

If a species is abundant and lives in environments that support growth, it may separate into different populations and occupy different habitats. Populations that become isolated from each other are likely to have a different genetic composition, depending on which individuals migrated together. Smaller populations can have a lower range of genetic variation, making them less resilient in the face of changes in the environment and more susceptible to disease.

Biodiversity of Australia

Australian flora (plants) and fauna (animals) stand apart from those of the rest of the world for several reasons. First, they are quite different from those found anywhere else on Earth. The eucalyptus trees that characterise much of the Australian landscape are not found naturally outside Australia and South-East Asia, although eucalypts have been introduced to other regions, and have grown widely in climates such as those of California and the Mediterranean. Perhaps even better known are our unique fauna, including many different types of marsupial, which for many people typify Australian wildlife.

The second important difference is diversity. Australia has approximately 1 million species of plants, animals and micro-organisms, representing approximately 7% of the world's total. Australia is one of only two developed nations, along with the US, to be recognised as a 'megadiverse' country, a country possessing particularly diverse ecosystems.

Professor Chris Dickman of the University of Sydney says Australia's diversity of mammals is impressive. Having more than 300 native mammal species makes Australia a unique tourist destination. Three subclasses of mammals are represented in Australia: marsupials, placentals and monotremes, with marsupials being the dominant group. Approximately 80% (about 244 species) are found only in Australia. Scientists report that approximately 34 species and subspecies of native mammals have become extinct over the last 200 years. Sadly, this is the highest rate of loss for any region in the world.

Australia has more species of higher plants than 94% of countries on Earth, and more reptile species than any other continent. Most importantly, Australia has many endemic species that occur nowhere else on Earth. Australia's biodiversity is both large and unique, making it globally significant.

Auscape/Dave Watts

FIGURE 2.7 The northern hairy-nosed wombat, said to be Australia's most endangered marsupial, is an example of an endemic species unlike any found in other continents.

Creatures of the night: WA's frogs and geckos
If you have an interest in frogs and geckos, check out this lecture held at the Western Australian Museum.

Sustainable Fawkner
Find out about the link between climate change, fire intensity and biodiversity.

Question set 2.1

REMEMBERING

1. Describe the three levels of biodiversity.
2. Contrast the following three species concepts:
   a. biological species concept
   b. morphological species concept
   c. phylogenetic species concept.
3. In your own words, explain the term 'ecosystem'.

UNDERSTANDING

4. Outline some of the limitations of the biological species concept.
5. Define 'biodiversity' and provide an example that illustrates its meaning.
6. Dogs come in all sizes and colours, yet they are all one species. Explain why this is so.
7. Outline the relationship between species diversity and ecosystems.

CREATING

8. Imagine you are a scientist concerned about the biodiversity remaining in an area after an intense bushfire. You are seeking multimillion-dollar funding from the state and national governments to monitor, manage and protect the burned ecosystem. Create a rationale for the project.

SCIENTIFIC LITERACY

Ningaloo Reef and the Great Barrier Reef

The World Heritage Committee is made up of 21 representatives elected from 190 member countries who meet annually. One of the committee's tasks is to recommend inscriptions (inclusions) on the World Heritage List. The list aims to recognise and protect sites of cultural and natural significance.

In 2011, the Ningaloo Coast World Heritage Area was inscribed on the World Heritage List because it meets two of the natural World Heritage outstanding universal value criteria, by containing:

- areas of incredible natural beauty
- the most important and significant natural habitats for conservation of biological diversity.

Alamy Stock Photo/Nature Picture Library

FIGURE 2.8 Ningaloo Reef: a World Heritage site

Shutterstock.com/Edward Haylan

FIGURE 2.9 The Great Barrier Reef is the world's largest collection of coral reefs.

Ningaloo Reef is one of the longest and most pristine fringing reefs in the world. It has an unusually narrow continental shelf. Because it has deep oceanic waters, reef and coastline communities living close together, it has a huge variety of internationally significant and healthy marine life living in one area.

More than 200 coral, 500 fish, 650 mollusc, 600 crustacean, 1000 marine algae, 155 sponge and 25 echinoderm species, many of which are new discoveries and endemic to the area, are found in the shelf, slope and deep sea habitats.

Off the north-east coast of Australia, the Great Barrier Reef is a site of amazing variety and beauty, with the world's largest collection of coral reefs. It provides habitat for species such as the dugong and the large green turtle, both threatened with extinction.

The Great Barrier Reef is recognised on the world stage as outstanding, both for its scenery and wildlife. It includes approximately 2500 separate reefs and more than 900 islands, ranging from small sandy cays (low islands) to larger, vegetated cays, to large, hilly, continental islands, one of which reaches more than 1100 m above sea level. The cays and islands provide important breeding grounds for seabirds, marine turtles and other wildlife. Raine Island is the world's largest green turtle breeding area. Large numbers of butterflies overwinter on some of its continental islands. The Great Barrier Reef is home to more than 1500 species of fish, some 240 species of birds, approximately 400 species of coral, 4000 species of mollusc, as well as many species of crustaceans, anemones, marine worms, sponges and other species. It contains a significant number of threatened species.

With its variety of species and habitats, and the ecosystems they form, the Great Barrier Reef is one of Earth's richest sources of biodiversity: no other World Heritage site can compare. This diversity, and especially the endemic species, means the Great Barrier Reef is of huge scientific and inherent importance.

Questions

1 Define 'biodiversity' in the context of the Ningaloo and Great Barrier reefs.
2 After looking at Figures 2.8 and 2.9, describe two reasons why the reefs should be protected.
3 One of the selection criteria for inclusion on the World Heritage List is 'to contain the most important and significant natural habitats for *in situ* conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation'. How does the Great Barrier Reef meet this criterion?
4 Evaluate the goals and efficacy of declaring natural areas as World Heritage Sites.

2.2 MEASURING BIODIVERSITY

Biodiversity is the number, variety and variability of organisms present in a specified area or grouping. Scientists study how biodiversity is changing and the causes and consequences of these changes. Measures of biodiversity are used to make comparisons across locations (on spatial scales) and at different times (on temporal scales). Measuring biodiversity is difficult even with the latest technology and resources available, so even the best measurements are usually estimations. Measures of biodiversity along spatial and temporal scales reveal biodiversity patterns and can help answer questions such as:

- Does biodiversity increase productivity?
- Is the world experiencing the sixth mass extinction?
- Do introduced species decrease native biodiversity?

Spatial scales

Spatial refers to the space being occupied. Scientists study spatial patterns to understand the extent (size of an area) and distribution of all the individuals in a species (the species biodiversity). Distribution is the location-pattern of members of a species in an area; in other words, where individuals of the same classification group are distributed in an area.

The distribution of individuals can be observed in patterns. Common patterns of distribution are random (where distribution of individuals is irregular, such as cacti in the desert), clumped (where individuals are in different-sized groups and the groups are spaced out in a non-uniform manner, as seen with gangs of meerkats) and uniform (evenly spaced individuals in a uniform pattern, such as trees in a forest competing for sunlight).

To determine distribution patterns, spatial studies can be conducted, which means the locations of individuals are studied over time. Such studies range from local to global, in terrestrial and aquatic ecosystems. **Terrestrial** ecosystems are those on dry land and **aquatic** ecosystems are those in water.

An example of a scientific study that included spatial studies was released by the Victorian Environmental Assessment Council in 2014. Scientists carried out a spatial study of a population of King George whiting fish recruited to Port Phillip Bay. The study was conducted because Victorians rely on this species of fish for commercial and recreational fishing. The spatial scale over which distribution and migration was examined was approximately 800 km and extended from the South Australian border to Western Port, Victoria.

Spatial distribution of the different life stages of King George whiting revealed important factors that affect biodiversity and survivability of their population and other populations in the same ecosystems. Significant locations included those of the spawning grounds (where eggs and sperm are released), the transport of the larvae as they drifted eastward from South Australia to Port Phillip Bay in Victoria, their distribution in the seagrass beds until they emerged as 'recruitment' (adult fish that contribute to the population) and the migration of the young fish back to South Australia to spawn. The fish only settle in Victoria for the first 2–4 years of their 20-year life (Figure 2.10).

A population's distribution may be described, for example, as large or small, uniformly or randomly distributed, or clustered or concentrated in one area. Usually, relatively large terrestrial animals are distributed in these patterns. In contrast, micro-organisms such as **bacteria** that inhabit soil usually have a larger scale and their distribution is across a wider area with a more even spread (fewer clusters).

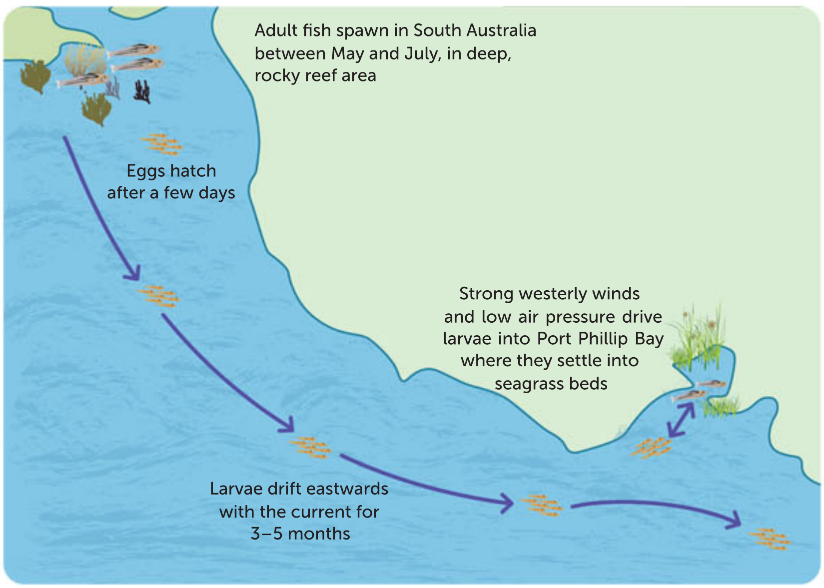


FIGURE 2.10 The movement of King George whiting larvae into Port Phillip Bay

The Atlas of Living Australia contains maps of spatial scales in their spatial portal interface, based on observations. The snapshots it provides can be compared over time to show a temporal scale for a group of organisms.

Temporal scales

Temporal refers to time. Temporal patterns are studied to provide details about biodiversity in a certain area over a certain time period. Studies may be over time frames varying from geological periods (prehistoric to modern day), to seasons, to generations. For example, temporal studies were also included in the study of King George whiting described previously (page 41). The adult fish spawn between May and July in South Australia, then the larvae drift with the current for 3–5 months to Port Phillip Bay, where they settle into seagrass beds. Temporal studies show activity from April (spawning) to November (settlement at Port Phillip Bay).

The spatial and temporal studies were used to learn about factors that may affect post-settlement of juveniles and recruitment rates, which in turn helps facilitate sustainable fishing. Scientists can use a temporal pattern to monitor a population. If changes occur, then scientists may be able to look for causal factors, such as changes in weather patterns due to climate change. Scientists who record changes in populations over geological time can also estimate extinction rates. Studying patterns of biodiversity over time can help scientists to plan conservation strategies.

Monitoring spatial and temporal changes is also important for plant communities. WA has incredible plant diversity, including more than 11 000 native plant species. However, land clearing, fragmentation, over-grazing, weed invasion, salinity, dieback disease, wildfires and feral animals have all had huge impacts on WA's original native plant communities, including in hotspot areas. Strategies aimed to protect and conserve what is left include the WA Government allocating $66 million in 2015–16 for the broad task of conserving habitat, species and ecological communities. Part of this funding is being used to monitor the spatial and temporal changes in ecosystems, so that planning for conservation and restoration of the native vegetation can be more strategic. Such studies have been made easier with the use of remote sensing technologies to get up-to-date data with minimal effort and cost.

Measures designed to protect biodiversity rely on scientists being able to identify species. Therefore, such conservation measures rely on classification.

Key concept

Scientists study and measure the biodiversity of organisms, including spatial (how organisms are distributed over space) and temporal (how organisms are distributed over time; e.g. day, year) patterns.

Question set 2.2

REMEMBERING

1 Define the following terms:
  a terrestrial
  b aquatic.

UNDERSTANDING

2 Compare spatial and temporal scales used in biological studies.

3 Describe a benefit of studying spatial and temporal scales for biodiversity conservation.

APPLYING

4 Numbats (*Myrmecobius fasciatus*) are an endangered species in Australia. Scientists carried out spatial studies during a reintroduction program between 1985 and 2010 in two sanctuaries run by the Australian Wildlife Conservancy. Females had home ranges of 28.3 ± 6.8 ha and males had home ranges of 96.6 ± 18.2 ha, which leads to an estimated sustainable population of

413–502 individuals at the sanctuary at Scotia. Captive-bred animals from Perth Zoo had a high mortality rate upon reintroduction at Scotia, due to starvation and predation by raptors. The study showed that numbats can be successfully reintroduced into areas of their former range if they are protected from introduced predators.

a Explain why spatial ecology (recording the space the numbats occupied) was of benefit in this study.

b Explain how temporal measurements could also be of benefit.

2.3 BIOLOGICAL CLASSIFICATION

Biological classification is a vital tool for the study of biodiversity. Classification is hierarchical and is based on molecular sequences, levels of similarity of physical features (morphology) and methods of reproduction.

Why classify organisms?

Classification systems provide methods of sorting, so that similar or related organisms are grouped together. Throughout this section you will learn how biologists use similarities and differences to classify organisms, but why do we need to do this?

Classification of organisms is important for several reasons. First, the diversity of life on Earth is so enormous that classifying organisms is a way of organising information. This allows us to see patterns and trends, and to better understand relationships between organisms. So, the second reason to classify organisms is to allow biologists to analyse information about organisms. Classification systems enable data collection, comparison and evaluation.

The third reason is that classifying organisms allows biologists to communicate with one another. Because classification systems are standard worldwide, biologists can identify organisms that have already been discovered and more accurately compare their findings with one another, enabling international collaboration.

Finally, classification means invasive species can be identified more easily and accurately. Classification reduces the risk of confusing an invasive species with an endangered species. For example, the red-eared slider turtle is a declared pest in Australia and other parts of the world. This aggressive freshwater turtle competes with native Australian species for food and space in waterways and can inflict a painful bite on unsuspecting turtle fans. It was introduced into Australia through the illegal pet trade and can be confused with native species such as the oblong turtle in south-western WA. Red-eared sliders can withdraw their heads into their shells, whereas Australian species of turtles are unable to do this. In addition, the upper shells of native turtles are fairly flat, whereas the upper shell of the red-eared slider is domed. These differences are used to identify the invasive species as distinct from native species.

Alamy Stock Photo/ImageBroker

FIGURE 2.11 A red-eared slider turtle. Classification helps us to distinguish this pest species from native Australian turtle species.

The Nature Conservancy
Read the information and watch the video to find out about our endangered animals and the work done by groups like this to conserve animals such as the black-flanked rock-wallaby.

Key concept

Classification is used to identify and organise information about organisms, describe the biodiversity in ecosystems, investigate patterns in relationships between organisms, aid in universal scientific communication and assist in the identification of invasive species.

Question set 2.3

REMEMBERING

1 List three reasons why biologists use classification systems.

APPLYING

2 Humans use classification systems in many aspects of life, not just in biology.
   a List two other situations in which classification systems are used.
   b Using what you have learned about why biologists classify, explain why classification systems are used in these situations.

3 a Classification systems can be useful. Can you think of a limitation they might have?
   b Do you think that these limitations outweigh the usefulness of these systems? Justify your response.

Atlas of Living Australia
The Atlas of Living Australia is designed for use by researchers and environmental managers, but it is accessible to anyone.

2.1 APPLICATION

Atlas of Living Australia

The Atlas of Living Australia (ALA) can quickly tell you information such as the conservation status of a species. It will give you the status for each state. For example, if you investigate the platypus, an endemic monotreme, ALA will tell you it is of 'special least concern' in Queensland but 'endangered' in South Australia. ALA provides details about many biological and ecological aspects of many species that live in Australia.

2.4 LEVELS OF CLASSIFICATION

Scientists classify organisms into a number of groups that form a hierarchy or series of nested levels. These groups are known as **taxa** or **taxonomic levels**. The names of the major taxa, from largest to smallest, are domain, kingdom, phylum, class, order, family, genus and species. At each taxonomic level, organisms can be further grouped according to features that they share. Each organism is therefore able to be defined by the taxa to which it belongs.

The higher taxonomic levels are larger groupings and show more diversity between individual members than there is between members of lower levels. For example, Class Amphibia, to which all frogs belong, is a large group of more than 7000 species that also contains other organisms such as toads and salamanders. The genus *Rana* is a smaller taxon within Class Amphibia and contains around 90 different species of frog.

Initially, organisms are classified into very large groups called domains. The domains are then divided up into kingdoms. Organisms within a kingdom can be further grouped according to the features that they share. This grouping is called a phylum; for example, Phylum Chordata includes all living things that at some stage of their development possess a dorsal notochord ('dorsal' means back, 'notochord' means primitive backbone), gill slits and a hollow **dorsal nerve cord**. Humans belong to this phylum.

Organisms within a phylum can be further grouped according to similar features. These smaller groupings are called classes. For example, any members of Phylum Chordata that nourish their young on milk produced by the female (such as dogs, humans and kangaroos) are grouped within Class Mammalia.

Organisms within a class can be further grouped into orders according to similar features. Humans are grouped within Order Primate along with monkeys, orangutans, chimpanzees and gorillas. Orders are subdivided into families, which can be further subdivided into genera (singular **genus**). Finally, genera are further subdivided into species. The order of this hierarchy is shown in Figure 2.12.

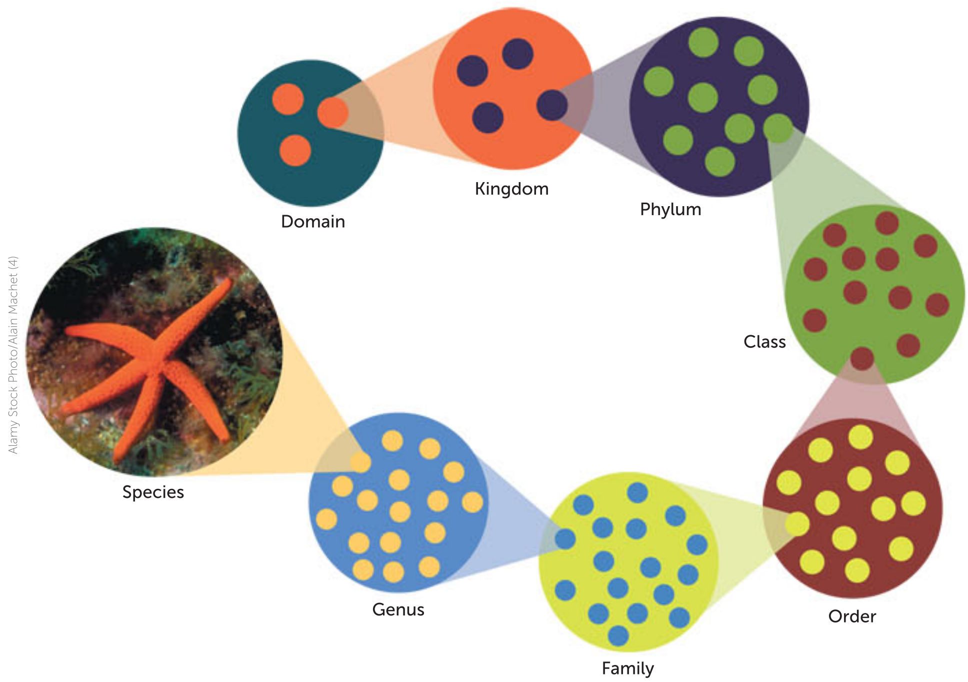


FIGURE 2.12 The hierarchy of the taxa. Each taxonomic level can be divided into multiple groups in the level below.

Key concept

Organisms are classified into a hierarchy of groups called taxa. The names of the taxa are domain, kingdom, phylum, class, order, family, genus and species.

The initial division of life into three domains (Figure 2.13) is based on cellular **characteristics**. Members of Domain Eukarya, called **eukaryotes**, contain their **DNA (deoxyribonucleic acid)** within a nucleus and have other membrane-bound compartments called **organelles** within their cells. Domains Archaea and Bacteria contain **prokaryotes**: organisms that lack these features.

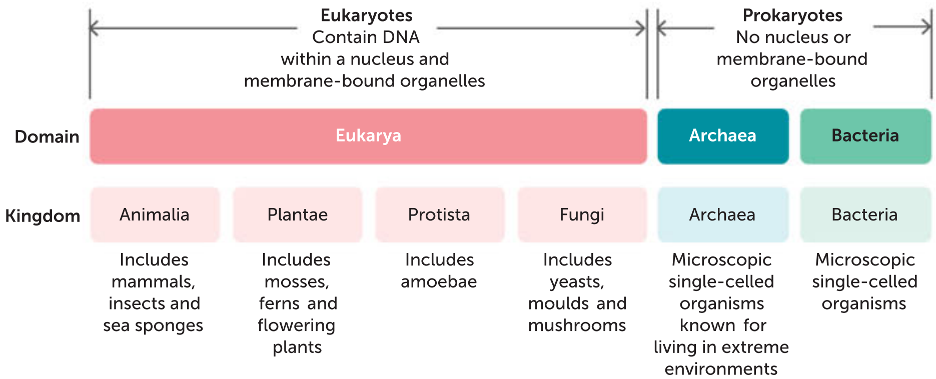


FIGURE 2.13 The initial divisions of life: the domains and kingdoms

Prokaryotes are microscopic, single-celled organisms. Despite their similarity, organisms in domains Archaea and Bacteria have differences in the way DNA is stored and how proteins are synthesised, which means that they are classified in separate domains. Many of the members of Domain Archaea live in extreme environments (such as areas of high temperature or salt concentration).

There are four kingdoms in Domain Eukarya: Animalia, Plantae, Protista and Fungi. You may be familiar with many of the organisms within these kingdoms. Kingdom Animalia contains all of the animals. Plants (Kingdom Plantae) obtain energy from the Sun using organelles called chloroplasts, and their cells have cell walls that contain cellulose. Yeasts, mushrooms and moulds all belong to Kingdom Fungi and are characterised by having cell walls made of a specific polysaccharide (chitin). The protists (Kingdom Protista) are a diverse group of organisms that are mostly single-celled and live in aquatic environments.

Interestingly, there is still debate among **taxonomists** as to how some of these groups should be divided. The Archaea and Bacteria used to be considered part of a single kingdom, the Monera, and this terminology is sometimes still used. Other taxonomists have suggested different kingdoms. Also, you will notice that viruses are not listed in this classification system. This is because they do not meet the current criteria for living organisms and are considered to be non-living. They have a separate classification system.

Naming organisms: the binomial system

There are multiple ways of naming organisms. Most organisms have at least two names: a common name and a scientific name. Common names (such as grass wren or echidna) may refer to individual species or to larger taxonomic groups. They can vary between languages and are not always used consistently. The scientific name (or **binomial name**) is used by scientists around the world and refers only to a single species.

A binomial name consists of two parts: a generic name and a specific name. The first part (generic name) denotes the genus and is common to all organisms within that genus, whereas the second part is unique to a single species. For example, golden wattle, Australia's floral emblem, has the name *Acacia pycnantha*. Related species of wattle, such as black wattle (*Acacia mearnsii*) and WA's prickly Moses wattle (*Acacia pulchella*), share the same first part of their name, *Acacia.* However, the different second part of the name (specific name) indicates that these are different species.

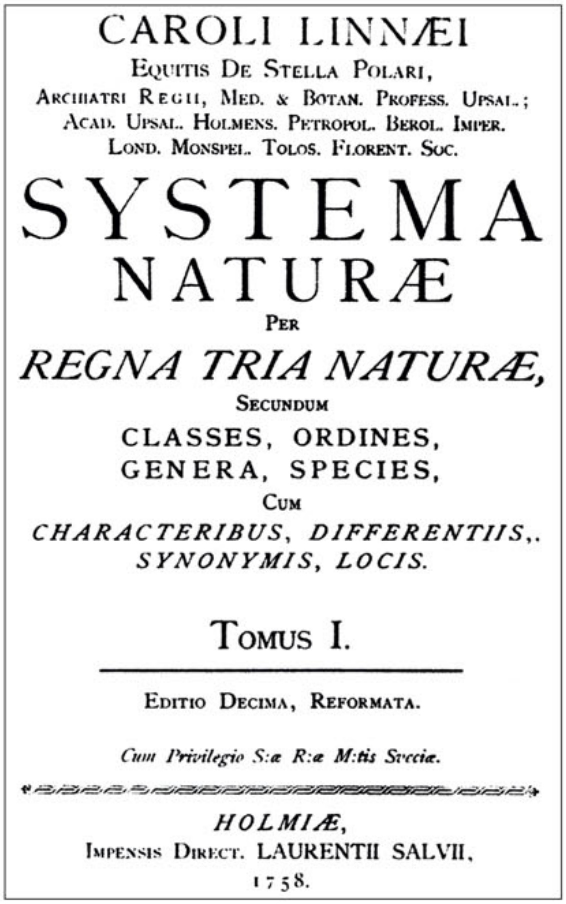
FIGURE 2.14 a Black wattle (*Acacia mearnsii*); **b** prickly Moses wattle (*Acacia pulchella*).

Key concept

All organisms have a binomial (scientific) name. Binomial names consist of two parts: the first denotes the genus and the second is specific to the species.

Binomial names are written using Latin grammar, but can come from various sources. Sometimes they describe features of the organism. For example, the binomial name for the short-beaked echidna (*Tachyglossus aculeatus*) means 'fast-tongued and covered with spines'. In other cases, species may be named after a distinguished person, a location or a mythological character. The binomial name for humans, *Homo sapiens*, comes from the Latin phrase for 'wise man'.

The **binomial system** of naming organisms was developed by 18th-century Swedish botanist and zoologist, Carl Linnaeus. Considered the father of modern taxonomy, Linnaeus first used this system in his book *Systema Naturae,* in which he classified organisms into kingdoms, classes, orders, genera and species. These taxa are different from the ones we use today, but Linnaeus' work formed the basis of the system we still use.


CAROLI LINNÆI
EQUITIS DE STELLA POLARI,
ARCHIATRI REGII, MED. & BOTAN. PROFESS. UPSAL.;
ACAD. UPSAL. HOLMENS. PETROPOL. BEROL. IMPER.
LOND. MONSPEL. TOLOS. FLORENT. SOC.
SYSTEMA
NATURÆ
PER
REGNA TRIA NATURÆ,
SECUNDUM
CLASSES, ORDINES,
GENERA, SPECIES,
CUM
CHARACTERIBUS, DIFFERENTIIS,
SYNONYMIS, LOCIS.

TOMUS I.

EDITIO DECIMA, REFORMATA.

Cum Privilegio S:æ R:æ M:tis Sveciæ.

HOLMIÆ,
IMPENSIS DIRECT. LAURENTII SALVII,
1758.

Alamy Stock Photo/INTERFOTO

FIGURE 2.15 The title page from Linnaeus' pivotal 10th edition of *Systema Naturae*

Binomial nomenclature
Check out this introduction to binomial nomenclature.

There are conventions for writing scientific names. The name is usually given in italics, and the genus name, but not the specific name, is capitalised. When the name of a species has already been mentioned, the genus name can be abbreviated. For example, the name of the bacterium *Escherichia coli* can be abbreviated to *E. coli* when it is written for the second time. Sometimes you may see sp. (singular) or spp. (plural) in place of the second part of the name. These are used when the author is not referring to a particular species. For example, *Lasiorhinus* sp. means 'a member of genus *Lasiorhinus* (hairy-nosed wombats)', and *Macropus* spp. refers to 'members of genus *Macropus* (kangaroos)'. When you hand-write a scientific name, you should underline the genus and species names.

Key concept

In the binomial system for naming species:

- the genus name has the first letter capitalised
- the species name is not capitalised
- when hand written, they are underlined; for example, <u>Homo sapiens</u>
- when in print, they are in italics; for example, *Homo sapiens*

Question set 2.4

REMEMBERING

1. Describe Linnaeus' contribution to biological classification.
2. List the kingdoms that make up Domain Eukarya.
3. Define 'taxonomic level'.

UNDERSTANDING

4. Explain the relationship between a phylum and a class.
5. Using a specific example, explain what the two parts of the binomial name of an organism represent.

2.5 CLASSIFICATION AND THE CHARACTERISTICS OF ORGANISMS

The refinement of classification systems never stops. Taxonomist's opinions differ; some will group species together and others will reclassify a species to split it into new species. At the same time, new species are regularly being discovered. We will now explore the characteristics that taxonomists use to group organisms.

Characteristics are features that can be used to describe an organism. Classification is based on the idea that members of the same group share characteristics that are not present in members outside the group. Platypuses, for example, have a backbone, are covered in fur and lay eggs. All of these are characteristics are used to classify platypuses into Phylum Chordata (with other vertebrates), Class Mammalia (with other animals with fur) and Order Monotremata (with echidnas, the other egg-laying mammals). Order Monotremata is further divided based on the characteristics of its members. Echidnas and platypuses have many different characteristics, so they belong to different families and genera.

Physical characteristics

When creating the classification system presented in *Systema Naturae*, Linnaeus used the physical (or morphological) characteristics of organisms as the basis for his groups. Taxonomists today still use physical characteristics to classify organisms. Almost any aspect of an organism that you can describe could be used in this way.

Can you think of some of the physical characteristics that could be used to define humans? Examples include the fact that humans have cells with nuclei, possess a backbone and have hair. You will learn later on how these physical features are used to classify humans.

Methods of reproduction

The ability to reproduce is a fundamental characteristic of life on Earth. It is unsurprising that there is considerable variation in how organisms do this. Methods of reproduction are an important characteristic that can be used to classify organisms.

One major difference is between organisms that reproduce sexually (with mixing of gametes from two individuals) and those that reproduce asexually (without forming gametes). There are species of both plants and animals that reproduce each way. Some species are able to reproduce both sexually and asexually, depending on environmental conditions.

Shutterstock.com/Worakit Sirijinda

FIGURE 2.16 A kangaroo suckling her joey; like all other mammals, kangaroos have fur and produce milk.

Among mammals (animals that produce milk for their young and have fur), the method of reproduction is used to separate three main groups. Eutherian (or placental) mammals give birth to live young after a gestation period during which the foetus develops inside the mother. The majority of mammal species are in this group. Marsupials give birth to live young at a very early developmental stage. These young then develop in a pouch on the belly of the mother until they are mature enough to survive outside. This group of animals, which is predominantly found in Australia, includes kangaroos, koalas and possums. Monotremes are the very small group of mammals that lay eggs, comprising echidnas and platypuses.

Molecular sequences

More recently, the chemical sequences in molecules such as DNA (deoxyribonucleic acid) and proteins have also been used to classify organisms. Now that technology allows for the analysis of these sequences, they can also be used in classification.

DNA is made up of sequences of four bases: adenine (A), thymine (T), cytosine (C) and guanine (G). The order of these bases within different genes affects the physical features of an organism. Individuals within a species have some differences in the order of these bases. However, these differences are much smaller than the differences in sequence between organisms of different species. Looking at the similarities and differences between DNA sequences can help scientists to classify organisms.

DNA evidence has been particularly useful when morphological evidence is not clear. Scientists have discovered a new subspecies of the red-tailed black cockatoo (*Calyptorhynchus banksii*). Genetic data had been used already to confirm five morphologically different subspecies of this iconic Australian bird; and now there is a newly classified subspecies, called *escondidus*, which has a different genetic makeup. *Escondidus* means 'hidden', the name given because the bird looks so similar to *samueli*, another subspecies, that it has not been recognised until now. It is thought that the two birds evolved similar features because they both feed on the ground and live in similar arid and semi-arid habitats.

Similarly to how DNA sequences are used, information about protein structure can also be used in classification. Proteins are made up of sequences of **amino acids**, and the order of these amino acids can vary in different groups of organisms. Table 2.2 (page 50) shows the sequence of the first 38–40 amino acids in the protein cytochrome c for five different animal species. These sequences have been aligned so you can compare them. Each letter stands for a different amino acid. You can see that when a species has a different amino acid from that in the human sequence, it has been coloured red.

You will notice that these amino acid sequences for humans and chimpanzees are identical. This supports the classification of humans and chimpanzees into the same order (Primates). Humans are less similar to emus than they are to chimpanzees. As such, although they are in the same phylum (Chordata), they are in different classes. Emus have four amino acids that differ from humans in this protein sequence, supporting their difference in classification. Fruit flies have 13 amino acids that differ from humans in this sequence. This supports the fact that, unlike all the other animals listed, fruit flies are in Phylum Arthropoda.

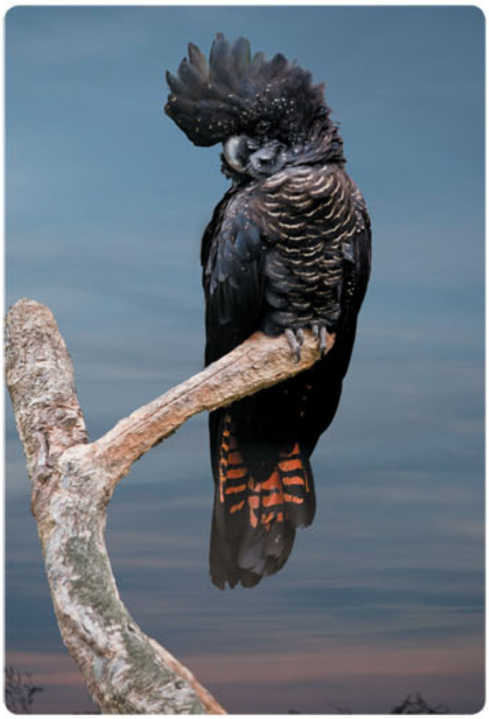


FIGURE 2.17 DNA evidence revealed a new subspecies of the red-tailed black cockatoo, *Calyptorhynchus banksii escondidus*.

TABLE 2.2 The first 38–40 amino acids in the protein cytochrome c

Human (*Homo sapiens*)	MG--DVEKGK	KIFIMKCSQC	HTVEKGGKHK	TGPNLHGLFG
Chimpanzee (*Pan troglodytes*)	MG--DVEKGK	KIFIMKCSQC	HTVEKGGKHK	TGPNLHGLFG
Emu (*Dromaius novaehollandiae*)	MG--DIEKGK	KIFVQKCSQC	HTVEKGGKHK	TGPNLNGLFG
Lamprey (*Lampetra tridentata*)	MG--DVEKGK	KVFVQKCSQC	HTVEKAGKHK	TGPNLSGLFG
Fruit fly (*Drosophila melanogaster*)	MGSGDAENGK	KIFVQKCAQC	HTYEVGGKHK	VGPNLGGVVG

Question set 2.5

REMEMBERING

1 State the 'idea' that classification is based on.

UNDERSTANDING

2 Provide one example of how each of the following characteristics can be used in classification.
   a physical characteristics
   b methods of reproduction
   c molecular sequences

CASE STUDY

21st century classification and DNA barcoding

Traditionally, classification of unknown species was based on observed physical (morphological) features. When an unidentified specimen was acquired by a scientist, they would rely on descriptive or diagrammatic classification keys. This method of assigning a scientific name to a specimen was slow and had limited reliability. Additionally, when traces of a living thing were found, such as some fur, it was nearly impossible to identify the organism because classification keys may not have had the detail required.

DNA barcoding is a modern method developed for use by taxonomists that is emerging as a more reliable and relatively quick method of identifying unknown specimens. DNA barcoding identifies organisms based on short, standardised fragments of genomic DNA. The short segment of DNA required can be easily sequenced (the order of DNA bases is determined), and is unique in every species.

DNA barcoding involves a simple extraction of a tiny DNA sample, sequencing the DNA using a software program and comparing it to an existing database of known sequences. Scientists find this incredibly useful because they can identify where a species has been, using any traces of body tissue it has left behind to track its movement. Furthermore, using this technique scientists can make more informed decisions about conservation strategies.

Museums have traditionally been the repository (a place of storage) for taxonomic information about species. Many museums have started using DNA barcoding as the modern method of cataloguing the world's species. For example, the Western Australian Museum's Dr Mark Castalanelli has developed barcodes for 2090 specimens from a specific group of spiders. This has enabled the study of the distribution of the highly diverse infraorder of spider commonly known as tarantulas. Based on the identification of specimens using DNA barcoding, the distribution of the spiders is described as 'short range endemics'. This means they are only found in limited areas and may need conservation.

Pauline Charman is a passionate science educator who works in biotechnology and biomedical science education. Pauline recently designed and became the founding manager of the first biomedical education centre in WA, the Lotterywest BioDiscovery Centre at the Harry Perkins Institute of Medical Research. As well as lecturing at Curtin University, Pauline conducts research into teaching approaches to Australian STEM education and global developments in biotechnology. DNA barcoding combines her interests and she most recently has started bringing high-level barcoding technology to classrooms all over WA, with BioBarcode Australia.

Pauline believes the extreme weather events of recent times, the result of climate change, have produced unprecedented changes in Australian ecosystems. DNA barcoding will enable scientists to identify remaining species, assess the damage to ecosystems and help with the rehabilitation and cataloguing of species. She believes the next generation of adults, our current students, must be skilled in the life sciences. Understanding the biology of our planet is vital to 21st century scientists, because they will no longer be working only in their specialised fields. Instead, they will use a range of techniques from technology and biology to engineer and solve problems of sustainability and conservation on our planet.

Pauline is using equipment from the International Barcode of Life to include Australian students in a globally accessible, DNA-based system for the discovery and identification of all multicellular life. The program comprises the following steps.

Step 1: Isolate DNA from the sample.

Step 2: Amplify the target DNA barcode region using a technique called PCR (polymerase chain reaction).

Step 3: Sequence the DNA in the PCR products.

Step 4: Compare the resulting sequences against reference databases to find the matching species.

Questions

1. Describe a DNA barcode.
2. Explain how DNA barcoding may help classification be more accurate.

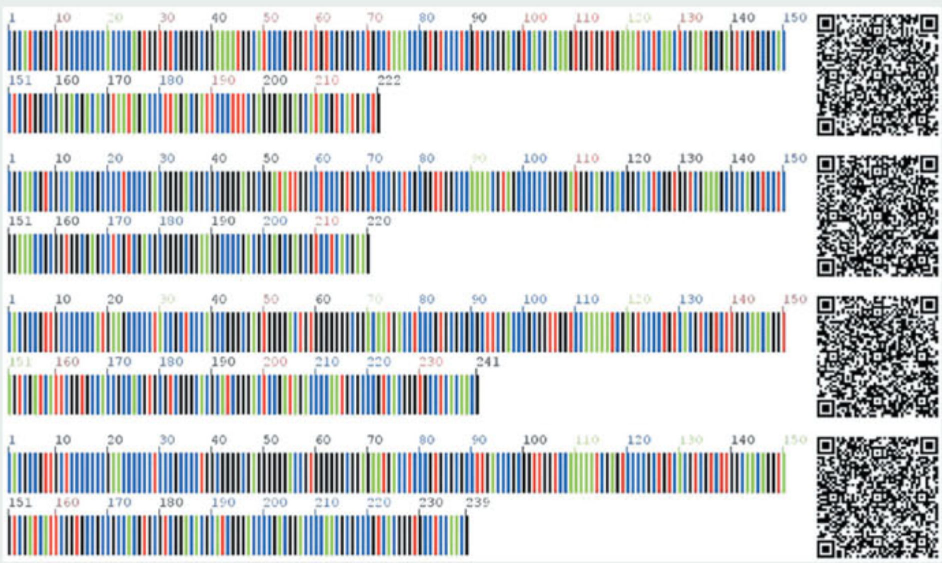


FIGURE 2.18 DNA barcodes

2.6 CLASSIFICATION IN KINGDOM ANIMALIA

Animals are a kingdom of consumers. They are multicellular heterotrophic eukaryotes that are classified based on their body plans and developmental pathways. Their classification is fundamentally related to their phylogeny (i.e. evolutionary ancestry), morphology (i.e. structure) and, due to advancements in biotechnology, molecular data (i.e. DNA and proteins). The animal kingdom is classified into 36 recognised animal phyla, of which nine (Mollusca, Porifera, Cnidaria, Platyhelminthes, Nematoda, Annelida, Arthropoda, Echinodermata and Chordata) contain the vast majority of known living species (Figure 2.19). These phyla are described in Table 2.3.

The five main classes of Chordata share the morphological features of having a dorsal nerve cord and notochord, as well as some features in the **embryo** that may persist into adulthood. Table 2.4 (page 55) displays the morphological and reproductive features that distinguish between the five classes of Chordata.

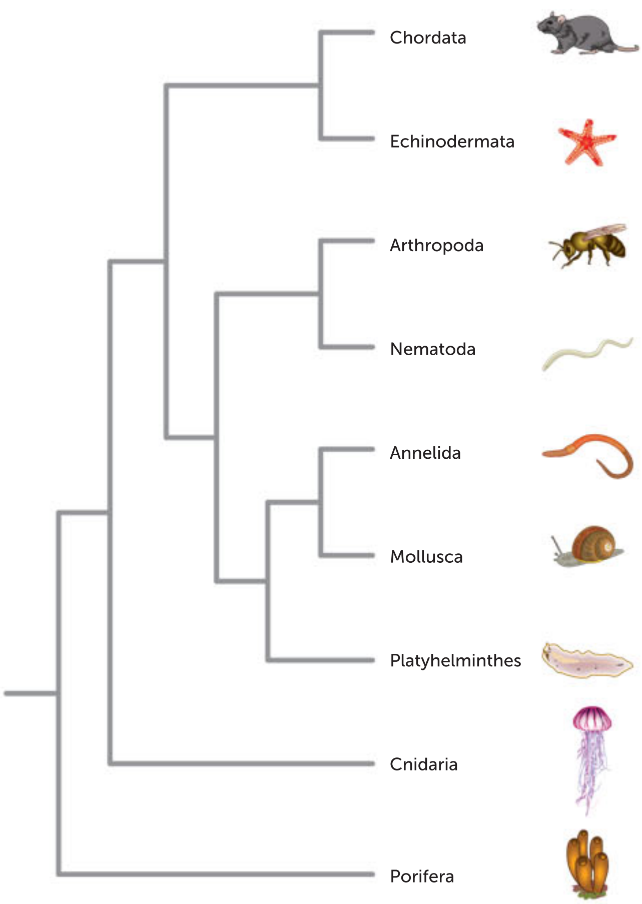


FIGURE 2.19 A simplified phylogenetic tree of Kingdom Animalia showing the nine most species-rich phyla. Chordata includes vertebrates.

Western Australian Museum
Download the Western Australian Museum's Field Guide app to learn more about WA's animals.

Key concept

The animal kingdom is made up of organisms that share similar phylogeny, morphology and molecular data. The animal kingdom is classified into 36 phyla, with most species placed in nine of these phyla.

TABLE 2.3 Some features of the nine most species-rich phyla in Kingdom Animalia

PHYLA (NUMBER OF SPECIES)	DESCRIPTION OF ANIMAL PHYLUM	EXAMPLES
Porifera (5500) Sponges **Porifera** Learn more about Porifera.	**1** **Asymmetrical** (no definite symmetry) **2** Body is multicellular, with few tissues and no organs **3** Cells and tissues surround a water-filled space but there is no true body cavity **4** All are sessile (as an adult, live attached to something) **5** Reproduce sexually or asexually	 Alamy Stock Photo/WaterFrame **FIGURE 2.20**
Cnidaria (10 000) Jellyfish, sea anemones and corals **Cnidaria** Watch the movies found here to learn more about Cnidaria.	**1** **Radially symmetrical** (body plan is circular with structures that radiate out) **2** Gastrovascular cavity with single opening that serves as both mouth and anus **3** Reproduce sexually or asexually **4** Simple, net-like nervous system **5** Live in aquatic environments, mostly marine	 iStock.com/Bridgendboy **FIGURE 2.21**
Platyhelminthes (20 000) Flatworms **Platyhelminthes** Watch this video to reinforce your knowledge of Platyhelminthes.	**1** **Bilaterally symmetrical** (left and right halves of body are mirror images) **2** Gastrovascular cavity with single opening that serves as both mouth and anus **3** Body has three layers of tissues, with organs **4** Body without cavity **5** Body has blind gut (mouth but no anus) **6** Flattened body shape	 Shutterstock.com/Jesus Cobaleda **FIGURE 2.22**
Mollusca (100 000) Molluscs **Mollusca** Scroll through this webpage to find out more about Mollusca.	**1** Bilaterally symmetrical **2** Body without cavity **3** Body has through gut (with mouth and anus) **4** Uses muscular foot for locomotion **5** Open circulatory system with heart and aorta	 Shutterstock.com/Vladimir Wrangel **FIGURE 2.23**
Annelida (16 500) Segmented worms **Annelida** Reinforce your knowledge of Annelida classification by watching this video.	**1** Bilaterally symmetrical **2** Body has more than two cell layers, tissues and organs **3** Body cavity, nervous system and closed circulatory system **4** Body has through gut (with mouth and anus)	 Shutterstock.com/Bernatskaia Oksana **FIGURE 2.24**

PHYLA (NUMBER OF SPECIES)	DESCRIPTION OF ANIMAL PHYLUM	EXAMPLES
Nematoda (25 000) Roundworms **Nematoda** Watch this video to reinforce your knowledge of Nematoda.	**1** Bilaterally symmetrical **2** Cylindrical morphology **3** Body covered by tough cuticle (of collagen and chitin) **4** Alimentary canal (digestive system) with mouth and anus, but no circulatory system **5** Found in most aquatic habitats, soil, moist tissues of plants, and body fluids and tissues of animals	 Alamy Stock Photo/Science Photo Library **FIGURE 2.25**
Arthropoda (1 000 000) Arthropods	**1** Usually bilaterally symmetrical **2** Segmented **3** Hard exoskeleton (external skeleton) of protein and chitin **4** Most have through gut (with mouth and anus) **5** Jointed appendages (body parts attached to main trunk such as arms, legs, wings); have 3–400+ pairs of jointed legs	 Shutterstock.com/Audrey Snider-Bell **FIGURE 2.26**
Echinodermata (7000) Starfish **Echinodermata** Reinforce your knowledge of Echinodermata.	**1** Five-rayed symmetry, mostly radial, sometimes bilateral **2** Body has more than two cell layers, tissues and organs **3** Thin epidermis covering an endoskeleton; most species prickly due to skeletal bumps and spines **4** Most have short, through gut (with mouth and anus) **5** Body shape highly variable, but with no head	 Shutterstock.com/Adam Ke **FIGURE 2.27**
Chordata (57 000) Chordates	**1** Ninety per cent are **vertebrates** (have backbones), but Chordata does include two invertebrate groups **2** Have the following features during development (possibly as embryo): • **pharyngeal slits**: series of openings connecting inside of throat to outside of 'neck'; often, but not always, used as gills • dorsal nerve cord: bundle of nerve fibres running down the 'back'; connects brain with lateral muscles and other organs • notochord: cartilaginous rod running underneath nerve cord • post-anal tail **3** Closed circulatory system with blood transported in arteries, veins and capillaries **4** Bilaterally symmetrical	 Alamy Stock Photo/Auscape International Pty Ltd **FIGURE 2.28**

TABLE 2.4 The five main classes of Chordata and their distinguishing features

CLASS	BODY COVERING	GAS EXCHANGE SURFACES	REPRODUCTION	OTHER
Fish	Scales made of bony plates	Gills	External fertilisation of eggs by sperm that are released into the environment	**Ectothermic** (internal body temperature conforms to external environmental temperature) Fish can be grouped into jawless fish such as hagfish with no bones, Chondrichthyes such as sharks which have a skeleton composed of cartilage and Osteichthyes such as salmon which have a skeleton composed of bones.
Amphibia	Moist skin	Moist skin permeable to gases Gills during larval stage Lungs as adults	External fertilisation (usually spend larval stage in water, adult stage on land)	Ectothermic
Reptilia	Scales made of keratin	Lungs with extensive folding	Internal fertilisation; females lay eggs with soft shells	Ectothermic
Aves (birds)	Feathers made of keratin	Lungs with bronchial tubes	Internal fertilisation; females lay eggs with hard shells	**Endothermic** (able to regulate internal body temperature)
Mammals	Skin with follicles which produce hair or fur made of keratin	Lungs with alveoli	Internal fertilisation; females feed young with milk from mammary glands	Endothermic Mammals classified into three groups (subclasses): • monotremes lay eggs • marsupials carry their young in a pouch • placentals all bear live young, which are nourished (via the placenta) for a relatively long time in the mother's uterus before birth

FIGURE 2.29 Examples of the three subclasses of mammals: **a** short-beaked echidna (a monotreme); **b** red kangaroo (a marsupial); **c** dingo (a placental)

Question set 2.6

REMEMBERING

1 Copy and complete Table 2.5 by listing three distinguishing features of the nine most species-rich phyla of Kingdom Animalia. Use only morphological or reproductive features.

TABLE 2.5 Distinguishing features of invertebrate phyla

PHYLUM	THREE DISTINGUISHING FEATURES

UNDERSTANDING

2 After thinking about the classification of the echidna, conclude whether an echidna is an endotherm or ectotherm and provide the rationale for your conclusion.

APPLYING

3 At the zoo, a small child asked you if a bat was a bird. Using your knowledge of the features of vertebrate groups, prepare a logical answer to share with the child.

2.7 CLASSIFICATION IN KINGDOM PLANTAE

Plant classification
Plant classification is more fully described in this video.

All plants are eukaryotic. Most known members of Kingdom Plantae are terrestrial plants, although there are exceptions, such as water lilies and sea grasses. Plants are autotrophic; that is, they produce their own simple sugars through photosynthesis. Plant cells are surrounded by a plasma membrane, as animal cells are, but plant cells have the addition of a cellulose cell wall which surrounds the plasma membrane.

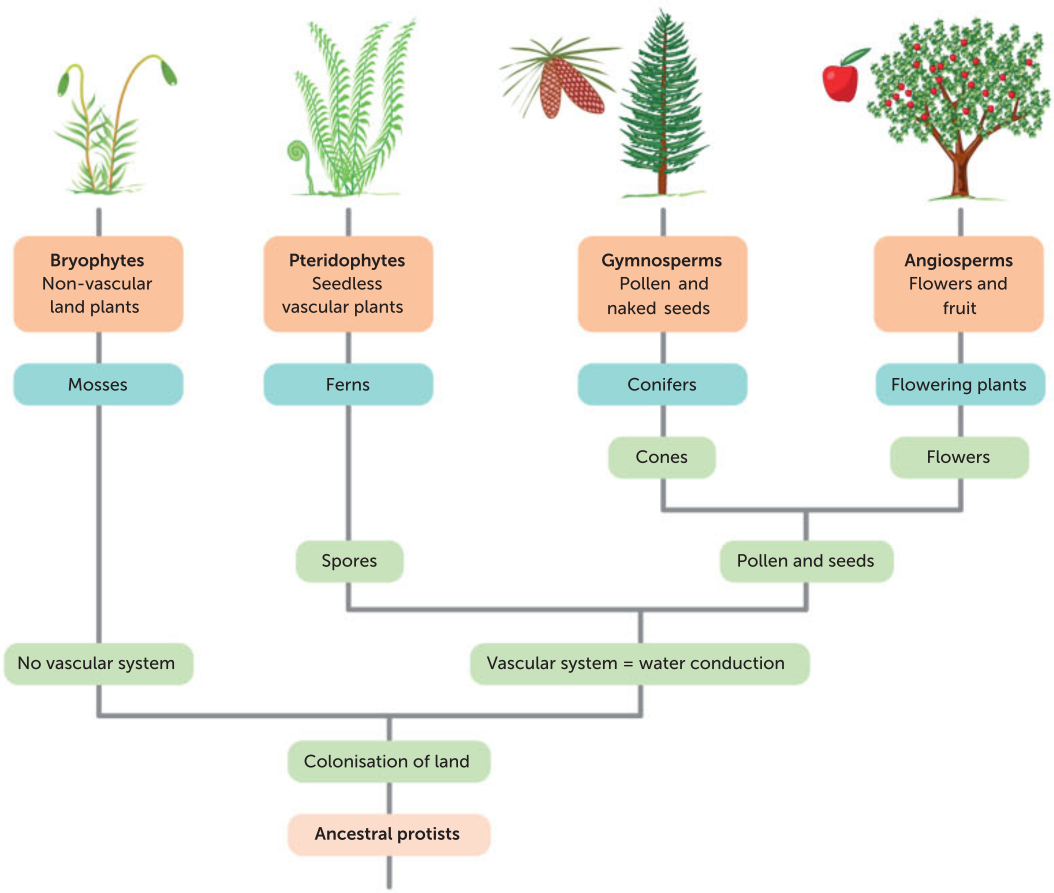


FIGURE 2.30 Plant taxonomy

Plants are first classified into two groups according to whether or not they have vascular tissue. **Vascular tissue** is comprised of phloem and xylem, which are tubes of connected cells that transport nutrients and water through the plant. Vascular plants include angiosperms, gymnosperms and ferns (also called pteridophytes). Non-vascular plants are called bryophytes, and include liverworts and mosses. Bryophytes are photosynthetic, but, since they lack vascular tissue, water moves through them by osmosis.

When plants evolved vascular tissue, they were able to transport more water at a faster rate and therefore became able to grow larger. Ferns were the first type of vascular plants to evolve. They are seedless and reproduce using spores. The two groups that reproduce using seeds are the gymnosperms and angiosperms.

A **seed** is an embryo with a stored food supply. Gymnosperms are non-flowering plants which have both male and female sex cells (gametophytes) in cones. In contrast, angiosperms (flowering plants) have male and female sex cells (gametes) in parts of the flower. When angiosperms first germinate they produce one of two types of cotyledon (embryonic leaf). This feature is used to further classify angiosperms into groups called monocotyledons and dicotyledons.

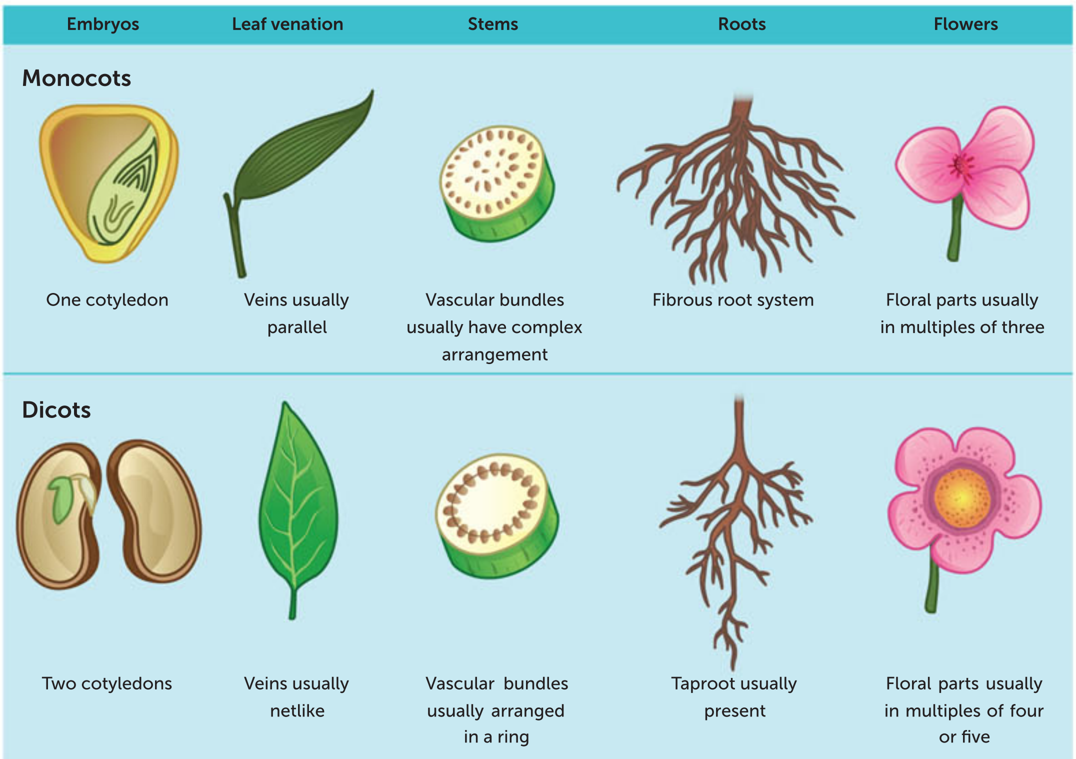


FIGURE 2.31 The features of monocotyledons and dicotyledons

Bozeman Science Plants
This is a survey of Kingdom Plantae, including discussion of its features, evolution and major groups.

Key concept

Members of the plant kingdom are eukaryotic, photosynthetic and often terrestrial. They are classified by whether or not they contain vascular tissue, and whether they reproduce by spores, cones or flowers.

Question set 2.7

REMEMBERING

1 Copy and complete Table 2.6 by listing three distinguishing features of the four main groups of plants. Use only morphological or reproductive features.

TABLE 2.6 Distinguishing features of the four main groups of plants

PHYLUM	THREE DISTINGUISHING FEATURES

UNDERSTANDING

2 Compare monocotyledons with dicotyledons.

2.8 CLASSIFICATION KEYS

Classification keys are tools used by scientists to identify organisms that belong to species that have already been discovered. Using information about the physical features and habitats of organisms, classification keys guide scientists through the identification process of, for example, an Australian sea snail (Figure 2.32).

At the start of a classification key the user is given a choice between several options, one of which describes the organism to be identified. Each choice leads to more options to choose between. The user continues to make choices until they reach an endpoint. Most classification keys are **dichotomous**, meaning that at each step the user has to choose between two options.

Tim Alexander

FIGURE 2.32 This species of sea snail is commonly found in Australian waters. How would you identify it?

Dichotomous keys are usually very long and it is not practical to present them here in full. Figure 2.33 and Table 2.7 are simplified examples of two types of dichotomous keys. Figure 2.33 is a flow chart, whereas Table 2.7 presents the choices as a list of numbered pairs.

We can use the key in Table 2.7 to identify the phylum of our sea snail from Figure 2.32. The body is symmetrical with a single plane of symmetry, so we choose option 1a and then 2b. The body is unsegmented, so we choose option 4b, which directs us to pair 6. The sea snail has a shell so we choose option 6a, which identifies our sea snail as belonging to Phylum Mollusca. A more detailed key is needed to identify any further taxa.

One of the difficulties with dichotomous keys is that if the user cannot distinguish between two options, they become 'stuck' and cannot keep going. To help overcome this problem, many keys are now available on the Internet or as computer software. These digital keys allow users to input information about the organism's features in any order. The program eliminates options until enough information has been entered to uniquely identify the organism.

The Pea Key
This digital key allows you to distinguish between 1500 species of Australian pea plants.

Key concept

Dichotomous keys are tools used to identify organisms. They involve choosing between a series of two options until an organism is identified.

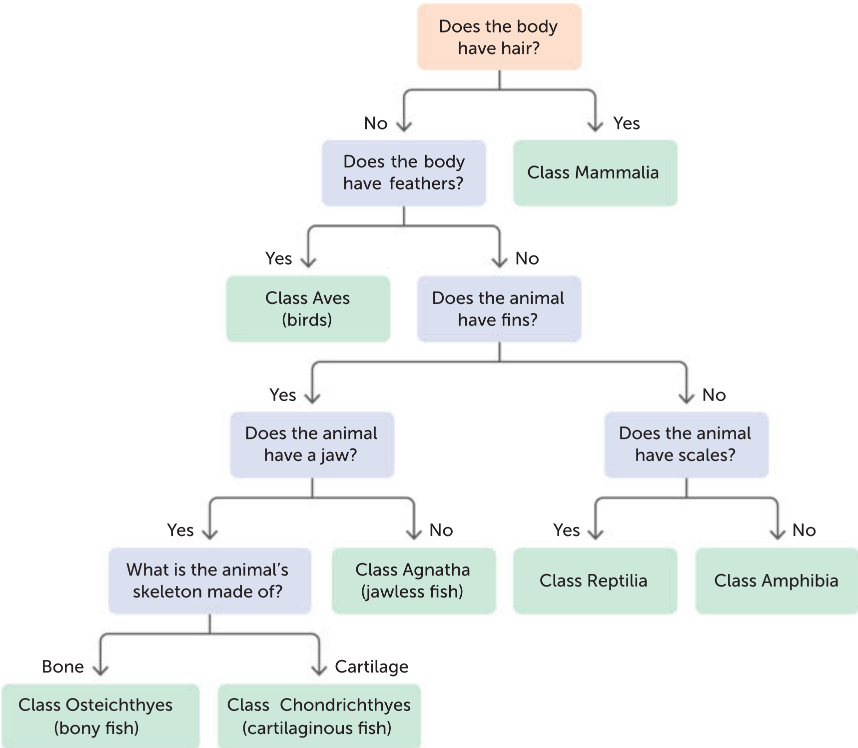


FIGURE 2.33 A dichotomous key for identifying the class of vertebrate animals

TABLE 2.7 A dichotomous key for classifying animals into phyla

1a	Body symmetrical	go to 2
1b	Body asymmetrical with no structure/organs	Phylum Porifera
2a	Body with multiple planes of symmetry (radial symmetry)	go to 3
2b	Body with a single plane of symmetry (bilateral symmetry)	go to 4
3a	Tentacles present, body soft	Phylum Cnidaria
3b	No tentacles, body hard and rough	Phylum Echinodermata
4a	Body divided up into segments (segmented)	go to 5
4b	Body unsegmented	go to 6
5a	Body divided into 2–3 segments; jointed legs present	Phylum Arthropoda
5b	Body divided into many segments; jointed legs absent	Phylum Annelida
6a	Body with internal or external shell	Phylum Mollusca
6b	Body without shell	go to 7
7a	Body flat and worm-like	Phylum Platyhelminthes
7b	Body not worm-like	Phylum Chordata

Key concept

There are two ways of displaying a dichotomous key: as a diagram (Figure 2.33) or using descriptive sentences (Table 2.7).

Question set 2.8

REMEMBERING

1 List three different types of characteristics that can be used to classify organisms.
2 Describe what a dichotomous key is.

UNDERSTANDING

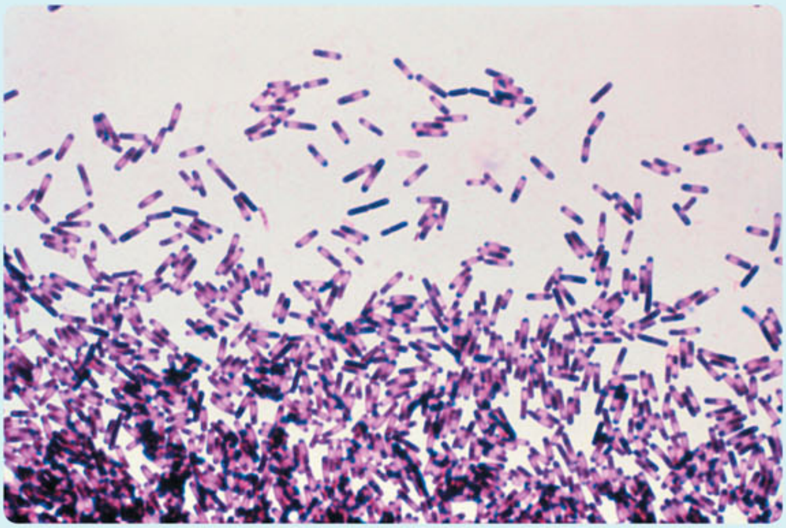
3 Explain how protein structure can be used to classify organisms.

APPLYING

4 Shown below is a simplified dichotomous key for identifying several species of bacteria that can cause disease in humans. Using this key involves performing a Gram stain, which places bacteria into either of two groups based on characteristics of their cell wall.

1a	Gram positive (stains purple with a Gram stain)	go to 2
1b	Gram negative (stains pink with a Gram stain)	go to 4
2a	Bacteria are cocci (sphere-shaped)	go to 3
2b	Bacteria are bacilli (shaped like rods)	*Clostridium difficile*
3a	Cocci are arranged in chains	*Streptococcus pneumonia*
3b	Cocci are arranged in bunches	*Staphylococcus aureus*
4a	Bacteria are cocci (sphere-shaped)	*Neisseria* spp.
4b	Bacteria are bacilli (shaped like rods)	*Escherichia coli*

a State which of the listed species are sphere-shaped.
b Using the dichotomous key, determine what species of bacterium is shown in Figure 2.34.



Alamy Stock Photo/Science Photo Library

FIGURE 2.34 A light micrograph of a species of bacterium stained with a Gram stain

c Using this key, not all bacteria can be identified to the species level. Which group are you unable to identify? Provide a reason for your answer.

TABLE 2.8 A character matrix of the major plant groups

	BRYOPHYTES (E.G. MOSSES)	PTERIDOPHYTES (E.G. FERNS)	GYMNOSPERMS (E.G. CONIFERS AND CYCADS)	ANGIOSPERMS (FLOWERING PLANTS)
Performs photosynthesis	+	+	+	+
Has vascular tissue (xylem and phloem)	–	+	+	+
Produces seeds	–	–	+	+
Has seeds enclosed in an ovary	–	–	–	+

The groups can then be arranged in different ways until the simplest cladogram is found. An alternative way of arranging the major plant groups based on the same character matrix (Table 2.8) is shown in Figure 2.37. For this cladogram to be correct, the presence of seeds would have had to evolve twice, once for gymnosperms and separately for angiosperms. This is unlikely and consequently, Figure 2.36 is considered to be the most likely arrangement.

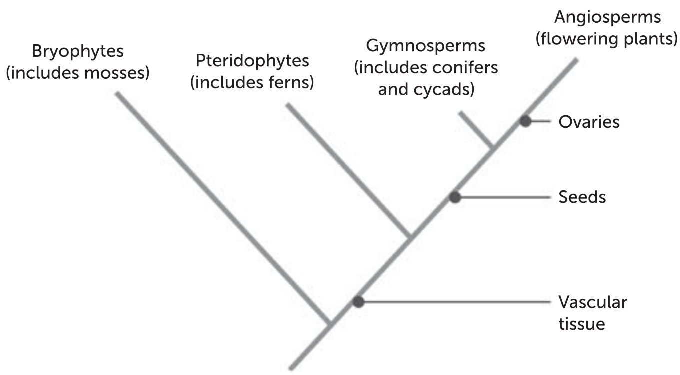


FIGURE 2.36 A cladogram showing the evolutionary relationships between major plant groups. The pointers indicate when each characteristic evolved.

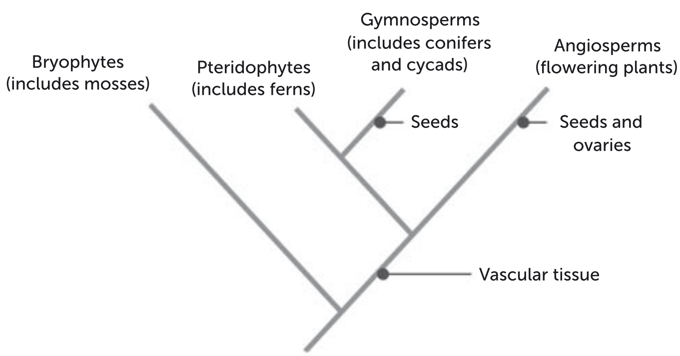


FIGURE 2.37 An alternative cladogram showing the relationship between major plant groups. This option is far less likely to have occurred.

Taxonomists try to ensure that classification reflects the evolutionary relationships between organisms. Ideally, each taxonomic group contains all of the organisms descended from the same common ancestor. This means that a group on a cladogram contains all of the organisms on a branch. When this occurs, that group is called a **clade** (or its members can be referred to as **monophyletic**).

Three classes of animals are shown in the cladogram in Figure 2.38. You can see that both Class Aves and Class Mammalia are clades because they contain all of the animals on that branch. Class Reptilia, however, is not a clade. This is because it does not contain birds, which also descended from a reptilian ancestor. Class Reptilia can be called a **paraphyletic** group. This arrangement has occurred because birds and reptiles were classified into separate classes before their evolutionary relationships were known. More recently, it has been determined that birds evolved from dinosaurs and as such, share a recent common ancestor with crocodiles and alligators. Some scientists have suggested that these taxonomic groups need to be reclassified to ensure that all are clades.

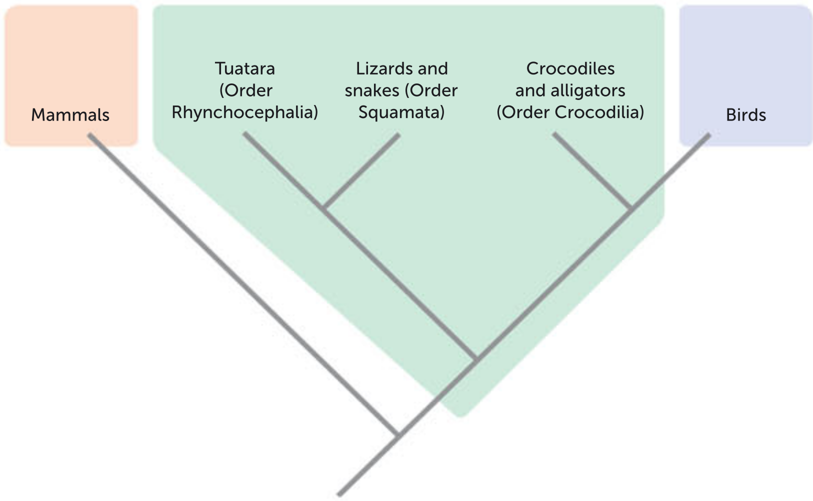
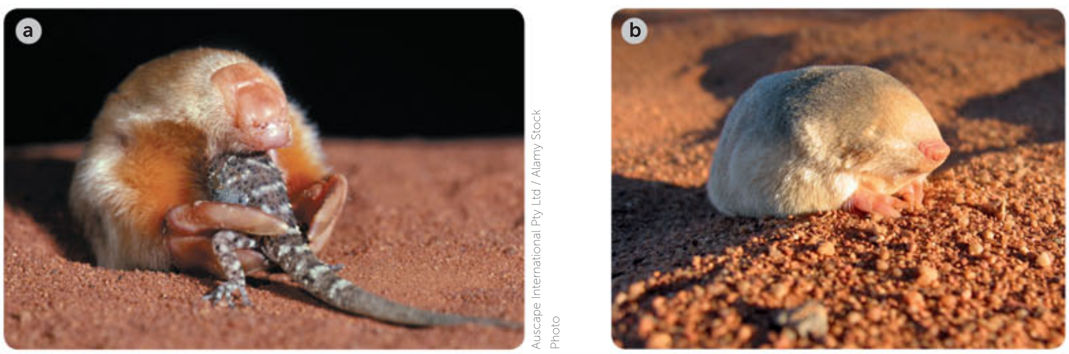


FIGURE 2.38 A cladogram showing the major classes of amniotes (animals whose embryos develop inside a membrane called an amnion). Classes Aves and Mammalia are monophyletic/clades; Class Reptilia is paraphyletic.

One of the limitations of cladistics occurs when unrelated organisms have evolved similar characteristics independently. This can occur with organisms that inhabit similar niches in different parts of the world, as in the case of marsupial moles and African golden moles. The marsupial moles (*Notoryctes typhlops*) that live in central Australian sandy deserts look remarkably like African golden moles (*Chlorotalpa* spp.). They have almost identical size and body shape. Both are blind and lack external ears, have several spade-like claws on their front feet, a horny shield protecting the snout, a stubby tail and silky fur (Figure 2.39). Should marsupial moles and golden moles be grouped together? Not if we think about their method of reproduction. Like other marsupials, marsupial moles give birth to live offspring that are extremely young. These young then develop in a specialised pouch until they are mature enough to survive outside. Golden moles are placental mammals, so their young develop inside the mother until the time of birth. Golden moles cannot be grouped with marsupials even though, externally, marsupial moles and golden moles appear almost identical.



Auscape International Pty Ltd / Alamy Stock Photo

Galen Rathbun © California Academy of Sciences

FIGURE 2.39 a Marsupial moles and **b** golden moles are superficially similar, but have evolved their characteristics independently.

It is important to understand that cladograms represent theories about the way that organisms are related. Like all scientific theories, they can be supported or challenged when more evidence becomes available. Cladograms can, and do, change as our understanding of these relationships improves. Figure 2.40 shows two possible cladograms for the evolution of the three groups of mammals: placental mammals, marsupials and monotremes. Most evidence based on physical characteristics supports cladogram A. However, there is some evidence based on teeth and molecular data that suggests that monotremes and marsupials are more similar to one another than either is to placental mammals. This would support cladogram B. Has there been a verdict? Yes – molecular sequencing of DNA supports cladogram A.

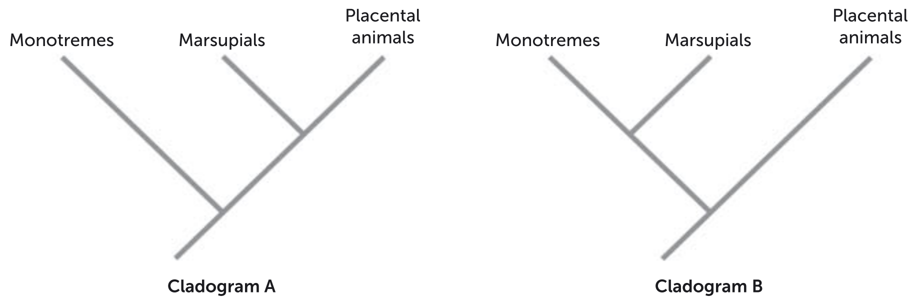


FIGURE 2.40 Two cladograms showing the possible evolution of monotremes, marsupials and placental mammals. Cladogram A is currently regarded as correct.

SCIENTIFIC LITERACY

Wattle lot of fuss over a name

In 2011, the name of the genus of African plants previously known as *Acacia* was changed to *Vachellia*. Below is an extract from *The Age* just before this historic decision was finalised.

It is rare that controversy strikes the botanical world. However, six years ago, when the International Botanical Congress met in Vienna to vote on what plants could carry the name *Acacia*, the simple question of what's in a name divided the usually unified global group.

Essentially the world's botanists were at odds over changing the rules so that the name *Acacia* would apply only to Australia's 1000-plus species, meaning a smaller number of species, mainly from Africa, would have to change their name to *Vachellia*.

The alternative – which for some was too problematic to even contemplate – was to rename Australia's acacias, including the wattle, *Racosperma*.

Shutterstock.com/Lev Kropotov

FIGURE 2.41 The floral emblem of Australia, golden wattle (*Acacia pycnantha*). The name 'acacia' has symbolic value in both Africa and Australia.

'Given the iconic status of acacias both in Australia and in Africa it was probably inevitable that there was going to be this controversy,' said Bill Aitchison, leader of the acacia study group section of the Australian Plants Society.

While the wattle is Australia's botanical emblem and informs our national colours, the silhouette of the flat-topped thorn tree against a rust-red sunset is symbolic of Africa. Both, botanically speaking, are acacias. Until now.

The International Botanical Congress meets in Melbourne from today and it is anticipated that 'the acacia issue' – one of the most contested botanical cases debated to date – will finally be resolved … come this Friday, a final vote in favour of Australia using the name *Acacia* is expected to be little more than a formality. Meanwhile, 163 species formerly classed as *Acacia* will now be known as *Vachellia*.

A proposal to compromise by adding a prefix to the name *Acacia* – so *Austroacacia* would refer to Australian acacias and *Acanthacacia* to species in Africa, India, the Middle East, South and Central America – was rejected by 70% of voters.

'Africa is the home of the acacia, in that it is where the first *Acacia* species was described. But Australia is the hot spot for acacia because there are more than 1000 species here – none of which were known at the time the acacia was first described. So you can see why it's been so controversial.'

Adapted from Smith, B. (2011) 'Wattle it be? Name claim for Africa or Australia', *The Age*, 25 July 2011

Questions

1 List the three potential solutions to 'the acacia issue' that the article discusses.
2 Explain why the Australian and African groups cannot both have the name *Acacia*.
3 Which group of plants (Australian or African) do you think should keep the name *Acacia*? Justify your answer.

New technologies and taxonomy

New technologies have transformed cladistics and taxonomy. One of the most important developments has been the use of DNA technology to provide new and highly detailed information about evolutionary relationships. In some cases, DNA evidence has supported previous hypotheses about these relationships, but in other cases it has led to reclassification of organisms. Additionally, because some changes in DNA occur at a predictable rate, DNA technology has allowed scientists to understand when certain groups evolved.

The information provided from DNA evidence is so detailed that classification systems have changed to reflect this. It is now possible to classify organisms down to many more levels than the traditionally recognised taxa. The prefixes super- (above) and sub- (below) can be added to existing taxa to create additional ranks (e.g. subphylum) and some newer taxa (e.g. tribe) are also recognised.

Explore the Tree of Life
You can browse the branching phylogenetic tree and find information about the organisms it contains.

Question set 2.9

REMEMBERING

1 How do phylogenetic trees reflect how organisms are related?
2 List the three assumptions that are used in the construction of cladograms.
3 Define 'clade', using the term 'monophyletic'.

UNDERSTANDING

4 Explain why some taxonomists have suggested that the taxa containing birds and reptiles should be reorganised.

9780170452847

CHAPTER 2 INVESTIGATION

INVESTIGATION 2.1

Identifying insects

In this experiment you will use two types of keys to aid in the identification of some Australian insects: a dichotomous key and a digital key. These keys will allow you to identify the insects down to the level of order. Further keys would be needed to identify to the levels of family, genus and species.

Aim

To practice using classification keys

Materials

- preserved insect specimens and/or appropriate photos and diagrams of insects
- stereo (dissecting) microscope
- computer with access to the weblink
- forceps
- dissecting needle
- hand lens

What group do I have? Insect orders of Australia
This matrix key can be used to identify Australian insects down to their order.

Procedure

1 Familiarise yourself with some of the terms used to describe insect parts (shown in Figures 2.42, 2.43 and 2.44). The digital key contains further images that help explain the terms used.
2 Using the key shown on pages 67–9, 'key out' each specimen to identify the order to which they belong. You can use the stereo microscope, forceps and dissecting needle to help you look more closely at the insects.
3 Repeat the process using the digital key. To use the digital key, you should select any features you can identify. Orders that the insect could belong are shown in 'entities remaining'. Continue to select features until only a single order remains.
4 Record your results in a table like Table 2.9.

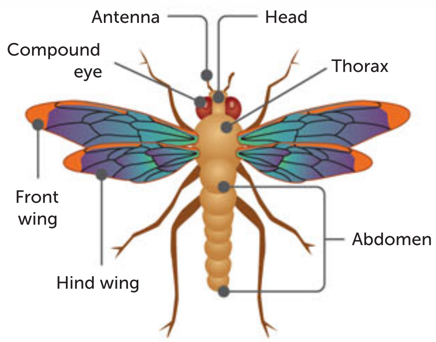


FIGURE 2.42 The main parts of a typical insect

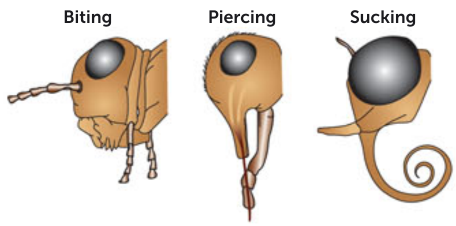


FIGURE 2.43 Insect mouthparts

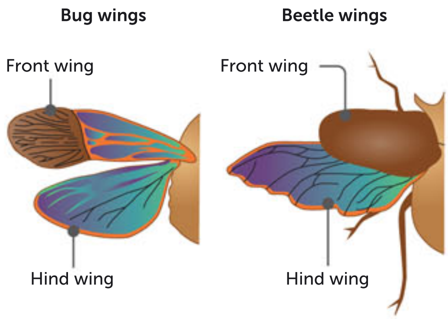


FIGURE 2.44 A comparison of beetle wings and bug wings

Results

TABLE 2.9 Insects identified using the keys

SPECIMEN NUMBER	ORDER IDENTIFIED (PRINTED KEY)	ORDER IDENTIFIED (DIGITAL KEY)

TABLE 2.10 Insect descriptive dichotomous key

1a	Winged insect	go to 2
1b	Wingless adult insect	go to 25
2a	Two pairs of wings, one of the pairs being either partly or wholly hardened, or parchment-like (papery) and opaque (non-transparent)	go to 3
2b	One pair of wings or two pairs resembling one another in appearance and texture	go to 12
3a	Front wings forming a pair of hard covers meeting in a straight line down the centre of the back. Mouthparts of biting type (unsuitable for sucking)	go to 4
3b	Front wings overlapping (not meeting in a straight line down the back). Hind wings membranous and often fan-like	go to 6
4a	Front wings very short, covering less than half the abdomen	go to 5
4b	Front wings covering all or most of the abdomen. Beetles	Order Coleoptera
5a	Abdomen with two hardened pincer-like (or forceps-like) extensions behind. Earwigs	Order Dermaptera
5b	Abdomen without a pair of pincer-like (or forceps-like) extensions behind, though often with a pair of short segmented processes. Some beetles	Order Coleoptera
6a	Each front wing divided into two sections sharply marked off from each other, the fore-section being leathery and opaque, the hind-section membranous. Mouthparts in the form of a jointed piercing tube (suitable for sucking). Bugs	Order Hemiptera
6b	Front wings parchment-like, more or less uniform in texture	go to 7
7a	Mouthparts of piercing type. Hind wings not fan-like. Most planthoppers and froghoppers	Order Hemiptera
7b	Mouthparts of biting type. Hind wings fan-like	go to 8
8a	Hind legs much longer than other legs, suited to leaping. Grasshoppers and crickets	Order Orthoptera
8b	All legs more or less equal in length	go to 9
9a	Broad, flattened insects with legs pressed close to the body. Usually rapid runners. Head partly or completely hidden when viewed from above. Cockroaches	Order Blattodea
9b	Elongated, slow-moving insects with extended legs and clearly visible head	go to 10
10a	Front legs markedly different in shape from other legs	go to 11
10b	Front legs similar to other legs; first segment of thorax (segment bearing front legs) very short; second segment of thorax very long. Stick insects, phasmatids	Order Phasmatodea
11a	Front legs greatly broadened and adapted for digging. Front wings very short and round. Mole-crickets	Order Orthoptera
11b	Front legs adapted for securing prey. First segment of thorax (segment bearing front legs) very long. Mantids	Order Mantodea

12a	One pair of wings. (Hind wings reduced to pair of balancers, often obscured by pair of scale-like processes arising from side of thorax.) True flies	Order Diptera
12b	Two pairs of wings	go to 13
13a	Wings and body completely covered with fine scales or hairs visible at low magnification (though occasionally part or whole of wing may lack scales)	go to 14
13b	No scales or hairs visible at low magnification	go to 16
14a	Insects resembling moths, but with hairy wings (scales rub off). Mouthparts never in form of sucking tube	go to 15
14b	Insects with fine scales covering wings and body. (Wings of a few species partly or wholly transparent.) Mouthparts often in form of long, coiled sucking tube. Butterflies and moths	Order Lepidoptera
15a	Distinct biting mouthparts. Wings with numerous short cross-veins leading from one of the main wing veins to front margin of wings. Pattern of wing veins very complex with much branching and numerous cross-veins. Some lacewings	Order Neuroptera
15b	Mouthparts non-functional. Wing veins much simpler, without the series of cross-veins between long wing vein and front margin of wings. Caddisflies	Order Trichoptera
16a	Mouthparts in form of piercing tube only (often folded underneath)	go to 17
16b	Distinct, separate mouthparts, suited for biting, or some forming a sucking tube and some used for manipulation	go to 18
17a	Very small, elongated insects, with short, piercing beak and very narrow wings with long fringes of hairs. Nearly always found on buds and flowers of plants. Thrips	Order Thysanoptera
17b	Small, medium or large insects with mouthparts in the form of a long, piercing beak; wings of normal width, without long fringes of hairs. Aphids, psyllids (lerps), cicadas etc.	Order Hemiptera
18a	Stiff wings, with thick wing veins. Hind wings linked to front wings by row of hooks (visible with hand lens). Abdomen connected to thorax by a 'waist', often very narrow. Sawflies, wasps, ants, bees	Order Hymenoptera
18b	Wings not linked by row of hooks	go to 19
19a	Insects with long, segmented filaments extending from end of body	go to 20
19b	Insects without long, segmented filaments extending from end of body	go to 21
20a	Front wings distinctly narrower than hind wings, which are partly or mostly fan-like; antennae long. Stoneflies	Order Plecoptera
20b	Front wings much broader than hind wings; antennae extremely short and bristle-like. Mayflies	Order Ephemeroptera
21a	Wing veins very simple with few cross-veins. Pale, soft-bodied insects with very weak flight. Termites	Order Isoptera
21b	Wing veins more complex with numerous cross-veins and much branching	go to 22
22a	Antennae extremely short and bristle-like; eyes very large, taking up most of head. Wing venation extremely complex. Wings held stiffly to sides (dragonflies), or over abdomen (damselflies) when at rest. Dragonflies and damselflies	Order Odonata
22b	Antennae of more normal length, often very long (if short, never bristle-like). Eyes of more normal size	go to 23
23a	Wings without series of cross-veins linking long wing veins to front margin of the wings. Wings long and thin; legs usually very long; head elongated into a snout. Scorpionflies	Order Mecoptera
23b	Wings with numerous short veins linking one of the main long wing veins to front margin of wings. Wing venation usually very complex	go to 24
24a	Main veins in wings branch near ends. Wings held tent-like over abdomen when at rest. Lacewings and ant lions	Order Neuroptera
24b	Main veins in wings unbranched near ends. Wings folded flat over abdomen when at rest. Alderflies or dobsonflies	Order Megaloptera

25a	Minute insects with a 'spring' present at tip of abdomen, enabling insect to spring strongly. Springtails	Order Collembola
25b	Insects lack this spring	go to 26
26a	Insects with pincer-like or forceps-like processes extending from tip of abdomen	go to 27
26b	Abdomen without processes, or with processes coming from tips of abdomen and divided into segments	go to 28
27a	Segments of abdomen clearly separated from each other by membranous sections. Body very soft. Mouthparts internal, not visible externally. Japygids	Order Diplura
27b	Abdominal segments telescoped to some extent so that membranous parts between segments not visible dorsally. Mouthparts for biting and clearly visible. Earwigs	Order Dermaptera
28a	Abdomen with long, segmented, thread-like processes (filaments) extending from tip	go to 29
28b	Tip of abdomen without processes, or with short ones	go to 30
29a	Three filaments; body often covered with silvery scales (which rub off). Silverfish	Order Thysanura
29b	Two filaments; body bare (without scales)	Order Diplura
30a	Soft-bodied, pale insects parasitic on feathers of birds or hair of mammals. Lice	Order Phthiraptera
30b	Other insects. If parasitic on birds or mammals then not particularly soft-bodied or pale	go to 31
31a	Body strongly compressed from side to side; hind legs long and suited to leaping. Parasitic on birds or mammals. Fleas	Order Siphonaptera
31b	Body not strongly compressed from side to side; not parasitic on birds or mammals	go to 32
32a	Minute insects, with pale, soft bodies, found among old books and papers; rapid runners. Booklice	Order Psocoptera
32b	Larger insects of different appearance and habits	go to 33
33a	Abdomen constricted to form a 'wasp waist'. Ants and wingless wasps	Order Hymenoptera
33b	Abdomen broadly joined to thorax (no 'wasp waist')	go to 34
34a	Mouthparts of biting type	go to 35
34b	Mouthparts not of biting type	go to 38
35a	Hind legs much longer than other legs and suited to leaping. Wingless grasshoppers	Order Orthoptera
35b	All legs more or less equal in length	go to 36
36a	Pale, soft-bodied, slow-moving insects tunnelling in soil or timber, often living in colonies made up of several distinct castes. Termites	Order Isoptera
36b	Insects differing in appearance and habits from 36a	go to 37
37a	Large, broadly flattened insects with legs pressed close to the body; usually rapid runners. Head partly or completely hidden when viewed from above. Wingless cockroaches	Order Blattodea
37b	Elongated stick-like insects with first segment of thorax (segment bearing front legs) short and second segment of thorax very long. Phasmatids	Order Phasmatodea
38a	Very furry, slow-moving insects with abdomen much larger than head and thorax. Some female moths	Order Lepidoptera
38b	Insects without hairy covering	go to 39
39a	Very small, slow-moving insects with long, thin legs. Abdomen with pair of short tubes on back through which wax is secreted. Aphids	Order Hemiptera
39b	Insects of different form, without tubes on back	go to 40
40a	Head with distinct neck. Wingless flies	Order Diptera
40b	Head usually set into thorax. Many bugs	Order Hemiptera

Analysis of results

1. Were you able to identify all specimens using both keys? If not, identify where you became 'stuck'.
2. Did both keys identify the insects as belonging to the same order? If not, suggest some reasons why this occurred.

Discussion

1. List three of the features that were used to identify the insects.
2. Suggest some other resources you could use to confirm your identification.
3. Compare and contrast the features of the printed key and digital key you used. Do you prefer one over the other?

Taking it further

1. The weblink on page 66 also contains keys that allow you to identify the family of insects within a particular order. Identify what family your insects belong to.

Chapter 2 Activity sheet

CHAPTER 2 SUMMARY

- Life on Earth is characterised by its great diversity, at levels ranging from genes to ecosystems.
- Biodiversity can be considered at a range of different levels: genetic, species and whole ecosystems.
- The concept of a species is fundamental to how we classify organisms and understand evolution. A species can be defined in different ways, but an essential characteristic is that it shares a gene pool.
- Definitions of a species include the biological species concept, the morphological species concept and the phylogenetic species concept.
- Measures of biodiversity rely on classification and are used to make comparisons across spatial and temporal scales.
- Organisms live in interacting populations within specific physical environments, which vary in different locations.
- An ecosystem is an interacting community of populations of organisms and the physical environment in which they live.
- Ecosystems vary widely in response to different physical conditions and have also varied greatly over time.
- Australian ecosystems exhibit great diversity. The south-west coast of WA is classified as one of the world's biodiversity hotspots.
- Scientists classify organisms into groups to help organise, analyse and communicate information about species.
- Organisms are classified into a hierarchy of groups called taxa. From order of the largest to smallest groups, the taxa are known as domains, kingdoms, phyla, classes, orders, families, genera and species.
- Organisms are given scientific names using the binomial system. This means that names have two parts; the first part is the genus name and the second part identifies the species.
- The species definition is based on morphological or genetic similarity or the ability to interbreed to produce viable offspring.
- Classification is based on the characteristics of organisms that include morphological (physical) features, reproductive methods and molecular sequences.
- Tools known as classification keys are used to identify organisms. The most common one used in biology is the dichotomous key.
- The classification of organisms into groups reflects their evolutionary relationships. These relationships can be shown using phylogenetic trees.
- Classification and phylogenetic trees can change as new evidence becomes available. In particular, technological advancements such as DNA amplification, sequencing and analysis have made new evidence available that has sometimes changed the way these trees are constructed.
- DNA barcoding uses modern techniques to help manage living organisms, especially in conservation of endangered species, while also helping identify and control pest species such as agricultural weeds.

CHAPTER 2 GLOSSARY

Abiotic factor a non-living factor within an ecosystem, such as the physical landscape or weather

Amino acid a nitrogen-containing compound that is the building block of proteins

Asymmetrical having no definite symmetry

Aquatic relating to water, fresh or salt

Bacteria microscopic unicellular organisms that are prokaryotic; that is, they do not have nuclear membranes or membrane-bound organelles

Bilaterally symmetrical having left and right halves of the body that are mirror images

Binomial name a scientific two-part name consisting of a genus name (a capital first letter) and a species name (all lower case)

Binomial system a system of naming organisms using two parts: a generic name and a specific name

Biodiversity the full range of different living things in a region; can be described at various levels, including the range of species, the genetic diversity in species, and the diversity of ecosystems present in a larger area

Biodiversity hotspot an area with numerous endemic species and a large number of endangered and threatened species; must contain at least 1500 species of endemic vascular plants and have lost at least 70% of its primary native vegetation.

Biological species concept a definition of species based on whether members can interbreed to produce fertile offspring

Biology the study of living things

Biosphere any area on Earth that living things inhabit; includes most regions of land, most bodies of water such as oceans, and the atmosphere to an altitude of several kilometres

Biotic factor a living factor within an ecosystem, such as an animal or a plant

Character matrix a table that lists the characteristics of organisms and that is used to construct cladograms

Characteristic a feature or quality of an organisms that can be used to classify and identify it

Clade a taxonomic group that contains all of the descendants of a common ancestor

Cladistics a method of classifying organisms based on the characteristics they share

Cladogram a diagram constructed using cladistics that shows the evolutionary relationships between organisms

Classification key a tool used to identify organisms based on their characteristics

Common ancestor a species from which two different species both evolved

Dichotomous describes a classification system where each branch has two options

DNA (deoxyribonucleic acid) an information molecule that is the universal basis of an organism's genetic material; it contains instructions, written in a chemical code, for the production of proteins by the cell

Dorsal nerve cord a bundle of nerve fibres which runs down the 'back', connecting the brain with the lateral muscles and other organs

Ecosystem a self-sustaining unit made up of a community of organisms in an area, the physical environment in which they live, and the interactions between them

Ectothermic unable to control metabolic rate and therefore unable to regulate body temperature using internal metabolic processes

Embryo an early stage of development; in humans, refers to the first three months of growth after fertilisation

Endemic describes a species that is native to a particular geographic region

Endothermic able to generate heat via metabolic activity and therefore able to regulate internal body temperature using internal metabolic processes

Eukaryote a complex type of cell with a nucleus and membrane-bound organelles; a member of Domain Eukarya

Extant living (of a species), as opposed to extinct

Food web a diagram that shows how different organisms feed on each other, thereby transferring energy through an ecosystem; comprises interconnecting food chains in an ecosystem

Gene a section of DNA in a chromosome that encodes an instruction for a specific protein which, when expressed, can affect a certain characteristic; can be inherited by offspring; every gene can come in different forms

Gene pool the sum of all the genes, including all of their different forms, in a given population of one species

Genus the classification level immediately above species; the genus name is included in the binomial naming system (e.g. modern humans are *Homo sapiens,* where *Homo* is the genus)

Hybrid the non-viable, infertile offspring that can result from the mating of two individuals from different species

Monophyletic describes organisms that are grouped together as a clade

Morphological species concept a definition of a species based on physical characteristics

Organelle a specialised structure or compartment within a cell that has a specific function

Organisms living things that can respire to produce energy, grow, respond to stimuli, consume nutrients, reproduce and regulate their internal environment

Paraphyletic describes a group that does not contain all of the organisms descended from the most recent common ancestor

Pharyngeal slits a series of openings that connect the inside of the throat to the outside of the 'neck'; often, but not always, used as gills

Photosynthesis a chemical reaction using energy from the Sun to convert carbon dioxide and water into glucose and oxygen

Phylogenetic species concept a definition of species that states a species comprises the smallest group of individuals sharing a common ancestor, often determined through genetic analysis

Phylogenetic tree a system of classification based on common ancestry, often determined through genetic analysis; a diagram that shows the evolutionary relationship between organisms

Phylogeny the evolutionary ancestry of a species

Population a group of individuals belonging to the same species living in a particular area at the same time

Prokaryote a simple type of cell that lacks a nucleus and membrane-bound organelles; a member of domains Archaea or Bacteria

Radially symmetrical having a circular body plan with structures that radiate out

Seed a plant embryo with a stored food supply

Species a group of morphologically similar organisms that share a gene pool; members of a species can interbreed in natural conditions to produce fertile and viable offspring

Taxa/taxonomic level a group of organisms; the major taxa are domains, kingdoms, phyla, classes, orders, families, genera and species

Taxonomist a scientist who studies organisms and places them into taxa

Terrestrial living or growing on land

Vascular tissue (in plants) the tissue devoted to the bulk transport of water, nutrients, sugars and other substances; comprises the xylem and the phloem

Vertebrates animals that have a backbone

CHAPTER 2 REVIEW QUESTIONS

Remembering

1 Explain what a hybrid is.

2 Name the eight major taxonomic levels.

3 Describe what a common ancestor is.

Understanding

4 Define 'binomial system'.

5 Summarise the reasons why biologists classify organisms into groups.

6 Explain why the biological classification system is described as hierarchical.

7 The following questions relate to Figure 2.45 (page 74). Copy the diagram and answer the questions.

- a State whether the circled group (known as strepsirrhines) is monophyletic or paraphyletic.
- b On your diagram, circle the clade that contains macaques and gibbons but not marmosets.
- c State which other primate in the figure is also descended from the most recent common ancestor of humans and gibbons.

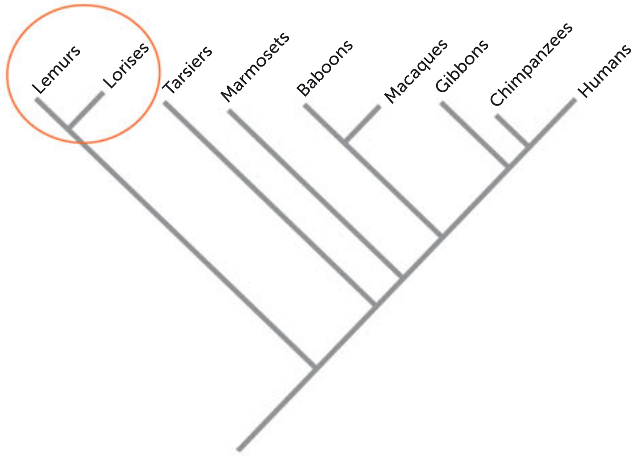


FIGURE 2.45 A cladogram showing the relationship between several groups of primates

8 Determine whether individuals in the same phyla will contain more or less diversity than individuals classified in the same class.

9 Explain why some organisms that share physical similarities (e.g. the marsupial mole and the African golden mole) are classified separately.

Applying

10 Describe how you would explain biodiversity to one of your friends studying Year 11 science, but not biology. How would you explain why biodiversity is important to species survival?

11 Irukandji jellyfish (*Carukiabarnesi*) live in the waters around the north of Australia. Even though they are only a couple of centimetres long, the highly venomous sting of this jellyfish can cause symptoms of severe pain, vomiting and blood pressure changes. Rarely, the sting can be fatal.

- a List three characteristics of the Irukandji jellyfish that could be used to help classify it.
- b Identify what domain, kingdom and genus the Irukandji jellyfish belongs to.

Analysing

12 The southern corroboree frog (*Pseudophrynecorroboree*) is a critically endangered species that is found in a small region in NSW. Individuals are small (2.5–3 cm long), poisonous and are marked with a bright yellow and black pattern.

- a List five characteristics of the southern corroboree frog that could be used to classify it.
- b Use the dichotomous key in Figure 2.33 (page 59) to determine the class to which the southern corroboree frog belongs.
- c There is a large conservation program, including captive breeding, trying to save the southern corroboree frog from extinction. Explain why accurate identification is important for this program.

Evaluating

13 Distinguish between members of Domain Eukarya and members of domains Bacteria and Archaea by referring to the specific characteristics of each domain.

14 Do you think that the binomial name, common name or both should be used to describe an organism? Justify your response.

Creating

15 Use the information in the character matrix shown in Table 2.11 to create a cladogram, marking in which characteristics evolved at each branch.

TABLE 2.11 A character matrix showing several groups of aquatic vertebrates

	LAMPREY (ORDER PETROMYZONTIFORMES)	SHARK (CLASS CHONDRICHTHYES)	LOBE-FINNED FISH (CLASS SARCOPTERYGII)	RAY-FINNED FISH (CLASS ACTINOPTERYGII)
Jaw	–	+	+	+
Fins attached to body on a fleshy stalk	–	–	+	–
Skeleton made of bone	–	–	+	+

PRACTICE EXAM QUESTIONS

1 A biologist discovered a new prehistoric species and classified it into the same class as the dog.
This means that the new species:
- A is more closely related to dogs than other mammals.
- B belongs in the same order as the dog.
- C shares phylum features with the dog.
- D could interbreed with modern breeds of dog.

2 A community of interacting organisms and their physical environment is best termed:
- A an ecosystem.
- B a biosphere.
- C a habitat.
- D a biome.

3 Use this dichotomous key to classify the insect in Figure 2.46 (page 76) into its taxonomic order. State three features of this order. (4 marks)

1a	Wings present	2
1b	Wings absent	Order Apterygota
2a	One pair of wings	Order Diptera
2b	Two pairs of wings	3
3a	Front wings of coarser texture than hind wings	4
3b	All wings membranous. May be hair- or scale-covered	8
4a	Basal two-thirds of front wing thickened, remainder membranous	Order Hemiptera
4b	Whole of front wing of same texture	5
5a	Front wings hard and horny	Order Coleoptera
5b	Front wings slightly thickened with distinct veins	6
6a	Mouthparts of piercing type	Order Hemiptera
6b	Mouthparts of biting type	7
7a	Hind legs much longer than other legs	Order Orthoptera
7b	All legs more or less equal in length	Order Blattodea
8a	Wings and body completely covered by fine scales or hairs	9
8b	Wings only covered by fine scales or hairs	Order Plecoptera
9a	Hind and front wings linked by row of hooks; front of abdomen narrowed to form a 'waist'	Order Hymenoptera
9b	Wings not joined. No 'waist'	Order Lepidoptera

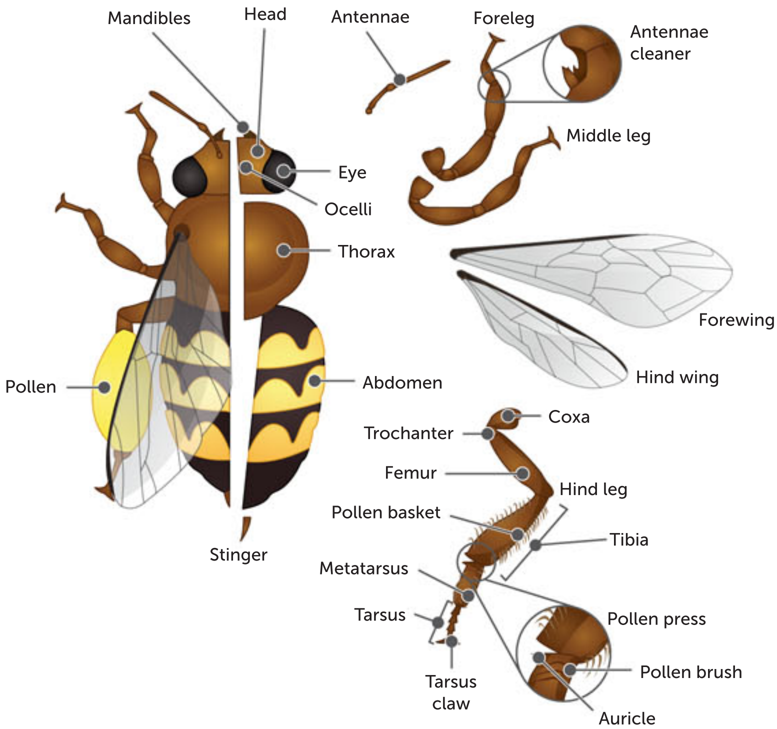
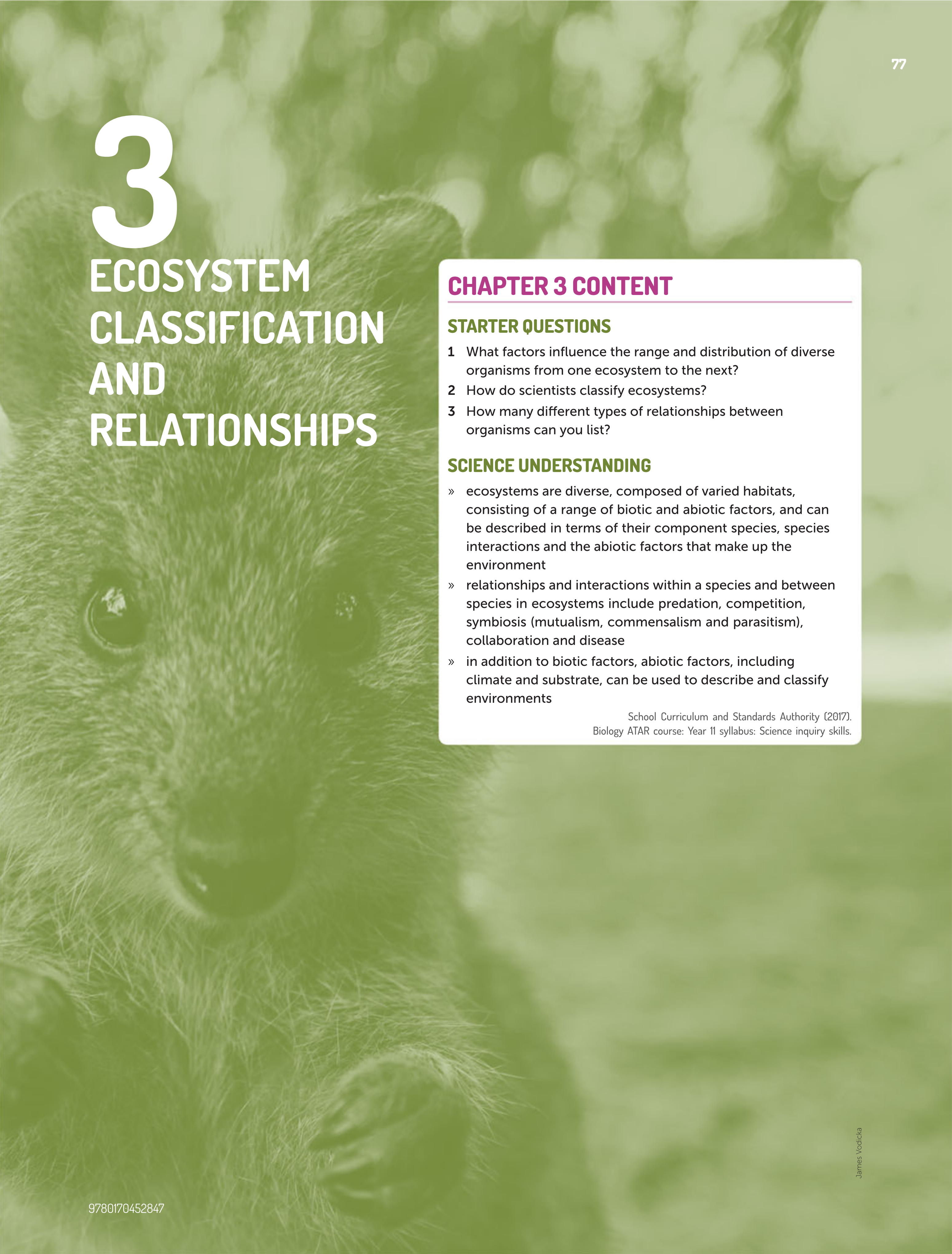


FIGURE 2.46 An unknown insect

4 State four conventions that should be used when naming a species using the binomial system. (4 marks)

5 Describe the three levels of biodiversity and provide three detailed arguments why we should conserve biodiversity for each of the three levels. (10 marks)



3 ECOSYSTEM CLASSIFICATION AND RELATIONSHIPS

CHAPTER 3 CONTENT

STARTER QUESTIONS

1. What factors influence the range and distribution of diverse organisms from one ecosystem to the next?
2. How do scientists classify ecosystems?
3. How many different types of relationships between organisms can you list?

SCIENCE UNDERSTANDING

» ecosystems are diverse, composed of varied habitats, consisting of a range of biotic and abiotic factors, and can be described in terms of their component species, species interactions and the abiotic factors that make up the environment

» relationships and interactions within a species and between species in ecosystems include predation, competition, symbiosis (mutualism, commensalism and parasitism), collaboration and disease

» in addition to biotic factors, abiotic factors, including climate and substrate, can be used to describe and classify environments

School Curriculum and Standards Authority (2017).
Biology ATAR course: Year 11 syllabus: Science inquiry skills.

James Vodicka

3.1 ECOSYSTEMS AND THEIR CLASSIFICATION

Terrestrial biomes
Gain more information on the world's terrestrial biomes.

NASA: Biomes
Investigate the seven major terrestrial biomes by clicking on each image.

Ecology is the study of the interactions of organisms with their physical environment and with other organisms. You were introduced to ecosystems in Chapter 2; in this chapter, you will learn more about ecosystems from an ecological point of view. An **ecosystem** is an ecological system which includes the organisms in an area (biotic factors), their physical environment (abiotic factors) and the interactions of these factors. Ecosystems can vary greatly in their biotic and abiotic factors, and scientists use these diverse characteristics for classification.

Life on Earth is comprised of ecosystems. The sum of all ecosystems across the world is called the **biosphere**. The biosphere can first be classified into major life zones known as **biomes**. Biomes are regions of the world with similar climate, animals and plants. Biomes can then be further classified into ecosystems, smaller units where communities that are almost distinct interact.

Large-scale images of Earth and its biosphere show patterns of browns and blues that identify the large terrestrial and aquatic biomes. The world's terrestrial biomes roughly correspond to major variations in vegetation types, climate, **topography** (the arrangement of physical features, both natural and artificial, of an area) and soil type. Tropical rainforests, deserts, grasslands and tundras are some examples of Earth's major terrestrial biomes. Figure 3.1 shows Earth's major biomes and their distribution.

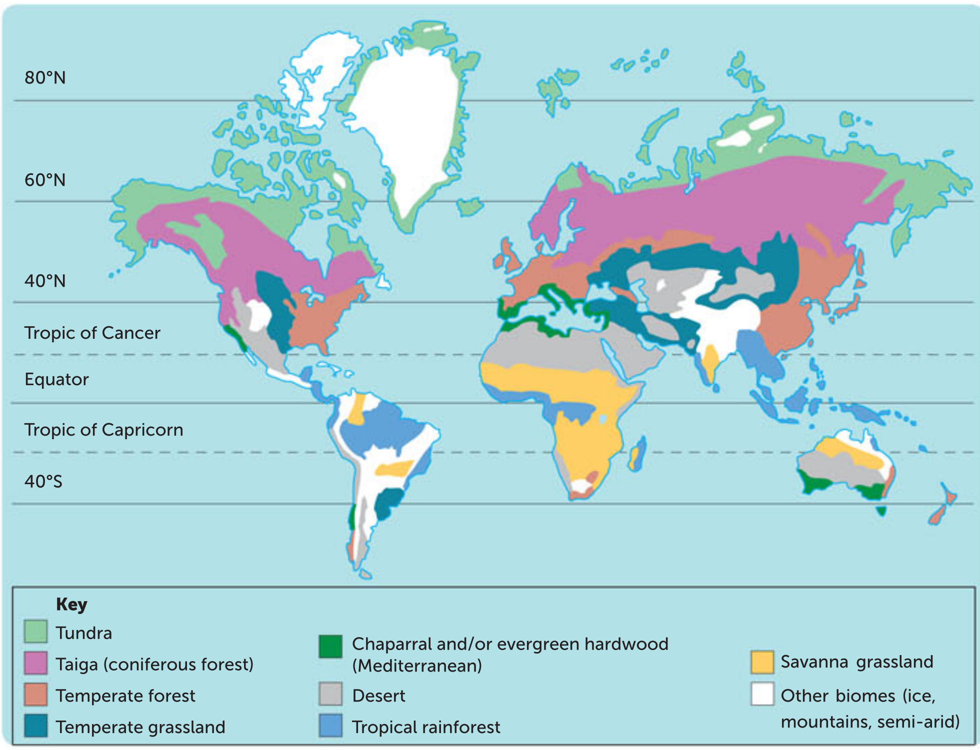


FIGURE 3.1 The distribution of the world's major terrestrial biomes

Each type of biome shares similarities; for example, a savanna grassland, whether it is in Australia or Africa, has similar features (Figure 3.2). All savanna grasslands across the world are characterised by an area with grass and with very few trees, a dry season that can either be very hot or cool, and a wet season that is warm. Typically, savanna grasslands receive less than 490 mm of rainfall annually.

Lakes, oceans and rocky shores are examples of aquatic biomes, which form the largest section of the biosphere. Several factors influence the kinds of organisms that inhabit an aquatic biome and the relationships between these organisms. These include how permanent the body of water is, its salinity, its depth and nutrient availability.

Shutterstock.com/Oleg Znamenskiy

Alamy Stock Photo/redbrickstock.com

FIGURE 3.2 Compare the savanna grasslands of **a** Africa and **b** Australia.

Ecosystems, environments and habitats

Biomes are subdivided into ecosystems. A biome can accommodate a number of different ecosystems. An ecosystem is classified as a **community** and its **environment**, and the interactions between them. Specifically, the community is the sum of all the living organisms in a habitat and the environment is the abiotic and biotic components of the ecosystem.

Environments can be classified based on their biotic and/or abiotic factors. **Abiotic** factors are physical and chemical factors such as temperature, light intensity, texture and pH of the soil, concentration of significant gases in water or air, nutrient availability and the availability of water. **Biotic** factors include the presence or absence of other living organisms that affect an organism, such as other members of their own species, competitors, collaborators, **predators**, disease-causing organisms, **parasites** and the availability of mates. The other organisms may compete for food against the individual or prey upon it. They may even change the chemical or physical environment.

Ecosystems are relatively self-contained and are able to support themselves by cycling or exchanging materials. For example, in a forest, leaves fall and decompose, and their nutrients are returned to the soil. In turn, living plants remove these nutrients from the soil and use them in growth. This is a highly simplified explanation of how an ecosystem operates. Chapter 4 explains in more detail how energy and nutrients are cycled through ecosystems.

Earth's ecosystems can contain many different habitats. A **habitat** is an area or environment within an ecosystem where an individual of a species lives, feeds and reproduces. Habitats are therefore specific for each **population**. A population is a group of individuals belonging to the same species, living in the same habitat at the same time. For example, a woodland ecosystem has several habitats. The ground level is home to the emu, a flightless bird, whereas the canopy level is home to the brush-tailed possum. The habitat for the emu is different from that of the possum, despite both species living in the same ecosystem.

Earth's ecosystems are interconnected and many of them are under threat. Damage or change to one ecosystem can affect connected ecosystems because they are interdependent. Ecosystems are classified so that scientists who monitor change in ecosystems can accurately share information.

Biodiversity ecosystems and ecological networks
What contributes to a stable ecosystem? Improve your understanding of ecosystems by watching this video.

9780170452847

Key concept

Ecosystem: a community (the biotic factors), its environment (the abiotic factors) and the interactions between them

Community: the interacting populations of different species inhabiting an area at one particular time

Environment: abiotic and biotic factors of an area

Question set 3.1

REMEMBERING

1 Identify the two major groups of biomes in the biosphere.

2 Compare the biotic and abiotic factors in an environment, using examples.

3 Define the following terms:
   a community
   b population
   c topography.

UNDERSTANDING

4 Distinguish between:
   a population and community
   b environment and habitat
   c environment and ecosystem.

5 Draw a concept map to show the relationship between the following: biosphere, habitat, ecosystem, community, biome, environment, biotic factors, abiotic factors, population.

3.2 CLASSIFICATION OF ECOSYSTEMS USING ABIOTIC AND BIOTIC FEATURES

Ecologists study the relationships between living things and their surroundings. The term 'ecology' was first used by Ernst Haeckel in 1869. In the early days, ecology was largely descriptive, providing qualitative data based on observational studies. Over time, ecology has become a more exact science by utilising quantitative data measurements and through the development of models and theories that help us better understand relationships. Today, ecologists use both qualitative and quantitative data to classify ecosystems and environments based on their abiotic and biotic components.

Terrestrial environments and abiotic features

Ecosystems are diverse, composed of varied habitats, consisting of a range of biotic and abiotic factors, and can be described in terms of their component species, species interactions and the abiotic factors that make up the environment (an organism's physical and biological surroundings). Therefore, instead of only classifying the biosphere into biomes, scientists find it helpful to classify them based on whether an organism lives on land (terrestrial) or water (aquatic).

A grassland is a type of biome because it occupies a major area of the biosphere and has a particular climate and a unique community of grass and animals. It can also be classified as terrestrial because the dominant organisms are living and growing on land. There are two main divisions of grasslands, both of which are terrestrial: savanna (with some individual trees scattered around; see Figure 3.2) and temperate grasslands (where trees are absent).

The distribution of **terrestrial environments** such as tundras, deserts, open forests and temperate grasslands is mainly the result of climatic variation. **Climate** is the atmospheric weather of an area, measured and averaged over a long period of time. Temperature, water, light and wind are the four main elements of climate. Both water and temperature significantly affect the geographic range of organisms living in an environment. For example, the climate of the desert differs considerably from that of a tropical rainforest. Deserts are generally found at latitudes of approximately 30° north or south of the equator, where the climatic conditions are drier.

Temperatures in a desert environment range widely, from below 0°C overnight to above 40°C during the day. Rain is generally unpredictable and is less than 250 mm annually.

Limited numbers of species are found in an Australian desert. These include small mammals such as the spinifex hopping mouse (*Notomys alexis*), invertebrate herbivores such as grasshoppers and crickets, and mulga trees (*Acacia aneura*). The **biodiversity** of the desert is low due to the abiotic features of the region.

In contrast to the arid desert, tropical rainforests are generally found between the Tropic of Cancer (23.5°N) and the Tropic of Capricorn (23.5°S), but can extend slightly outside these boundaries. They are extremely biologically dense and are home to around 50% of all animal and plant life, as well as numerous species of fungi and bacteria.

Temperatures in tropical rainforests range from 20°C at night to 35°C during the day all year round. Rainfall and humidity are high. Commonly, tropical rainforests have 1500–2500 mm of precipitation annually. However, they are also characterised by poor soil due to high levels of nutrient leaching caused by the high rainfall. Rainforest organisms are supplied with nutrients from the continual decomposition of plant and animal debris, known as **humus**. The rate of this decomposition is a **limiting factor** to forest growth: the slower the humus is formed, the slower the nutrients become available to the rainforest organisms, and the slower their growth rate.

The availability of substrates is another abiotic feature of an environment. A **substrate** is a supporting surface on which an organism such as a plant grows. The substrate may simply provide structural support, or may provide water and nutrients. A substrate may be inorganic, such as rock or soil, or it may be organic, such as wood.

When classifying environments it is important to identify the physical and chemical features of the soil. Understanding the features of the soil helps scientists determine which plants will grow best in a particular region. Soil type is determined based on a number of different properties. These include location, depth, texture, colour, porosity, pH, water-carrying capacity and nutrient status.

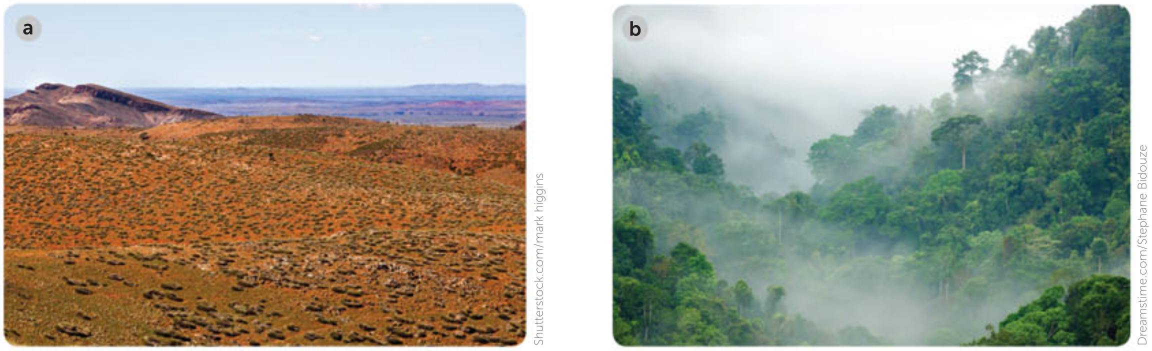


FIGURE 3.3 a Low rainfall in deserts limits biodiversity. **b** High rainfall in tropical forests promotes greater biodiversity.

Arid Australia

3.1 APPLICATION

The arid areas of Australia have ancient soils that are very infertile. Their phosphorous and nitrogen levels are on average 50% lower than other arid areas of the world! Antarctica is the only place drier than Australia. Of all the mammals that have become extinct in the last 200 years, 50% of them are Australian. They include the desert rat-kangaroo and the desert bandicoot.

Aquatic environments

Aquatic environments include both marine (saltwater) and freshwater environments. They make up the largest part of the biosphere. The oceans alone cover 71% of Earth's surface. Examples of aquatic environments include the moving waters of oceans, bays, **estuaries**, creeks, streams and rivers, and the still waters of lakes, ponds and swamps.

The major substance that defines whether a body of water is marine or fresh is the concentration of sodium chloride (salt). Marine environments have a salt concentration of approximately 3%. On the other hand, freshwater environments have a salt concentration of less than 1%. Estuaries have fluctuating salt concentrations. During high tide, the salt concentration increases to almost equal to that of the ocean, and as low tide approaches, it decreases. As you move up the estuary, the salt concentration almost equals that of fresh water.

Ocean environments are classified according to depth, distance from the shoreline and the way they are formed. The first 200 m of ocean depth is known as the **photic zone**. This is the only part of the water that light can penetrate and reach photosynthesising organisms. Approximately 90% of marine life lives in the photic zone. The temperature ranges from approximately 34°C to 10°C. As the depth increases, water temperature decreases.

As ocean depth increases, organisms also feel the effects of increased pressure. This is another limiting factor that affects the distribution of marine organisms.

CASE STUDY

Ecological research in an Australian tropical savanna ecosystem

Samantha Setterfield is an Associate Professor in the Faculty of Science, School of Biological Sciences at the University of Western Australia and an expert in tropical ecological research. Her interrelated areas of research include tropical savanna and wetland ecology, invasive plant ecology and weed risk management. The Australian tropical savanna is a region (a biome) in the north of Australia, defined as having a tropical climate and a landscape made up of tall grasses with scattered trees and shrubs. It covers the northern section of Western Australia, the Northern Territory and Queensland.

Shutterstock.com/Sara Winter

FIGURE 3.4 Dr Samantha Setterfield at work in a tropical savanna ecosystem

The plants of the Australian savanna are adapted to survive fire. After a fire, grasses grow new green shoots from their roots which have remained safe underground. Many shrubs and trees shed seeds or have seeds in the soil that germinate after fire and rain. Eucalypts are often able to survive fires due to the presence of lignotubers (masses of buds at ground level that can quickly produce new shoots) and epicormic buds (which also produce new shoots on the branches and trunk).

Dr Setterfield's team demonstrated that some weed species in tropical savannas are operating as ecosystem transformers by initiating a self-perpetuating grassfire cycle of degradation. Areas of the tropical savanna have been invaded by weeds such as gamba grass (*Andropogon gayanus*), which threatens native plants and animals, and impedes access to parts of the landscape. Gamba grass also carries a high fuel load, ultimately leading to more intense fires. The research has predicted the long-term implications of these changes to Australia's tropical ecosystem structure and function, and the cost and approaches of effective management. This has been achieved by detailed ecological studies, which have been used to develop innovative models describing how weeds spread over specific areas and how to manage them.

Dr Samantha Setterfield, The University of Western Australia

Fire weeds in the top end
Learn about research into managing weeds and changes in fire regimes in northern Australia.

Questions

1 Using Table 3.1, calculate the average annual temperature in the Australian tropical savanna.

TABLE 3.1 The monthly mean temperatures of the Australian tropical savanna

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Mean (°C)	35.9	35.0	35.5	35.2	32.7	30.1	30.5	32.6	36.5	38.5	38.9	37.1

2 Describe an Australian tropical savanna ecosystem.
3 Describe the positive impact a fire can have on an Australian tropical savanna ecosystem.

Classifying ecosystems using biotic features

Environments and ecosystems are not classified only by their abiotic features; they may also be classified by their component species and species interactions (biotic factors). Ecosystems are often named after the **dominant species** present. For example, an aquatic ecosystem can also be classified by the dominant species being the mangrove, thus the area is known as a mangrove forest. Mangrove forests can be further classified by their location. In WA this is based on five regions: Kimberley, Pilbara, mid-west, south-west and Nullarbor Plain. Other examples of ecosystems named for a particular species include Jarrah forests in the south-west coastal region, and hummock spinifex grasslands found in the Pilbara, Ashburton and northern Gascoyne regions. The dominant species of an ecosystem is often a plant.

As discussed in the previous section, the distribution of ecosystems depends on abiotic factors such as soil type and climate. Figure 3.5 shows that the major vegetation patterns correspond to different climates. Vegetation is classified according to:

- the percentage of ground shaded or covered by the tallest layer of vegetation
- the form (tree, shrub or grass) of the tallest layer.

For example, open forests have 30–70% of the ground shaded by trees that are 10–30 m tall. If the trees are taller, the forest is classified as a tall open forest. If the percentage cover is 10–30%, it is classified as woodland. Table 3.2 (pages 84–5) shows the ground cover features of the major Australian ecosystems.

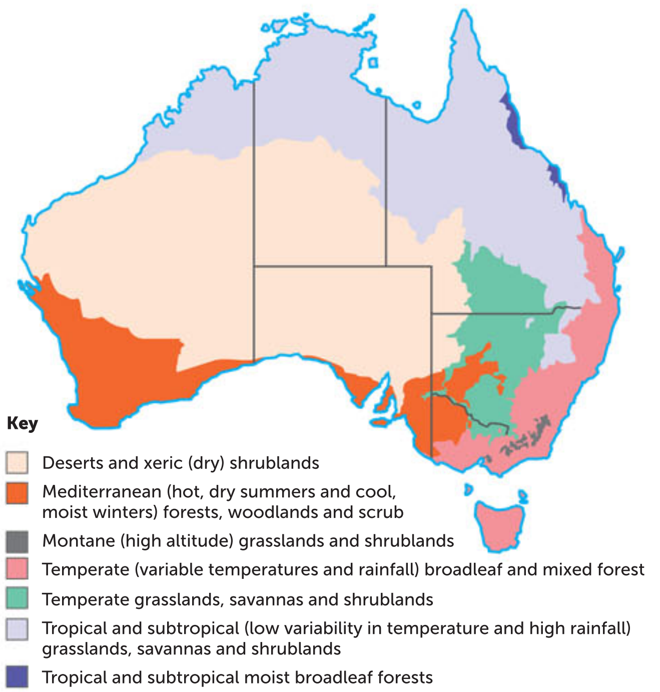


FIGURE 3.5 The major ecosystems in Australia

Key concept

Environments can be classified based on their biotic and abiotic features. Ecosystems can also be classified by their biotic or abiotic components, but are often named after their dominant species.

TABLE 3.2 The ground cover features of major Australian ecosystems

ECOSYSTEM	GROUND COVER AND DESCRIPTION
Deserts 	Ground cover is in patches, widely spaced. True deserts are areas with rainfall less than 100 mm a year on average; 18% of mainland Australia is desert. Many desert plants are ephemerals, short-lived species that appear following good rain. They rapidly germinate, grow, flower and set seed, while the desert soil is still moist. Deserts also feature xerophytes, plants that have physical adaptations suited to the dry environment, such as having fewer, smaller leaves to minimise water loss. The Australian mulga (*Acacia aneura*) is a common wattle in Australian deserts.
Grasslands 	In arid regions, ground cover is typically hummocks and tussocks with a very low cover of <30%. The dominant species are grasses, which vary in height from 2 cm to 2 m. Many species are adapted to fire and drought.
Scrublands 	Foliage cover of 30–70%. Scrublands can also be called shrublands and heathlands, and they contain many different vegetation types. The typical vegetation is shrubs with a variable overstorey of small trees such as mulga (*Acacia aneura*) or eucalypts. Scrublands are adapted to drought, fire and low (but highly variable) rainfall.
Woodlands 	Widely spaced canopy cover of 10–30%; well-developed shrubs and grasses. The widely spaced trees are fewer and more scattered than in forests. Woodlands are mainly dominated by eucalypts and found mostly in southern, temperate Australia.
Alpine 	Low, fairly continuous ground cover. Alpine ecosystems are found in cold mountain regions, including above the tree line (where altitude makes even summer temperatures too low for much tree growth). This ecosystem has rocky landscapes, and may contain glacial lakes and have seasonal snow coverage.

ECOSYSTEM	GROUND COVER AND DESCRIPTION
Open (sclerophyll) forests 	Fairly open canopy cover of 30–70%; good understorey and ground cover. These forests are 25–35 m high, with fairly even height and moderately dense canopies that often join up. The forest floor can range from dry to damp and is covered with grasses and shrubs. These forests are dominated by eucalypts and are the most common forest type in Australia (the bush).
Closed (rainforest) forests 	Dense canopy cover of 70–100%; distinct layers or storeys within forest. Rainforests are filled with mostly evergreen trees and typically receive high amounts of rainfall. Tropical rainforests are found near the equator, with high average temperatures and humidity, while temperate rainforests lie mostly in coastal, mountainous areas within the mid-latitudes.
Reefs and marshes 	Dense growth. A reef is a ridge of material at or near the surface of the ocean. Reefs can occur naturally. Natural reefs are made of rocks or coral, which is the remains of skeletons of small animals. A marsh is a wetland, an area of land where water covers ground for long periods of time.

If you travel from one ecosystem to the next, it may be hard to notice where one ecosystem ends and another begins. In neighbouring ecosystems, physical conditions such as soil type and temperature gradually change or merge and the ecosystems overlap. Some animals, such as birds, will be part of multiple communities because they move from one area to another. These ecosystems are described as open; in fact, it is rare that ecosystems are truly 'closed'.

Question set 3.2

REMEMBERING

1 Identify the different factors used to classify an ecosystem.

2 Define 'substrate'.

3 List three different types of aquatic ecosystems.

UNDERSTANDING

4 Distinguish between:

a an open and a closed ecosystem

b an arid desert and a tropical rainforest

c savanna and temperate grasslands.

5 Using an example, show how some ecosystems are named after a dominant species.

CREATING

6 Create a set of flash cards to help you remember the ground cover features of the major Australian ecosystems.

3.3 RELATIONSHIPS AND INTERACTIONS BETWEEN LIVING THINGS

Ecosystems have many different relationships and interactions occurring within them. A community is a group of populations of different species living in close enough proximity, in an ecosystem, to interact. The relationships between living things affect the biodiversity of a region, some being harmful to it and others, beneficial. For example, imagine what parasites can do to a carpet python, or what would happen to a karri forest if the fungus it depends on for survival died.

Every living thing and environment is profoundly affected by the presence or absence of other living and non-living things. Organisms of a soil community, for example, are affected by the texture, mineral content and water content of the medium in which they live. However, the properties of the soil itself are affected by the activities of burrowing worms and decomposers. The burrows of the worms allow air and water to penetrate into the soil, and the decomposers increase the fertility of the soils by recycling organic material. An animal such as a wallaby does not exist in isolation. It not only interacts with other wallabies but also with the vegetation it eats, the ticks, mites, flies and other parasites that pester it, and the wedge-tailed eagle or dingo that may attack its young.

Understanding the relationships and interactions between organisms can help us understand how an ecosystem works. Some interactions can be straightforward but others are extremely complex. It is only by experimentation and painstaking studies of behaviour that scientists can come close to unravelling these relationships.

Competition and collaboration

Communities consist of populations of individuals and the complex interactions between them. **Competition** occurs when individuals compete for a resource that limits their survival and reproduction. If a resource is not limited, then competition will not happen. Oxygen is needed for survival and reproduction but because the supply is not limited, organisms do not compete for it.

Competition within and between species is a common feature of all communities. For example, various species of seemingly harmless sea anemones compete with each other for the same food source. They can detect slight genetic variations in intruders. Both rivals discharge a battery of stinging cells, normally used to paralyse and catch **prey**. In the end, one will be defeated, close up and detach from the sea floor or rock to find a new home elsewhere.

RODGER JACKMAN rodger.jackman@gmail.com
RODGER JACKMAN rodger.jackman@gmail.com

FIGURE 3.6 Different sea anemone species compete for food sources. This is an example of interspecific competition. Here, a sea anemone stings its neighbour.

Members of some species solve the problem of catching their prey by collaborating with each other, such as wolves do when hunting or dolphins when herding schools of fish. **Collaboration** can occur when members of the same species work together to benefit all. These are examples of **intraspecific** interactions: relationships between members of the same species. On the other hand, the **association** that wolves or dolphins have with their respective prey is **interspecific**: it occurs between members of different species.

The way in which one organism competes against or works with another organism to obtain their food helps shape the biodiversity of an ecosystem.

Predation: predator and prey

An obvious interaction within every ecosystem is the predator–prey relationship (Figure 3.7). In this **predation** relationship, one organism, the predator, kills another organism, the prey, or consumes part of it for its food. Although there is usually a preferred prey species, it is unusual for a predator to depend on only one species. It is an advantage for a predator to be a member of a network of food chains. Then if one prey species becomes in short supply, the predator can turn to others.

The dynamic relationship between predator and prey is usually balanced, but sometimes conditions can change and upset this balance. Under favourable conditions, with increasing availability of prey, the number of predators can increase, although it usually still remains less than that of the prey. During a period of adverse conditions, the prey population can decrease. When this occurs, there is increased intraspecific competition in the predator population. Predators turn to alternative prey species as a new food source, decreasing their population, while the original prey population increases again.

Predation includes animals preying on plants, plants preying on animals (such as the Venus flytrap or pitcher plants) and animals preying on other animals. However, it is helpful to classify the preying of herbivore animals on producers as herbivory (animals that consume plants). One example of herbivory influencing an ecosystem is seed predation. **Seed predators** can have a large effect on plant populations and their distribution throughout an ecosystem. These animals only feed on the seeds of plants, causing the seeds to become unviable as they pass through the predator's digestive system. Another example of the effect of predation on the biodiversity of an ecosystem is the release of nutrients into the soil from decomposing animal carcasses left behind by predators, which provide nutrients for micro-organisms in the ecosystem.

Ecological relationships
Watch the videos and look at the images to investigate different relationships between species in an aquatic ecosystem.

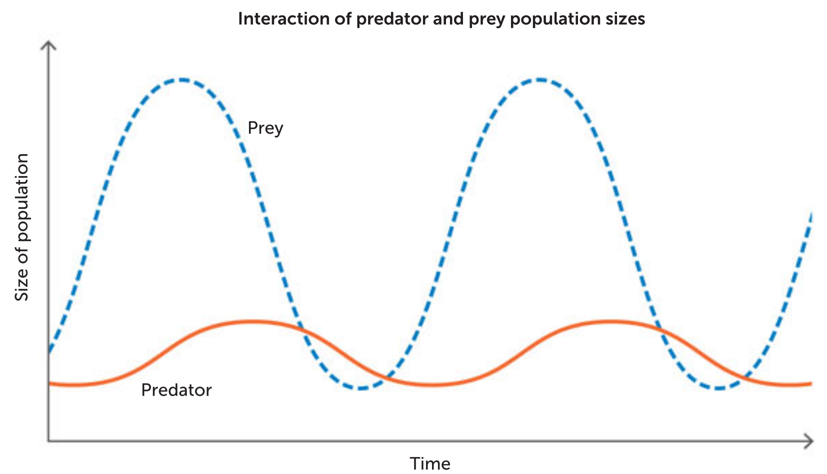


FIGURE 3.7 The predator–prey relationship affects the size of both populations over time.

Key concept

Relationships between organisms include competition, collaboration and predation.

Competition is when individuals compete for a resource that limits their survival and reproduction.

Collaboration is when organisms work together to benefit all; this can be intraspecific or interspecific.

Predation is when one species eats another species for food.

Disease

The interaction between a disease-causing organism and the host can also affect the biodiversity of an ecosystem. For example, the myxomatosis virus causes disease in rabbits. In Australia, this virus is deliberately used to reduce the rabbit population to allow native animal populations to increase. In this case, the disease allows the biodiversity of the Australian ecosystem to increase, by reducing rabbit populations and stopping them from outcompeting native animals for resources. In other cases, disease can decrease the biodiversity of an ecosystem. Chlamydia can cause disease in koalas, affecting the reproductive tract and reducing their ability to produce offspring. The disease can reduce both the numbers of koala and the genetic diversity present in affected ecosystems.

Question set 3.3a

REMEMBERING

1 Using an example, explain collaboration.
2 Explain how disease can affect the biodiversity of a region.

UNDERSTANDING

3 Using examples, compare interspecific and intraspecific relationships.
4 Identify and explain the distinctive feature of a predator–prey relationship.

APPLYING

5 Using an example, explain how predator–prey relationships can shape the biodiversity of an ecosystem.

Symbiosis
Refresh your understanding of symbiosis by watching the video.

Symbiotic relationships

Symbiosis is the general term for a relationship between individuals of two or more species that benefits at least one of the species. There are three main types:

1 **parasitism**: one species, the parasite, benefits at the expense of the other, the host
2 **mutualism**: both species in the relationship benefit and neither is harmed
3 **commensalism**: one species benefits and the other neither benefits nor is harmed.

These relationships help shape the biodiversity of ecosystems.

Parasitism

Parasitism is an interactive relationship between two species: a parasite and a host. Most species, including humans, harbour parasites in every conceivable part of their body. The parasite is an organism (such as a bacterium, virus, fungi, worm or arthropod) that lives on or in another organism, known as the **host**. The parasite derives its nutrients from the host organism, which is harmed during the process but not always killed. **Ectoparasites**, such as lice and ticks, live and feed on the external surface of their host organism. **Endoparasites**, such as tapeworms, live and feed within their host organism. Unlike in predation, the host is not immediately killed by the parasite, though it may sicken and die over time. Examples of common parasites found in the ocean include nematodes, leeches and barnacles. A barnacle may root itself within a crab's reproductive system. While the crab does not die from this interaction, its reproductive capabilities are greatly diminished. Dogs can be a host to many different parasites. They may suffer from ectoparasites, such as fleas and ticks, and endoparasites, such as heartworms and hookworms.

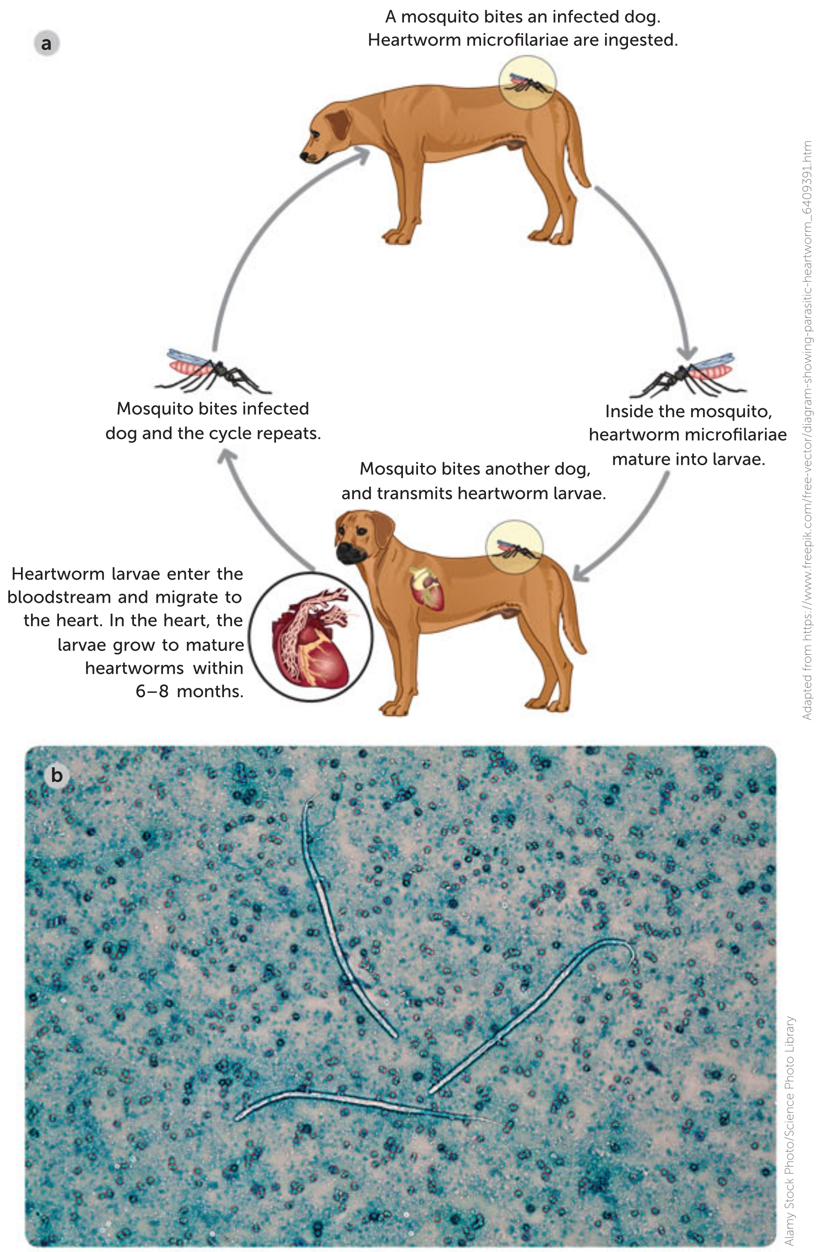


FIGURE 3.8 a The life cycle of the dog heartworm; **b** heartworms viewed by light microscope

Parasites are extraordinarily well-adapted in their life cycle, structure and physiology to find their host and survive the hazards of being dependent on them. Hosts have **coevolved** strategies for surviving the effects of their unwelcome invaders.

The interaction of parasites and hosts in an ecosystem is yet another factor that shapes the unique diversity of the region. For example, native mistletoe is a parasitic plant that uses eucalypt trees as hosts. The mistletoe plant is transferred from one tree to another by the mistletoe bird, spreading it throughout the eucalypts in an ecosystem. This parasitic plant can reduce the diversity of the ecosystem by killing numerous varieties of eucalypts.

FIGURE 3.9 The mistletoe plant is spread by mistletoe birds that eat the berries and defecate the sticky seeds onto the branches of eucalypts.

Pistol shrimp and goby fish
See how the pistol shrimp and goby fish work together.

Mutualism

Not all relationships cause harm to a species. One type of interactive relationship, known as mutualism, benefits both species. Mutualism is a common relationship in communities. There are differing levels of mutualism, from a rather loose association in which the partners seem to gain little from each other, to associations that are so intimate that the two partners can be regarded as a single organism.

The relationship between the pistol shrimp and the goby fish is an example of mutualism. The shrimp digs a burrow to live in, but it is relatively blind and cannot detect approaching predators. The goby fish uses the burrow for protection from predators and, in return, acts as the 'eyes' for the shrimp. During the day the shrimp maintains continual contact with the goby's tail, which the goby will flick several times if a predator approaches and the two need to retreat into the burrow. During the night they rest and share the burrow.

Pollinators are essential for many flowering plants to reproduce. Some plants, such as grasses, can be pollinated by wind. However, flowering plants generally rely on insects, birds, small mammals and even reptiles to transfer pollen from one plant to another. This is another example of mutualism; the pollinator benefits from feeding on the nectar while the plant benefits by being pollinated.

Some pollinators are generalists, able to pollinate a range of different plant species, whereas specialists will only pollinate the kind of plant with which they have coevolved. In these partnerships, both members depend on each other so much that if one disappears, the other would not survive. The plants would be sterile without a pollinator and the pollinator would starve without the plant as its food source.

FIGURE 3.10 While collecting nectar from eucalypt blossom, pygmy possums are also acting as pollinators.

CASE STUDY

The Canberra spider orchid

The critically endangered Canberra spider orchid, *Caladenia actensis*, is on the brink of extinction. Population numbers are extremely low and the plant only exists in two locations, Mount Ainslie (30 plants) and Mount Majura (220 plants) in the Australian Capital Territory. The orchid relies on the thynnid wasp species to pollinate it. The orchid has coevolved to resemble the wasp. The orchids fool the wasps into attempting to mate with them, and are pollinated instead.

FIGURE 3.11 The rare spider orchid, *Caladenia actensis*

Seed dispersers are also intrinsic to ecosystem biodiversity. These include mammals and birds that eat fruits and seeds. When such an animal defecates, it deposits the seeds in a new location where they can germinate and grow. Seed dispersers are distinct from seed predators in that the seeds do not get damaged in the animal's digestive system and therefore remain viable for germination. The symbiotic relationship between the seed disperser and the plant is another example of mutualism, because both organisms benefit from the interaction. The woylie or brush-tailed bettong (*Bettongia penicillata*) may have a role as a seed disperser in WA. Its ability to disperse sandalwood seeds could help with the regeneration and recruitment of the WA sandalwood *Santalum spicatum*. Scientists have found that where woylies are present, significantly more seedlings grow at a distance from sandalwood trees. Sites where there were no woylies had lower seed dispersal and less sandalwood regeneration.

In the absence of these pivotal relationships, many species would become threatened or extinct because they cannot continue to survive by themselves. Plants would not reproduce without the pollinators and in turn the pollinators would not have a food source. Without seed dispersers, some plants would not germinate and could become extinct. Diverse ecosystems would not be maintained.

Commensalism

Commensalism is a one-sided interaction between species. Only one of the two organisms involved, the commensal, benefits from the interaction; the other organism does not benefit, but it is not harmed. Some relationships are easy to identify as commensal, such as the relationship between the remora fish and the shark. The remora gets a free ride, and possibly free leftovers, by attaching to the shark using a suction pad on the back of its head. The shark is otherwise unaffected.

Another example of a commensal relationship occurs between the cattle egret and livestock. This migratory bird is widespread across the world, including Australia. It is generally found foraging for food next to large livestock. The livestock disturb insects in the grass that the egret then feeds upon. Egrets will sit on the back of livestock to have a better vantage point to spot insects. They have a much higher foraging success rate when feeding near livestock. In this relationship, the bird is the commensal and the livestock are undisturbed and unharmed by the bird feeding near them.

Epiphytes are climbing plants, such as lianas, which use trees to support them as they reach for light. Their seeds germinate on the forest floor and the rapidly growing shoots spread out. If they reach a vertical surface, they take hold of it. Other seeds, such as those of orchids, are wafted high up to the branches and take hold there. In both of these instances, the tree offers support without apparently gaining anything in return and without being harmed in any way.

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FIGURE 3.12 Examples of commensalism. **a** Cattle egrets benefit from feeding on insects that zebras disturb. **b** Barnacles have a home on the skin of the whale and are transported by their host to plankton-rich waters, where they filter-feed on the micro-organisms.

Key concept

Symbiotic relationships include parasitism (where one species benefits and the other is harmed), mutualism (where both species benefit) and commensalism (where one species benefits and the other is not harmed).

CASE STUDY

Life support

Australia is home to more than 3000 lichens. Lichens are comprised of two species of organisms living in a symbiotic relationship: a fungus and one or more algae or a cyanobacterium. The autotrophic algae and cyanobacteria contain chlorophyll and are able to photosynthesise, supplying a carbohydrate food source for the heterotrophic fungi. The roles of the fungi are to anchor to a substrate such as a tree or rock, and to provide structure and protection for the algae. Lichens grow readily in the south-west of WA, especially during late winter. A number of factors can help you identify a lichen. Their colours range from grey to orange. They grow in a variety of places, including on dead branches, rotting logs, the soil and rocks. They can appear crusty or leafy, or look like tiny, soft shrubs.

Lichens play an important role in food webs by being a food source for small invertebrates. They also contribute to soil formation when they die, as they break down into smaller organic components. This leads to fertile soil, which makes a viable home for plants to grow.

Alamy Stock Photo/Sally Robertson

FIGURE 3.13 Lichens can look like a single organism, but they are a composite of a fungus and one or more algae or cyanobacteria.

Question set 3.3b

REMEMBERING

1 Define the following terms:
   a symbiosis
   b predation
   c parasitism
   d mutualism
   e commensalism.

UNDERSTANDING

2 Using examples, outline why it is essential to have pollinators and seed dispersers in an ecosystem.

3 Using the symbols + (beneficial), – (harmful) and 0 (unaffected), create a table that summarises the three symbiotic interactions.

4 Using an example for each, explain how each symbiotic relationship shapes biodiversity.

APPLYING

5 Compare the interaction between seed predators and plants with the interaction between seed dispersers and plants.

SCIENTIFIC LITERACY

Threatened ecological communities in WA

The federal Department of Agriculture, Water and the Environment has developed a state-by-state database of species profiles and threats. It can generate lists of species and whole communities in specific ecosystems that are currently threatened or endangered. Of the 25 communities it lists, 24 are described as **endemic**. In 2020, four communities were classified as critically endangered, twenty were classified as endangered and one was classified as vulnerable.

For example, from 2016 the Banksia woodlands of the Swan coastal plain ecological community was listed as endangered. A Threatened Species Scientific Committee was formed and gave advice to the then Federal Minister for the Environment and Energy about the listing and conservation strategies for the threatened ecological community.

The ecosystem was described in the following way: 'A key diagnostic feature is a prominent tree layer of *Banksia*, with scattered eucalypts and other tree species often present among or emerging above the *Banksia* canopy. The understorey is a species-rich mix of sclerophyllous shrubs, graminoids and forbs. The ecological community is characterised by a high endemism and considerable localised variation in species composition across its range. Due to the dominant banksia species, the ecosystem was named "Banksia woodlands"'. The Banksia woodlands ecological community is in south-west WA, which is recognised as a global biodiversity hotspot.

Forty endemic mammal species are thought to have been present in the Swan coastal plain bioregion at the time of colonisation, including iconic species such as the bilby, numbat and woylie. Ten of these mammal species are now entirely extinct from the bioregion. Of the native ground mammal fauna known to be in the Swan coastal plain at the time of non-Indigenous colonisation, more than 70% have become regionally extinct. Other species have declined in numbers or contracted their range, generally to the northern plain, which is relatively less disturbed. The larger patches of Banksia

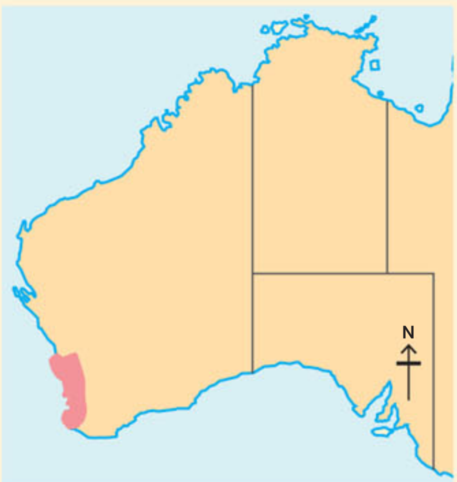

FIGURE 3.14 The distribution of the Banksia woodlands community of the Swan coastal plain

woodlands can still support viable populations of *Tarsipes rostratus* (noolbenger, honey possum), and *Pseudomys albocinereus* (noodji, ash-grey mouse). Being nectar feeders, noolbengers particularly rely on *Banksia* flowers as a food resource and have a key role in the ecological community as pollinators. Other characteristic mammal species in the ecological community include *Macropus irma* (Kwoora, western brush wallaby) and *Isoodon obesulus* (quenda).

Clearing for urbanisation, fragmentation, dieback due to plant diseases, altered fire regimes, an increase in invasive weed species, climate change and groundwater decline are thought to be contributing factors to why the whole community is endangered.

Disturbances to a community are more likely to occur to patches in urban and peri-urban areas, because of how close such areas are to humans. Such patches of community are prone to impacts such as:

- rubbish dumping (which can include garden waste, a source of weeds)
- access by unauthorised vehicles
- having paths created by people trampling through the vegetation
- illegal removal of vegetation (including for firewood)
- destruction of vegetation cover
- inappropriate fire regimes
- introduction of domestic and feral animals.

These impacts are likely to spread out into other remnants as urban developments encroach on the remaining native vegetation of the Swan coastal plain.

A recovery plan was not recommended by the minister because he decided management plans already existed, such as the threat abatement plan for disease in natural ecosystems caused by *Phytophthora cinnamomi*. The management plan for the area will be reviewed regularly.

Questions

1. Differentiate between an endangered species and an endangered community.
2. List four mammals found in this endangered community.
3. Describe three likely causes of the degradation of this community.

CHAPTER 3 INVESTIGATION

Developed exclusively by Southern Biological

3.1 INVESTIGATION

Evidence for predator–prey relationships and ecosystems from owl pellets

Owls are birds of prey that hunt at night, and frequently swallow their catch whole. When they are not able to swallow their prey whole, they ingest it in large pieces. After it is swallowed, the food moves to the owl's stomach, which has a unique structure that includes the proventriculus (the upper portion) and a ventriculus or gizzard (lower portion). During the first stage of digestion, the acids and enzymes in the proventriculus partially digest the prey. The remains then move to the gizzard, where the indigestible parts of the prey, such as hair, bones, teeth and feathers, are compressed to form a matted pellet. The pellet then re-enters the proventriculus to remain there until the owl regurgitates it. Common barn owls are nocturnal hunters and typically produce one or two of these pellets a day. This activity uses pellets from the US, where common barn owls survive on a diet of rodents, such as mice, rats and voles. Due to their hunting efficiency and ability to reduce rodent populations, some farmers intentionally attract owls to their land by constructing artificial nests.

Aim

To investigate the feeding relationships between barn owls and their prey

Materials

- owl pellets
- dissection tray
- magnifier
- wooden probe
- dissecting forceps

WHAT ARE THE RISKS IN DOING THIS INVESTIGATION?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Dissecting the owl pellet will create small debris and dust. Dust may cause some irritation if breathed in.	Do not inhale the dust produced by the pellet. Keep your face at a safe distance from the pellet at all times.
The bones contained within the owl pellet can be sharp and may cause injury if improperly handled.	Wear gloves at all times. Hold bones lightly in your hands and handle only one bone at a time where possible.
Owl pellets are an organic material that may contain microbes.	Owl pellets have been sterilised, and therefore are safe to use. They are not subject to any restrictions on use or disposal.

Procedure

1. Unwrap your owl pellet and place it on a clean tray. Note the colour, size and texture of the pellet.
2. Carefully separate the bones from the fur using a wooden probe and dissecting forceps.
3. Identify and categorise the bones, based on the type of bone and the animal it came from. Use the bone-sorting chart from the weblink to do this.
4. Record this information in a table such as Table 3.3 (page 96).
5. For the US-sourced pellets you are using, the average barn owl's diet is approximately 50% voles, 40% mice, 5% rats and 5% shrews. Barn owls typically regurgitate two pellets a day, with each pellet generally containing four skulls. Based on the results of your dissection, determine the type and quantity of animals the owl consumed (assume this occurred over 1 day). Gather data from another group to represent the second pellet. Using only whole numbers, record the figures in a data table like Table 3.4 (page 96).
6. To continue to fill out the table, calculate the following:
   a. the total mass of food consumed by the owl daily

Bone-sorting chart
Use this chart to identify the source and types of bones in the owl pellet.

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b the percentage of mass each type of consumed prey contributes to the owl's total daily consumption.

7 Based on the assumption the owl weighs 550 g, calculate the percentage of the owl's body weight it consumed.

Results

TABLE 3.3 Owl pellet dissection results

PREY	NUMBER AND TYPE OF BONES FOUND

TABLE 3.4 Barn owl diet calculations

ANIMAL CONSUMED	NUMBER CONSUMED	AVERAGE MASS OF ANIMAL (g)	TOTAL MASS (g)	PERCENTAGE OF DIET
Mouse		45		
Vole		28		
Rat		300		
Shrew		10		
Total				

Discussion

1 Using Table 3.5, construct a diagram of a food web (of at least five animals), with an owl at the top trophic level. Use arrows to show which organisms are consumers and which are predators. Ensure you label the trophic levels and class of consumer. Include the Sun as the energy source for plants.

TABLE 3.5 The barn owl's prey and their diets

FOOD SOURCE	DIET
Mouse	Seeds, grain, invertebrates, carrion
Vole	Plants, roots, tree bark, nuts, fruits
Rat	Grains, fruit, vegetables, invertebrates, vertebrates, carrion
Shrew	Insects, slugs, spiders, worms, amphibians, small rodents

2 Using the information in the food web, identify the pattern in food mass consumed for the primary and secondary consumer trophic level.

3 Consider how the pattern of food mass consumed for the primary and secondary consumer trophic level can be explained using the laws of conservation of matter and conservation of energy.

4 Imagine what would happen if an owl consumed only rats. How would this affect the food web? Describe how the number of trophic levels and the percentage of initial energy transferred to the owl would be affected.

5 Illustrate a simple food chain. The food chain should include a predator and a prey. Is the predator considered to be lower or higher on the chain?

6 What is the source of the energy that enters a food chain?

7 Which is more sustainable over time, an ecosystem with a single food chain or one with a food web?

8 Owl pellets not only give us information about the diet of the owl, but also provide a habitat for other animals. An owl pellet is a little ecosystem all on its own. Describe the kind of organisms that are found in the owl pellet ecosystem.

WS Chapter 3 Activity sheet

CHAPTER 3 SUMMARY

- The biosphere can be broken up into major aquatic and terrestrial biomes.
- Each biome is comprised of numerous ecosystems, which are comprised of a number of habitats.
- Biomes can be classified based on types of climate and other factors, such as vegetation type (terrestrial) and salt concentration (aquatic).
- Major Australian ecosystems include desert, dry sclerophyll forests, open tropical rainforests, shrublands, woodlands, alpine, grasslands, and reefs and marshes. Canopy cover is one factor that is used in classification.
- An ecosystem is the living organisms in the community, their environment and the interactions between these.
- The environment is the set of biotic and abiotic factors in a particular area.
- A community is a group of populations that live and interact in the same habitat.
- Competition, predation, disease and symbiotic relationships and interactions affect the biodiversity of an ecosystem.
- Symbiotic relationships and interactions include parasitism, mutualism and commensalism.
- The biodiversity of an ecosystem is affected by abiotic and biotic factors, and the interactions between these factors.

CHAPTER 3 GLOSSARY

Abiotic non-living; used to describe components of an ecosystem

Aquatic environment a water environment, such as an ocean, lake, river, stream or swamp

Association a relationship or interaction between two or more species

Biodiversity the full range of different living things in a region; can be described at various levels, including the range of species, the genetic diversity in species, and the diversity of ecosystems present in a larger area

Biome a large-scale category of ecosystem across a large geographical area

Biosphere the sum of all ecosystems across the world

Biotic living; used to describe components of an ecosystem

Climate the atmospheric weather of an area measured and averaged over a long period of time

Coevolve simultaneously evolve adaptive features in two different species that place selective pressures on each other

Collaboration the beneficial working together of members of the same species

Commensalism a one-sided interaction between species, from which one organism benefits, the commensal, and the other does not benefit, but it is not harmed

Community a group of populations of different species in an ecosystem living in close enough proximity to interact

Competition an interaction between living things that occurs when individuals compete for a resource that limits their survival and reproduction

Dominant species the most common or abundant species in a particular ecosystem

Ecologist a scientist who studies the relationships between living things and their surroundings

Ecology a branch of biology that explores the relationships between living things and their surroundings

Ecosystem a self-sustaining unit made up of a community of organisms in an area, the physical environment in which they live, and the interactions between them

Ectoparasites parasites, such as lice and ticks, that live and feed on the external surface of their host organism

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Endemic describes a species that is native to a particular geographic region

Endoparasites parasites, such as tapeworms, that live and feed within the internal environment of their host organism

Environment the abiotic and biotic factors of an area

Epiphyte a type of climbing plant, such as lianas, which uses trees as support as they reach for light

Estuary the transitional region where fresh water from a river meets with salt water from the ocean

Habitat an area or environment within an ecosystem where an individual of a species lives, feeds and reproduces

Host an organism that another organism lives on or in

Humus the dark brown organic matter in soil, derived from decomposed plant and animal remains (detritus)

Interspecific describes interactions or relationships between members of different species

Intraspecific describes interactions or relationships between members of the same species

Limiting factor an element of the environment that restricts the survival of an organism to a region

Mutualism a symbiotic relationship which benefits both species in the relationship

Parasite an organism, such as a bacterium, virus, fungi, worm or arthropod, that lives on or in another organism (the host)

Parasitism a relationship between two species, a parasite and a host, in which the parasite derives its nutrients from the host, which is harmed but not always killed, though it may sicken and die over time

Photic zone a region of water that light can penetrate, allowing photosynthesis to occur

Pollinator an organism that is able to transfer pollen from one flower to another

Population a group of individuals of the same species living in a particular area at the same time

Predation an interaction between species in which one species, the predator, kills and eats the other, the prey

Predator a species that eats another (usually animal) species, the prey

Prey an organism that is consumed by another organism, a predator, for food

Seed disperser an organism that feeds on fruits and seeds for nutrition and, by defecating, deposits seeds in new locations where they can germinate and grow

Seed predator an organism that feeds on seeds

Substrate a supporting surface on which an organism grows

Symbiosis a relationship between individuals of two or more species that is beneficial to at least one species

Terrestrial environment a land environment, such as tundra, desert or rainforest

Topography the composition of the natural and artificial features of an area

CHAPTER 3 REVIEW QUESTIONS

Remembering

1 Summarise how terrestrial and aquatic environments are classified, stating what factors are used.

2 Compare a terrestrial environment and an aquatic environment in terms of the relative levels (less or more) of these abiotic factors: pressure, temperature and gas availability.

3 Explain the difference between a competitor and a collaborator.

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Understanding

4 Compare the following terms:
   a biosphere and biome
   b environment and ecosystem
   c ecosystem and habitat
   d population and community
   e habitat and environment.

5 Outline how symbiotic relationships may increase the biodiversity of an ecosystem. Provide an example.

Applying

6 Copy and complete Table 3.6, which summarises the relationships and interactions between species.

TABLE 3.6 A summary of relationships and interactions between species

RELATIONSHIP OR INTERACTION	DESCRIPTION	EXAMPLE
	Different species living together and sharing the same resources	
Commensalism		
	Rivalry between species for particular resources	
Mutualism		
	Transfers pollen between flowers	
	An animal that kills for food	
Seed disperser		

7 a Using the information given in this chapter and an atlas, predict the names of the ecosystems that occur in the areas labelled A–D on Figure 3.15.
   b Identify the rainfall and temperature ranges likely to occur in each area.

8 Suggest the possible effects on the biodiversity of an ecosystem if a new species is introduced.

FIGURE 3.15 Locations of ecosystems

Analysing

9 Elephant dung contains a great deal of fibrous matter, including seeds. Some plant species that elephants eat have evolved to produce seeds that have a coating of rind to protect them from the elephant's digestive juices. Unless these seeds have passed through the elephant's digestive system, they are unable to germinate. Analyse and explain the relationship described and use a visual medium for communicating your analysis.

10 Use Figure 3.16 to answer the following questions.

- **a** Identify the dominant species.
- **b** Calculate the percentage coverage of the dominant species.
- **c** Based on the information obtained from this plot, identify the name this environment would be classified as having.
- **d** Explain the limitations of using only one sample plot.
- **e** Suggest reasons for the differences in species distribution.

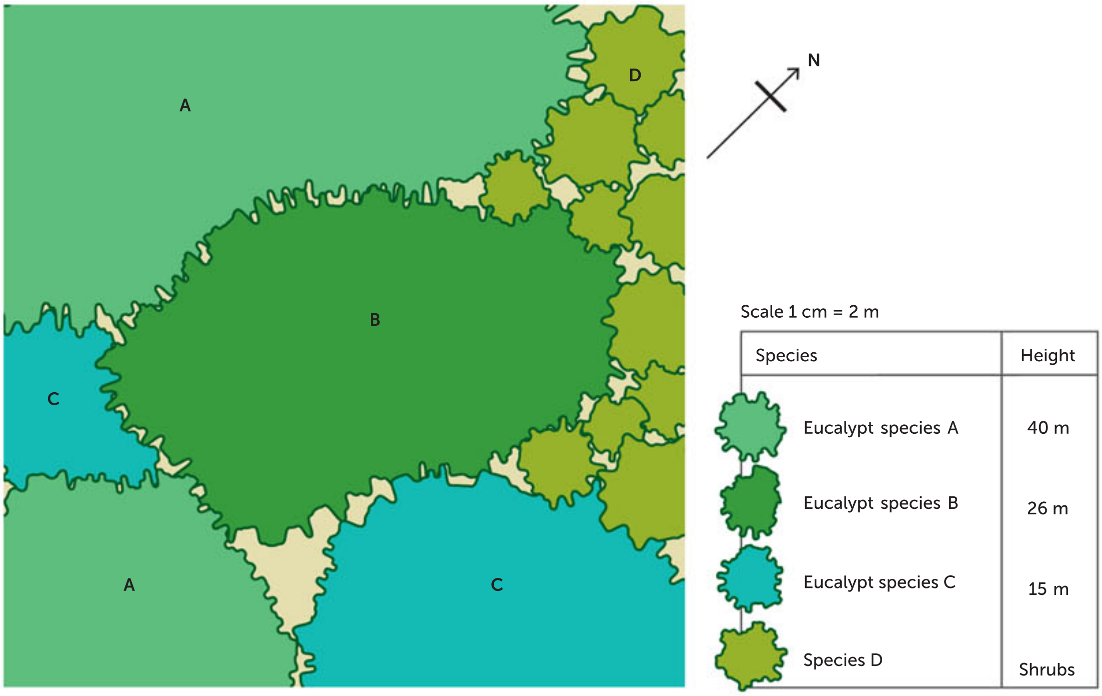

FIGURE 3.16 Surface map (aerial view) of sample plot

11 Use Figure 3.17 to answer the following questions.

- **a** List the temperature range and precipitation range for the ecosystems listed.
- **b** Which ecosystem has the largest temperature range?
- **c** Which ecosystem has the largest precipitation range?

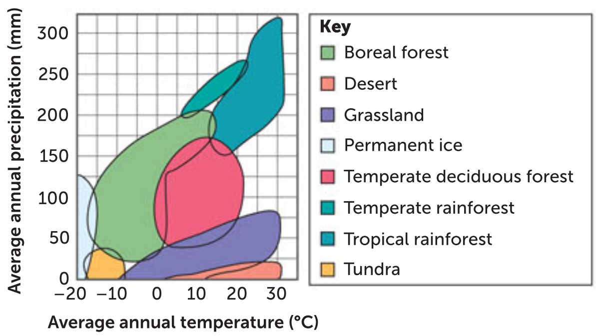

FIGURE 3.17 Climograph for some major ecosystems of North America

12 **a** Explain, using an example, why a prey population usually has a greater number of individuals than a predator population.

b Suggest a reason that a prey population may have fewer individuals than a predator population.

Evaluating

13 Evaluate this statement: 'Ecosystems are diverse and composed of varied habitats'.

Creating

14 Using the terms from the glossary, create a graphical organiser such as a concept map to summarise your understanding of the chapter.

Reflecting

15 Justify this statement: 'The world is a more diverse place because of the relationships found within ecosystems'.

PRACTICE EXAM QUESTIONS

1 Which of the following habitats would show the greatest daily temperature variation?

A A shallow coral reef
B An inland treeless scrub plain
C A large inland freshwater lake
D A tropical rainforest

2 The woylie is a small, rare marsupial that is endemic to Australia. It was abundant in the 19th century, but became almost extinct after the introduction of the red fox in the 1920s. It is currently critically endangered. In the past, it was found in temperate locations near Margaret River, but in 2010 it was only found in limited areas such as an ecosystem south of Perth that has a widely spaced canopy cover of 10–30% with well-developed shrubs and grasses. During the 19th century it was found in a wider array of ecosystems, including those with a fairly open canopy cover of 30–70%, good understorey and ground cover.

Which of the following correctly lists the described ecosystems the woylie inhabited before and after the introduction of the red fox?

	BEFORE THE RED FOX	AFTER THE RED FOX
A	Desert	Alpine
B	Woodlands	Open dry sclerophyll forests
C	Grassland	Open dry sclerophyll forests
D	Closed tropical rainforest	Dryandra woodland

3 Copy and complete Table 3.7 to discuss the difference in three named abiotic features in aquatic and terrestrial environments. (3 marks)

TABLE 3.7 Abiotic factors in aquatic and terrestrial environments

ABIOTIC FACTOR	AQUATIC ENVIRONMENT	TERRESTRIAL ENVIRONMENT
Temperature variation		
Availability of gases		
Availability of light		

4 Compare and contrast interspecific and intraspecific competition. (2 marks)

5 Identify, describe and provide a detailed example for each of five relationships that could exist in an ecological community. (10 marks)

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4 ENERGY AND MATTER IN ECOSYSTEMS

CHAPTER 4 CONTENT

STARTER QUESTIONS

1 Can you describe what biogeochemical cycling is?
2 Are there keystone species in local Western Australian food webs?
3 Should scientists concentrate their efforts on single-species conservation or community conservation?
4 Can you describe the ecological niche of your favourite animal?

SCIENCE UNDERSTANDING

» the biotic components of an ecosystem transfer and transform energy, originating primarily from the Sun, and matter to produce biomass; and interact with abiotic components to facilitate biogeochemical cycling, including carbon and nitrogen cycling; these interactions can be represented using food webs and biomass pyramids
» species or populations, including those of microorganisms, fill specific ecological niches; the competitive exclusion principle postulates that no two species can occupy the same niche in the same environment for an extended period of time
» keystone species play a critical role in maintaining the structure of the community; the impact of a reduction in numbers or the disappearance of keystone species on an ecosystem is greater than would be expected, based on their relative abundance or total biomass

SCIENCE AS A HUMAN ENDEAVOUR

» keystone species theory has informed many conservation strategies. However, there are differing views about the effectiveness of single-species conservation in maintaining complex ecosystem dynamics

School Curriculum and Standards Authority (2017). Biology ATAR course: Year 11 syllabus: Science inquiry skills.

James Vodicka

4.1 ENERGY AND MATTER

Wherever life exists, in the deep-sea trenches kilometres below the surface of the oceans, in the geothermal springs of New Zealand or in the Antarctic, it depends on a **source** of energy and a supply of matter. Ecosystems across the world are linked in networks of energy and nutrient (matter) exchange between living things (**biotic** components) and their non-living surroundings (**abiotic** components).

Matter consists of atoms and is anything that takes up space and has mass. It makes up and maintains complex structures throughout the universe. The atomic building blocks interact with each other to create organic substances (which almost always contain carbon–hydrogen bonds; e.g. table sugar $C_{12}H_{22}O_{11}$) and inorganic substances (which don't contain carbon–hydrogen bonds; e.g. table salt, NaCl). Earth's matter has been cycling for 4.5 billion years. In contrast, energy input is required by ecosystems to continue to function. **Energy** is the capacity to cause change, particularly to do work. It can exist in a variety of forms, such as heat, light and chemical, and can be transformed from one form to another. It cannot be created or destroyed, but only converted from one form to another.

Anna Grigorjeva / Alamy Stock Photo

FIGURE 4.1 The energy from sunlight is transformed into chemical energy in biomass.

Key concept

Energy is essential for a system to do work. Unlike matter, energy cannot be recycled in an ecosystem, but must be supplied continuously.

Energy sources

The Sun provides most of Earth's energy in a form of electromagnetic radiation that is known as **solar energy**. Energy in the form of heat energy warms our planet's surface, and this in turn warms the atmosphere, driving all the processes such as tides, weather systems and ocean currents. A **biogeochemical cycle** refers to the pathway of matter through the living components (organisms) and non-living components (such as soils, rocks, water and the atmosphere) of an ecosystem. It involves the chemical interactions in surface reservoirs such as the atmosphere, hydrosphere, lithosphere and biosphere, whereas a **geochemical** cycle refers to the chemical interactions that exist in crustal and subcrustal reservoirs, such as the deep Earth and lithosphere (crust). The amount of energy in sunlight depends on the wavelength of the incoming light. Because the Sun **emits** light in the visible spectrum (all the colours we see), infrared radiation and ultraviolet light, the associated energy is very large.

A small percentage of solar energy is captured by plants and **transformed** into a form that can

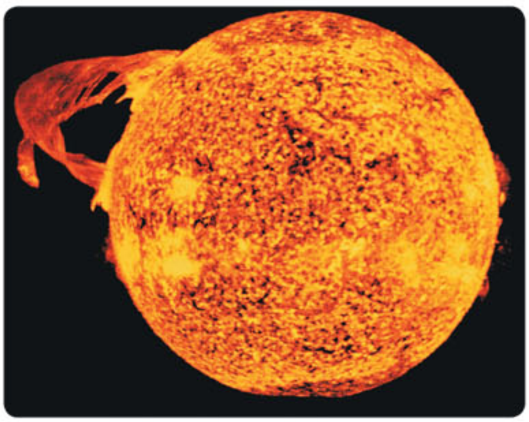

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FIGURE 4.2 The Sun provides energy to Earth as heat and light. It is the major source of energy that drives the diverse ecosystems on Earth.

cycle through an ecosystem. Plants transform light energy into chemical energy by the process of photosynthesis. The chemical energy stored in plants is **transferred** to consumers, which then transform it into other forms of energy for storage and use during respiration and movement. The stored energy is then available for higher-order consumers.

A small proportion of the energy used by ecosystems comes from geothermal energy, which is heat generated from Earth's core. Some of this extreme heat escapes to generate geothermal activity on Earth's surface and in the ocean. The Wai-O-Tapu geothermal reserve, near Rotorua in New Zealand, has numerous hot springs and geysers (Figure 4.3). These environments are home to diverse communities that can tolerate the lack of sunlight, high temperatures, extreme pressures and acidity. Large communities of chemotrophic single-celled organisms (Archaea) use simple inorganic chemical compounds that contain sulfur and iron as their source of energy and matter. Chemotrophic bacteria have also been found in the deep-sea trenches of the Pacific Ocean, where despite the extreme conditions, they provide energy to support colonies of giant tube worms.


Getty Images/Christopher Chan

FIGURE 4.3 Hydrothermal vents and geothermal regions, such as this one in Wai-O-Tapu geothermal reserve, New Zealand, sustain ecosystems containing organisms that thrive in extreme environmental conditions.

Question set 4.1

REMEMBERING

1 Recall the original source of energy for the majority of ecosystems of organisms on Earth.

2 Define:

- a matter
- b biogeochemical cycling.

UNDERSTANDING

3 Distinguish between energy that is transformed and energy that is transferred.

4 Is it possible for ecosystems to survive on geothermal energy instead of sunlight? If so, provide an example.

4.2 BIOTIC COMPONENTS OF ECOSYSTEMS TRANSFER AND TRANSFORM ENERGY AND MATTER

Light energy enters an ecosystem via **producers** such as plants and algae, which are organisms that have evolved the features to manufacture food in the form of organic matter using the energy in sunlight and simple inorganic substances. Producers begin all food chains, and all other organisms in an ecosystem rely on producers for energy, either directly or indirectly. Producers are also known as **autotrophs**, meaning 'self-feeders' ('auto' means self and 'troph' refers to feeding). They are able to synthesise organic compounds (e.g. nucleic acids, lipids, proteins and carbohydrates) from inorganic raw materials. Energy is stored in the chemical bonds in the organic compounds and is released when the chemical bonds are broken.

The biochemical process that producers use to transform the energy in sunlight into chemical energy is called photosynthesis. Plant cells have specialised organelles called chloroplasts that contain the pigment chlorophyll, which enables photosynthesis to occur. This pigment is able to absorb most of the wavelengths in sunlight. Photosynthesis in green plants makes greatest use of the red and blue wavelengths of light to produce carbohydrates. The essential inorganic raw ingredients for synthesis of **carbohydrate** (an organic food) are water and carbon dioxide, and they are usually in plentiful supply.

Photosynthesis can be represented as:

$$\text{Carbon dioxide + water} \xrightarrow[\text{chlorophyll}]{\text{light energy}} \text{glucose + oxygen}$$

FIGURE 4.4 Photosynthetic autotrophs, including **a** algae, **b** plants and **c** cyanobacteria, transform energy from sunlight and store it as chemical energy in the bonds of glucose.

Organisms such as humans are **heterotrophs** – living things that cannot synthesise their own organic compounds (food) from inorganic materials. Heterotrophs depend on autotrophs directly or indirectly for their energy needs and their supply of matter. They acquire energy and matter by consuming other organisms, and are therefore also called **consumers**. Consumers include animals (Figure 4.5), fungi and many kinds of bacteria.

FIGURE 4.5 A lion is an example of a heterotroph that consumes large prey.

Producers, biomass and productivity

Plants produce chemical energy from light energy using photosynthesis. The chemical energy stored in plants as organic matter can be measured and is called biomass. **Biomass** is the total mass of biological matter (living or dead) in a given area, at the time of measurement, that can be used as an energy source. Since living biological matter contains water, an inorganic substance that does not contain energy, biomass is normally expressed as the dry weight per unit area, measured, for example, in grams per metre squared (g m^{-2}). The percentage of energy entering an ecosystem that is incorporated into biomass is known as productivity. The percentage of energy that is incorporated into biomass by the primary producers in an ecosystem is known as the primary productivity.

Not all producers make the same amount of biomass per unit of time. How well a producer converts light energy into carbohydrates during photosynthesis is referred to as its **photosynthetic efficiency**. This depends on the availability of raw materials and sunlight. Temperature influences the rate at which chemical reactions occur, so prevailing environmental temperatures can affect this efficiency as well. Therefore, the production of organic materials from the glucose made in photosynthesis is greater in some seasons compared with others, and also varies according to latitude and altitude. For example, tropical forests cover only about 4% of Earth's surface but contribute about 25% of the world's yearly **gross primary productivity (GPP)** of organic matter. GPP is the total amount of energy that flows through the producers. It is measured in kilojoules of energy per square metre per year (kJ m^{-2} $year^{-1}$).

The oceans cover a large area of Earth's surface. Ocean ecosystems depend on producers, such as phytoplankton, which trap huge amounts of light energy. This in turn results in vast amounts of organic material for higher-order consumers. However, light does not penetrate deep water and nutrients are not freely available; therefore, phytoplankton must be highly efficient producers of energy in order to transform the available energy for the ocean ecosystem.

Not all of the material made by producers is available to consumers for food to meet their energy requirements. Some of this material is used by the producers themselves for their own energy needs. The amount of energy available to consumers is the total amount of energy transformed by producers (GPP) minus the amount of energy used by producers for cellular respiration. This remaining amount of energy that is available to consumers is called the **net primary productivity (NPP)**.

NPP for an ecosystem can be calculated if we know the amount of biomass produced (in grams) over an area (in metres squared) in a given time frame, usually a year. It is important to understand that this is a rate of change of biomass or energy over one year and it must be expressed in the appropriate units, such as:

- mass: gm^{-2} $year^{-1}$
- energy: kJ m^{-2} $year^{-1}$.

NPP can be calculated using the following equation:

Net production = gross production − energy used in respiration

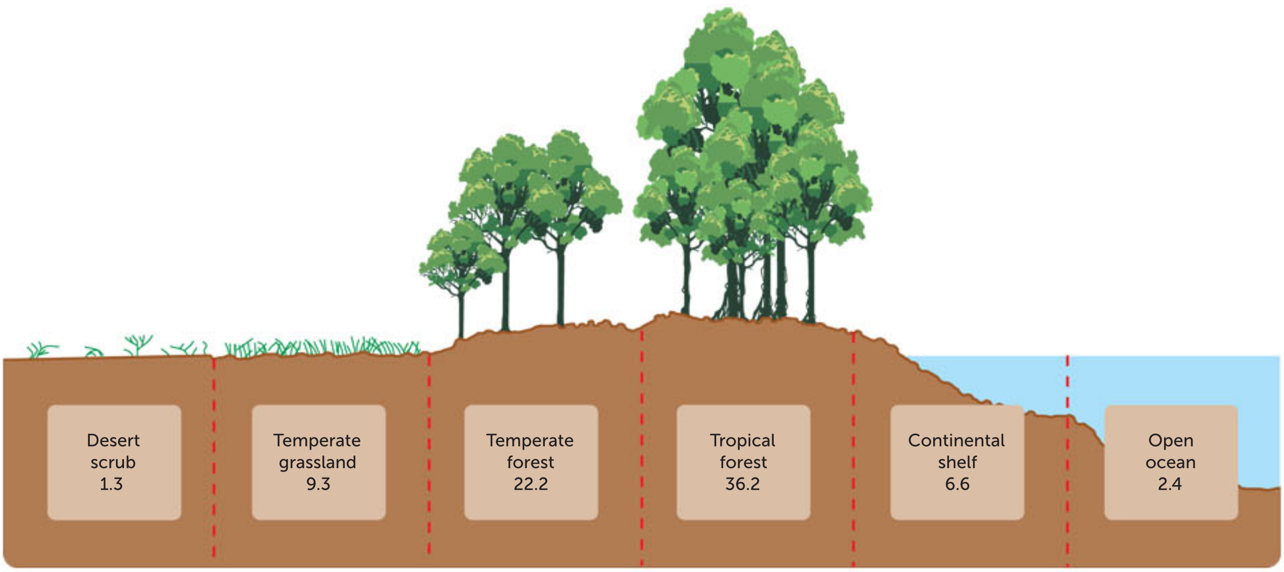

FIGURE 4.6 Different ecosystems have different primary productivity rates. The numbers refer to the rate of chemical energy produced per square metre per year (i.e. kJ m^{-2} $year^{-1}$).

4.1 APPLICATION

Super kelp!

Giant kelp, such as those found off the east coast of Tasmania, are among the fastest-growing photosynthetic species on Earth and in favourable conditions can grow more than 30 cm per day. Unfortunately, in the past few decades kelp forests around Australia have been stressed by the warming of the ocean and pollution. Scientists working on their conservation hope the kelp that have survived the warming waters will continue to grow and spread, replacing the kelp that has died.

Consumers and energy flow

A consumer is an organism that depends on other organisms for its nutrients and energy requirements. Many consumers are herbivores, animals that feed on plants. Herbivores, including grazing animals, consume large amounts of plant material. They extract energy stored in chemical bonds by a process called **cellular respiration**. Cellular respiration is a metabolic process. It is the chemical breakdown of organic matter in order to release energy.

Cellular respiration can be represented as:

Glucose + oxygen ⟶ carbon dioxide + water (+ energy in the form of ATP)

It is important to note that, although only producers perform photosynthesis, both producers *and* consumers perform cellular respiration. This is because the cells of producers and consumers need a constant supply of energy in order to carry out their functions.

Herbivores have enzymes that can digest cellulose, the major component of the plant cell wall. These enzymes break the chemical bond between individual glucose molecules making up the cellulose, which is the crucial first step in a herbivore's ability to extract the Sun's energy from plants. Cellular respiration involves a series of chemical reactions that transform the energy into a usable form. This involves the extraction of the energy stored in the bonds of ATP (adenosine triphosphate). This molecule provides cells with the energy they need to perform their many functions.

When herbivores feed, the energy transfer from plant to herbivore is not 100% efficient. Not all of the plant material is eaten, not all the material is absorbed in the gut, and some of the energy that is passed is lost in movement and respiration. The same is true for carnivores eating prey animals. Only about 10% of the energy in producers is transferred to herbivores and a similarly low percentage of energy is passed from herbivores to carnivores.

Question set 4.2

REMEMBERING

1 Identify the groups of organisms that are able to photosynthesise and explain how the structures they possess enable them to do this.

2 Copy and complete Table 4.1 to compare producers and consumers.

TABLE 4.1 A comparison of producers and consumers

	PERFORMS PHOTOSYNTHESIS	PERFORMS RESPIRATION	AUTOTROPIC OR HETEROTROPHIC
Producer			
Consumer			

UNDERSTANDING

3 Producers are sometimes referred to as 'energy converters'.

a Explain what this means in your own words.

b Explain the significance of producers to an ecosystem.

4 Distinguish between GPP and NPP.

4.3 ANALYSING ENERGY AND MATTER TRANSFER

Ecologists use **models** to study how biotic and abiotic factors interact within communities, and the effect these interactions have on the ecosystem as a whole. By representing an ecosystem with a simplified model, scientists can limit the number of dependent and independent variables they analyse to those considered relevant or of critical importance to the system. This allows scientists to make reliable predictions about what might happen in the real system if adverse changes were to occur. This predictive power means that ecologists can use models to know when to intervene to prevent an ecological catastrophe, such as an animal becoming extinct through loss of habitat or food.

Food chains

Food chains and **food webs** are examples of qualitative, predictive models that allow ecologists to monitor the sustainability of feeding relationships in an ecosystem (Figure 4.7). Each organism in a food chain obtains its energy from the preceding one. The position an organism occupies in a food chain or web is called its **trophic level**. The arrows in a food chain or web represent the flow of energy from one trophic level to the next and link species according to who eats whom.

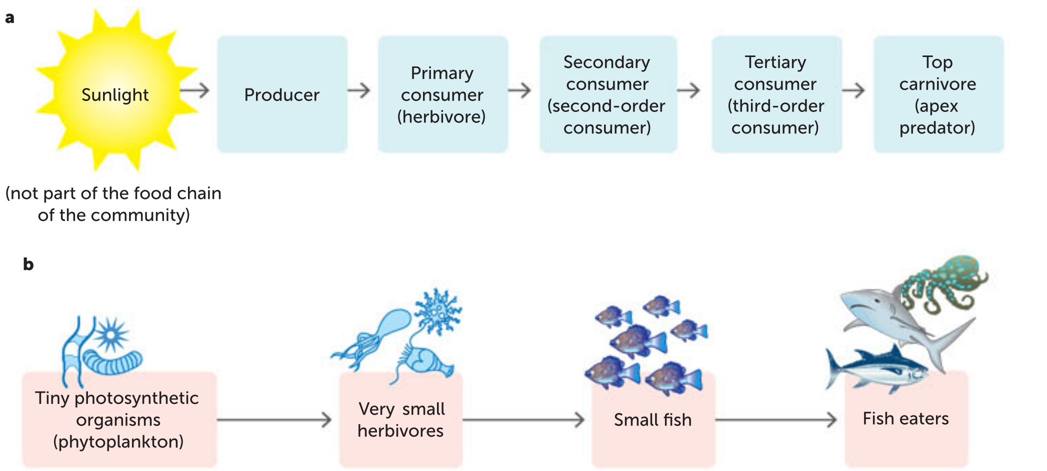

FIGURE 4.7 a A generalised food chain; **b** a model of a food chain for an ocean ecosystem

Plants are autotrophs: they make their own food by transforming light energy from the Sun during photosynthesis. The potential chemical energy stored in plants is the beginning of the food chain. When **primary consumers** (**herbivores**; also called first-order consumers) feed on producers (plants), energy is transferred up the food chain. **Carnivores** and **omnivores** are **secondary consumers** (or second-order consumers). When secondary consumers feed on primary consumers, stored energy is again transferred up the food chain. The food chain can therefore be thought of as an energy chain. At each trophic level or link in the chain, a proportion of the available energy is used during essential biological processes and lost due to inefficiencies during transfer. Some energy is lost from the food chain as chemical energy in organic wastes of dead plant and animal tissues, collectively called **detritus**. The remaining energy is transferred to the next level.

The **top consumers** are not preyed upon but they do die of old age, disease or injury. Energy can then be transferred from the top consumers to scavengers and detritivores. **Scavengers** are animals that feed on the dead remains of other animals. **Detritivores** feed on the detritus and help speed up the process of decay by breaking it down into smaller pieces. **Decomposers** then continue this process by breaking down the complex organic material into simpler inorganic material and returning these nutrients to the soil or water.

TABLE 4.2 Roles of consumers in ecosystems

TYPE OF CONSUMER	ROLE IN ECOSYSTEM	EXAMPLES	
Primary consumers (herbivores)	Feed directly on producers	Wombats, kangaroos, sheep, many insects	 Shutterstock.com/Mike Charles
Secondary consumers (carnivores)	Feed on primary consumers	Dingoes, kookaburras, fur seals, platypuses	 Shutterstock.com/Johan larson
Top consumers (sometimes called apex predators)	Feed on secondary consumers	Australian wedge-tailed eagles, sharks	 Shutterstock.com/ Stubblefield Photography
Omnivores	Feed on both plants and animals	Foxes, humans, bandicoots, bilbies	 Shutterstock.com/Tom Wang
Scavengers	Feed on dead remains of other organisms	Foxes, Tasmanian devils, ravens, dingoes, goannas, quolls	 Shutterstock.com
Detritivores	Feed on dead or decaying organic remains and wastes. They are relatively large organisms that help speed up decay by breaking down large pieces of detritus into smaller pieces, increasing the surface area for decomposers to work more efficiently	Dung beetles, maggots, earthworms, yabbies	 Shutterstock.com/john michael evan potter
Decomposers	Decompose (break down) complex organic molecules into simpler inorganic forms and return nutrients to the soil or water	Fungi, some bacteria	 Shutterstock.com/Steve Bower

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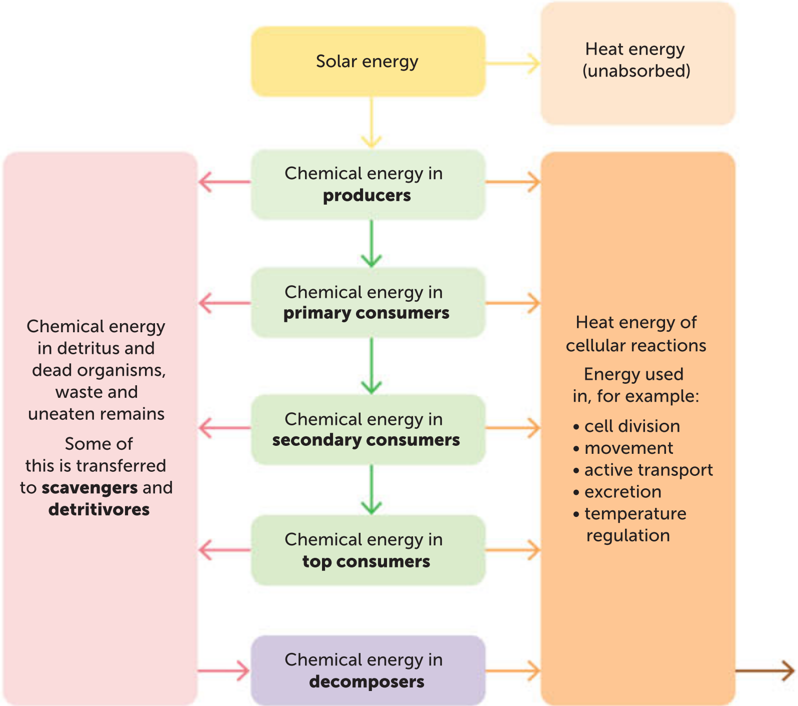


FIGURE 4.8 Energy is transferred between trophic levels in food chains, but at each level, some is lost.

Energy loss in food chains

Progressively less energy is available at each trophic level as you move up a food chain. The percentage of the energy at one trophic level that is transferred to the next trophic level is referred to as **trophic efficiency**. Some of the highest trophic efficiencies are found in the ocean. For example, the trophic efficiencies of **zooplankton** feeding on **phytoplankton** can be more than 40%. It is important to monitor what is happening to populations of these and other organisms that form the links in the food chains.

A useful rule in ecology is that, on average, about 10% of the energy at one trophic level is passed on to the next level. The remaining 90% is lost to the surroundings as heat energy and chemical energy in wastes.

Key concept

The 10% rule in ecology states that, on average, only about 10% of the energy at one trophic level is passed on to the next level. The remaining 90% is lost to the surroundings as heat energy and chemical energy in wastes.

If populations of lower-order consumers are reduced, the small population of top consumers is at risk of being drastically affected or even wiped out. For example, the population of eagles in an ecosystem is much smaller than the populations of rabbits and small native animals on which they feed. Reductions in numbers of these prey populations significantly affect the eagle's ability to obtain its energy requirements.

Despite the 10% rule, animals differ considerably in how efficiently they use the energy from their food. The efficiency of energy transfer can vary from less than 0.1% to well over 10%. For example, insects do not use energy to keep their bodies warm. Therefore, more of the energy they derive from feeding is available to be passed on to the next trophic level. In contrast, kangaroos maintain a warm body temperature and they use considerable energy to do this. The loss of energy at each link in a food chain limits the number of trophic levels it can have (Figures 4.9 and 4.10).

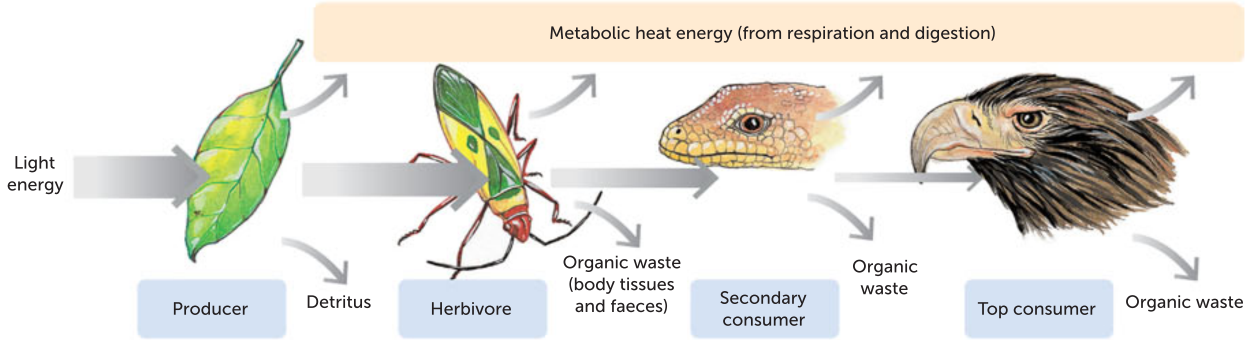


FIGURE 4.9 Energy losses are inevitable as energy moves through any food system. The size of these losses depends on how efficiently energy passes from one trophic level to the next.

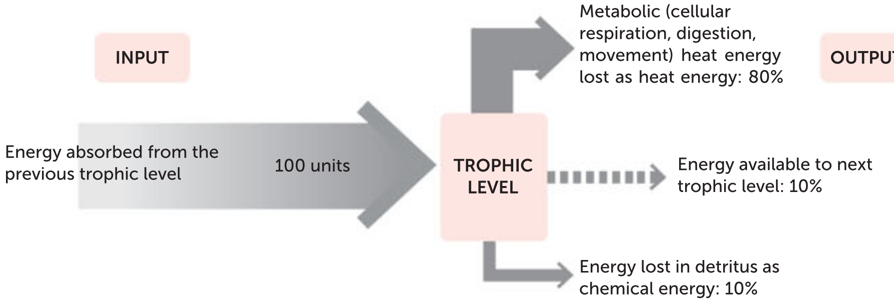


FIGURE 4.10 Trophic efficiency describes how much energy is available from one level to the next within a food chain. An estimate of the average amount available to successive levels is 10%, which means that organisms higher up the food chain must consume more food to meet their energy needs.

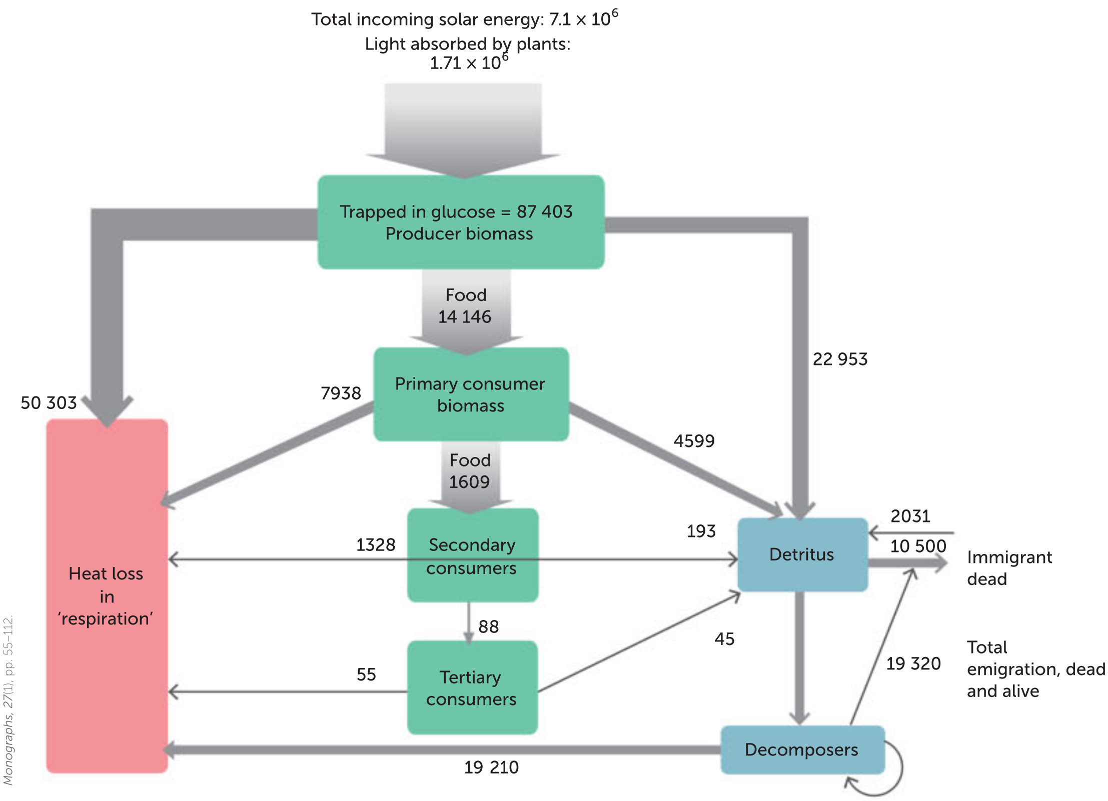
Koalas are efficient

4.2 APPLICATION

Eucalypt leaves are very low in energy. Koalas are adapted to thrive on this low-energy food. Koalas are efficient energy conservers, using about 50% less energy to stay alive than most placental mammals of similar size.

Quantifying trophic efficiency

The first study to quantify trophic efficiency was undertaken by H.T. Odum in Florida, over 4 years in the mid-1950s. The results of his work are summarised in Figure 4.11 (page 112). This model is still used by ecologists to calculate the trophic efficiencies of a variety of ecosystems. The units used are kilojoules of energy per square metre per year (kJ m^{-2} $year^{-1}$). As shown in Figure 4.11, energy trapped from the Sun and stored by plants in carbohydrates is used up by the fourth trophic level (tertiary consumers) and so this limits the number of links in the chain. In other words, there is not enough energy to support a fifth trophic level because by this stage the energy input equals the total energy output.



Odum, H. T. (1957) Tropic Structure and Productivity in the Silver Springs Community, Florida. *Ecological Monographs*, 27(1), pp. 55–112.

FIGURE 4.11 The movement of energy (in kJ m^{-2} $year^{-1}$) shows the trophic efficiency in a biological community from Silver Springs, Florida.

Food webs are integrated food chains

Simple food chains are rare. Most species depend on more than one kind of organism for their food. A herbivore as a primary consumer will feed on a number of species of plants and, in turn, will be eaten by several different kinds of carnivores. These secondary consumers are eaten, in turn, by other carnivores. Such networks of energy and matter form food webs. A food web is a group of food chains that are linked together, showing the interactions between food chains within a community. The feature that distinguishes a food chain from a food web is that an organism can occupy different trophic levels in different food chains. For example, it can be a secondary consumer or a tertiary consumer, like the kookaburra in Figure 4.12. In other words, food webs represent the dynamic interactions between organisms in an ecosystem.

Humans are omnivorous consumers and can occupy more than one trophic level in food chains. When they are being primary consumers, humans can obtain more of the energy available in plants, because they are not exposed to the energy losses that occur by eating foods higher up the food chain. When humans consume livestock, they only obtain 1% of the total energy that is available in producers.

Members of populations of different species move in and out of different ecosystems, so an organism may be part of one food chain or web at one time but not at another time. For example, insects, birds and seeds commonly move between ecosystems wherever their needs are met. On a larger scale, migration of whole populations of animals such as albatross, mutton-birds, salmon or moths results in great changes to the pathways of energy and matter. Phytoplankton is a producer and a fundamental food source for marine animals. Phytoplankton can be carried great distances in ocean currents. As producers, organisms in the next trophic level, such as whales, migrate along with this food source.

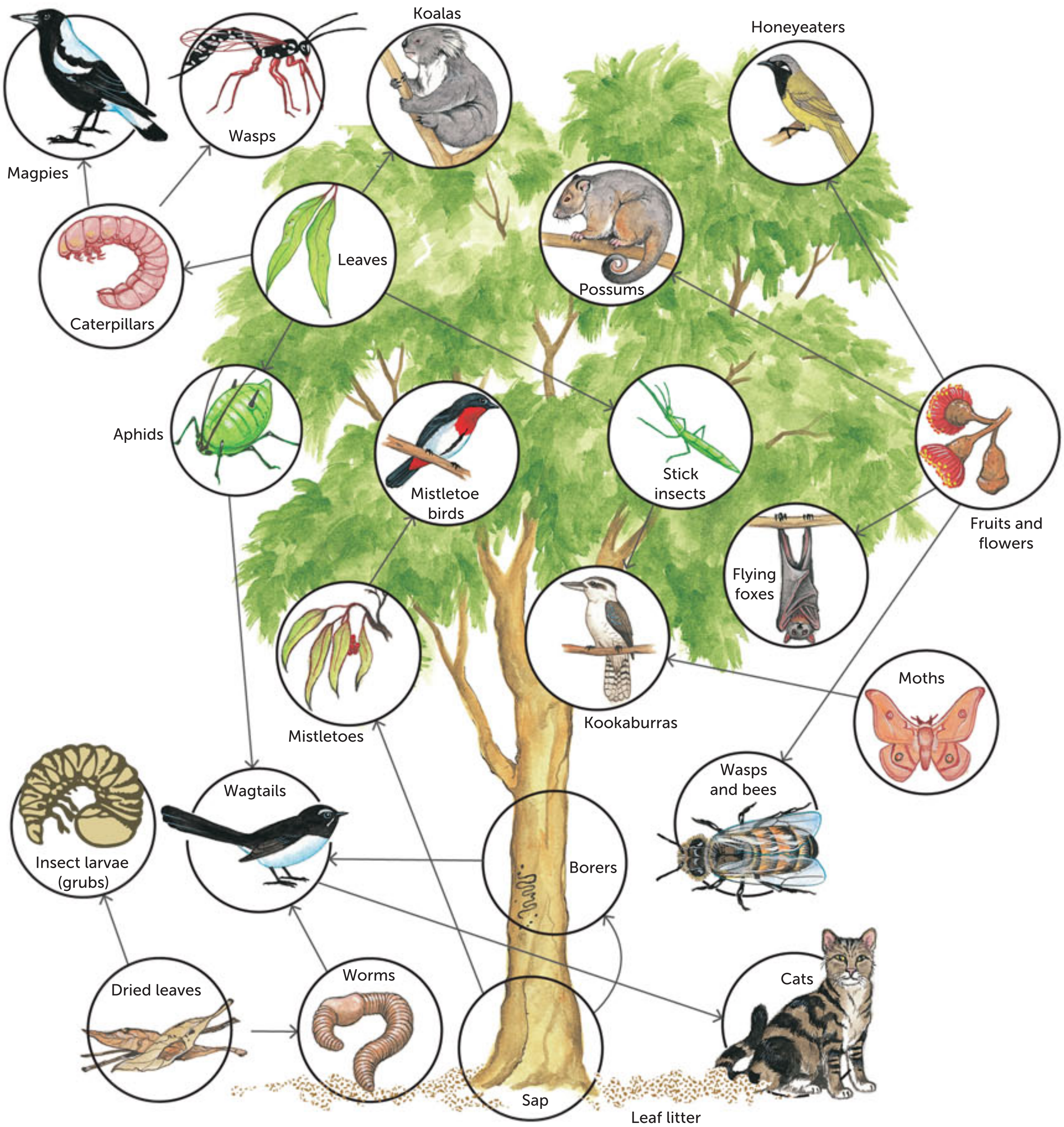


FIGURE 4.12 A food web in an Australian forest ecosystem

Question set 4.3

REMEMBERING

1 Describe how producers are vital to a community.
2 Describe the concept of food chains and food webs.
3 Match the terms on the left with the definitions on the right.

a producers	i herbivores, carnivores, omnivores
b consumers	ii break down organic remains and products
c decomposers	iii photosynthetic autotrophs

4 Define the following terms:
   a scavengers
   b detritivores
   c decomposers.

5 Analyse the food web in Figure 4.13 and name an organism that occupies two different trophic levels.

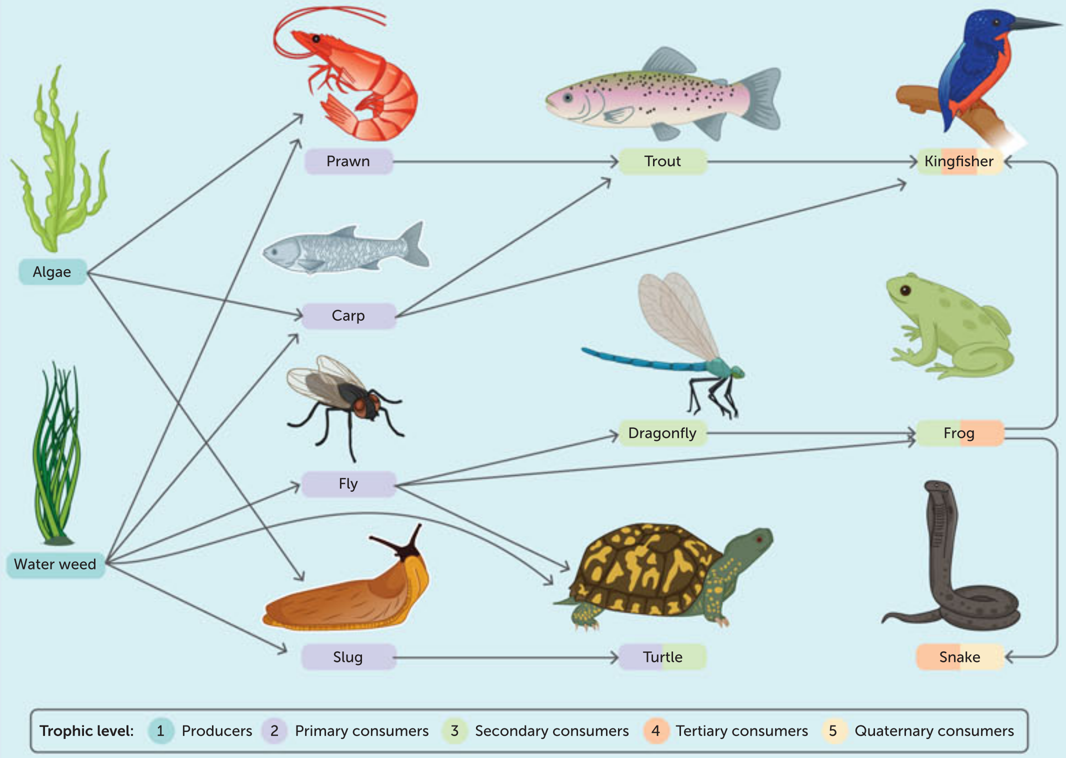


FIGURE 4.13 A semi-aquatic food web

6 Define 'detritus'.

UNDERSTANDING

7 Distinguish between:
   a a food chain and a food web
   b a herbivore and a carnivore
   c a second-order consumer and a third-order consumer.

8 Predict what would happen to the food web in Figure 4.13 if a member of one trophic level was eliminated.

4.4 ECOLOGICAL PYRAMIDS: ENERGY FLOW AND CHANGE

Ecological pyramids are diagrams that illustrate the relative levels of one of three different factors present at each trophic level in an ecosystem. The three types of ecological pyramids provide quantitative relationships between trophic levels of a community in terms of:

- the *numbers* of organisms at each level
- the biomass (the *amount* of organic matter in terms of mass) present
- the *amount* of energy transferred from one trophic level to the next.

Pyramids of numbers

A so-called 'typical' food chain tends to have a drop in the number of organisms at each level. This is represented as a **pyramid of numbers**. Figure 4.14 shows this progressive fall in numbers at each trophic level.

Pyramids of numbers may not always have an apex representing higher trophic levels. For example, a single very large producer, such as a eucalypt tree, may support a large number of primary consumers. Numerous organisms along the food chain depend on the eucalypt, including the larvae of sawflies; cup moths; and wattlebirds, which feed on nectar, pollen, fruits and insects. Beetles and silvereyes feed on native fruits and berries in addition to insects. In these cases, an inverted pyramid of numbers results.

Inverted pyramids of numbers can also result when communities contain parasites. Imagine a native mammal, such as a bandicoot or a wallaby, infested with ticks or fleas. These parasites are in the trophic level above these animals, yet their numbers are much greater. An example of an inverted pyramid of numbers is shown in Figure 4.15.

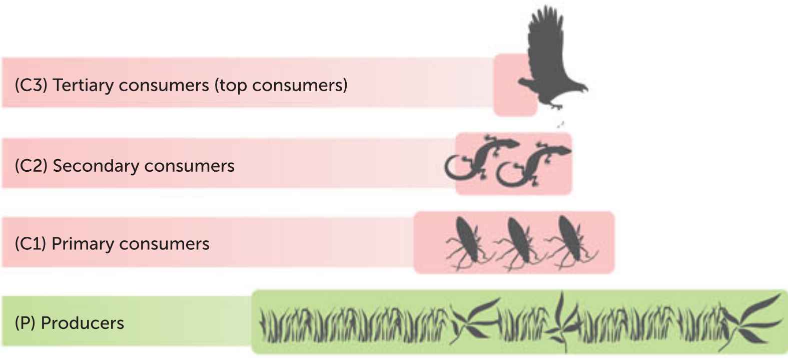


FIGURE 4.14 A pyramid of numbers in a grassland. The width of each rectangle indicates the relative numbers of organisms at each trophic level.

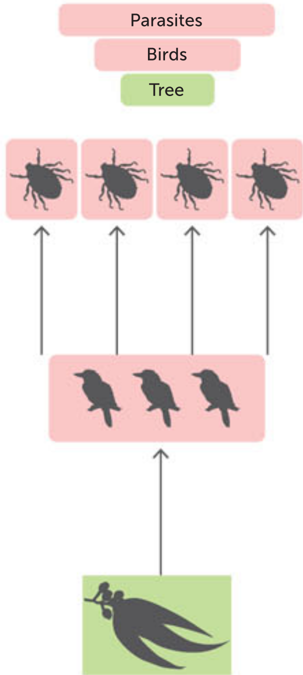


FIGURE 4.15 An inverted pyramid of numbers results when more organisms occupy the trophic level above the preceding level.

Pyramids of biomass

A **pyramid of biomass** is another type of ecological pyramid that can be constructed for a community. While the pyramid of numbers is only concerned with the *numbers* of organisms at each trophic level and their dependence on each other, the pyramid of biomass records the *total mass* (amount of dry organic matter) of organisms at each level. Measurements for such a pyramid can be made at one particular time or they can be calculated as rates (productivity) from measurement of dry mass in a given area for the duration of a year (e.g. g m^{-2} $year^{-1}$).

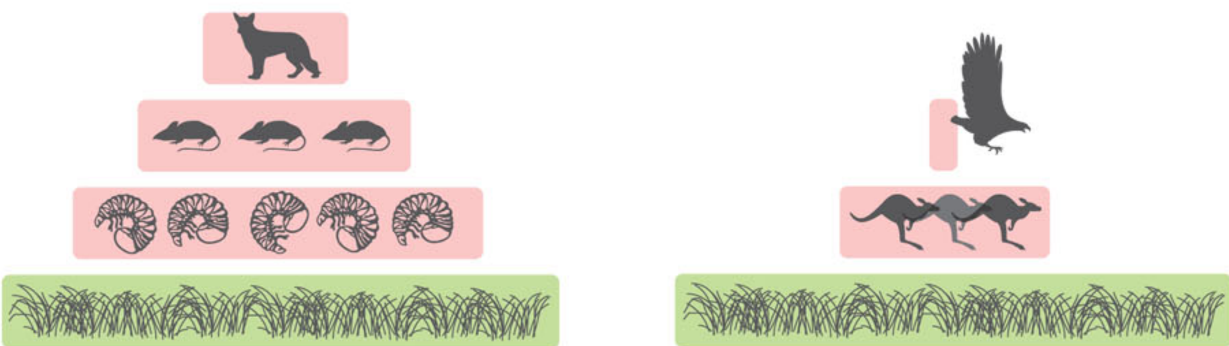


FIGURE 4.16 Pyramids of biomass. Note that at each successive trophic level, the amount of biomass decreases. The consumers must eat considerable amounts of food to fulfil their energy needs.

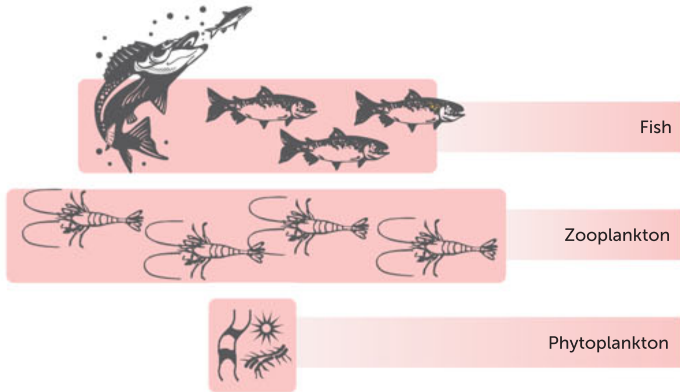


FIGURE 4.17 An inverted pyramid of biomass

Pyramids of biomass are almost always pyramidal in shape but, in certain circumstances, measurements may give an inverted pyramid. For instance, at particular times of the year, the biomass of the tiny herbivorous organisms that float in lakes and oceans (zooplankton) may exceed the biomass of the tiny photosynthetic organisms (phytoplankton) on which they feed (Figure 4.17). How can this be?

The organisms that make up the phytoplankton are smaller than the zooplankton that depend on them and they have shorter life cycles. As a result, at any one time, the biomass of the phytoplankton may be less than that of the zooplankton. This loss is made up for by the tremendous productivity and high levels of turnover of phytoplankton as they rapidly live their lives, reproduce and die.

Pyramids of energy

Although pyramids of numbers and biomass provide ecologists with useful information, to get a fuller understanding of what happens to energy transfer in communities, **pyramids of energy** are constructed (Figure 4.18).

Pyramids of energy are expressed in units of energy per area in a given time; for example, kilojoules per square metre per year (kJ m^{-2} $year^{-1}$). They show the rate at which energy is transferred from one trophic level to another. This dynamic view of a community contrasts with the 'snapshot' picture provided if energy is only measured at one time. Pyramids of energy allow ecologists to describe the rate of energy transfer in a community. This allows them to make predictions about whether a community can be sustained and what impact any changes to rates of energy transfer will have on the community.

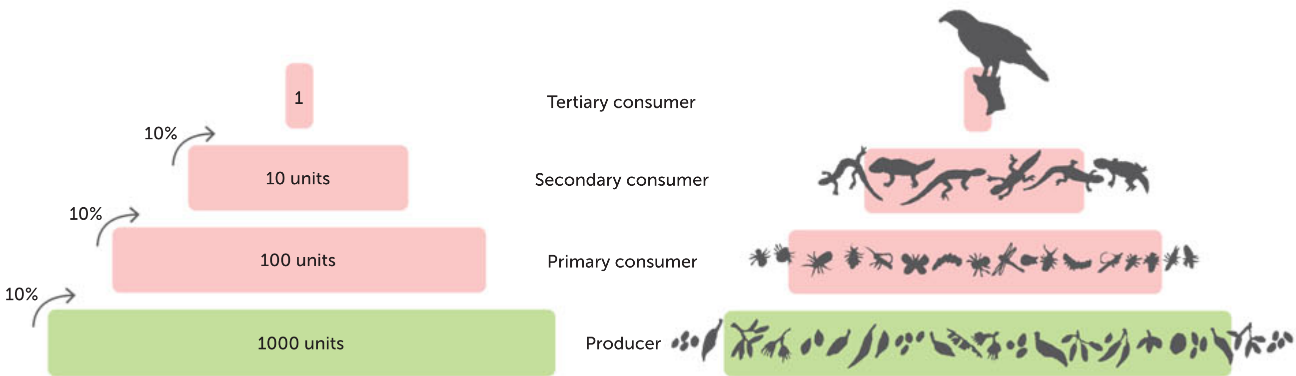


FIGURE 4.18 A pyramid of energy shows the rate of energy transfer through successive trophic levels. The pyramids shown here are not drawn to scale. The organisms at the top of the food chain receive only a small amount of the total energy stored by producers. This ultimately limits the number of possible trophic levels.

As we have seen, only some of the energy stored in a trophic level is transferred to the next trophic level (on average, 10%), so pyramids of energy can never be inverted in the way that pyramids of numbers or biomass sometimes are.

Drawing pyramids of energy

1 The bottom level should always represent a producer.
2 Subsequent levels should be labelled primary consumer, secondary consumer and tertiary consumer.
3 As far as possible, each trophic level should be drawn to scale. Unless you have alternative data, measure one-tenth the length of the preceding trophic level (this represents the average energy transfer efficiency of 10%).
4 Use labelled arrows to indicate energy leaving each trophic level in the form of heat.

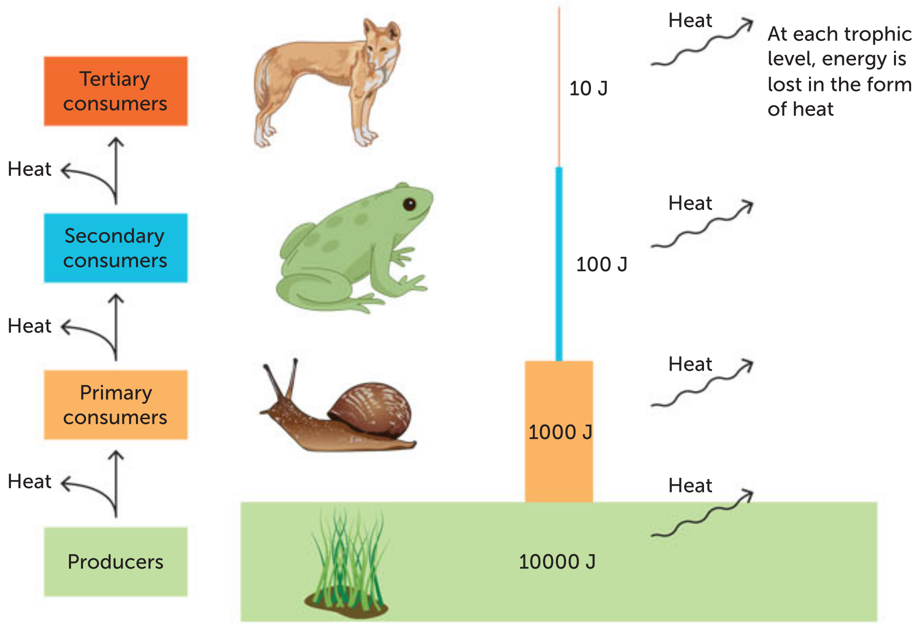


FIGURE 4.19 A pyramid of energy, showing the typical relationship between trophic levels

Question set 4.4

REMEMBERING

1 Describe a convenient way to quantify species within a food chain.
2 Describe the features of an inverted pyramid of biomass.

UNDERSTANDING

3 Explain with an example how you would construct a pyramid of energy.
4 Explain why a pyramid of numbers is not always pyramidal in shape.
5 Explain why pyramids of energy can never be inverted.

APPLYING

6 A forest clearing has 1 km^2 of thick grass and is home to a community of rabbits, foxes and hawks. In 1 year the grasses produce 150 000 kJ m^{-2} year^{-1} of energy. This food is consumed by the rabbits, which are prey for the foxes. The foxes are food for the hawks. Construct a pyramid of energy and calculate the energy extracted by the top consumer. Explain what happens to the energy as it is transferred between each level.
7 Grass → rabbit → snake → kookaburra → wedge-tailed eagle.
From the food chain listed above, construct a pyramid of biomass.

4.5 BIOGEOCHEMICAL CYCLING OF MATTER

In ecosystems, an important difference between energy and matter is that the Sun provides a constant, external supply of energy, while the total matter is a fixed resource and therefore matter must be recycled. Matter is made of atoms. Some of these atoms can be part of the atmosphere one day, part of a plant the next day, part of an animal a few days after and part of the atmosphere again the day after that.

Matter is cycled between the living (biotic or biological) components and the non-living (abiotic) components of an ecosystem (Figure 4.20). Abiotic components, which are also known as the geochemical part of Earth, include soils, rocks, water and the atmosphere. Given the interdependent relationships between these biotic and abiotic components, scientists describe the cycling of matter as biogeochemical cycling. A biogeochemical cycle is a model describing how chemical elements (e.g. nitrogen, carbon) or molecules (e.g. water) are transformed and stored in both biological and geological components of Earth's biosphere. These chemicals are recycled through biological food webs and through geological processes, such as weathering, erosion and volcanic activity. Biogeochemical cycles important to living things include the water, carbon, nitrogen, phosphorous and sulfur cycles. The water cycle is especially important, because water provides a habitat for a diverse range of living things and is the medium in which most biological reactions take place. In this course we focus on the carbon and nitrogen cycles.

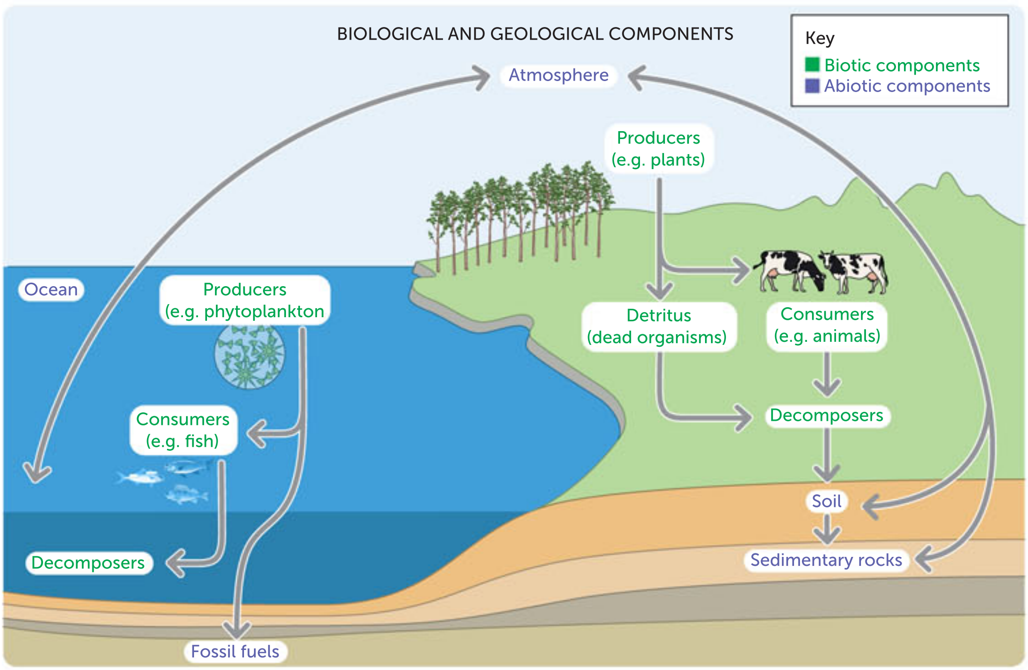


FIGURE 4.20 Matter cycles between the biotic components (such as food webs) and abiotic components (including soil, rock, water and atmosphere) of an ecosystem. This means matter moves through the biological and geological components of Earth as different chemical forms.

The carbon cycle

Carbon is constantly moving between different forms throughout the biosphere. It is stored in **reservoirs**, and it moves between these reservoirs through a variety of processes, including photosynthesis, the burning of fossil fuels and the release of breath from the lungs (respiration). The **carbon cycle** is the biogeochemical cycle by which carbon is exchanged between the biosphere, geosphere, hydrosphere and atmosphere of Earth.

In living things, carbon is the most abundant chemical **element**, closely followed by hydrogen, nitrogen and oxygen. Carbon is able to bond with many other elements and is present in an enormous variety of the biological molecules essential for life. Carbon is in all organic matter, including carbohydrates, lipids, proteins and nucleic acids, which are the chemical building blocks of cells and the source of their energy.

We noted earlier that energy is lost along food chains through the production of organic wastes such as faeces and dead tissues. However, the matter comprising this detritus is not lost from the biosphere. Detritivores, such as worms, feed on plant detritus and scavengers feed on the dead carcasses of animals. Decomposers break down complex organic matter into simple inorganic molecules (nutrients). In this way, the organic matter is recycled so that it may re-enter food chains via producers. Fungi and bacteria are common decomposers.

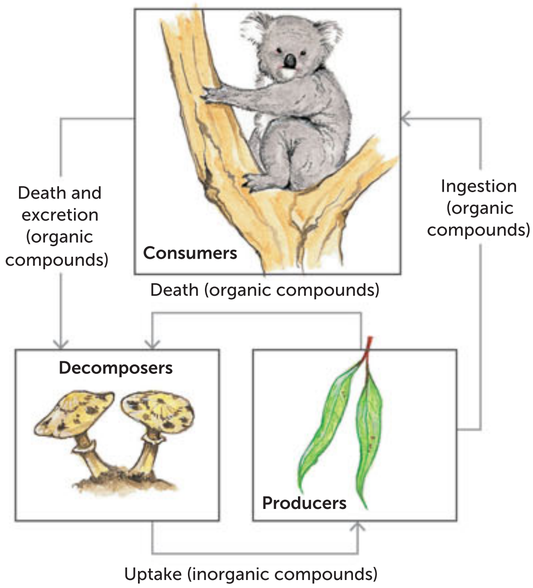


FIGURE 4.21 The relationship between producers, consumers and decomposers. Each member of the food chain can absorb organic compounds as the products, by-products or waste material of another member.

Carbon atoms circulate between the organic compounds of living things and their non-living surroundings through a number of pathways, and together these form the carbon cycle (Figure 4.22, page 120).

Carbon cycles through four major reservoirs, which are interconnected by pathways or processes. The reservoirs are the atmosphere, the terrestrial biosphere (which usually includes freshwater systems and non-living organic material, such as soil), the oceans (which includes dissolved inorganic carbon, and living and dead marine biota) and the sediments (which includes fossil fuels). Some of these reservoirs, such as plants and oceans, act as **carbon sinks** because they absorb and store more carbon than they release.

The carbon cycle is unique among nutrient cycles because it does not necessarily involve decomposers. Autotrophs take in carbon as carbon dioxide gas from the atmosphere and carbon dioxide is given out by all organisms as a result of cellular respiration.

As a result of slow geological processes, organisms can become fossil fuels, such as peat, coal, oil and gases derived from them. Carbon is an essential element in fossil fuels, which are of great economic value to humans, but the burning of fossil fuels is resulting in the rapid increase in carbon dioxide in our atmosphere.

In the past, the amount of carbon dioxide in the atmosphere was relatively stable, largely because of a balance between photosynthesis, which withdraws carbon dioxide from the atmosphere, and cellular respiration and combustion, which add carbon dioxide to the atmosphere. Scientists have shown that the level of carbon dioxide in the atmosphere has risen considerably during the last 200 years. Humans use large amounts of fossil fuels for energy, and their combustion releases carbon dioxide, producing a surplus that has disrupted the natural balance. Plants are photosynthesising more rapidly because more carbon dioxide is available. However, the excess carbon dioxide is not being taken in fast enough because of rapid deforestation over the last century. In addition, increased ocean temperatures have also affected the cycling of carbon by reducing the amount of carbon dioxide that can dissolve in the ocean sink (reservoir).

Carbon cycle
The ocean is a major sink for carbon and a critical component in the global balance of carbon dioxide. Visit this link to explore more about the role oceans play in the carbon cycle.

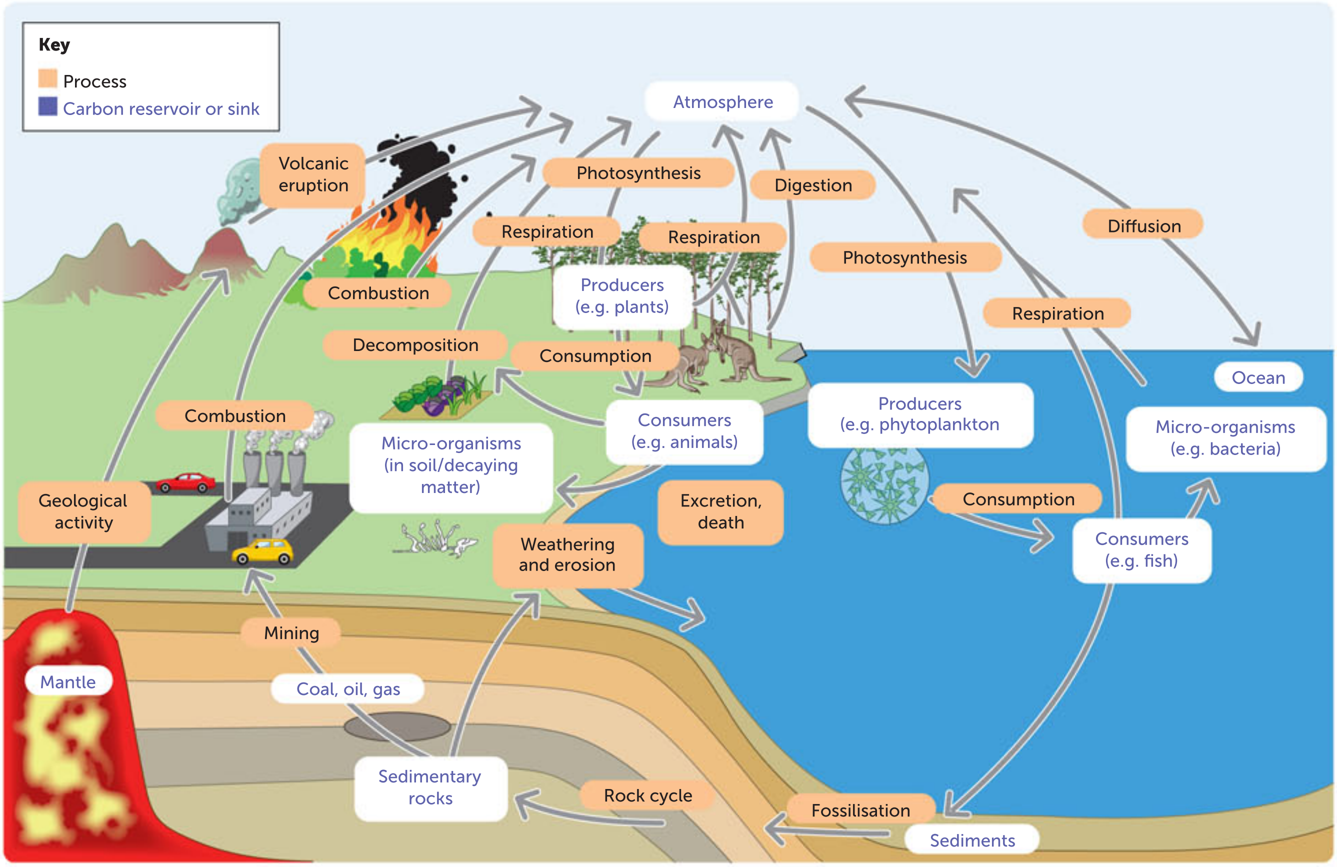


FIGURE 4.22 The carbon cycle. Atmospheric carbon dioxide is trapped by autotrophic organisms and incorporated into carbohydrates during photosynthesis. This carbon-rich biomass is consumed by members of the food chain and provides energy and matter. Carbon is released into the atmosphere as carbon dioxide from cellular respiration and the combustion of fossil fuels.

Ecology
Play the Bioman game 'Ecology' to test your knowledge of the carbon cycle.

Analysing the carbon cycle

Carbon exists in the atmosphere mainly as carbon dioxide gas. This gas is absorbed from the atmosphere and transformed by producers such as plants to build leaves and stems (biomass). Carbon dioxide is a reactant in the process of photosynthesis, whereby autotrophs use light energy to convert carbon dioxide and water into high-energy carbohydrates (commonly glucose). The solar energy harnessed from the Sun is used by these organisms to form the covalent bonds that bond carbon atoms together. These chemical bonds thereby store this energy for later use in the process of cellular respiration. In plants, respiration releases carbon in the form of carbon dioxide back into the atmosphere.

Carbon dioxide can dissolve into and is stored in oceans, where some of it is captured by the many types of photosynthetic marine organisms. When carbon dioxide dissolves in water it quickly transforms into carbonic acid. Marine autotrophs acquire carbon in this dissolved form. Some organisms, such as clams and coral, use carbon to form shells and skeletons.

Heterotrophs acquire high-energy carbon compounds from autotrophs by consuming them, and ultimately breaking them down by respiration to obtain cellular energy. The process of a consumer feeding on a producer or another consumer is called **consumption**. Herbivores and carnivores use the carbon compounds to build their own biomass but also carry out cellular respiration, which returns some of the carbon to the atmosphere as carbon dioxide.

On land, carbon is stored in soil, and as a result of the decomposition of living organisms (by decomposers) or from **weathering** of terrestrial rock and minerals, it is released back into the atmosphere. Most of the carbon on the planet is contained within rocks, minerals and other sediment buried beneath Earth's surface. Weathering is the breaking down or dissolving of rocks and minerals into smaller forms due to rain, ice, acid or salt, and this releases carbon.

Fossil fuels found underground are the remains of plants that have partially decomposed in **anaerobic** conditions. They take millions of years to form. Combustion of fossil fuels returns the carbon stored in them to the atmosphere, in the form of carbon dioxide. Fossil fuels are considered a non-renewable resource because their use far exceeds their rate of formation.

Another way for carbon to enter the atmosphere is from land (including land beneath the surface of the ocean) by the eruption of volcanoes and other geothermal systems. Carbon sediments from the ocean floor are taken deep within Earth by the process of subduction: the movement of one tectonic plate beneath another. Carbon is released as carbon dioxide when a volcano erupts or from volcanic hydrothermal vents.

The farming of animals also releases carbon to the atmosphere, because the animals undertake cellular respiration and also produce methane. The large number of farm animals raised to feed Earth's growing population is increasing the levels of carbon-containing gases in the atmosphere.

Question set 4.5a

REMEMBERING

1 State why scientists summarise all cycles of matter as biogeochemical cycles.
2 Name two living and two non-living reservoirs matter can cycle through.
3 Copy and complete Table 4.3 to provide examples of the main reservoirs of carbon.

TABLE 4.3 Forms and reservoirs of carbon

MAIN FORMS	RESERVOIRS
Carbon dioxide gas	
Glucose in producers	
Glucose, proteins and fats in consumers	
Methane	
Fossil fuels	
Carbonic acid	

4 Match the correct carbon process (a–g) with the biotic or abiotic component (i–vii).

TABLE 4.4 Processes and their links to biotic and abiotic components

PROCESS	ASSOCIATED BIOTIC OR ABIOTIC COMPONENT
a Photosynthesis	**i** Any living organism
b Consumption	**ii** Volcano
c Cellular respiration	**iii** Fossil fuels, wood
d Combustion/fire	**iv** Producer
e Geological activity; e.g. volcanic eruption	**v** Oceans, other water bodies
f Dissolving	**vi** Decaying organisms
g Decomposition	**vii** Consumer

UNDERSTANDING

5 Describe the roles of photosynthesis and cellular respiration in the carbon cycle.

APPLYING

6 In terms of a carbon sink, explain what happens when a bushfire burns a vast area of forest.
7 Identify the points in the carbon and nitrogen cycles where interconnections occur.
8 Predict what would happen at each step in the carbon cycle if:
   a large quantities of fossil fuels continue to be consumed
   b major deforestation occurred.

Nitrogen cycle

Nitrogen is an essential element, along with other elements (e.g. carbon, hydrogen and oxygen), for living things to make protein and nucleic acids. These molecules are essential for the structure and function of all living things, including controlling cell activities and the growth of new cells. The nitrogen cycle includes many processes which together balance the amount of nitrogen in the atmosphere (Figure 4.23). Plants take up available nitrogen from the soil in the form of ammonium (NH_4^+) or nitrate (NO_3^-). In addition, a small amount of gaseous nitrogen is removed from the atmosphere by lightning. **Nitrogen fixation** also removes nitrogen from the atmosphere due to the metabolic activities of specialised bacteria. The use of nitrogen is balanced by the return of nitrogen to the atmosphere by abiotic processes, including volcanic activity, and by the bacterial conversion of nitrites to nitrogen gas.

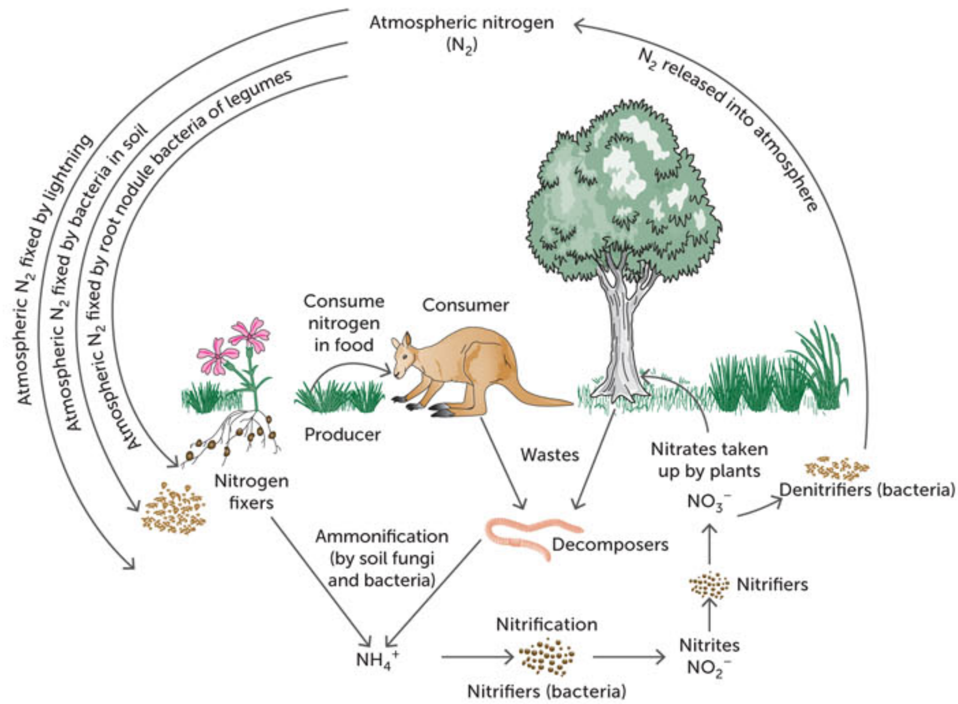


FIGURE 4.23 The nitrogen cycle. A balance is maintained between processes that withdraw nitrogen from the atmosphere (nitrogen fixation) and those that add nitrogen to the atmosphere (denitrification and volcanic emissions).

Nitrogen fixers

Air is 80% gaseous nitrogen (N_2), but plants are unable to absorb this form of nitrogen directly from the atmosphere. Gaseous nitrogen is converted to nitrates and nitrites by nitrogen fixation carried out by certain prokaryotes. Some specialised bacteria (e.g. *Azotobacter* and *Rhizobium*) invade the fine root hairs of plants such as legumes and native wattles, causing the formation of **nodules**. This symbiotic relationship provides the bacteria with the carbon they need, and in turn the bacteria deliver additional nitrogen to the plants.

Other nitrogen fixers live freely in the soil. These prokaryotes are able to absorb the nitrogen gas from the air spaces in the soil and build it up into amino acids, the building blocks of proteins.

FIGURE 4.24 a A healthy and productive crop of pea plants (a legume) could fix up to 200 kg ha^{-1} of nitrogen; **b** root nodules; **c** examples of legumes.

Nitrogen and legume crops

4.3 APPLICATION

At maturity, 30–40% of the nitrogen in legume crops is in the seeds or grain, which are typically 25–30% protein. When this grain is harvested, much of the nitrogen that has been fixed is taken away. However, the nitrogen remaining in the shoot and root residues means that legumes usually add to soil nitrogen reserves.

Key concept

Ammonifiers (bacteria and fungi)	waste	⟶	ammonia, NH_3
Nitrifiers (bacteria)	NH_3	⟶	nitrites, NO_2^-
Nitrifiers (bacteria)	NO_2^-	⟶	nitrates, NO_3^-
Denitrifying (bacteria)	NO_3^-	⟶	nitrogen gas, N_2
Nitrogen fixers (bacteria)	N_2	⟶	ammonium ions, NH_4^+

Nitrifiers convert decaying material into nitrites and nitrates

Nitrifying bacteria convert the ammonia released in urine and from the decay of faeces, dead plants and animals to nitrites (NO_2^-). This takes place in a series of chemical steps during which energy is released as heat. The bacteria use this energy for building up their own organic compounds. Other bacteria convert the nitrites to nitrates that, only then, can be absorbed by plants.

Denitrifiers convert nitrites into atmospheric nitrogen

Plants growing in waterlogged soils have a particular problem to overcome: there is a shortage of available oxygen. However, denitrifying bacteria convert nitrates in the soil into gaseous nitrogen, and this process releases the oxygen required for their metabolic processes. The combined action of nitrifiers and denitrifiers results in the recycling of nitrogen between plants and the atmosphere.

How does nitrogen reach the ocean?

In the oceans, some available nitrogen (such as nitrate and ammonium compounds) is brought in by rain and run-off and the activities of nitrogen-fixing organisms. This **nitrogenous** material circulates through the ocean's plants and animals. Some of the available nitrogen, however, sinks below the upper 100 m of the surface, beneath which photosynthetic organisms are absent. It may then descend all the way through to the sediments at the bottom of the ocean. Here the nitrogen compounds are unavailable to most organisms unless eventually returned to the atmosphere by volcanic emissions and other processes. This sinking of nitrates and other nutrients makes the ocean a relatively poor environment in terms of available nutrients.

Question set 4.5b

REMEMBERING

1 What are the basic components of a biogeochemical cycle?

2 Copy and complete Table 4.5 by providing examples of the main nitrogen reservoirs.

TABLE 4.5 Forms and reservoirs of nitrogen

FORM	RESERVOIRS
Nitrogen gas, N_2	
NO_2, NO_3, NH_3	
Protein	

3 Match the correct nitrogen process (a–e) with the biotic or abiotic component involved (i–v).

TABLE 4.6 The main processes in the nitrogen cycle

PROCESS	BIOTIC OR ABIOTIC COMPONENT INVOLVED
a Nitrogen fixation	i Bacteria and fungi convert nitrogenous substances in dead and decaying matter into ammonia in the soil
b Ammonification	ii Consumers pass nitrogen through food chains
c Assimilation/absorption	iii Micro-organisms/bacteria/prokaryotes found in root nodules of legumes or lightning/volcanoes fix nitrogen
d Consumption	iv Soil bacteria convert soil nitrate into nitrogen gas
e Denitrification	v Plants absorb/assimilate nitrates through their roots

UNDERSTANDING

4 Which processes or activities:

a contribute to nitrogen in the atmosphere?

b withdraw nitrogen from the atmosphere?

(Note: 'Atmosphere' also refers to air spaces between soil grains.)

APPLYING

5 Identify the points in the carbon and nitrogen cycles where interconnections occur.

ANALYSING

6 a Draw an annotated diagram to represent cycling of matter in a woodland ecosystem in summer.

b Describe the consequences to the woodland ecosystem of little or no activity by decomposers.

c Describe the same woodland in autumn. Assume the majority of trees in the woodland are deciduous trees.

4.6 ECOLOGICAL NICHES

Ecosystems around the world are unique and diverse in their own ways. The organisms that inhabit a particular ecosystem are able to survive because of the particular set of biotic and abiotic factors present. The way in which species function within their environment – for example, the time they feed, what they feed on, where they live and when they reproduce – is known as an **ecological niche**. To place this concept into context, US biologist Eugene Odum made the analogy that if a species' habitat is its home address, then its ecological niche is its home address and profession.

The concept of a niche includes the food sources and feeding activities of a species, its spatial habitat, its reproductive site and activities, its relationships and interactions with other species, and any abiotic factors that help the species persist. The ecological niche of the Australian numbat is summarised in Table 4.7.

TABLE 4.7 The ecological niche of the Australian numbat

ASPECT OF ECOLOGICAL NICHE	NUMBAT'S SPECIFIC NICHE
Food sources and feeding activities	Numbats are insectivores and only feed on termites. They don't need access to water because they extract water from the food they eat (20 000 termites per day on average). They are diurnal (active during the day) because their daily activity coincides with the activity of their food source. Numbats are not able to break into termite mounds so they source termites that are just below the soil surface or high up in termite mound chambers. They also need to travel large distances to find termites so their home range is 25–50 hectares.
Habitat	Numbats live in eucalypt woodlands where old and fallen trees provide hollow logs for shelter, nest sites and foraging opportunities. Numbats need shelter to survive and the trees provide some protection from birds of prey. They rest in burrows in hollow logs, trees or underground in chambers 1–2 m long. They use shredded grass, bark, feathers, leaves and flowers to make nests at the ends of their burrows. They can climb logs and trees, using their long, sharp claws, to find shelter.
Reproductive site and reproductive behaviour	Numbats live alone until it is time to mate. Mother numbats live with their young and require nesting sites because their young are born very under developed. Females are ready to breed after 1 year, males when they are 2 years old. In mating season, males exude a pungent, oily substance which turns the fur red. They rub their chests over surfaces such as logs and rocks to advertise to females that they are looking to mate. This also warns other males to stay away from that territory. Baby numbats suckle from their mother's teat until they are about 9 months old, then they learn to forage and eat termites.
Relationships with other species in the community	Numbats are active during the day and they are in danger of being eaten by native birds of prey, snakes and goannas. Numbats are also very vulnerable to predation by introduced predators such as foxes and cats, as well as competing for termites with native birds and reptiles, including the goanna.
Abiotic factors	Cool mornings and afternoons allow numbats to forage for termites, which are sensitive to temperature and only come in reach when it is cool.

FIGURE 4.25 a The numbat, shown here in its natural habitat, is the WA animal emblem; **b** termites are the food source for numbats.

The fundamental niche versus the realised niche

American zoologist G.E. Hutchinson distinguished between the **fundamental niche** and the **realised niche**. The fundamental niche (potential niche) is the ideal niche a species would occupy if there were no competitors, predators or parasites. The realised niche (actual niche) is narrower. It results from an organism's inability to exploit the resources of its habitat because of restrictions caused by other organisms. Such restrictions mean that a species may not be distributed evenly throughout its potential geographic range.

Abiotic factors that suit the laughing kookaburra (*Dacelo novaeguineae*) extend virtually all the way down the eastern coast of Australia, from Cape York Peninsula in far north Queensland to the eastern Eyre Peninsula in South Australia, including Tasmania. However, the species is not distributed evenly throughout this geographical range because successful competitors occupy the kookaburra's

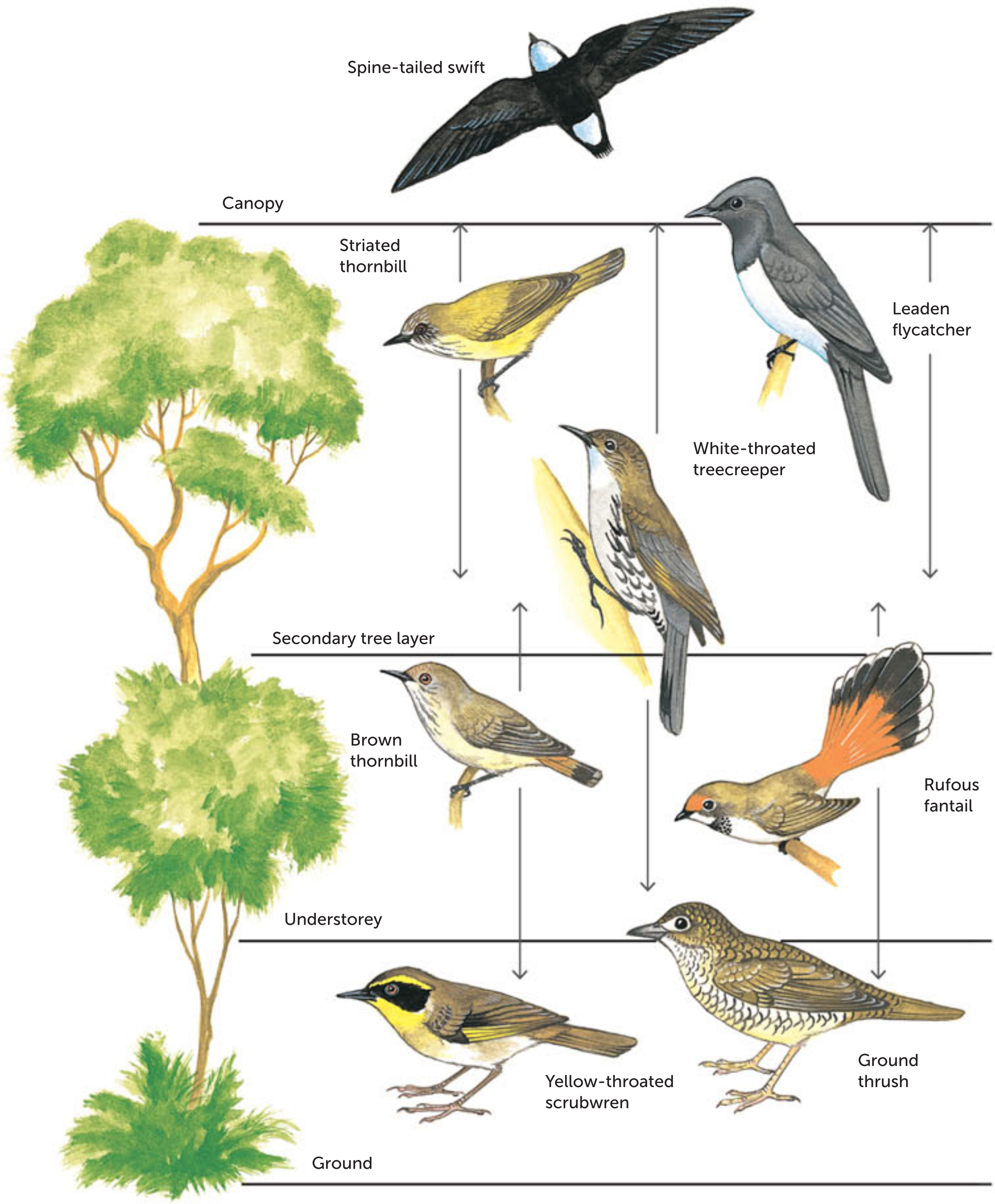


FIGURE 4.26 An example of resource partitioning is the diversity in the feeding height used by birds in an eastern Australian eucalypt forest.

niche in certain areas. On the other hand, the kookaburra is an introduced pest to WA and is a predator to many native WA species.

Different species within an ecosystem generally do not feed on the same food sources at the same time. Instead they usually differ in the food source they prefer, their use of space and even the timing of their activities. For example, different forest birds feed at varying heights above the ground, and some animals feed at night while others feed during the day. Species of shorebirds have different leg lengths and varying beak shapes. This allows them to exploit particular parts of the mud flats and reduces competition. This division in the use of resources is called **resource partitioning**.

Niches
Watch a video illustrating the difference between an organism's fundamental niche and its realised niche.

Competitive exclusion principle

The **competitive exclusion principle** postulates that no two species can occupy the same niche in the same environment for an extended period of time. Russian ecologist G.F. Gause completed an experiment in 1934 using *Paramecium aurelia* and *P. caudatum*, two closely related species of protists. Gause found that when he grew the species as two separate cultures, with a constant source of food, the population numbers increased exponentially until they reached what is known as a carrying capacity of the culture. However, he found that when the two species were grown in the same culture, *P. aurelia* had a competitive advantage. *P. aurelia* was able to obtain the food more effectively than *P. caudatum* and drove it to extinction. Based on the interpretation of the data collected, Gause concluded that two species so similar, competing for the same resource, cannot coexist in the same community. One will be able to obtain and use the resource more effectively and in turn reproduce more quickly than the other. Further models and experimentation have supported Gause's idea. However, note that two ecologically similar species can coexist in the same community if they have one or more differences in their niche.

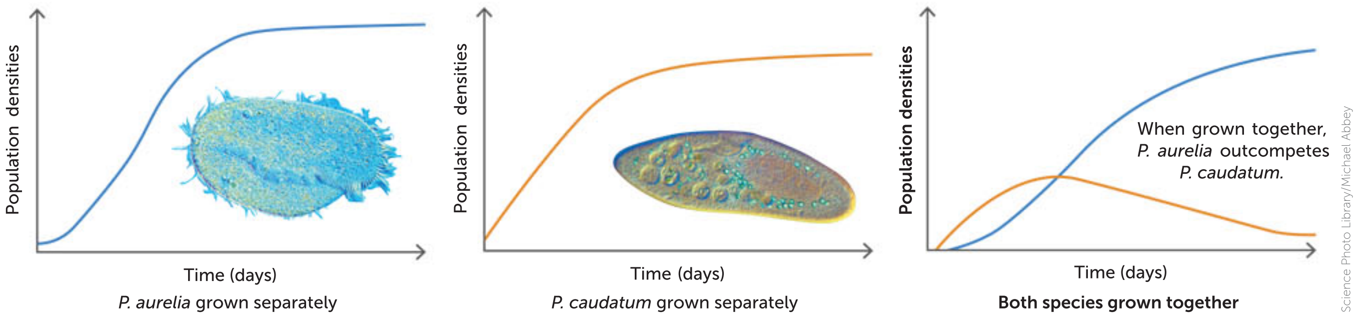


FIGURE 4.27 Data from Gause's experiment with *P. aurelia* and *P. caudatum*

Key concept

The competitive exclusion principle states that two similar species that compete for a resource cannot coexist in the same community.

Community ecology
Learn about competition and the competitive exclusive principle by watching this video.

Question set 4.6

REMEMBERING

1 Define 'ecological niche'.
2 Describe the ecological niche of a chosen animal.

UNDERSTANDING

3 Compare and contrast the fundamental and realised niches of an organism.

4 Summarise how Gause developed his idea of the competitive exclusion principle.

APPLYING

5 Five different types of warbler species live in a North American spruce tree (Figure 4.28): the Cape May warbler, bay-breasted warbler, myrtle warbler, Blackburnian warbler and black-throated green warbler. Explain how the five species can inhabit the same spruce tree and coexist.

FIGURE 4.28 How can five different species of birds inhabit this spruce tree?

4.7 COEXISTENCE AND KEYSTONE SPECIES

A **keystone species** is not necessarily abundant in number in a food web, yet it can exert a large effect on population numbers of other species in the community. The niche of a keystone species includes highly influential relationships with a number of other species in a food web. An ecosystem that is very stable is one that is able to resist disturbance and is highly resilient to changes. But even a stable ecosystem can be disturbed by the addition or removal of a keystone species. The disturbance can happen because of the keystone species' role in such areas as nutrient recycling (e.g. termites), seed dispersal (e.g. the southern cassowary) or predation (e.g. the purple sea star). Keystone species may have different niches, but they each have a disproportionate effect on how their ecosystem functions.

The purple sea star (*Pisaster ochraceus*) is an example of a keystone species that is also a predator. It is a natural predator of mussels in the intertidal zones of Pacific Ocean seashores. When researcher Robert Paine removed purple sea stars from this environment, the population of resident mussels expanded. The mussels displaced other sessile (non-moving) organisms, such as barnacles and limpets, as they spread. Over 3 years, the diversity of species in the area decreased from 15–20 invertebrates and algae to less than 5 species. When the sea stars were returned, the mussels were again preyed upon and the barnacles, limpets and other species were able to reoccupy the space. The predatory purple sea star allowed the coexistence of other species with the same requirements for food and space.

Alamy Stock Photo/William Ragosta

FIGURE 4.29 The purple sea star, *Pisaster ochraceus*

The idea of keystone species was developed by Robert Paine, based on his removal experiments in the intertidal areas of western North America. Since this initial study, many scientists have collected data that supports Paine's theory. Many ecologists believe that efforts to amplify biodiversity should focus on keystone species. They argue that conservation of a single keystone species should be central in the management strategies for an entire community. Scientists have also put forward arguments that keystone species are essential in the re-establishment of ecological structure and sustainability. However, others believe that the definition of a keystone species is not yet refined enough to form the basis of conservation efforts. They also speculate that focusing on keystone species could be detrimental to species that are not considered key to species richness, yet are indicators of habitat health.

Key concept

A keystone species can have a large effect on population numbers of other species in a community even though it may not be abundant. It can prevent organisms from lower trophic levels from monopolising food resources and space.

SCIENTIFIC LITERACY

Rainforest Rescue campaign

Following is an extract from the Rainforest Rescue 'Save the Cassowary' campaign.

We need your help now to save the endangered southern cassowary

Listed as endangered, the Australian southern cassowary (*Casuarius casuarius johnsonii*) has fewer than 4600 birds left in the wild. These living dinosaurs play a crucial role in rainforest ecology and regeneration.

Southern cassowary are regarded as a 'keystone' species. Through eating the fruits of over 240 species of rainforest plants and excreting the seeds great distances from the parent plant, the cassowary plays a vital role as a 'rainforest gardener'. Many rainforest plants depend on the cassowary to move about the landscape … without them, the structure of the rainforest would permanently change.

Rainforest Rescue Save the Cassowary campaign

With so few birds left in the wild, we must act now to help save the endangered southern cassowary. If it becomes extinct, we stand to lose not just one of Australia's most iconic animal species, but also the magnificent Daintree rainforest – as we know it. Your donation will help us to restore the Daintree rainforest, create wildlife corridors and provide food plants for the cassowary.

The greatest threat to cassowaries is us … People! Rapid urban development has either destroyed or fragmented much of their territory, particularly in lowland areas – territory such as the habitat associated with feeding and breeding activities. By 1997, 81% of native vegetation had been cleared, and remaining rainforest habitat was substantially fragmented. While the rate of clearing in the Wet Tropics has slowed considerably since 1997, land clearing for housing development continues and threatens local populations of cassowaries already subsisting in degraded or fragmented habitat outside of protected areas. The disruption of their habitat forces them to travel further, exposing them to threats like dog attacks and road fatalities.

Rainforest Rescue Save the Cassowary campaign. photo © Jeff Larsen

FIGURE 4.30 From 1986 to 2004, car strikes accounted for 55% of the cassowary mortality rate, followed by dog attacks at 18%.

Cyclones are the main natural threat to habitat and food loss. In the wake of Cyclone Larry in 2006 one-third of the cassowary population died as a result of the impact of the cyclone, loss of their natural food sources, dog attacks and vehicle strikes as they left the fragmented and destroyed habitat in search of food. In 2011, thousands of hectares of prime cassowary habitat were also severely damaged by Cyclone Yasi.

Thanks to Rainforest Rescue supporters, we are taking positive action to help save the southern cassowary through buying back high conservation value rainforest, as well as restoring rainforest habitat and creating wildlife corridors through the planting of trees which will provide habitat, food, and a safe passage for generations of cassowaries to come.

FIGURE 4.31 Cassowary habitat destroyed by Cyclone Yasi in February 2011

To date, we have been able to achieve significant outcomes such as rescuing 36 properties in Australia, establishing 22 nature refuges classified as 'essential' cassowary habitat and planting 282 040 trees in Australia … 151 685 of those in the Daintree Rainforest. Your support is vital to carrying out these types of long-term projects to protect and restore critical cassowary habitat within Queensland's Wet Tropics.

- $50 helps to buy back and protect 10 square metres of Daintree lowlands rainforest.
- $200 could help restore or create 'nature corridors' through the planting and maintenance of 20 native rainforest trees.
- $500 could contribute to the protection of 100 square metres of cassowary habitat.

Source: Rainforest Rescue Save the Cassowary campaign

Questions

1. Identify the threats to cassowary numbers, according to this website extract.
2. List examples of persuasive language used in this extract. Describe the general tone.
3. Assess whether or not you found this to be factual and credible. Discuss your views, using examples from the extract.
4. Using this information, propose the most effective way to scientifically manage the threats to the cassowary and help restore the population. Evaluate the distribution of money for long-term projects by this group.

Question set 4.7

REMEMBERING

1. Define 'keystone species'.

UNDERSTANDING

2. Explain why a keystone species increases an ecosystem's biodiversity.
3. Many ecosystems are classified by the dominant species present in the system. Compare and contrast the difference between a keystone species and a dominant species.

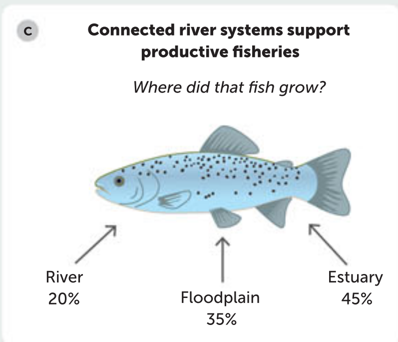
CASE STUDY

Food web case study – Professor Michael Douglas

When we think of tropical rivers in northern Australia we think of the large flooded wetlands covered with waterlilies and of water plants – like we see in Kakadu's globally important floodplain wetlands. The areas are highly productive, teeming with water birds and supporting commercial and recreational fisheries, tourism, and hunting and harvesting by local Indigenous landowners.

Professor Michael Douglas from the University of Western Australia (UWA) has spent the past three decades leading research teams investigating Australia's tropical freshwater ecosystems and the ecosystem processes that connect them, particularly food webs. The food webs describe 'who is eating who' in an ecosystem – from the microscopic algae at the bottom of the food chain to the top predators, such as fish and crocodiles. These complex interrelationships are a cornerstone of ecology – they govern how rivers function and help explain patterns of biodiversity. Essentially, they tell us how the ecosystems are 'put together'.

Professor Douglas' team identify the sources of organic carbon supporting the food web by measuring the naturally occurring isotopes of carbon and nitrogen which act as a natural 'signature' (marker). Food web studies using stable isotopes have revealed that even though they may be very abundant, the water lilies actually contribute very little to the aquatic food webs. What actually drives these foods webs are the microscopic algae that



Photos: Professor Michael Douglas

FIGURE 4.32 a A northern Australian tropical wetland; **b** Professor Michael Douglas from UWA investigating tropical freshwater food webs; **c** Professor Douglas' research reveals what proportions of barramundi grow in different parts of the ecosystem.

grow on the water plants and other surfaces. These tiny algae are the main energy source for aquatic snails and insects, which are then eaten by small fish, which become food for bigger fish and water birds. All of these may in turn be eaten by saltwater crocodiles.

This research uses the naturally occurring carbon isotopes to trace the movement of carbon through the food web. This work found that the floodplains surrounding these river systems are 'hot spots' for algal growth in the wet season and that this energy (in the form of carbon) is transported upstream by small fish such as bony bream to other parts of the river ecosystem. Algae growing in the estuaries are also an important energy source that supports consumers high in the food web, such as the commercially and recreationally important barramundi.

Tracing the sources of energy through the food web has revealed other surprising results. This was the case for mature barramundi caught in the river channel during the dry season. Even though they were more than 100 km upstream from the estuary and were caught 6 months after the floodplains had dried, the carbon in their muscle tissue was comprised largely of carbon from the estuary (45%) and floodplain (35%), with relatively little carbon coming from the river channel itself. Although barramundi do not eat algae, the carbon that the algae fix through photosynthesis made its way to these large fish through links in the food web. At present the movements of consumers are unimpeded by dams and other structures. This highlights the importance of maintaining connections between the river, floodplain and estuary in these ecosystems, so that all these sections have access to the most productive parts of the ecosystem.

Professor Michael Douglas, The University of Western Australia

Questions

1. Draw a diagram of the aquatic food web in the river systems, showing the primary, secondary and tertiary consumers.
2. Indicate where barramundi (or crocodiles) appear in the food web and then draw a biomass pyramid to include barramundi (or crocodiles).
3. Predict what happens to the biomass of the water lilies and other larger water plants if barramundi (or crocodiles) were added to the food web.
4. Explain how dams on these rivers could affect the food webs and predict the effect on the sustainability of commercial and recreational fisheries.

CHAPTER 4 ACTIVITIES AND INVESTIGATION

Analysing productivity

4.1 ACTIVITY

Table 4.8 shows the average productivity of various ecosystems.

TABLE 4.8 Ecosystem productivity and biomass

ECOSYSTEM	AVERAGE PRODUCTIVITY (g m^{-2} $year^{-1}$)
Algal beds and coral reefs	2500
Tropical rainforests	2200
Swamps and marshes	2000
Estuaries	1500
Temperate deciduous forests	1200
Boreal forests	800
Temperate grasslands	600
Lakes and streams	250
Tundras	140
Open oceans	125
Deserts	90
Extreme deserts	3

What did you discover?

1 Lake Eyre (Kati Thanda) is in South Australia, 700 km north of Adelaide. Approximately every 3 years, floods fill the lake basin that, in the dry season, has very little water. Using the information provided in Table 4.8, what plant productivity would Kati Thanda be most likely to have during flood? Explain why.

2 Identify which ecosystems have the highest and lowest productivity. Account for the difference between these two ecosystems.

3 Explain how biomass can be used to calculate productivity.

4 Critically evaluate where the annual production of organic matter (i.e. GPP) would be greater: in a coral reef or an alpine meadow of the same size. Explain your answer.

5 Urban expansion has involved the draining of swamps and marshes in many parts of the world, in order to build housing and cities. Assess the effect of this practice on the amount of energy available.

6 Between 2000 and 2005, the Amazon rainforest was being cleared at a rate of 22 392 km^2 per year. Calculate:

a the total area cleared in those 5 years

b the total productivity lost over that time (in gm^{-2} $year^{-1}$).

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4.2 ACTIVITY

Competitive exclusion principle experiment: second-hand data analysis

The competitive exclusion principle postulates that no two species can occupy the same niche in the same environment for an extended period of time. Experiments can be used to test this principle and produce models of this interaction. Models can then be used to make predictions about biodiversity when changes occur within an ecosystem.

A team of scientists investigated Gause's competitive exclusion principle by conducting a field experiment. They studied two sessile (fixed or non-moving) species, A and B, introduced onto an intertidal rock face. Over a period of 18 months, population density data was collected within the test quadrats. Table 4.9 is a summary of the data.

TABLE 4.9 Population density of two species

TIME (MONTHS)	POPULATION DENSITY OF SPECIES A	POPULATION DENSITY OF SPECIES B
0	5	5
1	12	8
2	17	14
3	36	24
4	55	60
5	50	67
6	43	62
7	45	104
8	50	100
9	38	104
10	25	115
11	30	119
12	16	125
13	18	133
14	21	139
15	14	158
16	8	141
17	0	158
18	0	164

What did you discover?

1 Draw a graph of the tabled data.
2 Which species had the competitive advantage in the first 3 months?
3 For what period of time can the two species coexist in the same area?
4 Which species had the overall competitive advantage over the 18 months?
5 a Outline what has occurred to species A throughout the 18-month period.
  b Predict the consequences of this scenario for the biodiversity of an ecosystem.
6 If a disease were to affect the reproductive success of species B at 10 months, predict what would happen to the relative abundances of species A and B.
  a A non-native species, species C, is introduced to the intertidal rock face. It competes for the same resources as species A and B, but has a shorter gestation period than either species. Predict the impact this would have on the relative abundances of all three species.
  b Discuss the impact this scenario would have on the diversity of the ecosystem.
7 Assess the validity of Gause's competitive exclusion principle when applied to this experiment.
8 Design an experiment to measure the impact of species C on the ecosystem.

4.3 ACTIVITY

Rate of photosynthesis

An experiment was conducted to determine the effect of light intensity on the rate of photosynthesis in a sample of the aquatic plant *Elodea*. Plants were exposed to a range of light intensities at a constant temperature of 25°C. The rate of photosynthesis was measured by the volume of oxygen, in millilitres (mL), collected in 10 minutes. The results are shown in Table 4.10.

TABLE 4.10 The rate of photosynthesis of *Elodea*

RELATIVE LIGHT INTENSITY (ARBITRARY UNITS)	VOLUME OF OXYGEN COLLECTED IN 10 MINUTES (mL × 10^{-3})
50	3
100	7
200	17
250	20

What did you discover?

1. Graph the data from the table. Use the values 0 to 250 arbitrary units for relative light intensity.
2. The 'compensation point' is defined as the light intensity that produces a rate of photosynthesis equal to the rate of respiration in a plant sample. At this point the volume of oxygen collected is zero. Using your graph or the data in the table, estimate the value of the compensation point in this experiment.
3. State the dependent variable in this experiment.
4. The experiment was conducted at 25°C. State two factors other than temperature that would need to be kept constant in this experiment.

SOUTHERN Biological

Developed exclusively by Southern Biological

4.1 INVESTIGATION

The competitive exclusion principle

The competitive exclusion principle, or Gause's law, proposes that two species competing for the same limited resources cannot sustainably coexist or maintain constant populations. Within a single population, organisms of the same species compete for resources. This is called intraspecific competition, and it leads to the population growing until it reaches its carrying capacity. Carrying capacity refers to the maximum population size a species can sustain within the limits of its environment. Competition for resources also occurs between different species – this is called interspecific competition. Species can be limited by both their carrying capacity (intraspecific competition) and by interspecific competition. When two species compete within the same ecological niche, the competitive exclusion principle predicts that the better adapted species, even if it is only slightly better adapted, will drive the other species to local extinction.

In the 1930s, biologist G.F. Gause explored the idea of interspecific competition in a ground-breaking study of competition in *Paramecium*. *Paramecia* are aquatic, single-celled protozoans with cilia and they survive on a diet of bacteria, yeast, algae and other small protozoans. Gause developed the competitive exclusion principle based on the findings of this experiment and other research.

Aim

To test the competitive exclusion principle using two *Paramecium* species: *Paramecium aurelia* and *P. caudatum*

Materials

- pure cultures of *Paramecium caudatum*
- pure cultures of *Paramecium aurelia*
- *Paramecium* culture medium
- 3 deep Petri dishes
- Sedgewick Rafter cell
- graduated cylinder

- mosquito net/cheesecloth
- sterile plastic pipettes
- compound microscope

WHAT ARE THE RISKS IN DOING THIS INVESTIGATION?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Paramecia are harmless to humans, but swamp or pond water may contain pathogens.	Wash hands after working with *Paramecia*.

Procedure

1 State your hypothesis.
2 Label three clean Petri dishes as shown in Figure 4.33.

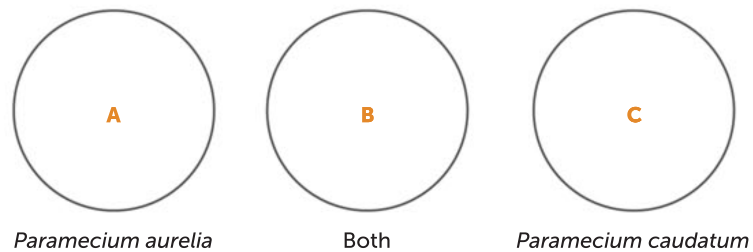

FIGURE 4.33 Labelling of Petri dishes

3 Add 50 mL of *Paramecium* culture medium to each dish.
4 Using a graduated cylinder, transfer 20 mL of *Paramecium aurelia* into Petri dish A.
5 Transfer 20 mL of *P. caudatum* and 20 mL of *P. aurelia* into Petri dish B.
6 Transfer 20 mL of *P. caudatum* into Petri dish C.
7 Cover each of the Petri dishes containing the *Paramecium* cultures with cheesecloth.
8 Store the Petri dishes at a consistent temperature of 24°C on a flat surface where they will not be disturbed. Keep them away from direct sunlight.
9 Using a pipette, collect 1 mL of liquid from Petri dish A and transfer it into a Sedgewick Rafter cell. To fill the cell, place the cover glass across the top of the chamber at an angle (this allows the air bubbles to escape). Then carefully transfer the contents of the pipette into the chamber (Figure 4.34).

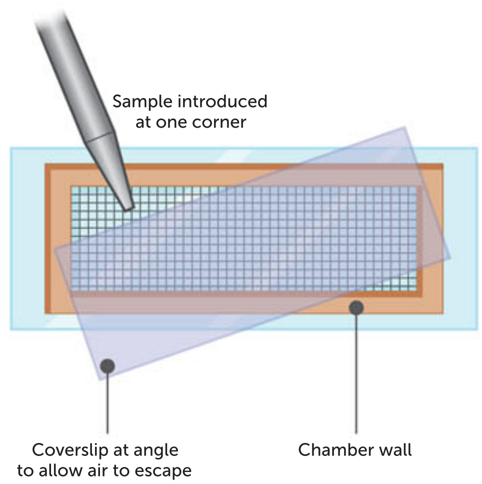

FIGURE 4.34 How to fill the Sedgewick Rafter cell

10 Once the slide is filled, let the liquid sit for approximately 5–10 minutes to allow the culture to settle into a single layer. (This makes counting easier.)
11 Place the cell under a compound microscope, set the microscope to its lowest focus and bring the sample into focus. Be sure you are focusing on the sample in the slide and not on the top of the coverslip.
12 Change the focus to the next strongest magnification and bring the sample into focus. Repeat until you are using the best magnification possible.
13 Count only one transect of the Sedgewick Rafter cell. Choose a random vertical transect (20 squares, representing 20 μL) and multiply the count you obtain by 50 to get the population density per millilitre.
14 Using your pipette, return the specimens to the Petri dish. This reduces the amount of the population that is lost as a result of the counting procedure.
15 Thoroughly wash the Sedgewick Rafter cell to fully remove all *Paramecium* specimens.
16 Repeat steps 9–15 for Petri dishes B and C. For Petri dish B, count the two species separately. The *Paramecium* species can be differentiated by their size. *P. caudatum* is approximately four times the size of *P. aurelia*.
17 Record your data in a table like Table 4.11.
18 Repeat the counting procedure every second day for 3 weeks, recording your results each time.

Results

TABLE 4.11 Paramecium population figures

		DAY 1	DAY 3	DAY 5	DAY 7	DAY 9	DAY 11	DAY 13	DAY 15	DAY 17	DAY 19	DAY 21
Separate cultures (Petri dishes A and C)	*Paramecium aurelia*											
	Paramecium caudatum											
Combined cultures (Petri dish B)	*Paramecium aurelia*											
	Paramecium caudatum											

1 Plot the results of your experiment on a linear graph.
2 Plot the growth of both species in Petri dish C, with time (every 2 days) represented on the x axis, and the y axis representing the population size (*Paramecium* per 1 mL). This graph provides one population growth line for each species.
3 Plot the class experiment results on a linear graph.
4 Describe what has occurred in populations A, B and C. Identify whether the populations increased or decreased, or remained stable.

Discussion

1 Was your hypothesis supported? Why or why not?
2 What are the advantages and disadvantages of this counting technique?
3 What are some limitations in the experimental design? Suggest how it might be improved.

4 Compare the population sizes of each *Paramecium* species in the separate cultures (A and C) and the mixed culture (B). What do the results reveal about how competition affects population growth?

5 Do your results support or disprove the competitive exclusion principle? Explain.

Taking it further

Exponential growth describes population growth that is unlimited. Logistic growth describes growth rates that are limited by a number of factors, including predators, food scarcity, and competition for food and habitat. Which type of growth was exhibited in the *Paramecium* populations containing only one species? Determine the carrying capacity of the organism in this model environment.

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Chapter 4 Activity sheet

CHAPTER 4 SUMMARY

- Sunlight is the original source of energy for ecosystems.
- Matter is a finite resource on our planet and is recycled through systems.
- Systems such as an ecosystem are a set of interacting biotic and abiotic components that together form a larger entity.
- Producers (autotrophs) capture the energy from sunlight in a reaction (photosynthesis) that uses carbon dioxide and water and forms glucose. Consumers (heterotrophs) cannot make their own energy and must acquire it by eating producers or other heterotrophs.
- Ecologists represent complex systems by constructing simplified models such as food chains and food webs.
- Energy from producers can support whole communities of different animals. The size of a food chain is limited by how efficiently energy is transferred to each trophic level.
- Matter is transferred between trophic levels.
- Some energy is transformed to less useful forms during each transfer, so the possible number of trophic levels is limited.
- The efficiency of energy transferred to each trophic level can be modelled using biomass pyramids and calculations of gross and net primary productivity.
- All matter is cycled through biogeochemical processes. Carbon, oxygen, water, phosphorous and nitrogen are essential for life and are cycled through ecosystems.
- A self-sustaining ecosystem depends on detritivores to recycle detritus into a form that producers can use to gain nutrients.
- Each species or population has an ecological niche, a particular role within an ecosystem.
- A species has a fundamental niche that it could potentially inhabit when no predators or competition are involved, and a realised niche that it actually does inhabit, due to competition from other species.
- The competitive exclusion principle stipulates that no two species can occupy the same niche for an extended period of time.
- Resource partitioning allows multiple species to coexist in one area without reducing their relative abundance.
- A keystone species is a species of relatively low abundance in a higher trophic level that allows the coexistence of a number of lower trophic level organisms.
- Biodiversity can be reduced if a keystone species is removed.

CHAPTER 4 GLOSSARY

Abiotic non-living; used to describe components of an ecosystem

Anaerobic without oxygen

Autotroph an organism capable of making its own food from inorganic substances using light energy (through photosynthesis) or chemical energy (through chemosynthesis); includes green plants, algae and certain bacteria

Biogeochemical cycle the cycling of matter through the living components (organisms) and non-living components (such as soils, rocks, water and the atmosphere) of an ecosystem

Biomass the total mass of biological matter (living or dead) in a given area, at a given time, that can be used as an energy source

Biotic living; used to describe components of an ecosystem

Carbohydrates organic compounds that serve as a structural component and a major energy source in the diet of animals; includes sugars, starches and celluloses

Carbon cycle the biogeochemical cycle in which carbon moves through living and non-living reservoirs in ecosystems in our biosphere; carbon cycles quickly through organisms and the atmosphere via cellular respiration and photosynthesis

Carbon sink a biogeochemical reservoir, such as plants or the oceans, that stores carbon because it absorbs more carbon than it releases

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Carnivore an organism that feeds on other animals

Cellular respiration a series of cellular biochemical reactions and processes that use glucose and oxygen, and produce carbon dioxide and water; the energy released is used to convert ADP to ATP

Competitive exclusion principle the theory that no two species can occupy the same ecological niche for an extended period of time

Consumer an organism that uses other organisms as a food source; also called a heterotroph

Consumption when a consumer feeds on a producer or another consumer, transferring matter along a food chain

Decomposers organisms that break down complex organic matter into simple inorganic molecules (nutrients); fungi and bacteria are common decomposers

Detritivore an organism that feeds on small pieces of dead plant or animal matter

Detritus organic wastes, including faeces and dead tissues

Ecological niche the role an organism has in its ecosystem and the conditions it requires to persist, including food sources, feeding activities, spatial habitat, reproduction and relationships

Element a pure substance, containing only one type of atom

Emit to give or send out (light)

Energy the capacity to cause change, particularly to do work; exists in a variety of forms, such as heat, light and chemical, and can be transformed from one form to another (not created or destroyed)

First-order consumer see *primary consumer*

Food chain a model that represents the transfer of energy from its source in primary producers (autotrophs) through primary consumers (herbivores) to secondary and tertiary consumers (carnivores and omnivores) and decomposers

Food web a diagram that shows how different organisms feed on each other, thereby transferring energy through an ecosystem; the interconnecting food chains in an ecosystem

Fundamental niche the potential role an organism could fulfil if there were no competitors, predators or parasites

Geochemical describes the chemical interactions that take place in crustal and subcrustal reservoirs, such as the deep Earth and lithosphere (crust)

Gross primary productivity (GPP) the total organic matter in an ecosystem (or specified area) produced by photosynthesis

Herbivore a primary consumer that feeds on plant organisms

Heterotroph an organism that cannot synthesise its own organic compounds from simple inorganic materials; it depends on other organisms for nutrients and energy requirements

Keystone species a species of relatively low abundance that has a disproportionately large influence over lower trophic levels, determining the coexistence of these species in an area

Matter anything that takes up space and has mass; consists of atoms

Model an artificial conceptual or abstract simulation of a real-world process or system, developed by simplifying key steps that produce reliable and consistent agreement as verified by field studies; a model may be mathematical equations, a computer simulation, a physical object, words or another form

Net primary productivity (NPP) the amount of organic matter actually available to herbivores; the GPP less the energy required by the producers themselves

Niche see *ecological niche*

Nitrogen fixation the process by which free nitrogen is 'fixed' or combined to form ammonium (NH_4^+) or nitrate (NO_3^-) ions before living things can make use of it for growth; all nitrogen-fixing organisms are prokaryotes (bacteria)

Nitrogenous containing nitrogen

Nodule a local enlargement on the root of a plant that contains nitrogen-fixing bacteria

Omnivore an organism that feeds on a range of foods, including plant and animal matter

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Photosynthetic efficiency the percentage of light energy that is converted into chemical energy (i.e. carbohydrates) by a producer

Phytoplankton the collective term for the tiny photosynthetic organisms present in bodies of water

Primary consumer a consumer that feeds directly on producers; also known as a herbivore

Producer an organism that is able to make complex organic molecules, its own food, from simpler inorganic materials; also known as an autotroph. Producers begin all food chains

Pyramid of biomass a representation that shows the relationship between the total amount of (dry) organic matter at each trophic level in a given area of an ecosystem

Pyramid of energy a representation that shows the rate at which energy is transferred from one trophic level to another in a given area of an ecosystem

Pyramid of numbers a representation that shows the number of individual organisms at each trophic level in a given area of an ecosystem

Realised niche the actual ecological niche a species inhabits

Reservoir a living or non-living component of a biogeochemical cycle that holds matter for a long time; the location of cycling matter in the biosphere; for example, the ocean is a reservoir for water, and sedimentary rock is a reservoir for carbon in the form of fossil fuels

Resource partitioning the divided use of resources that allows a number of species to coexist in an ecosystem

Scavenger a consumer that feeds on dead and decaying flesh or remains

Secondary consumer a consumer that feeds on primary consumers (herbivores)

Second-order consumer see *secondary consumer*

Solar energy the radiant energy from the Sun, which includes visible light and ultraviolet radiation

Source the place of origin of material or energy

Top consumer the last link in the food chain

Transferred (of energy) moved from one organism to another, such as from producer to consumer; it is still in the same form

Transformed (of energy) changed in form; for example, from light energy to stored potential chemical energy

Trophic efficiency the percentage of energy at one trophic level that ends up in the next trophic level

Trophic level a feeding level in a food chain of an ecosystem

Weathering the breaking down or dissolving of rocks and minerals into smaller particles due to rain, ice, acid or salt

Zooplankton the collective term for the tiny heterotrophic organisms present in bodies of water

CHAPTER 4 REVIEW QUESTIONS

Remembering

1 Distinguish between a food chain and a food web.

2 In a marine ecosystem, a food chain consists of phytoplankton, zooplankton, lantern fish and tuna. Name the primary consumer.

Understanding

3 Under what circumstances would an ecologist encounter an inverted ecological pyramid? Provide an example.

4 Describe the role of the three organisms that have no arrows assigned to them, at the base of the food web in Figure 4.35.

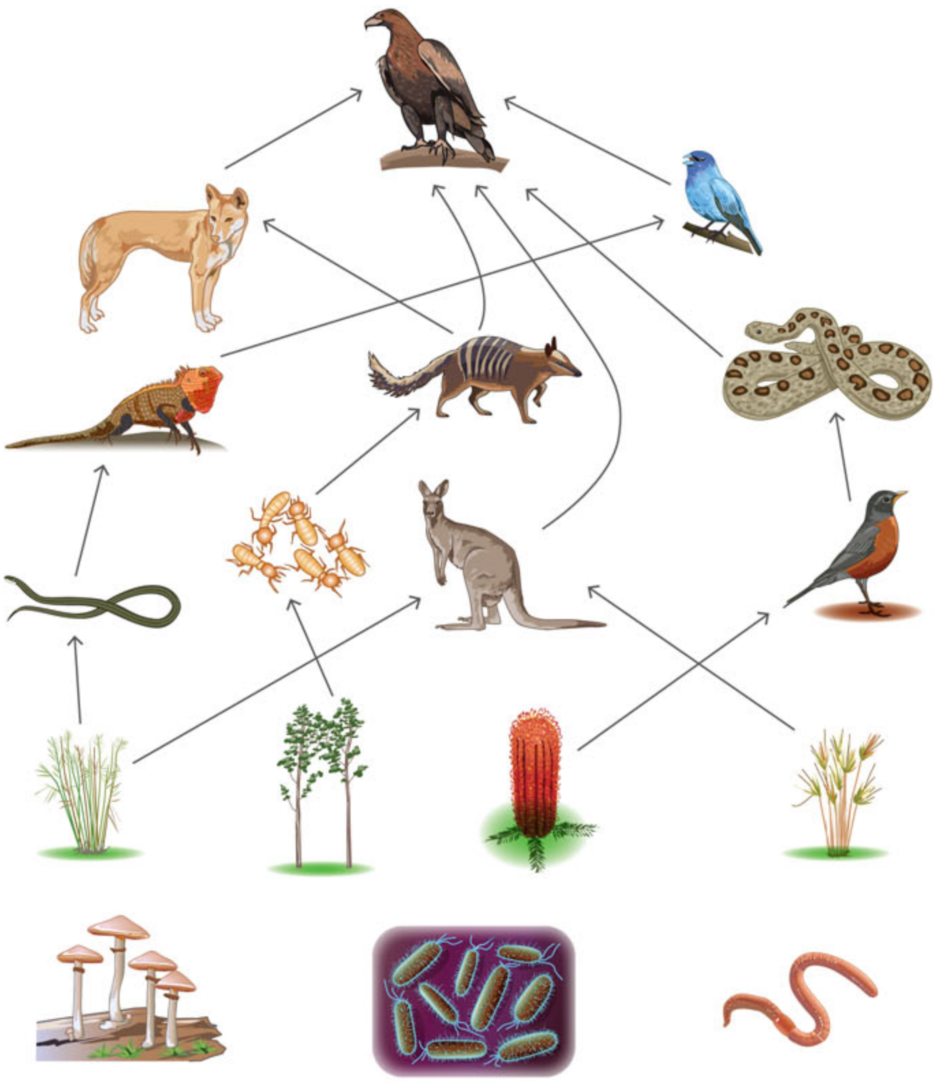

FIGURE 4.35 An Australian food web

Applying

5 A farmer grows grain that is fed to cattle. Humans eat the meat of the cattle. If the amount of energy available in the harvested crop is 800 kJ, how much energy is available for the human population? Show your calculations as annotations to the food chain.

6 Explain the advantages of being an omnivore, such as a fox.

7 What effect does the migration of organisms have on the pathways of transfer of both energy and matter in ecosystems?

Analysing

8 Explain how energy is ‘lost’ from food chains and the significance to ecosystems of this loss.

9 Based on knowledge gained from this chapter, explain whether the population sizes of certain species in the oceans should be monitored.

10 The Galapagos Rift is a deep-sea boundary between oceanic plates that receives no light. Sulfate in the sea water is converted into hydrogen sulfide at high temperatures. Chemosynthetic bacteria obtain energy from the hydrogen sulfide; they use this energy to convert carbon dioxide dissolved in the water into organic molecules. In the same area, clams that feed on the chemosynthetic bacteria are an energy source for crabs and octopods. Chemoheterotrophic bacteria return resources to the community.

Which one of the following combinations identifies the producer, the primary consumer, the secondary consumer and the decomposer for the community described above?

	PRODUCER	PRIMARY CONSUMER	SECONDARY CONSUMER	DECOMPOSER
A	Photosynthetic bacteria	Clams	Octopods	Chemosynthetic bacteria
B	Chemosynthetic bacteria	Clams	Crabs	Chemoheterotrophic bacteria
C	Photosynthetic bacteria	Octopods	Crabs	Chemosynthetic bacteria
D	Chemosynthetic bacteria	Crabs	Octopods	Chemoheterotrophic bacteria

11 An experiment was conducted to investigate the effect of temperature on the rate of photosynthesis in aquatic plants. The rate of photosynthesis was measured at 25°C and then at 15°C. Explain the most likely effect that this change in temperature would have on the rate of photosynthesis.

Evaluating

12 Table 4.12 shows estimates of the primary productivity of different ecosystems in kJ m^{-2} $year^{-1}$. Using the 10% rule, copy and complete the table to compare the value of 'food' energy available at different trophic levels in the four ecosystems.

TABLE 4.12 Estimates of the primary productivity of different ecosystems.

TYPE OF ECOSYSTEM	PRIMARY PRODUCTIVITY (kJ m^{-2} $year^{-1}$)	ENERGY AVAILABLE TO PRIMARY CONSUMERS (kJ m^{-2} $year^{-1}$)	ENERGY AVAILABLE TO SECONDARY CONSUMERS (kJ m^{-2} $year^{-1}$)
Grassland	8400		
Ocean	3350		
Tropical rainforest	3800		
Desert	<840		

a Define GPP and NPP, using the information given above as examples.
b Which ecosystem is least productive? Explain why.

13 Explain why the production of organic matter in deserts and cold climates is about 1 kg m^{-2}, whereas in tropical forests and grasslands it is about 5 kg m^{-2}.

Creating

14 An ecosystem is maintained by the constant supply of energy from sunlight and the recycling of material. Create a poster of the carbon cycle, showing the transfer and transformations of carbon forms in different parts of the biosphere and the processes involved during transformation.

Reflecting

15 Reflect on the relationship between keystone species and food webs.

PRACTICE EXAM QUESTIONS

Analyse Figure 4.36 to answer Questions 1 and 2.

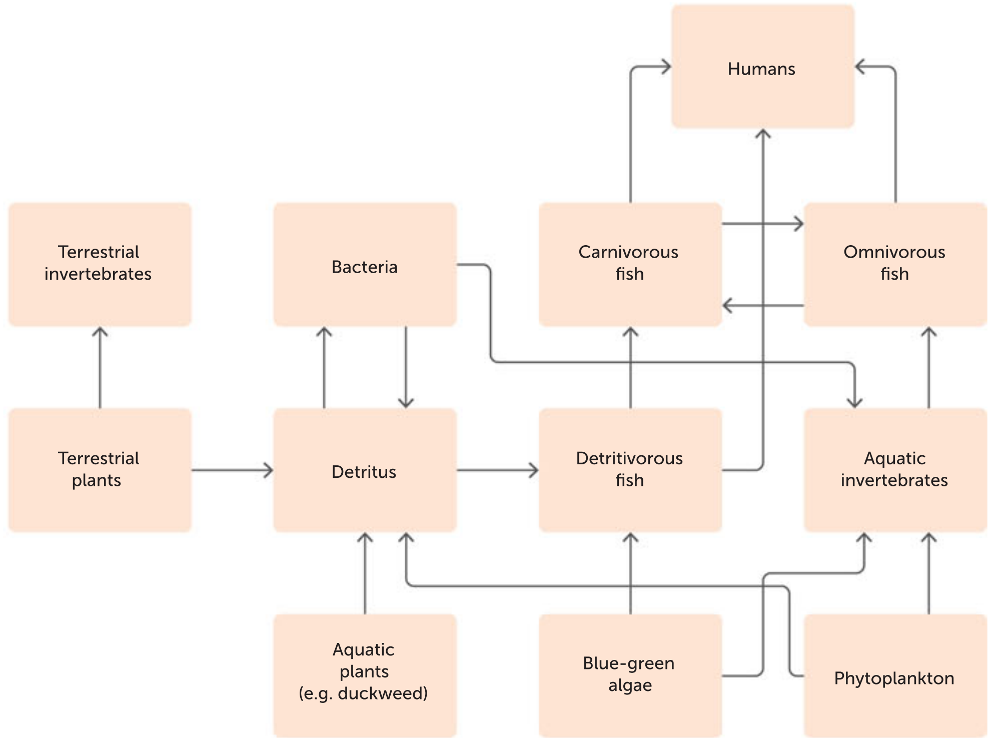

FIGURE 4.36 A generalised food web for a floodplain-river ecosystem

1 Which of the following options lists a producer and a primary consumer in correct order, and states the highest number of trophic levels in one food chain?

	PRODUCER	PRIMARY CONSUMER	HIGHEST NUMBER OF TROPHIC LEVELS IN ONE FOOD CHAIN
A	Aquatic plants	Terrestrial plants	5
B	Terrestrial plants	Detritus	4
C	Phytoplankton	Aquatic invertebrates	6
D	Blue-green algae	Carnivorous fish	4

2 Which of the following organisms occupy two or more trophic levels?

A terrestrial plants and aquatic invertebrates
B omnivorous fish and phytoplankton
C detritivorous fish and bacteria
D carnivorous fish and humans

3 Net primary productivity is best defined as:
- **A** the rate at which energy is stored by plants as organic matter minus the amount required by the plants for respiration.
- **B** the total amount of organic matter fixed in an ecosystem made via photosynthesis and respiration.
- **C** the amount of solar energy entering an ecosystem.
- **D** the total mass of producer organisms in an ecosystem.

4 In an aquatic food chain, lily plants are consumed by water snails, which are consumed by mountain ducks, which are consumed by cats.
- **a** Draw a food chain for these relationships. (1 mark)
- **b** Draw a labelled energy pyramid to represent each trophic level. Assume that 10 105 joules of energy are stored in the first trophic level. (3 marks)

5 Draw and label the biogeochemical carbon cycle, including all the different forms of carbon and processes that transform carbon. (10 marks)

James Vodicka

5 POPULATION DYNAMICS

CHAPTER 5 CONTENT

STARTER QUESTIONS

1 How do scientists measure the distribution and abundance of populations?
2 What factors cause population numbers to fluctuate?
3 What is Earth's carrying capacity for humans?

SCIENCE UNDERSTANDING

» the dynamic nature of populations influence population size, density, composition and distribution
» ecosystems have carrying capacities that limit the number of organisms (within populations) they support, and can be impacted by changes to abiotic and biotic factors, including climatic events

SCIENCE AS A HUMAN ENDEAVOUR

» contemporary technologies, including satellite sensing and remote monitoring enable improved monitoring of habitat and species population change over time

SCIENCE INQUIRY SKILLS

» conduct investigations, including using ecosystem surveying techniques (quadrats, line transects and capture–recapture) safely, competently and methodically for the collection of valid and reliable data

School Curriculum and Standards Authority (2017). Biology ATAR course: Year 11 syllabus: Science inquiry skills.

5.1 WHAT IS A POPULATION?

Determining and analysing the size and structure of various **populations** is important. It enables scientists and governments to research and implement strategies that help vulnerable species persist and contribute to the planet's **biodiversity**. For example, how are vulnerable species, such as WA's woylie populations in the Dryandra's woodlands in south-west WA, going to recover after being subjected to habitat loss and predation by feral animals? How many minke whales may be hunted near Iceland in one season and still sustain a viable population? What factors determine whether a population is thriving, surviving or on the brink of extinction? What is the critical population size and what needs to be considered when working to ensure that Earth's biodiversity is maintained?

The factors that require consideration vary greatly between species. For example, a minke whale population in any area can be as small as 6 animals or as large as 50–100 animals, depending on the availability of food and resources. In contrast, for krill (the minke's food source), a population of less than one million individuals is considered at risk.

Data about woylie population abundance has been used to assess its conservation status and help with conservation planning for control of foxes and feral cats. A baiting program and a predator-free sanctuary near Manjimup was a result of population monitoring.

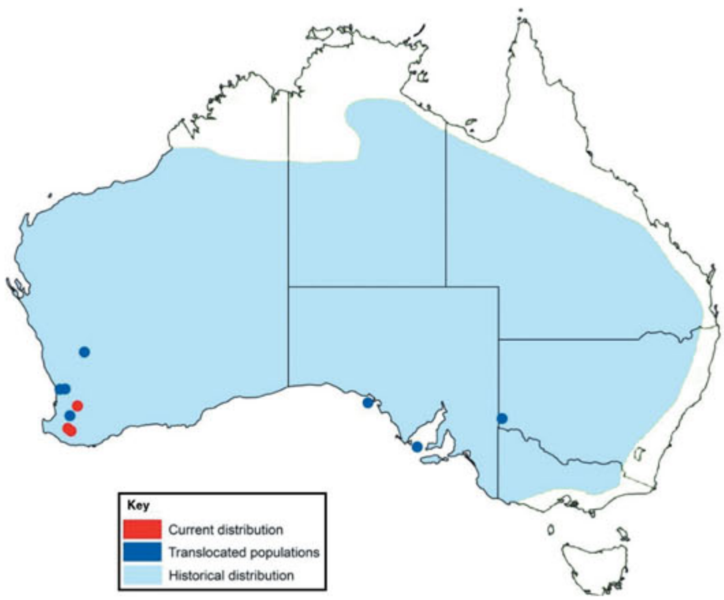

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FIGURE 5.1 The distribution of woylie populations has been severely reduced by habitat loss and predation.

Numbat and woylie populations
Watch the video to learn more about conservation efforts to support these species in Dryandra.

As a population grows within an area, it may experience effects from its increased density. In a given area, the maximum population size of the species that the environment can sustain is called the **carrying capacity**. Carrying capacity is determined by the amount of available resources (e.g. food, habitat, water). As the density of individuals in a population increases, these individuals within the same species begin competing with each other (i.e. intraspecific competition) or with other species (i.e. interspecific competition) for the available resources. If the population keeps growing, progressively fewer resources will be available to sustain it. This process, in which per capita population growth changes when population density changes, is known as density dependence.

Population dynamics refers to the ecological (biotic and abiotic) interactions that lead to fluctuations in population size. It includes how populations of a species change in size and structure over time. The **abundance** of a species is a specific measure of a population's size or density in an ecosystem. For example, the abundance of birds living on the edge of the lower south-west karri forests in WA decreased as logging of timber increased. Abundance is not solely a measure of the number of individuals; it includes specifically where in the habitat they live, breed or hunt. As karri

FIGURE 5.2 a Karri trees at Boranup Karri Forest in Leeuwin-Naturaliste National Park, WA. **b** Despite the efforts of conservation groups, logging of karri is still not strictly controlled.

tree regrowth occurs in the south-west, bird abundance increases along with the abundance of other species, such as the western ringtail possum.

Rates of reproduction, death, migration, available food and water sources, and competition are all important factors in population dynamics. The study of a species' population dynamics usually seeks to answer questions such as:

- What explains average abundance of a population?
- What causes fluctuations in abundance?

Populations in unstable environments

A traditional method of classifying populations is by reference to *r*-selected and *K*-selected species. In unstable, unpredictable ecosystems, such as those that occur after a fire or land clearing, opportunistic species move in and colonise quickly. In these environmental conditions, the colonising species undergo population explosions. This pattern of rapid increase, where the maximum reproductive potential of the species is reached, then the population declines (or crashes) in numbers, is called ***r*-selection**. As the environmental resources diminish, the numbers drop off just as rapidly as they grew and these species are replaced by competitors. To survive, these so-called ***r*-selected species** must colonise new environments quickly, and be able to reproduce rapidly and in relatively large numbers. The species in this group are characterised by being of smaller size, having short life cycles and, in animals, a lack of parental care for young. Examples of *r*-selected species include mice, toads, weeds, oysters and locusts.

Populations in stable environments

In stable ecosystems, slow and steady life strategies are more successful. Over time, larger, longer-lived species such as elephants, whales, gorillas, oak trees and eucalypts outcompete the smaller, faster-growing species. Such species have a steadier population growth pattern and can exist in numbers close to the carrying capacity of their environment.

For example, the female red kangaroo is able to manage the number of young that are born at any one time. At times when water and food are plentiful, the female may have up to three young at various stages of development: an older joey that spends most of its time outside the pouch and is no longer reliant on the mother for nourishment, a young joey that is firmly attached to a nipple in the pouch while it completes development, and a third embryo whose development and birth have been suspended until there is room in the pouch. If food or other requirements for life become scarce at any stage, the female can abandon any one of the three. Without her protection, it will almost certainly perish. This may seem a harsh reality; however, this reproductive strategy means that a sustainable population size is maintained. This strategy is defined as ***K*-selection**, and over the long term it offers stability to the ecosystem and equilibrium to its populations. ***K*-selected species** live longer, breed later in life, have fewer offspring and devote time and effort to ensuring the survival of the offspring to reproductive maturity.

Key concept

Populations are dynamic because they change in size and structure over time. Unstable environments favour *r*-selected species, which grow and reproduce quickly; whereas stable environments favour *K*-selected species, which are larger and slower-growing.

Question set 5.1

REMEMBERING

1 Define 'population'.
2 Explain why *r*-selected species are often described as opportunists.

UNDERSTANDING

3 *K*-selected species are described as competitor species. Explain why.
4 Biodiversity is a measure of an ecosystem's health. How is this so?

5.2 MEASURING POPULATIONS

Ecologists describe the total number of a particular species in a particular place at a particular time as the population size; for example, the number of jarrah (*Eucalyptus marginata*) in a forest community each year, the number of straw-necked ibises (*Threskiornis spinicollis*) in a wetland in a particular month or the number of possums in an urban area in summer. Populations in an ecosystem are dynamic. Maybe you have noticed changes in the number and kind of plants or insects in your neighbourhood from one season to another or from year to year. A scientist may measure a population's size or number, or they may measure **population density**, which is the number of that species per unit area (population size divided by total land area). Population size can be measured or estimated if the organism is easily observed and is slow moving or stationary. Sometimes it is difficult to distinguish individual plants, as with grass. In that case, density is measured as the amount of biomass (dry) per unit area (e.g. 0.6 kg of grass per square metre). In the case of diatoms in a pond, density is the number of organisms per unit volume (e.g. 300 per millilitre).

Abundance is the number of organisms per unit area which live in a particular part of an ecosystem. Abundance can be measured as either population size or density, and knowing the abundance can help determine population distribution. Total abundance refers to the total number of organisms in an area. Measures such as these are helpful when planning for conservation strategies, and when making decisions about fragmentation and wildlife corridors. Lastly, **population composition** can also be measured; this term includes the characteristics of a population, such as age, sex ratios, age structure (the number of organisms for each age group), population fertility rate and average number of offspring per female.

Population growth rate

A population is increasing if the sum of the birth rate and immigration rate exceeds the sum of the death rate and emigration rate. 'Rate' refers to the number of individuals being added or subtracted, per 100 or per 1000 present in the population per unit time (usually per year). **Birth rate** is usually given as the number of births per 1000 of a population over a given time, often using units of number of births per 1000 per year. Similarly, **death rate** refers to the number of deaths per 1000 (usually) of a population over a given time, often in units of number of deaths per 1000 per year.

Animals can move between populations for reproductive or seasonal reasons. Immigration is the movement of an organism into a population. The immigration rate refers to the number of organisms, per 1000, that enter a population over a given period. The emigration rate refers to the number of organisms, per 1000, that exit a population over a given period.

Population ecology
Watch this video to add to your knowledge of population ecology, including population size, growth rate, carrying capacity, density-dependent and density-independent factors, and predator–prey graphs.

The Great Cocky Count
Each year, this citizen science project has undertaken an annual count of roosting cockatoos in the Swan coastal plain region on a single day in April.

Kaarakin Black Cockatoo Conservation Centre
Fancy an excursion or incursion?

Measures of population growth and decline are vital to conservation efforts. For example, although bird populations are hard to measure, because they move from breeding to foraging areas, a decline in the numbers of Carnaby's black cockatoos in the south-west of WA has been observed over the last five decades. The species and its habitat are under threat from land clearing, invasive species, disease, fire and the effect of urban ecosystems being developed nearby. All of these factors are potentially made worse by climate change. Carnaby's black cockatoo is classified as endangered under both state and federal legislation. In 1985, the total population of Carnaby's black cockatoo was estimated to be a maximum of 60 000 birds, and a study published in 2013 suggested the total population was around 40 000 birds.

Between 2010 and 2019, surveys by scientists revealed a shift from a decline in Carnaby's black cockatoo population growth to a rise in yearly population growth. For the Perth-Peel coastal plain, the Department of Biodiversity, Conservation and Attractions and BirdLife Western Australia reported a count of 6330 in 2010 and 13 343 in 2019 (Table 5.1). Changes in the counts may be attributable to changes over time in survey effort and/or a documented westward shift due to habitat loss.

FIGURE 5.3 A Carnaby's black cockatoo

TABLE 5.1 Count summary for Carnaby's black cockatoo across all Great Cocky Counts (2010–2019) in the Perth-Peel coastal plain

YEAR	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
NUMBER OF COCKATOOS COUNTED	6330	3912	3791	5591	6662	4692	10 919	10 248	12 465	13 343

Extracted from Table 4, *The 2019 Great Cocky Count*, http://birdlife.org.au/documents/GCC_report_2019_final.pdf

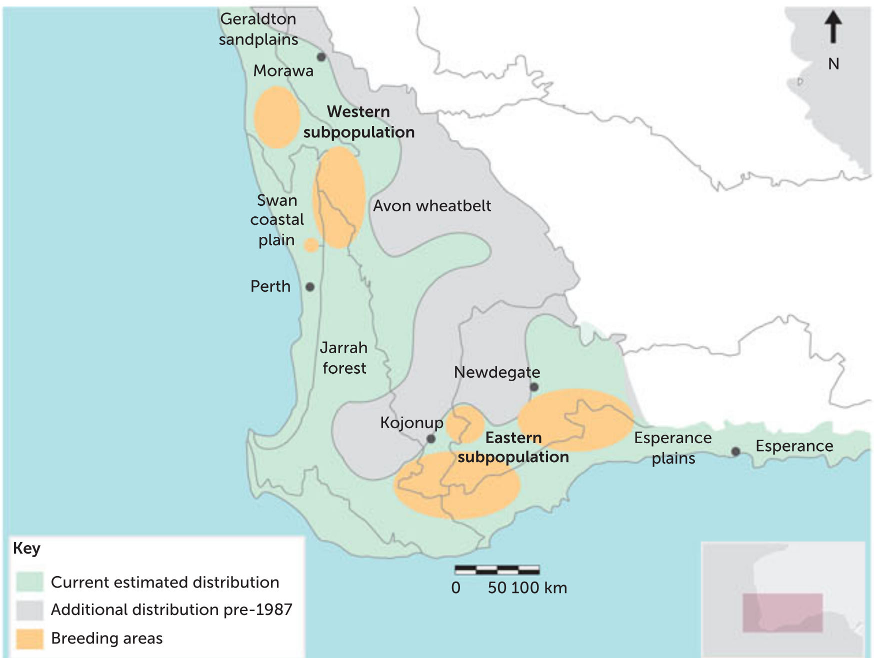


FIGURE 5.4 The estimated distribution of Carnaby's black cockatoo

Key concept

Calculating population growth rate

Population growth rate (r) = (birth rate + immigration rate) – (death rate + emigration rate)
$= (b + i) - (d + e)$

Worked example 5.1

Calculate the growth rate of a population of 1000 individuals where, every year, 100 individuals are born, 65 individuals immigrate into the population, 37 individuals die and 25 individuals emigrate to another population. (4 marks)

ANSWER	LOGIC	
Growth rate = $(b + i) - (d + e)$	Choose formula	1 mark
= (100 per 1000 + 65 per 1000) − (37 per 1000 + 25 per 1000)	Substitute	2 marks
= 103 per 1000	Calculate answer	1 mark

Therefore, the population has grown by 103 individuals per 1000 per year.
Growth rates can also be expressed as a percentage: +10.3% per year, if there is an increase, or −10.3% per year, if there is a decrease.

Practice questions

1 Calculate the growth rate of a population if, for every 1000 individuals, there are 59 born, 105 immigrants, 86 deaths and 40 emigrants (per year). Express your answer as both a whole number rate and a percentage. (4 marks)

2 Calculate the growth rate of a population if, for every 1000 individuals, there are 150 born, 59 immigrants, 29 deaths and 30 emigrants (in 1 year). (4 marks)

Analysing population composition and growth

Population studies provide useful information for monitoring ecosystems. Knowing the age structure of a population is significant in predicting future growth trends. For example, a population in which too many individuals are below reproductive age will have a limited ability to reproduce and maintain its numbers in challenging situations, as well as in favourable conditions. Similarly, populations that contain many individuals that are too old to reproduce will have a low rate of replacement of individuals lost to death or emigration.

A useful method of representing collected data is to construct population pyramids. Figure 5.5 (page 152) shows population pyramids for two different human populations. You can see that the pyramid for population A is wider at the bottom, indicating a healthy future reproduction rate because the number of children is quite high. Population A has a greater proportion of children than does population B.

Scientific data about age distribution and sex ratios can assist in the management of populations. Each year, federal, state and local governments collect and collate information on the state of wild fish stocks. This information is used to determine the sustainable levels for both recreational and commercial fishing. Sustainability means ensuring that overfishing does not drain the stocks, and that young (smaller) fish are able to contribute to the populations in the future. Information about population composition can be used to plan how to ensure sufficient young live to reach reproductive age, how to develop strategies for protecting endangered species and maintaining ecosystems, and how to restore degraded ones.

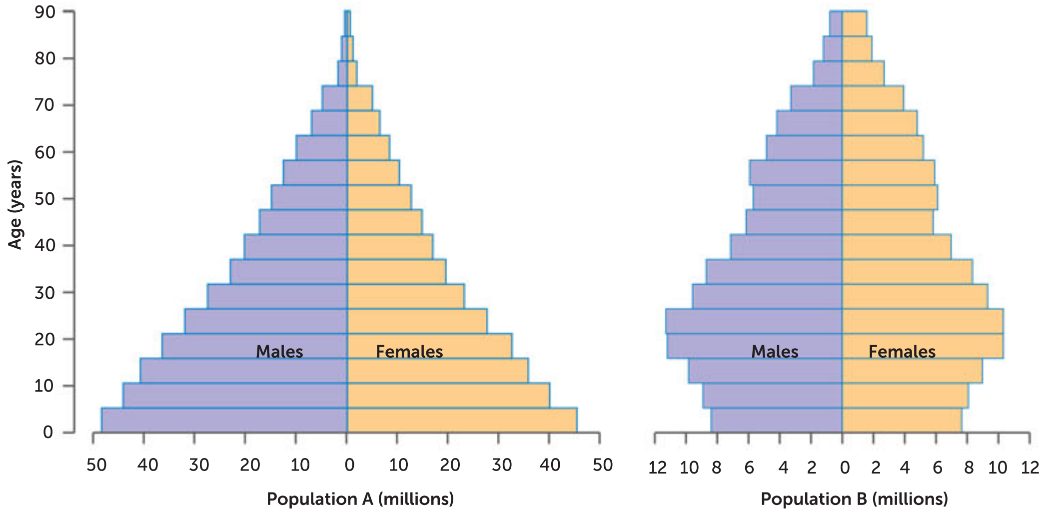


FIGURE 5.5 Population pyramids

Measuring distribution

Understanding how populations operate takes more than knowing what kinds of species are present or how they relate. It is also important to know their **distribution**: exactly where in the physical space members of the different species are found.

Members of a population are seldom spread evenly throughout the entire ecosystem. There can be patterns in the way populations are distributed.

- **Random distribution** organisms are spaced irregularly; the location of one organism does not affect the location of another (this is more common for plants than for animals).
- **Uniform (continuous) distribution**: organisms are evenly spaced; the presence of one organism determines how close or distant another will be. This is common in relatively high-density populations of some animals that set up breeding territories.
- **Clumped (grouped) distribution:a** number of individuals are grouped together and the groups make up the population as a whole. This sometimes results from social behaviour (e.g., schools of fish), or the occurrence of mini-habitats, where **biotic** and/or **abiotic** factors are favourable (e.g., clumping of vegetation).

Knowing the distribution and abundance of a species can help ecologists keep track of populations of significance. Knowledge of particular plant species can give clues about the distribution and abundance of animals that depend on them. The forestry industry needs to know about the distribution and abundance of valuable tree species, and the fishing industry needs to know about fish stocks. Keeping track of pest and plague species, such as mice and locusts, gives forewarning of potential outbreaks that would require management.

Techniques used to determine distribution and abundance depend on the species or community under investigation. Because plants are stationary, the methods used to determine their location, numbers and distribution are different from those used for animals (which are usually mobile). The method that gathers the most pertinent data for management of populations within ecosystems should always be selected. For example, a small population of a rare orchid species may be able to be counted individually, whereas estimating a colony of penguins or a school of oceanic tuna will require different methodology.

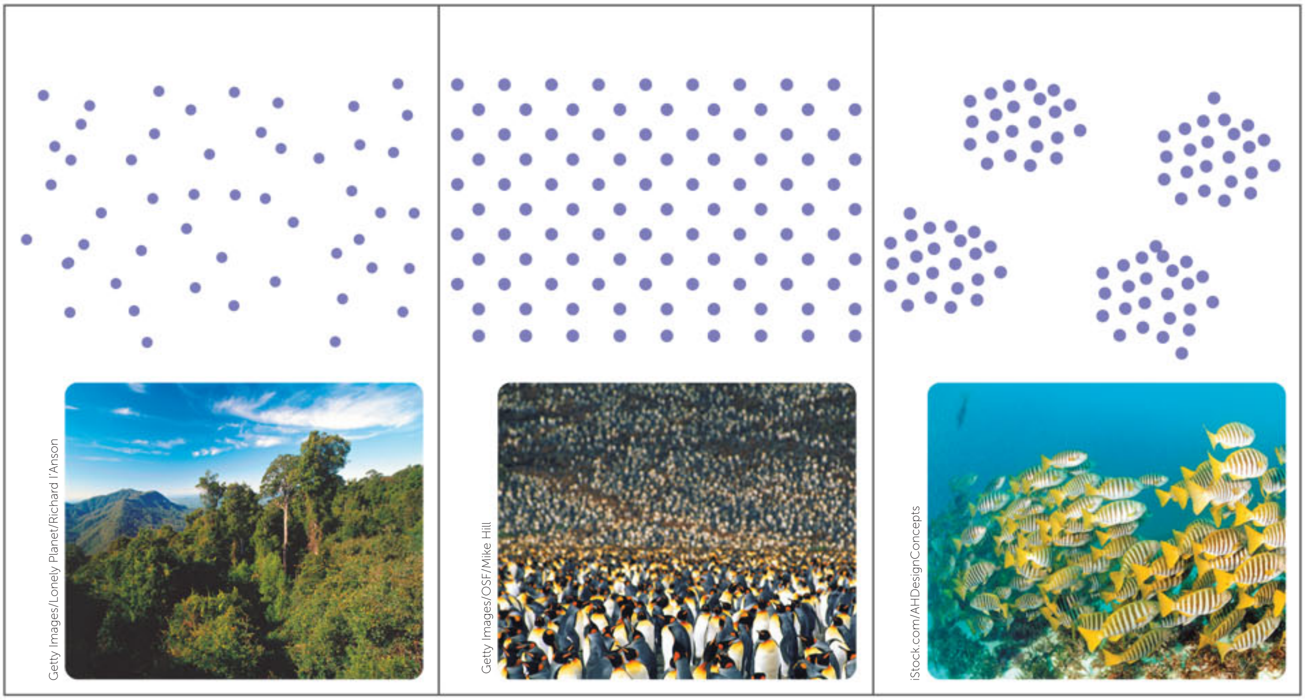


FIGURE 5.6 Distribution patterns: random, uniform and clumped

Measuring abundance (population size or density)

It is not always possible to determine the size of a particular population. Birds and insects are constantly on the move, and some animals move too fast to count. It may be difficult to work out what actually makes up an individual organism. How do you count individual plants of grass? However, there are still techniques that can be used to make estimates.

Quadrat and transect

For organisms that are fixed or do not move very much, the **quadrat** method of sampling can be used to estimate distribution and abundance. A quadrat is a square, rectangular or circular frame, the size of which is determined according to the organism being studied. It is used for measuring at ground level. It is most often used when measuring plant **density** because plants are stationary. It is also a relevant method for recording sedentary marine species that may be exposed along shorelines as the tide varies. Quadrat counts can be used to calculate the density of a population.

FIGURE 5.7 Quadrat sampling is often used to estimate plant population size.

If sufficient quadrats are chosen, and they are representative of the area under study, results can be used to estimate total population size. For each quadrat, the number of individuals of each species is counted and recorded, or percentage cover is estimated. Refer to Chapter 1 (pages 20–1) for the calculation method. After the individuals in each quadrat are counted or estimated, the totals are averaged.

A simple mathematical calculation can give the total number or percentage cover for each species in the whole area. The density can also be calculated.

Key concept

Estimating population size and density

$$\text{Population size} = \frac{\text{no. individuals in selected quadrats}}{\text{no. selected quadrats}} \times \text{total no. quadrats}$$

$$= \text{no. of individuals}$$

$$\text{Population density} = \frac{\text{population size}}{\text{area}} \times \text{total no. quadrats}$$

$$= \text{no. of individuals per m}^2$$

A **transect** ('trans' means across, 'sect' means section) is a line drawn through a community. Information is gathered from along the line and used to estimate the distribution of species within that community. Again, this is a useful method with species that are immobile, such as plants and fungi. To improve the data collected, quadrats may also be placed at intervals along the transect line and thus data on density in specific locations may also be recorded.

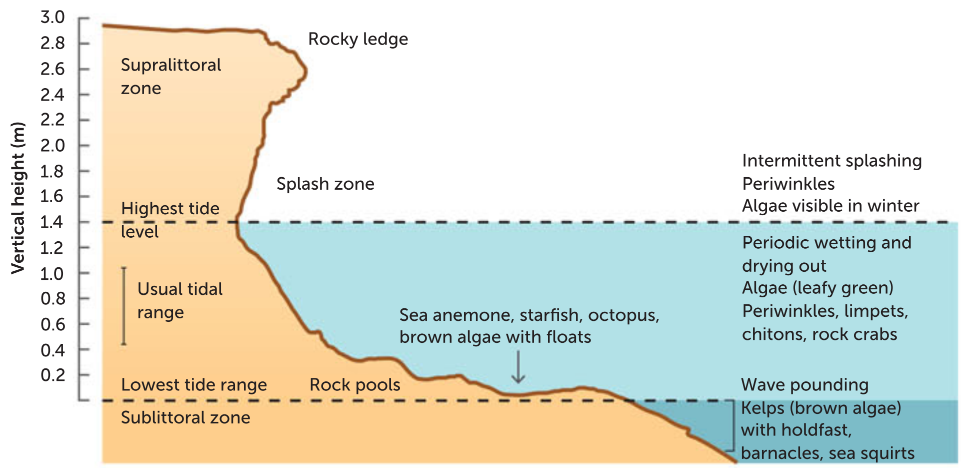


FIGURE 5.8 Transect profile of a marine rock platform

Worked example 5.2

If 35 individuals have been counted in 10 × 1 m² quadrats, what is the average density of that species? (3 marks)

ANSWER	LOGIC	
$35 \div 1\ \text{m}^2 \times 10$	Formula as in Key concept. Enter values	2 marks
$= 3.5$ individuals per m²	Calculate answer	1 mark

Try these yourself

1 Complete the following to determine the average density.

a 65 individuals in 24 × 2 m² quadrats (3 marks)

b 110 individuals in 12 × 5 m² quadrats (3 marks)

When an area has been selected for study and the data needed has been nominated, the transect line is measured out. For example, the transect line may be 10 m long, with regular segments (e.g. every metre) where information regarding changes in distribution of chosen species is recorded as you move across a tidal zone towards land. It may also be used to gather information on vertical features, such as the canopy of the forest, as well as a wider range of the species present. In contrast, if the study was looking at changes in the distribution of organisms in relation to change in abiotic factors with altitude along a mountainside, the transect line may need to be a kilometre long. It is best to use the line transect method if environmental factors such as soil type, pH and salinity change along the distance to be sampled.

For a full picture of population distribution and species abundance patterns in environments, a combination of methods is best. Data gathered using transects offers fairly accurate information regarding distribution of individuals and/or species, whereas quadrats offer a comprehensive picture of species abundance, but not distribution.

Capture–mark–recapture

The **capture–mark–recapture** method (often shortened to capture–recapture) is commonly used to estimate the size of a population of a mobile species. A random **sample** of individuals of a species is taken and an overall estimation of the abundance of the species is made. The number of animals caught in each sample must be large enough to produce reliable results.

Step 1 – Capture: animals are caught randomly (without being hurt). Small animals are trapped in cages or pitfalls in the ground, birds are trapped in fine nets and some animals are caught easily when they 'freeze' in spotlights. Flying insects are attracted to light traps.

Step 2 – Mark (tag) and release: each captured animal is marked so it is not obvious to predators or harmful to the organism. Insects are usually marked with a blob of paint, whereas birds are marked on the leg or wing. The animals are then returned to their habitat.

Step 3 – Recapture: a random sample is taken from the whole population and the number of marked individuals in it is counted. The timing of recapture needs to allow for the capture of a random mixture of individuals, but without leaving it so long that many of the original marked individuals have died. From this information the total population can be estimated. The procedure has to be planned carefully so that the chances of each individual being caught are equal. Sometimes 'trap happy' individuals will be sampled over and over.

Getty Images/Jonathan Blair

FIGURE 5.9 Playing tag: tagging a turtle

Population (*N*)	First capture and mark (*M*)	Release	Second capture (*n*)	Number of marked individuals in second capture (*m*)
Select a population →	Capture a sample of the population and mark all of them. Record this number. →	Release the marked sample back into the original population for mixing. →	Perform a second capture to gain another sample of the population. →	Count the number of marked organisms in the second sample. Record the marked number as well as the total number in the second capture (both marked and unmarked).

FIGURE 5.10 The steps of the capture–mark–recapture surveying technique

The first formula below shows that the proportion of marked organisms in the population is equal to the proportion of marked organisms in the sample. On the right, the first formula has been rearranged to make N the subject. This allows the population size (N) to be estimated.

$$\frac{M}{N} = \frac{m}{n} \qquad N = \frac{Mn}{m}$$

N is the population size to be estimated.

M is the number of members of the population that are captured initially and marked.

n is the number of members of the population that are present in the second capture.

m is the number of members of this second capture that are marked.

The capture–mark–recapture procedure will only work if the following assumptions are valid for the study population:

1. There is no death, immigration or emigration (i.e. the population is closed).
2. The sampling methods used are identical for the capture and recapture.
3. The marking (tag) does not affect the survival rate of the animals.
4. All members of the population mix randomly, and enough time was given between captures for the organisms to mix. In other words, each member of the population has an equal chance of capture each time.

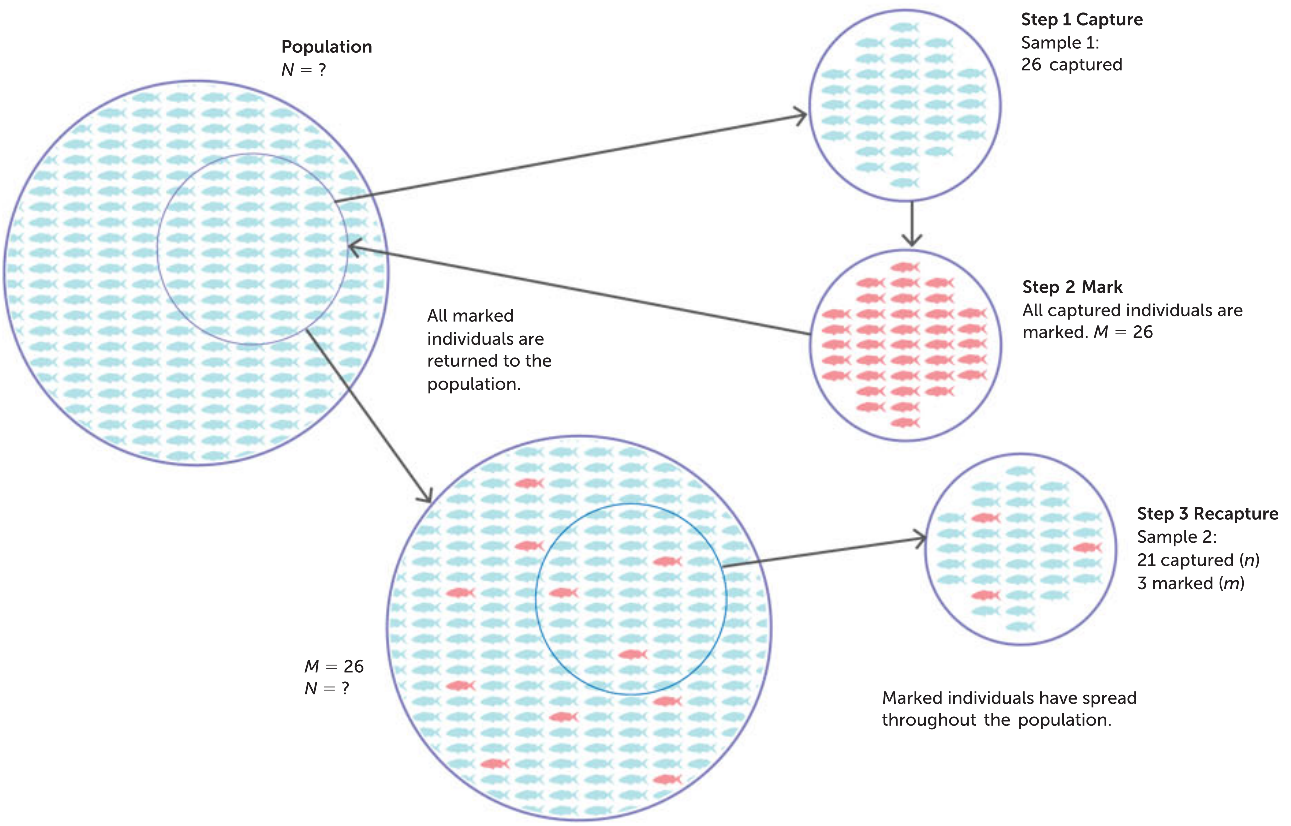


FIGURE 5.11 The capture–mark–recapture technique gives an estimate of total population size

Worked example 5.3

A population is surveyed using the capture–mark–recapture method. In the first sample, 20 individuals were marked. In the second sample, 50 individuals were recaptured and of these recaptured animals 10 were marked. What is the total population? (3 marks)

Total population (N) = [no. marked in first sample (M) × total number of animals recaptured (n)] ÷ no. of recaptured animals that are marked (m)

$$N = \frac{M \times n}{m}$$

ANSWER	LOGIC	
Total population $= \frac{20 \times 50}{10}$ $= \frac{1000}{10}$	Substitute into the formula above	2 marks
= 100 individuals in the total population	Calculate the answer	1 mark

Practice questions

1 In the first sample, 30 individuals were marked. In the second sample, 50 individuals were recaptured and 10 of these were marked. What is the total population? (3 marks)

2 In the first sample, 100 individuals were marked. In the second sample, 200 individuals were recaptured and 50 of these were marked. What is the total population? (3 marks)

Telemetry (remote tracking)

The management and conservation of species, whether native, endemic or pest species, increasingly relies on information gathered by a combination of the methods described previously and other methods that use technology. **Species distribution modelling** is a more recent technology that is also used to obtain data for conservation, and is particularly useful in studies examining the impact of climate change on populations, which is increasingly causing concern for the wellbeing of many species.

In order to collect data used in species distribution modelling, individuals in a population need to be tracked. For example, in Victoria, information regarding the foraging habits of little penguins during the non-breeding winter period was gathered when 21 little penguins were fitted with GPS (global positioning system) transmitters in July 2008. The data gathered indicated that the penguins went on short trips of 1–2 days around Phillip Island and then on longer foraging trips of 10–50 days out into Port Phillip Bay. The winter foraging trips appeared to be driven by the location of food sources such as anchovy, which are known to spawn in Port Phillip Bay during winter. This information was used to inform conservation groups on what areas needed to be monitored for human aquatic activity, such as shipping, fishing and trawling, to minimise disturbance to foraging penguins during these months.

FIGURE 5.12 A little penguin fitted with a transmitter

SCIENTIFIC LITERACY

The slaughtering of whales – an ongoing saga

By the early 20th century, whales had been driven almost to extinction by hunting. Some cultures, including Japan, Norway and Iceland, have traditionally consumed whale meat for centuries, and many other countries killed whales to obtain other valuable products. By the 1960s, more efficient catch methods and giant factory ships were developed, making it obvious that if hunting continued, whales would die out. So in 1986, all members of the International Whaling Commission (IWC) agreed to a hunting moratorium to allow whale numbers to recover. Traditional whaling countries assumed the moratorium would only last until everyone could agree on sustainable quotas, but instead it became a permanent ban. Exceptions to the rules allowed Indigenous groups to carry out whaling for scientific purposes, a clause Japan fully utilised. Japan has killed between 200 and 1200 whales each year since 1987, claiming this was to monitor stocks to establish sustainable quotas, but it doesn't hide the fact that the mammals end up as food.

Many conservation groups have taken direct action to try to stop whaling. In 2012, campaigners from the conservation group Sea Shepherd travelled from Australia to stop Japanese ships from slaughtering whales in the Southern Ocean. Among their haul, the whalers took endangered fin whales and humpback whales, both of which visit Australian coasts at various times of year. It was Captain Peter Hammarstedt's ninth campaign protecting whales, which have at times led to clashes at sea between the conservationists and the Japanese.

In 2013, Australia took Japan to the United Nations International Court of Justice to enforce an end to their scientific whaling. The judgement was delivered in March 2014, with the court ordering Japan to halt its Antarctic whaling research (Japan's North Pacific research programs were not covered by the case). Japan stopped its Antarctic research cruises for one year, then resumed them within new programs that it said were in line with the court's ruling.

Japan's noncompliance continued. In 2018, it announced it was withdrawing from the IWC and began commercial whaling in its own waters, to international disapproval. It sent out its first whaling fleet on 1 July, with permits to catch 227 whales. That year, Japan killed 333 minke whales, as well as approximately 100 endangered sei whales, claiming these amounts fell within its scientific whaling program. It argued that the sale of whale meat from these catches was incidental, but a Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) panel found that the commercial sale of sei whale meat was the main purpose of the slaughter. In early 2019, the Japanese government stated it would bow to international pressure and stop its hunts for sei whales in the open seas, so it could comply with CITES. Japan hopes it may have the support of the international community to continue with some whaling if it keeps within sustainable limits.

Getty Images/The Asahi Shimbun

FIGURE 5.13 A Japanese whaling ship in operation

Questions

1 Identify three important messages conveyed in this article.
2 The Australian government, Japanese government and the United Nations International Court of Justice are all involved in the issue of whether whaling should proceed. In your opinion, who should have the final say? Justify your response.
3 Suggest some of the difficulties involved in monitoring and managing the remaining population sizes of whale species.
4 All whale species have a *K*-selected life strategy. Identify their *K*-selected characteristics and outline how each of these would affect the ability of their population to recover if unregulated numbers were removed.

GPS tracking is also used to track the movements of migrating animals, such as wedge-tailed eagles (Figure 5.14) and whale sharks. The signal is received by a satellite that ensures the animals are tracked even when they are not in sight.

Radio tracking is an older technology than GPS tracking. In it, the signal is transmitted from a unit attached to the animal to a receiver. The animals are physically followed by the scientists who will have the receiver in a car, truck or aeroplane. The data collected shows the movements of the animals and their destination, and is used to determine the best management strategy to ensure their safety. This technique has been used by scientists to locate and observe the activities and behaviours of numbats and woylies in their natural habitat (Figure 5.15).

The measuring tools used to determine the abundance of organisms in a population are dependent on a number of factors, including the size of the population, the size of the organisms, whether the location is easily accessible, the life cycle of the organisms, migratory patterns, activity times and anything already known about the population, including the likelihood of population explosions or declines. Techniques should be suited to the species being studied; for example, there is no point in attaching a solar transmitter to a nocturnal animal that spends its daylight hours in burrows deep beneath Earth's surface!

Westpix/Simon Cherriman

FIGURE 5.14 This migrating wedge-tailed eagle has been fitted with a GPS tracker.


© The Sunday Times / WestPix

FIGURE 5.15 Scientists use radio tracking techniques to monitor numbat activity in the wild.

Question set 5.2

REMEMBERING

1 What characteristics of populations are usually studied when analysing ecosystems?
2 Describe three basic patterns of distribution of populations of organisms.
3 Using examples, explain the difference between abundance and distribution.

ANALYSING

4 Ecosystems can be open or closed to particular species. What effect does this have on the growth of a population?
5 A particular population of kangaroos has 1000 births during the year; 72 individuals also join the population, while 108 leave. There are 345 deaths. Work out the growth rate for this population of kangaroos for the year.

EVALUATING

6 Copy and complete Table 5.2 below by summarising three methods of estimating distribution and abundance of populations of organisms.

TABLE 5.2 Methods of estimating distribution and abundance

METHOD	BRIEF DESCRIPTION	BEST USED FOR

APPLYING

7 A study was carried out to determine the population size of a species of lizard living on three small islands. The lizard populations are isolated and considered separate. The capture–mark–recapture method was considered suitable for the purpose of this study. Use Table 5.3 to answer the questions that follow.

TABLE 5.3 Lizard population data

	POPULATION 1	POPULATION 2	POPULATION 3
Number of lizards captured and marked (first sampling)	170	315	400
Number of lizards recaptured (second sampling)	140	295	450
Number of marked lizards (second sampling)	34	35	25
Area (m^2)	2900	19 800	50 900

a Use the capture–mark–recapture formula to calculate the population size on each island.
b Calculate the population density for each island to determine which island has the same density.

GPS tracks illegal fishing
Albatrosses fitted with long-lasting transmitters collected data from fishing activities and provided evidence of illegal fishing.

APPLICATION

Animal GPS

Recent refinements in the use of GPS trackers have reduced intrusions into the lives of the animals being tracked. Some devices are now lighter and can be used on smaller animals. On larger animals, some transmitters can be loaded with extra batteries that last longer; for example, devices on elks can last up to 8 years. But the most innovative change is the use of solar cells to power the transmitters used on birds. This reduces the need for scientists to venture into the field, which can disturb the natural behaviour of the birds under study.

5.3 CARRYING CAPACITY AND POPULATION GROWTH CURVES

Carrying capacity

A habitat has limited resources and therefore can only support a certain number of individuals in a population. Populations rely on balanced relationships between their biotic and abiotic components. The abiotic aspects have been studied in Section 5.1. The biotic aspects are based primarily around communities and their component populations. So, when studying a specific ecosystem, its relative health may be measured by the populations that are supported. The maximum size of a population that an ecosystem can support with its limited resources is described as the carrying capacity of that ecosystem. For example, animal populations are monitored in the karri forests of WA. Many species, such as the endangered numbat and red-tailed black cockatoo, depend on tree hollows, particularly for breeding and safety from predators. If trees are cleared for agriculture or human resources, the carrying capacity of the karri forests for species that depend on tree hollows decreases.

Biotic and abiotic factors can be limiting for population growth and what determines the carrying capacity. These factors include:

- availability of resources such as water, food, sunlight, shelter (such as fallen logs) and percentage of oxygen in water (aquatic ecosystems)
- predation
- disease.

The carrying capacity of an ecosystem can change from time to time as environmental conditions change. In theory, a population will grow until limiting factors hinder its growth.

Python Ecological Services/Karlene Bain

FIGURE 5.16 Hollows in mature trees are a vital, limited resource for a whole range of species, including cockatoos, numbats and possums.

Key concept

The carrying capacity is the maximum size of a population that an ecosystem can support with its limited resources. Carrying capacities can be affected by changes to abiotic and biotic factors.

Modelling populations
Scroll down and watch the video of how the size of the lynx and snowshoe hare populations change over time.

Predator–prey cycles
See how the size of predator and prey populations can interact in a feedback loop.

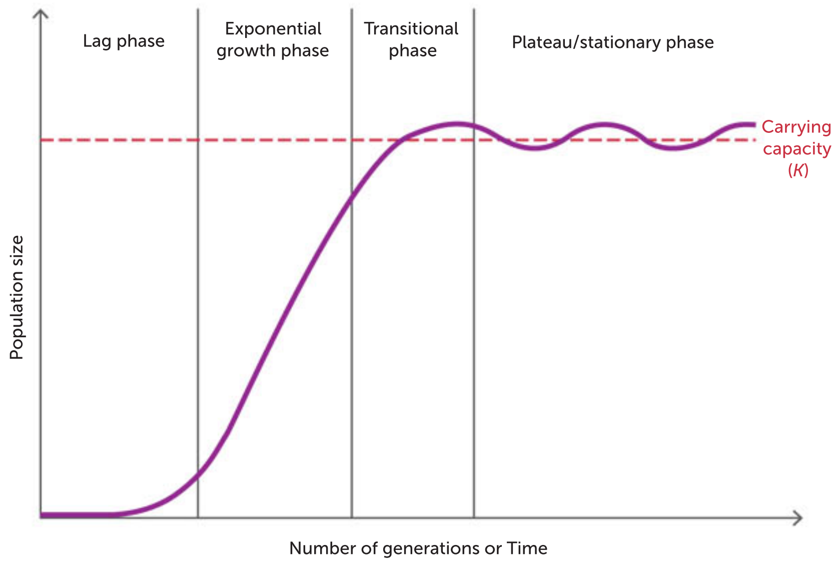
Modelling population dynamics
Investigate population dynamics by changing variables

Population growth curves

When a few members of a species colonise a new and favourable habitat, their population increases rapidly. However, this population growth cannot be sustained; resources are used and the population begins to level off. Despite minor fluctuations in the size of populations, there tend to be upper and lower limits. For a given species in a particular habitat, there is a certain equilibrium population that the ecosystem can support (Figure 5.18).

The population numbers of the Canada lynx and the snowshoe hare of northern Canada depend on each other. Every 8–10 years, the number of hares increases exponentially. The cause for this explosion is still under investigation. The lynx hunts the hare and, because there are so many hares, the lynx population also increases. This then puts pressure on the hare population and a slump in numbers follows. The stress of being hunted affects the health of the remaining hares and illness spreads through the hare population. This then affects the lynx population, even though the lynx is able to hunt and feed on other small animals such as squirrels, grouse and white-tailed deer. For the lynx, hunting these less-preferred prey takes its toll and its numbers decrease. Cyclic changes in population size are typical for predator and prey populations (see Figure 3.7, page 87).

FIGURE 5.17 a A Canada lynx; **b** a snowshoe hare. Their population increases and decreases are cyclic.



- **Lag phase:** slow growth phase, only a few reproductive individuals that are not yet widely distributed
- **Exponential growth phase:** rapid increase in population size as birth rate greatly exceeds death rate. Mortality is low because there are abundant resources and few environmental limits
- **Transitional phase:** population growth rate decelerates. Resources become limited, leading to competition for survival; birth rates fall and death rates rise
- **Plateau/stationary phase:** overall birth rate equals death rate. The population has reached the carrying capacity (K) of the environment and limiting factors keep the population stable. The population size is not constant, but fluctuates around the carrying capacity

FIGURE 5.18 A population growth curve (also known as an S-curve)

Limiting factors: density-independent and density-dependent factors

Various biotic and abiotic factors in the environment influence population growth. Limiting factors can be any resource or environmental condition that limits the growth, abundance or distribution of the population. The greater the density of a population, the more individuals die or fail to reproduce. **Density-dependent factors** are often biotic and include, for example, predation, interspecific and intraspecific competition, and the spread of diseases. These factors only come into play when the population reaches a certain level. The larger the population, the stronger the impact.

Density-independent factors are those that affect all individuals in a population regardless of how dense the population is; for example, severe weather conditions, volcanic activity or habitat destruction by clearing or fire. Such factors are seen following a catastrophic event such as a bushfire or flooding. Some extreme weather conditions are increasing in frequency, such as flooding and drought, due to climate change. The chance of individuals surviving the impact of density-independent factors is the same *independent* of the population density or size.

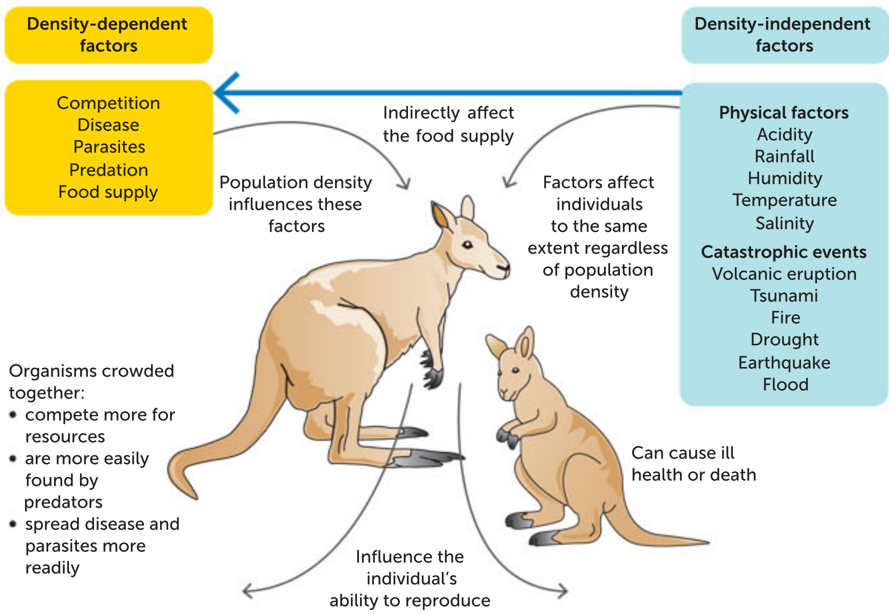


FIGURE 5.19 Populations are regulated by density-dependent and density-independent factors.

Population distribution and abundance

Density
The number of organisms per unit area

Distribution
The location of individuals within an area

Total abundance
The total number of organisms

Migration, immigration and emigration effect
- density and distribution
- population composition
- dynamic (overall change) in the population

Population
Males, females, young

Population composition

Sex ratios
The number of organisms of each sex

Population fertility
The reproductive capacity of the females

Age structure
The number of organisms of different ages

Population growth rate The change in the total population per unit over time = **Birth rate (+ immigration rate)** The number of organisms born per unit (plus immigrants into population) over time – **Mortality rate (+ emigration rate)** The number of organisms dying per unit (plus emigrants from population) over time

FIGURE 5.20 Features of populations

Black-flanked rock-wallaby
The Nature Conservancy helped relocate rock wallabies within the Western Desert with the aim of increasing their population size and spread.

Population dynamics interactive simulation
Launch the interactive and explore exponential and logistic curves. Change one variable at a time to show the effect on the population growth curve.

Question set 5.3

REMEMBERING

1 Define 'carrying capacity'.
2 List three density-dependent factors that can affect population growth.
3 Sketch a graph showing the S-curve – the generalised graph of population growth. Draw a second curve on the graph to show the difference in growth that would occur if resources were not limited.
4 Describe the population growth during the three main phases of an S-curve.

UNDERSTANDING

5 Explain why each of the four phases is different in the S-curve.
6 Reflect on your knowledge of density-dependent and density-independent factors that affect population growth. Which set of factors primarily regulates population size?

CASE STUDY

Improved monitoring of quokkas using contemporary technologies

Around 10 000 quokkas live on Rottnest Island today, the only habitat where the population is abundant. However, the population size is decreasing and the population is severely fragmented. Very small populations also survive in the mainland's south-west forests, such as those near Northcliffe. Overall, the species is listed as vulnerable due to predation by feral animals (cats and foxes), altered fire patterns and habitat loss.

The International Union for Conservation of Nature (ICUN) has classified the quokka as 'vulnerable' on its Red List of 28 000 species threatened with extinction.

Scientists need to keep track of population changes and any other data about the animals and are investing in digital technologies to help.

iStock.com/Adrian Wojcik

FIGURE 5.21 A quokka

A 'scat' is the biological term for animal droppings. Scientists can study the DNA that those droppings contain. Microsoft recently awarded an AI for Earth Compute Grant to the University of Western Australia (UWA) to study quokkas with new methods that could accelerate the UWA's research.

The UWA team is planning to trial a program to monitor the at-risk species in faster and cheaper ways, by using specially designed 'scat drones' along with high-powered cloud computing. 'Scat drones' are drones that spot quokka droppings.

'A scat drone has a little probe attached to it for DNA analysis. It can go and look for scat samples around the island, and analyse them in real-time for us', says UWA Associate Professor Parwinder Kaur, who is leading the research. This initial information can then be sequenced and analysed further in the cloud with the help of machine learning and artificial intelligence.

Used with permission from Microsoft

FIGURE 5.22 A Microsoft drone

The quokka project is part of an initiative by DNA Zoo, a global organisation made up of more than 55 collaborators in eight countries. It aims to use new digital technologies and scientific rigour to facilitate conservation efforts. They need ways to process and analyse large volumes of data on a massive scale.

'It's a classic big data challenge,' explains Dr Kaur, who is also a director of DNA Zoo's Australian node. 'The genome of a single mammal may run to 3.2 gigabytes (GB).

'To properly understand the genome, it needs to be read 50 times – creating a 172 GB data challenge for a single animal. Multiply that challenge across entire populations of threatened species and the scale of the computing and analysis problem is clear.

'By using supercomputing power and also Microsoft cloud, artificial intelligence and machine learning, we hope to automate and accelerate genome assemblies and subsequent analyses.'

With their AI for Earth grant, DNA Zoo will use the cloud to democratise genome assemblies worldwide. It will also come up with insights to help protect and preserve species that are now at risk.

Importantly, data collected through the DNA Zoo program is open source. When it is shared with other open-source data collections, machine learning can search for patterns that, in turn, can reveal new insights into the health and condition of species populations.

This sort of comparative genomics means scientists can study the DNA of a threatened species or population alongside those which appear to thrive in the same or similar habitats. Ultimately, that will help researchers learn more about how to slow or reverse population decline.

Among other things, the researchers will be looking for genetic clues that might help explain why quokkas thrive on Rottnest but struggle on the WA mainland, just 22 kilometres away.

Quokkas were common across much of the south-west of WA before the European colonisation of the area began, less than two centuries ago. But today's mainland populations of quokkas have dropped dramatically due to introduced predators and habitat loss from urbanisation and agriculture. The species now exists only in small scattered mainland locations and two offshore islands, including Rottnest, where it is out of the reach of these dangers.

Source: Adapted from Spencer, G. (2019) 'Cute but vulnerable: Scientists to use drones, cloud, and AI to protect Australia's Quokkas', 24 September, https://news.microsoft.com/apac/features/preserving-diversity-with-ai/


https://news.microsoft.com/apac/features/preserving-diversity-with-ai/

FIGURE 5.23 Dr Kaur (centre) with team members in her lab at UWA

Questions

1 Describe the contemporary technology being used to monitor quokka populations and analyse DNA.
2 Define the term 'scat'.
3 Theorise why the quokka population is more abundant on Rottnest Island compared to the mainland populations.

CHAPTER 5 ACTIVITY AND INVESTIGATIONS

5.1 ACTIVITY

Estimation of population size

When you are studying a population of organisms, whether it is a school of fish or a population of wombats in a certain area, it is not possible or even necessary to count all its members. Estimates of numbers within the population are therefore made on the basis of various sampling techniques. A sample is a small group of organisms, selected from the total population, which is representative of the whole population. But just how reliable are these sampling methods at estimating population size?

Aim

To estimate the size of a model population using the capture–mark–recapture method and to comment on its reliability as a technique

Materials

Each student will require:

- 160 white or black buttons (beads or matches may be substituted)
- plastic cup to mix or shake the buttons

Procedure

1 Using a permanent marker, mark 40 of the buttons with an 'X'. Alternatively, you could use buttons that are differently coloured from the rest; for example, 40 yellow buttons among all the black/white ones.
2 Thoroughly mix the marked buttons with the rest of the population of buttons by shaking them in the cup.
3 Take out a random sample of 20 of the buttons and count the number of marked ones.
4 We assume that if the sample taken is representative of the whole population, then the ratio of marked objects will be the same in both the sample and in the whole population:

$$\frac{\text{total marked}}{\text{total population (marked and unmarked)}} = \frac{\text{number marked in sample}}{\text{number (marked and unmarked) in sample}}$$

Thus:

$$\frac{\text{40 marked}}{\text{out of 160 total}} \text{ should produce } \frac{\text{5 marked}}{\text{out of 20 in a sample}}$$

$$\text{The formula for the total number} = \frac{\text{Number in sample}}{\text{Number marked in sample}} \times \text{total number marked}$$

$$\text{In this example, the total} = \frac{20}{5} \times 40$$

$$= 160$$

5 Calculate your estimate of the population under the heading Results.
6 Repeat the procedure an additional nine times, each time returning the sample and mixing the population to get a reasonable average. You should now have 10 population estimates based on 10 samples.
7 Draw a table and record your results.
8 Finally, count all the objects in your population.

Results

1 Record your calculations of your 10 estimates of population size.
2 Record your table of results.
3 Write your average estimated population size.

Discussion

1. Based on your calculations, explain how reliable this method is at estimating population size.
2. Can you suggest any ways of improving the accuracy of the method used in this experiment? Explain.
3. Discuss the advantages and disadvantages of using the capture–mark–recapture method to estimate a wild population of mice or blue whales.

Conclusion

Refer back to the aim of this experiment. Have you achieved this aim? Write a conclusion based on what you have learned.

INVESTIGATION 5.1

Distribution and abundance: how many plants?

Determining plant numbers and species present in an area is a lot easier than determining animal numbers and species present. Plants don't move! There are two sampling strategies that work well. One is used to determine the density and total number of plants in a given area. The other method allows you to determine the distribution of a range of species within a defined space. You will be using both in this experiment.

Aim

To investigate the distribution and abundance of local plants

Materials

- 10-m tape measure
- three 1-m rulers
- pencil and eraser
- note pad

WHAT ARE THE RISKS IN DOING THIS EXPERIMENT?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Insects or spiders living in the natural environment may bite	Wear gloves when touching plants or soil

Procedure

1. Select two sites to investigate: one will be a school oval, the other a forested area at least 10 m in length.
2. a On the oval: collect data about the number of plants on the total oval surface using a 1 m^2 quadrat.
   b In the forested area: collect data about the type and distribution of plants along a 10-m transect.

Results

1. Using your collected data, determine species type and number.
2. Do some research to determine the needs of each species.
3. Record your results in a table.

Conclusion

Make sure your conclusion includes quantitative data that relates directly to the measurable quantities you mentioned in your aim. If possible, make an estimate of the uncertainty in your results.

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5.2 INVESTIGATION

Carrying capacity in algae

Algae comprise a large group of aquatic organisms that includes seaweeds and many single-celled forms. Although they photosynthesise, many algae are not classified as plants and they don't have stems, roots, leaves or vascular tissue.

In this investigation you will work with *Chlorella*, a single-celled green alga that uses the green pigment chlorophyll for photosynthesis. When algae such as *Chlorella* experience rapid population growth, known as 'algal blooms', they can discolour water, turning it green, due to their high density.

In this investigation, you will prepare experimental culture tubes containing different proportions of spring water, algae and nutrient solution. Your class will be split into groups with each group assigned a specific nutrient concentration (0%, 10%, 20%, 30% or 40%) to formulate in the experimental culture tubes. You will use a counting cell to measure the mean population of each sample of five different nutrient concentrations over several weeks.

Aim

To investigate the relationship between the nutrient concentration of a culture and its carrying capacity for the green alga *Chlorella*

Materials

- *Chlorella* culture (10 mL)
- spring water (10 mL)
- concentrated nutrient solution (10 mL)
- culture tube rack
- four culture tubes
- three plastic pipettes
- Sedgewick Rafter counting cell
- permanent marker
- four laboratory tissues
- scissors
- rubber bands
- ruler

WHAT ARE THE RISKS IN DOING THIS INVESTIGATION?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Chlorella is generally harmless but may contain contaminants.	Wear a lab coat, safety glasses and gloves. Wash hands thoroughly after handling.
Glass could break and cut you.	Inspect all glassware. Discard any chipped or cracked glassware, no matter how small the damage. Sweep up broken glass with a brush and dustpan. Do not use your hands.

Procedure

Preparing samples

1. Using a permanent marker, label the bulb of a pipette with the letter A. This indicates that this pipette is to be used exclusively for the transfer of algae.
2. Label the bulb of a second pipette N, to designate this for transferring nutrient solution only.

3 Label the bulb of a third pipette S, to designate this for transferring spring water only.

FIGURE 5.24 Labelling of bulbs

4 As a class, you will test five different proportions of spring water, algae and nutrient solution. Each student group will set be assigned a different concentration of nutrient.

5 Label your group's culture tube rack with your group name and the nutrient concentration you have been assigned.

6 Collect three culture tubes and label them A1, A2, and A3. The letter A indicates that each of these experimental tubes contains algae, while the numbers identify each of three replicate tubes used in the experiment. Also label each culture tube with your assigned nutrient concentration.

7 Using the corresponding labelled pipettes, add algae, nutrient solution and/or spring water (according to your assigned nutrient concentration) to each of the three culture tubes. Follow the information provided in your group's assigned column of Table 5.4 to guide you in the specified volumes of each component.

TABLE 5.4 Components required for each tube

	PERCENTAGE NUTRIENT SOLUTION				
COMPONENT	0%	10%	20%	30%	40%
Chlorella algae – use pipette A	2 mL	2 mL	2 mL	2 mL	2 mL
Spring water – use pipette S	3 mL	2.5 mL	2 mL	1.5 mL	1 mL
Nutrient solution – use pipette N	0 mL	0.5 mL	1 mL	1.5 mL	2 mL
Total volume	5 mL	5 mL	5 mL	5 mL	5 mL
Final nutrient concentration	0%	10%	20%	30%	40%

8 Cap the culture tubes using petrifilm.

9 Collect a fourth culture tube and set up a blank culture tube that contains the same volumes of nutrient solution (or spring water) but does not contain any algae. Follow the information provided in Table 5.5 to guide you in the specified volumes of each component.

TABLE 5.5 Experimental design set-up for blank culture tubes

	CULTURE TUBE SYSTEM				
COMPONENT OF THE SYSTEM	0%	10%	20%	30%	40%
Spring water – use pipette S	5 mL	4.5 mL	4 mL	3.5 mL	3 mL
Nutrient solution – use pipette N	0 mL	0.5 mL	1 mL	1.5 mL	2 mL
Total volume	5 mL	5 mL	5 mL	5 mL	5 mL
Final nutrient concentration	0%	10%	20%	30%	40%

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Counting samples

1. Before sampling your algae culture, ensure it is evenly dispersed through the tube. Cover the top of the tube with a new piece of plastic wrap or parafilm and mix the solution by inverting the tube three times. (This will break up any clumps that may have formed.)
2. To fill the Sedgewick Rafter cell, place the cover glass diagonally across the chamber top. This allows the air bubbles to escape during the filling procedure.
3. Using a plastic pipette, collect a sample from A1 and carefully transfer the contents of the pipette to the chamber (Figure 5.25).

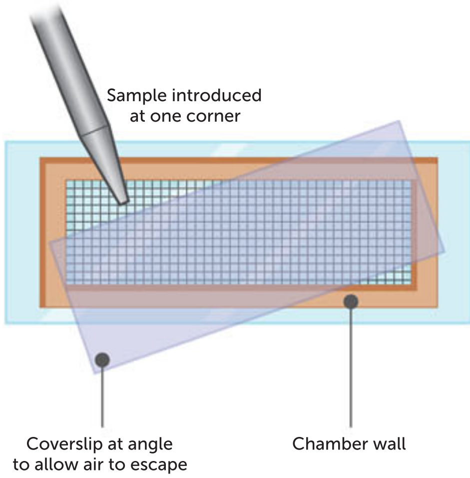

FIGURE 5.25 How to fill the Sedgewick Rafter cell

4. Once the slide is filled, let it rest for approximately 5–10 minutes to allow the algae to settle into a single layer. (This makes counting easier.)
5. View the cell with a compound microscope. Set the microscope to its lowest focus and bring the sample into focus. Be sure you are focusing on the sample in the slide and not on top of the coverslip.
6. Change the focus to the next strongest magnification and bring the sample into focus. Repeat until you are using the best magnification possible.
7. Count only one transect of the Sedgewick Rafter cell. Choose a random vertical transect (20 squares, representing 20 μL).
8. Methodically move through the slide and count each cell you encounter in your chosen transect.
9. Record your data in a table like Table 5.6.
10. Use your pipette to return your sample to the tube. Repeat steps 1–9 for the A2 and A3 samples.
11. Repeat the count every second day for 3 weeks.

Results

TABLE 5.6 Algal population figures

______% CONCENTRATION	DAY 1	DAY 3	DAY 5	DAY 7	DAY 9	DAY 11	DAY 13	DAY 15	DAY 17	DAY 19	DAY 21
Algae cells counted											
Squares counted											
Mean cells/μL											

1 Plot the results of your experiment on a linear graph. Plot the growth, with time (every 2 days) represented on the x axis and the population size represented on the y axis, using *Chlorella* per 1 mL (cells/μL × 1000).
2 Plot the class experiment results on a linear graph.
3 Describe what has occurred in the populations and identify whether the populations increased or decreased, or remained stable.

Discussion

1 Based on the available data, is there enough evidence to conclude that algal populations are limited by environmental conditions? Support your answer.
2 What are the advantages and disadvantages of this counting technique?
3 What are some limitations in the experiment design? Suggest how it might be improved.
4 Using the two growth models shown in Figure 5.26 – exponential growth and logistic growth – answer the following questions.
   a Would you describe the algae population growth you observed as exponential or logistic? Use the results of your experiment to support your answer.
   b Carrying capacity describes a population that has reached the largest size that is sustainable within its environment. Observe the population growth chart you created and determine the carrying capacity of the algae of your assigned nutrient concentration.
   c Identify two factors that may have limited the carrying capacity of the algae population you observed.

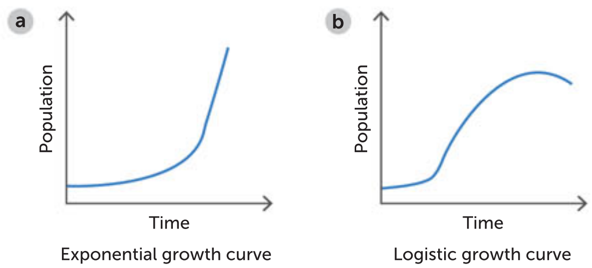

FIGURE 5.26 a Exponential growth curve; **b** logistic growth curve

Taking it further

Instead of counting cells individually, use a colorimeter or spectrometer to record light absorbance as a measure of population density.

Chapter 5 Activity sheet

CHAPTER 5 SUMMARY

- Population sizes and distribution, whether plant or animal, are dependent on interactions between biotic and abiotic factors.
- Biotic factors include relationships between species, available food resources and reproduction rates.
- Abiotic factors, which are generally measurable and mostly predictable, include water, soil and air quality, and availability of nesting sites.
- *r*-selection occurs in species in which the population undergoes rapid increase and decrease, such as locusts.
- *K*-selection is found in species that mature slowly and breed later, having fewer offspring, and that have offspring that benefit from prolonged parental care, such as primates and elephants.
- Methods of recording populations within their environments vary according to the species being observed, and include GPS and satellite monitoring, capture–mark–recapture techniques, and transect and quadrat techniques.
- Change in population is determined by birth and immigration (which increase the population), and death and emigration (which decrease it).
- Carrying capacity is the maximum population that can be supported in an environment, and is determined by the full range of biotic and abiotic factors.
- The density of a population can be affected by various factors, including biotic and abiotic factors and population size.
- Density-dependent factors do not affect all individuals equally, and include competition and predation.
- Density-independent factors that affect birth and death rates include abiotic or environmental factors; for example, drought, severe weather and natural disasters (such as intense fire).

CHAPTER 5 GLOSSARY

Abiotic non-living; used to describe components of an ecosystem

Abundance how many; the number of organisms of a particular species in a population

Biodiversity the full range of different living things in a region; can be described at various levels, including the range of species, the genetic diversity in species, and the diversity of ecosystems present in a larger area

Biotic living; used to describe components of an ecosystem

Birth rate the number of births in a population over a given time

Capture–mark–recapture an ecological surveying technique used to measure animal populations, in which individual animals are captured, marked and released; after a time, the population is re-sampled and the number of marked animals caught is used to estimate population size

Carrying capacity the maximum population size of a species that can be supported in a given environment; represented by *K*

Clumped (grouped) distribution individuals in a population are grouped together where biotic and/or abiotic factors are favourable; can be social (e.g. schools of fish) or clumping of vegetation

Death rate the number of deaths in a population over a given time

Density the number of individuals in a given area; can use biomass or volume for smaller individuals

Density-dependent factors the factors whose effects on the population vary depending on the density of population; the greater the density of a population, the more individuals die or fail to reproduce; examples include competition and predation

Density-independent factors the factors that affect all individuals in a population; regardless of population size, the impact of the factor is the same, usually leading to a drastic decline in population; examples include severe weather conditions, volcanic activity and habitat destruction by clearing or fire

Distribution the places in an ecosystem where individuals of species are found (usually they are not evenly spread)

***K*-selected species** a slow-growing, long-lived species typical of those in a long-established biological community

***K*-selection** a type of population growth in which initial growth may be slow, but over the long term a sustainable population is maintained

Population a group of individuals of the same species living in a particular area at the same time

Population composition the measurable characteristics of a population, such as age, sex ratios and fertility rate

Population density the number of individuals of the same species living in the same habitat at a particular time per unit area

Population dynamics the way in which populations of a species change in size and structure over time

Quadrat a square, rectangle or circular frame of convenient size, used to mark out an area in which organisms are to be sampled; also a survey technique where a frame is placed on the ground and each individual of a species within it is counted, to estimate abundance and density; useful for stationary organisms

Random distribution a type of distribution in which organisms are spaced irregularly

***r*-selected species** a fast-growing and reproducing species, often the first to take up unused resources and living space

***r*-selection** a type of population growth, in which opportunistic species quickly colonise an unstable ecosystem, leading to a pattern of rapid population increase and decrease (or crash), and their eventual replacement by competitors

Sample a set of individuals selected from a population (either randomly or non-randomly); population sampling involves counting individuals in small areas and then extrapolating to estimate population totals

Species distribution modelling a computerised modelling method used to predict future needs and resource management

Transect a method used in population sampling where a line is drawn through a community to determine the distribution of species; can be used with quadrats and is useful for stationary organisms

Uniform (continuous) distribution a type of distribution in which organisms are evenly spaced

CHAPTER 5 REVIEW QUESTIONS

Remembering

1 Describe the use of a specific contemporary technology used in measuring populations.
2 Define the types of population growth known as *K*-selection and *r*-selection.
3 Describe the differences between density-dependent and density-independent factors.
4 Name and describe the ways in which resources are distributed that lead to each of the population distribution patterns.

Understanding

5 Capture–mark–recapture is one method used to determine the age structure of mobile populations. What problems may arise if too much time is left between the initial capture and the recapture?

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Applying

6 In the following examples, determine the resource that has the greatest effect on the population distribution.
  a heath plants in clumps in a field
  b penguins distributed evenly across an ice sheet
  c alpine grasses randomly spread along the side of a hill

Analysing

7 a Draw a graph to show what would happen to a population of rabbits if there were no predators in the area.
  b Show on your graph what may be expected to happen to the rabbit population if a predator such as a fox was introduced into the area.

8 Describe the features that would indicate that a population is increasing.

9 How does the age structure of a human population indicate future growth patterns? What age group would need to show a steady growth to indicate a healthy overall population growth?

10 A student is asked to estimate the population size and density of beetles in an area shown in Figure 5.27. She collected data from 10 randomly placed quadrats of 10 cm × 10 cm (Table 5.7).

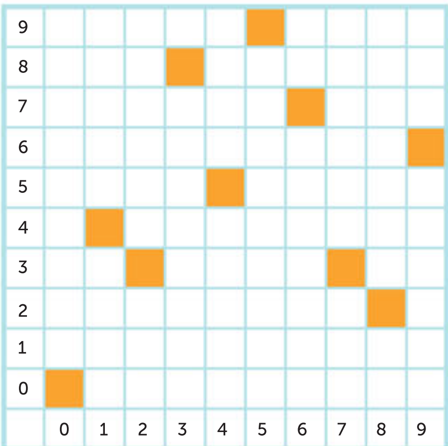


FIGURE 5.27 Quadrat samples

TABLE 5.7 Summary of results

QUADRAT COORDINATE	NUMBER OF BEETLES	QUADRAT COORDINATE	NUMBER OF BEETLES
(0,0)	10	(5,9)	14
(1,4)	0	(6,7)	3
(2,3)	45	(7,3)	6
(3,8)	32	(8,2)	12
(4,5)	48	(9,6)	16

  a Calculate the population size and density of the beetles in the total area.
  b Investigate two methods that could have been used to obtain the counts of beetles.

11 Two populations of different species within an area are measured at 3-year intervals. Over that time, the numbers of the two species vary as shown in Table 5.8.
  a Graph the results on one set of axes.
  b Describe the trend you see with the two species.
  c One species preys on the other. Explain which species you think is the predator and why.

TABLE 5.8 Counts of two species

YEAR	NUMBER OF SPECIES 1	NUMBER OF SPECIES 2
0	25	85
3	50	50
6	30	75
9	60	70

Evaluating

12 A pest controller wanted to estimate the rat population in an area. They set out traps, caught 50 small rodents and marked them inconspicuously. Two weeks later, traps were set out again and 200 rodents were caught, 10 of which were marked. What is the estimated rodent population size?

Creating

13 How does population sampling assist in each of the following situations?
   a maintaining a population of an endangered species of wallaby
   b maintaining bird populations during the duck-shooting season

14 Australia has about 700 endemic species of grasshoppers and locusts, but the one that usually hits the headlines is the Australian plague locust (*Chortoicetes terminifera*). Locust populations increase enormously in favourable climatic conditions, usually following rain. Many minor plagues occur regularly but there have been five major plagues in the past 60 years. Densities of 1000 locusts per m^2 have been recorded.
   a Outline the abiotic and biotic conditions that may give rise to locust outbreaks.
   b Are locusts *r*-selected species or *K*-selected species? Which features help you determine this?
   c Predict the impact of a locust plague on other species, including humans.
   d Suggest three ways to combat locust plagues in Australia.

15 Describe three limitations of the capture–mark–recapture technique.

PRACTICE EXAM QUESTIONS

1 If a fisheries and wildlife representative wished to determine the density of a particular species of fish caught in traps at different times of year, the best method would be:
   A calculating the average number of fish per trap per year.
   B calculating the average number of fish caught per trap per day.
   C calculating the average numbers of fish per year.
   D calculating the total number of fish caught per year.

2 Figure 5.28 illustrates the growth of two populations of a particular species of insect. In both of the populations there has been no immigration or emigration. Which of the following explanations is the most probable to explain why the graphs differ in their shape?

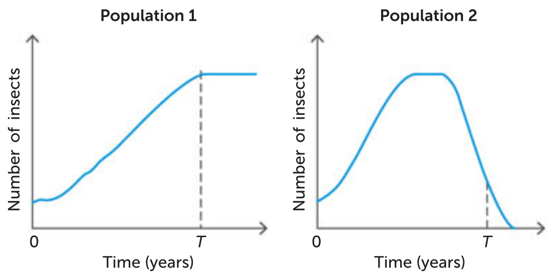


FIGURE 5.28 Growth of two insect populations

   A At time *T* years, population 1 has not outstripped its available resources, whereas population 2 has.
   B From 0 to *T* years, the birth rate of population 1 is higher than its death rate; population 2's death rate is higher than its birth rate in the second half of the time period.
   C The growth of population 2 has been inhibited by a lack of food and sites for colonies.
   D Population 1 is showing a trend for unlimited growth whereas population 2 has very limited growth.

3 **a** What is meant by the term 'carrying capacity'? (2 marks)

[Q35d 2010 Stage 2 SCSA]

b 'A population will grow more rapidly once it exceeds carrying capacity.' Indicate whether this statement is true or false and explain your answer. (2 marks)

4 A biologist wished to estimate the population size of a parrot species living in a strip of trees beside a golf course. He caught some parrots with a net (Sample 1), placed a coloured band on each bird's leg and then released them from where they had been caught. The following week (Sample 2) he returned and caught more parrots. Some of the captured parrots had a coloured band from the first sampling and some did not. The results are shown in Table 5.9.

[Q35a,b 2010 Stage 2 SCSA]

TABLE 5.9 Parrot counts

	PARROTS CAUGHT	
	SAMPLE 1	SAMPLE 2
Number of captured parrots without band	8	6
Number of captured parrots with band	N/A	4
Total	8	10

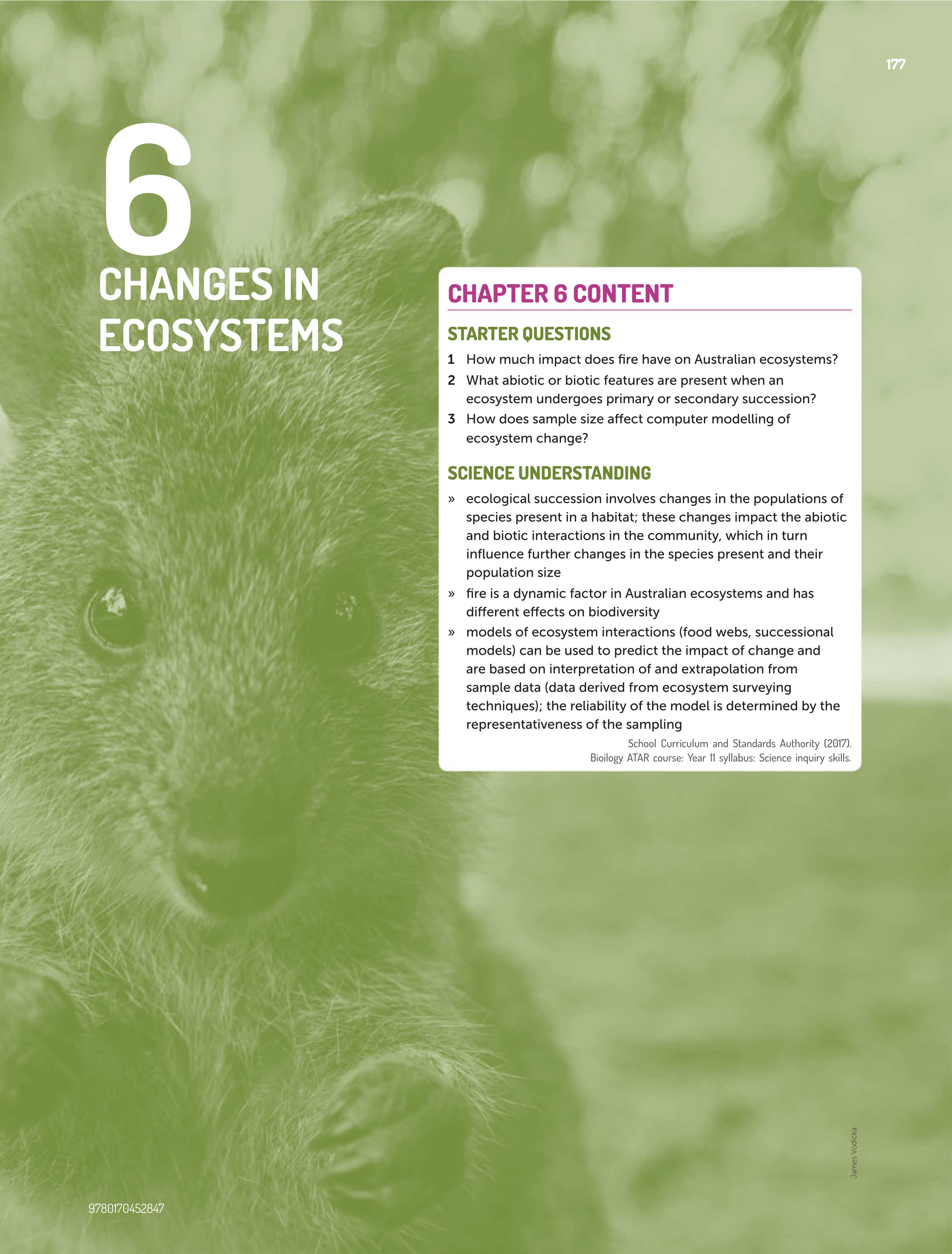
a Calculate the estimated population size of parrots beside the golf course. Show your working. (4 marks)

b List four assumptions required for your estimate in part (a) to be valid. (4 marks)

5 In 2020, kangaroo populations were described as 'out of control' in an area of western Queensland. In the previous 10 years, the population of kangaroos grew from 28 214 521 in 2010 to 34 303 677 in 2020. Farmers were concerned because the kangaroos were outcompeting livestock and other native species for feed and water. In addition to this, conservationists reported that the kangaroos' excessive grazing was degrading grassy habitats for other native species, such as the earless dragons. There are few natural predators (such as the dingo) left to control kangaroo numbers.

a Discuss three density-dependent factors and two density-independent factors that determine population growth in an ecosystem. (5 marks)

b Scientists needed to monitor the growth rate of the population of kangaroos. List the variables that are used to calculate population growth rate in a given area. Calculate the growth rate as an average per year. (5 marks)



James Vodicka

6 CHANGES IN ECOSYSTEMS

CHAPTER 6 CONTENT

STARTER QUESTIONS

1 How much impact does fire have on Australian ecosystems?
2 What abiotic or biotic features are present when an ecosystem undergoes primary or secondary succession?
3 How does sample size affect computer modelling of ecosystem change?

SCIENCE UNDERSTANDING

» ecological succession involves changes in the populations of species present in a habitat; these changes impact the abiotic and biotic interactions in the community, which in turn influence further changes in the species present and their population size
» fire is a dynamic factor in Australian ecosystems and has different effects on biodiversity
» models of ecosystem interactions (food webs, successional models) can be used to predict the impact of change and are based on interpretation of and extrapolation from sample data (data derived from ecosystem surveying techniques); the reliability of the model is determined by the representativeness of the sampling

School Curriculum and Standards Authority (2017). Bioilogy ATAR course: Year 11 syllabus: Science inquiry skills.

9780170452847

6.1 EVIDENCE OF CHANGE IN ECOSYSTEMS

Cockburn Range, in the east Kimberley region, is a tropical savanna. Grasslands are found in the northern end, and to the south there are desert sand dunes, which are expanding. Only highly specialised species such as the iconic boab tree (which can store moisture in the pith of its swollen trunk) can survive in this hot, dry environment. Many regions of WA were once covered in lush rainforest. Today, they are part of the driest vegetated continent on Earth, where the temperature can soar above 40°C at midday. As Earth turns away from the Sun and night falls, the temperature drops dramatically. The savanna comes alive with nocturnal animals such as geckos, small mammals and a rich diversity of insect life.

These daily and seasonal changes are examples of relatively short-term change. But over the last 15 million years, there have also been major long-term changes to ecosystems in Australia. These include the expansion of desert in central Australia, which has replaced the inland seas and tropical ecosystems that once existed. The desert ecosystems are still changing, becoming increasingly arid. The Cockburn Range, like other ecosystems, is always changing. Ecosystems have changed from what they were millions of years ago and will continue to change annually, seasonally and daily. Ecosystems are dynamic in nature.

In the early 1980s, **palaeontologists** studying the 110-million-year-old rock sequences at Dinosaur Cove in Victoria pieced together evidence of a different land. Australia, Africa and Antarctica didn't exist 110 million years ago (mya). In fact, none of the continents we know today existed at that time; they were all joined together to form a supercontinent called **Pangaea**.

Pangaea initially split into two large landmasses, **Laurasia** to the north and **Gondwana** to the south. The great southern continent of Gondwana contained what was to become the Australian landmass. By 110 mya, Gondwana was breaking up. South America was separating from Africa and India was beginning its long trek north. This was an important stage in the physical isolation that was to give Australia's biota (plants, animals and other organisms) such distinctive characteristics.

A combination of rapid speciation and isolation has meant that Australia's biota has, to a great extent, evolved distinctive features that made them suited to living with environmental challenges. The result is an unusually high degree of **endemic** species, species that occur naturally only in Australia.

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FIGURE 6.1 Cockburn Range, WA. Once a lush rainforest supporting an enormous array of plants and animals, this site is now part of the driest vegetated continent on Earth.

6.1 APPLICATION

Endemic animals and plants

More than 80% of our plant and animal species are endemic to Australia. There are seven families of mammals, four of birds and twelve of flowering plants that are unique to Australia. No other country has as many endemic flowering plant families.

Periods of low global temperatures resulted in ice ages, extended periods of time when glaciation occurred over large sections of the northern hemisphere and when the ice sheets expanded at both poles. There have been five major ice ages, the last reaching its maximum 15 000–18 000 years ago. As water froze, sea levels dropped and huge expanses of the ocean floor were exposed, providing a land link for species to move between Australia and the islands to the north.

Reductions in global temperatures and lower evaporation rates also affected the water cycle – lower levels of atmospheric water meant lower rainfall. A little more than 15 000 years ago, Australia became a desert: windblown, dry and, for more than three-quarters of the continent, treeless. Two-thirds of the land was covered in sand dunes and our topsoil was heavily wind-eroded.

Question set 6.1

REMEMBERING

1 a Define endemic.
  b Why does Australia have a particularly high number of endemic species?
2 State two abiotic factors that have changed over long periods of time that cause changes to the water cycle.
3 State how long ago Australia became mostly desert.

UNDERSTANDING

4 What effect did low sea levels that occurred during ice ages have on the species found in Australia?

6.2 ECOLOGICAL SUCCESSION

Change is a natural feature of dynamic ecosystems and occurs in different scales. When a tree falls in a forest or wombats dig holes, small-scale disturbances occur. On a slightly larger scale, one set of living things can change the environment in such a way that conditions no longer suit them but do suit a different set of living things. Communities change progressively over time, with one community being replaced by the next in serial replacement, a process known as **succession**. Succession is a process of change in community composition and structure, usually towards the establishment of a stable ecosystem. It includes changes in both the biotic and abiotic factors in an ecosystem over time. During succession, there are changes in the populations of species present in a habitat. Also, changes in abiotic factors mean the environment becomes more suitable for the survival of new species. Biomass increases at each stage of ecological succession. When a stable community is established, it is known as a climax community. There are two types of ecological succession: primary and secondary succession.

Key concept

Communities change progressively over time, with one community being replaced by the next in the process of succession. Ecological succession can affect the abiotic and biotic interactions in the community, which in turn can affect the species present and their population size.

Primary succession

When succession begins in a virtually lifeless area where **soil** has not yet formed, the process is called **primary succession**. Catastrophic events, such as volcanic eruptions, cyclones, earthquakes and tsunamis, can cause the development of barren sites with no organisms inhabiting the affected area. This process, called **nudation**, starts a long-term process of change, generally involving four main stages.

1 **Pioneer plants** colonise. The particular species of pioneer plants depends on the environmental factors in the habitat, such as coastal sand dunes or newly formed islands rising from the sea as a result of volcanic activity. Usually, the first pioneer plants to become established are **autotrophs**,

such as lichens in the harsh, bare surroundings exposed after glacial retreat. Organic acids secreted by the lichens attack the rocky surface in the process of weathering, allowing windblown dust particles to settle in the cracks.

2. Soil formation. As the pioneer plants die and decompose, a thin layer of soil is formed. The shallow soil makes it possible for mosses to become established. When they die, they add nutrients to the soil. Over time, bacteria, fungi and invertebrates are able to establish and assist with the formation of a simple community. When there is enough soil added for grasses, ferns and shrubby herbaceous plants to become established, they grow upwards and outwards, shading the living things below, and their roots speed up the process of weathering the rock.
3. These early colonising plants have characteristics that make them successful: effective seed dispersal, rapid growth and rapid reproduction. They are generally fast growing and typical of ***r*-selected species**. These species are often the first to occupy the unused resources and living space. Their numbers increase rapidly but often decline just as rapidly when more competitive species move in.
4. A new community forms. With the establishment of producer organisms (autotrophs), small herbivores such as insects have food and shelter, and they become the next link in the food chains. Gradually, a whole new community forms, colonised by immigrant species from the surrounding areas. Immigrant species survive or stay only if they can obtain the resources that they need for survival.
5. As the succession process slowly continues, biodiversity increases. Succession is a slow process, and dependent on the abiotic conditions. It may take hundreds or even thousands of years. Eventually, if there is no further disruption, a climax community is established.

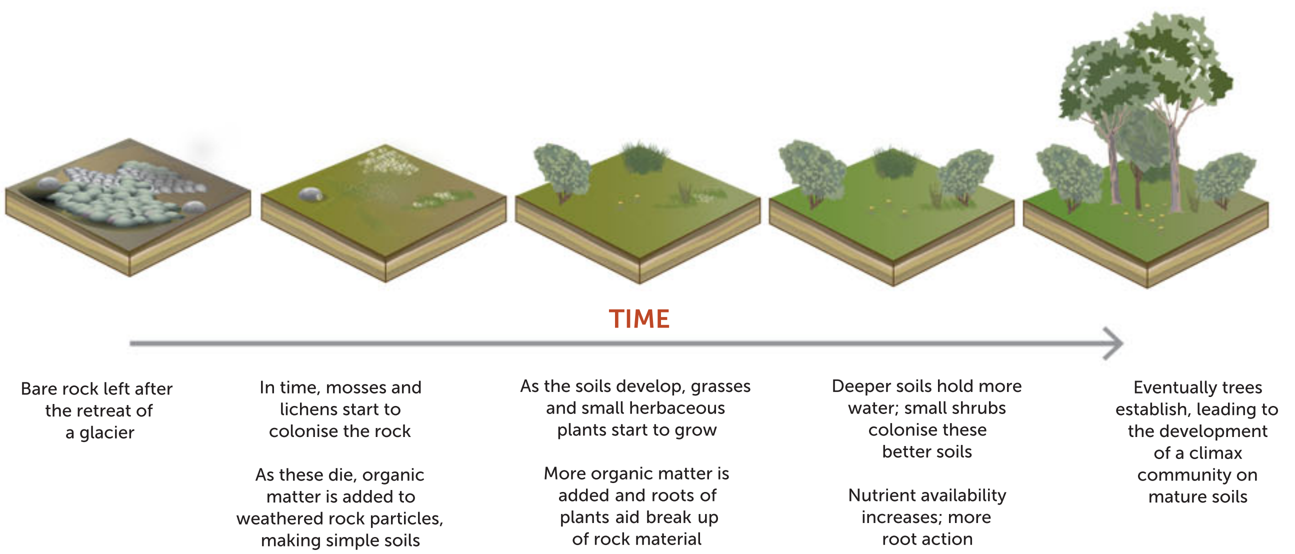


FIGURE 6.2 Primary succession following glacial retreat

Secondary succession

Secondary succession is a process of change in an ecosystem when a previously established community is taken over by a new group of organisms. Through natural disturbance (such as fire or flood) or human intervention (such as logging or land clearing for agriculture), dramatic changes to ecosystems occur. The cycling of matter and the flow of energy are interrupted as components of the ecosystems change. Organisms can recolonise recently disturbed communities via secondary succession, regaining equilibrium, although the number and kinds of organisms present may be different from the original ecosystem.

The process of secondary succession is similar to primary succession, but it begins at step two with soil formation. This is because organisms and some organic matter are present in the soil. Primary succession may take anywhere up to 1000 years to reach a climax community. Secondary succession, however, may only take between 50 and 100 years to become established.

FIGURE 6.3 Secondary succession can occur when an invasive weed enters a natural environment. Stinking passionflower (*Passiflora foetida*) is a vine from South and Central America that is one of the most significant weed problems in the Kimberley and Pilbara regions of northern WA.

Key concept

Secondary succession is a similar process to primary succession, except that it begins at the second step, with a few organisms and some organic matter and soil already present.

Bushfires ravaged Australian ecosystems during the 2019–20 bushfire season. Scientists across the country have studied the regeneration of ecosystems post-fire. Professor David Bowman at the University of Tasmania is one scientist deeply disappointed and saddened by the loss of some ecosystems. He has studied changes in affected ecosystems, such as fewer trees, which can cause a change in the quality of the habitat. Eucalypts are keystone species, which means when their numbers are reduced it has a disproportionately large knock-on effect on direct and indirect relationships in the community. He also forecasts that there will be fewer insects after fire, which results in fewer birds and mammals.

FIGURE 6.4 These three photos of the same location were taken **a** before the fire, **b** immediately after the fire and **c** 5 years later.

The results of a removal or reduction of a keystone species can be seen in all trophic levels, all the way up to apex predators. Additionally, land surface, soil and hydrology are affected. Other scientists are concerned that weed species with a faster growth rate could take hold, perhaps turning what used to be a thick forest into a thinner, grassier one. Invasive species could rapidly dominate. Only 6 weeks after fires devastated Kangaroo Island in 2019–20, lots of new regrowth on charred and standing timber could be observed. Fire-dependent fungi grew in the ash beds. Tracks and signs of small vertebrates such as lizards, marsupials and birds on the ground were seen. Many small animals took up new shelters in fallen timber and fire-hollowed logs. The gradual growth and development in the community after such destruction to an ecosystem can be described as secondary succession.

The process of secondary succession is summarised as follows.

1. A natural or artificial disturbance occurs.
2. New plants, such as fast-growing pioneer plants, colonise the area. Invertebrates enter the ecosystem.
3. Slower-growing trees begin to grow and stabilise the community. New herbivores, then carnivores and omnivores, arrive and become part of the food web.
4. A new community forms and eventually becomes a climax community. Note that secondary succession always follows primary succession and a disturbance.

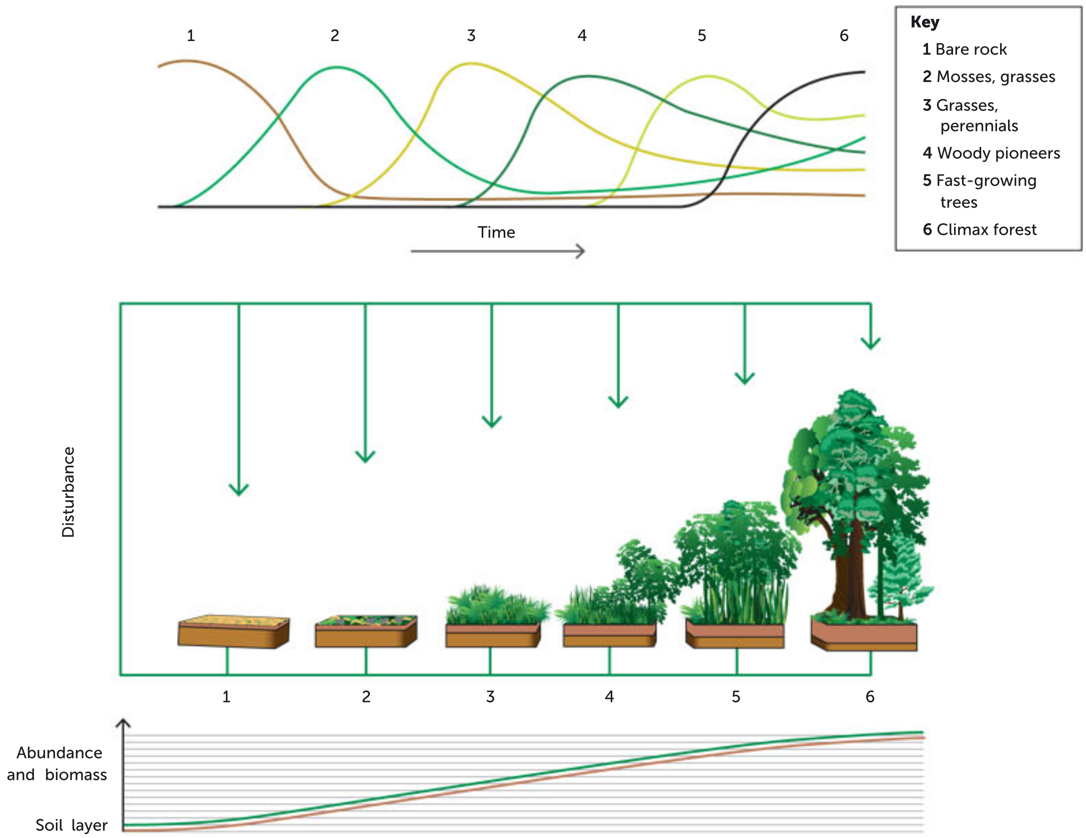


FIGURE 6.5 Forest succession over time in six stages

TABLE 6.1 A comparison of primary and secondary succession

FACTOR	PRIMARY	SECONDARY
Beginning conditions	A new area with no life; barren	Begins with disturbance of an already established ecosystem/begins after primary succession
Soil	No soil to begin with	Soil is present at the beginning
Plants	Pioneer plants, such as lichen	Seeds and roots of established vegetation already present
Primary productivity	Lower productivity due to fewer plants (biomass or energy)	Higher productivity due to there being more plants and faster regrowth
Biodiversity	Low biodiversity for a long time	Faster development of wider biodiversity

Climax community

The end of succession is marked by a climax community. A **climax community** is the stable community present at the final stage in a succession. It is stable as long as environmental factors remain unchanged. Such communities tend to be made up of slow-growing, long-lived ***K*-selected species**. These species, living in more stable environments than *r*-selected species, outcompete the others around them. They are often tall trees such as oaks or large conifers in the northern hemisphere, and trees such as jarrah or mountain ash in Australia.

Shutterstock.com/Coulanges

FIGURE 6.6 The jarrah forests of south-west WA are an example of a climax community.

Signs that the jarrah forests of south-west WA have reached the status of climax community include the establishment of large jarrah and marri trees as dominant species, with other large trees such as the white gum, bull banksia and common sheoak also present. Old growth is also a tell-tale sign. Tall shrubs like the balga tree, other shrubs such as couch honeypots, creepers and fungi are also established along with an array of animal species like the western grey kangaroo, western brush wallaby, common brushtail possum, chuditch and common dunnart. A variety of birds, reptiles, amphibians and many invertebrates are part of the community. Numbers of all trophic levels are stable, cycling of matter is continuous and there is a rich stock of resources for all members of the community. Unfortunately, mining, land clearing (habitat loss), disease (including phytophthora disease, which you will learn more about in the Year 12 course) and introduced species are causing significant change, and threatening the survival of many species, such as Baudin's black cockatoo.

Not all successions reach a climax community. A combination of factors, such as fire and selective grazing by herbivores, helps to create conditions that allow, for example, grasslands to persist.

Question set 6.2

REMEMBERING

1 Define 'climax community'.

2 Distinguish between primary and secondary succession.

3 Describe factors that may prevent succession from reaching a climax community.

UNDERSTANDING

4 Draw an annotated timeline to show the sequence of stages in primary succession.

5 Relate the characteristic features of *r*-selected species and *K*-selected species to the stages of succession they are most likely to be found in.

6.3 NATURAL DISTURBANCES AND SUCCESSION EVENTS

There are many instances of natural disturbances, such as erupting volcanoes, massive flooding, hurricanes, tornadoes, tsunamis and landslides, that change the biotic and abiotic interactions in a community. Depending on the severity, type and extent of the disturbances, primary or secondary succession will follow.

Tsunami

On 26 December 2004, plate movements in the Indonesian oceanic region generated a devastating tsunami. It was a reminder of the extent of destruction that can be caused by natural phenomena. Many thousands of people were killed as the waves sped across the hundreds of kilometres of coastline around the perimeter of the oceans, damaging or destroying everything in their path.

In the year after the tsunami, a team of scientists surveyed the region's coral reefs looking for signs of recovery at 60 sites along 800 km of Aceh coastline. They documented high densities of 'baby corals' and rapid growth in areas that were severely impacted by the tsunami. The researchers attribute the recovery to natural colonisation by resilient coral species, along with the reduction of destructive fishing practices by local communities. The scientists recommended re-establishing natural coastal vegetation, such as mangroves, as that might reduce the impact of any future tsunamis.

FIGURE 6.7 Seven years after the tsunami, Wan, who owns this Banda Aceh rice field in Indonesia, holds a picture of this same tsunami-affected area taken in 2005. Secondary succession is responsible for the current thriving biological community.

Fire

Fire can have varied effects on ecosystems. Fire intensities depend upon weather and fuel load. The rate of spread of a fire is affected by a variety of issues including wind speed, moisture content of the fuel, fuel particle size, vegetation height, fuel bulk density, percentage of dead fuels and topography. The immediate negative effects of fire on the biota of a community include loss of vegetation, reduction of leaf litter and an increase in animal suffering and decrease in numbers. The degree to which this changes the populations of species present in a habitat depends on the kind of fire (canopy, understorey or both), and its intensity and scope.

The United Nations estimated that over the weeks and months that followed the 2019–20 Australian bushfires, one billion animals were likely to die as a result of lost habitat and food sources. These losses increase the global decline in biodiversity. The intensity of the bushfires was likely to have been strengthened by climate change. Adding to this, the bushfires will further increase climate change, because trees are carbon sinks. During photosynthesis, trees absorb carbon dioxide from the atmosphere, then they store it in the form of carbohydrates. As the bush burned, carbon dioxide re-entered the atmosphere; it will be a long time before the ecosystems can reabsorb the greenhouse gases that were released. The UN environmental program estimates the 2019–20 bushfires have already emitted 400 megatonnes of carbon dioxide into the atmosphere. This is equivalent to as much as Australia's average annual carbon dioxide emissions, in just 3 months.

Prescribed burning is the process of planning and applying fire to a predetermined area, under specific environmental conditions, to lower fuel loads and to reduce the severity and size of bushfires. The best time to burn is usually between late June and early September, when cooler weather conditions create moisture in the vegetation. This causes the fire to burn cooler and for a shorter period of time. It is also important to have an appropriate wind speed, so the fire doesn't spread too quickly or too little.

Fire can also have positive impacts on a community. It removes the slow-growing but dominant trees and shrubs, thereby opening up space for other living things (e.g. herbaceous, grass-like species). Fire is important in returning nutrients to the soil that were previously locked up in plant biomass. Ash produced in fires creates nutrient-rich soil. The new, open spaces offer maximum light availability, but also remain vulnerable to the effects of the hot, drying sunlight or pelting rain. The heat of the fire can lead to biotic changes; for example, some species of bottlebrushes, hakeas, some acacias and eucalypts regenerate from fire-released seeds. Also, it has been found that smoke particles signal germination and growth in some species.

Smoke to sow and grow
View the slideshow and read about the effects of smoke on seed germination.

The proliferation of new growth in a post-fire community attracts many mobile species, such as wallabies, birds, small mammals and insects. The new growth sustains animals that may have survived the fire in underground burrows, such as wombats and echidnas.

AAP Image/PA

FIGURE 6.8 Smoke rises from this fire at Batemans Bay on 6 January 2020, one of the many massive bushfires of the 2019–20 season.

Key concept

In prescribed burning, fire is used as a management tool. Fire can positively affect a community by removing dominant plants and opening up space for other living things, and returning nutrients from plant biomass to the soil. Also, smoke can promote germination.

Fire is rapid and dramatic, but even though it changes ecosystems, the original ecosystem can potentially be re-established over many years by succession.

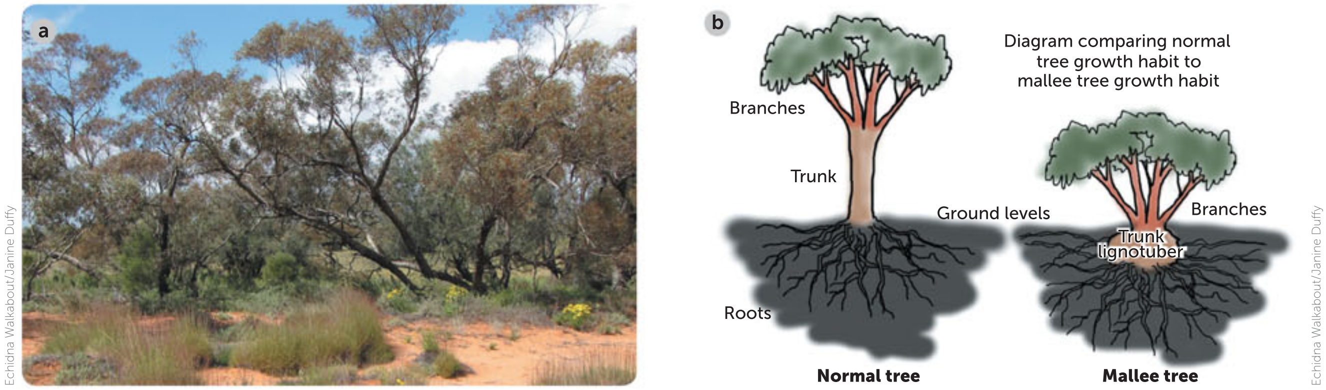


FIGURE 6.9 a Mallee habit is a type of tree growth where the tree has multiple stems. **b** Underground, mallee trees have a structure called a lignotuber, which stores energy. It can regenerate the tree if the top is damaged (e.g. by fire).

Key concept

Natural disturbances such as tsunamis and wildfires are followed by succession.

6.2 APPLICATION Bushfire smoke: a germination agent

For many plant species, bushfire smoke has been found to be a germination factor. Professor Kingsley Dixon is a conservation biologist, restoration ecologist and the director of the ARC Centre for Mine Site Restoration at Curtin University. He was also the 2016 Western Australian Scientist of the Year. Based on the knowledge that cellulose is a significant substance found in plant tissue, he and his team created an artificial version of bushfire smoke using filter paper and tested for specific chemicals found in smoke. The collaborative, 11-year study identified the specific molecule in smoke responsible for germination and named it karrikinolide to honour local Noongar culture ('karrik' means smoke).

Fire regimes

Long-term changes in an ecosystem can result from sequences of fire known as **fire regimes**. Fire regimes are determined by:

- the season in which fires occur
- the intensity of the fires
- most importantly, how frequently the fires occur.

Traditionally, Aboriginal and Torres Strait Islander Peoples burned sections of the bush to aid hunting and stimulate new growth of plants for food. So-called 'fire-stick farming' greatly increased the frequency of fires in many parts of Australia and gave rise to a pattern of vegetation that became dependent on regular burning. This human intervention disrupted regular succession patterns to maintain a grassland state. Plants with underground tubers and other adaptations for surviving fire became more common in these fire-dominated environments. Some were edible, such as yam daisies and many types of terrestrial orchids, and formed part of the staple diet for Aboriginal and Torres Strait Islander Peoples.

FIGURE 6.10 Fire-stick farming is a traditional method used by Aboriginal and Torres Strait Islander Peoples to clear areas of land as an aid for hunting and to encourage growth of food plants.

These traditional fire regimes are no longer widely used. In many areas of Australia, the once fire-tolerant landscapes are being buried alive by a spreading invasion of African grasses such as gamba, para, mission and buffel grasses. Vast areas of woodland in the north and centre of the continent are at risk. These introduced grasses build up huge fuel loads, supporting fires of an intensity and timing that native trees, shrubs and grasses cannot withstand. Eucalypts, acacias and shrubs that make up the unique Australian landscape thrive in the natural fires of lower intensity and frequency, but they do not survive these higher intensity blazes. Also, during intense fires the refuges that allow Australian native plants and animals to survive extreme drought are burned out. If these are destroyed, then nothing survives to recolonise the landscape. The Australian woodland will be replaced by grassland, becoming similar to an African grassland.

SCIENTIFIC LITERACY

Understanding the long-term impact of prescribed burning, with a focus on south-western Australia

Professor Stephen Hopper is a conservation botanist working in the south-west of WA, where the Noongar Aboriginal people and more recent settlers live, and the site of a global biodiversity hotspot. It has some 8000 species of native flowering plants as well as 1100 species of introduced invasive weeds. It is a biodiversity hotspot because it is a place rich in endemic species that are under threat. Professor Hopper has developed a series of hypotheses that may explain the accumulation of endemic plant richness over tens of millions of years.

He has also teamed with scientists to study prescribed burning. His team posed the following question: 'What is the impact of frequent prescribed burning on biodiversity?'. They used the south-west Australian biodiversity hotspot as an exemplar.

Essential to any debate on the impact of fire on biodiversity in the south-west Australian hotspot is knowledge of the fire regime(s) under which that biodiversity evolved. There is a strongly held belief, known as the 'historical-fire-regime concept', that replicating the pattern of fires ignited by lightning or pre-industrial humans best promotes native species in fire-prone regions. Aboriginal and Torres Strait Islander Peoples arrived in Australia approximately 50 000 years ago, but the biodiversity long predated this and evolved in concert with a pre-Indigenous fire regime.

Professor Hopper and his team reported that the best evidence of pre-Aboriginal fire regimes indicates that they were extremely variable, potentially of limited landscape-scale impact, and depended on location, with fire frequencies ranging from 12–14 years in

semi-arid parts of WA, to 80–100 years in the jarrah forest on the Darling Scarp and along the south coast. Significantly, a recent study of the impact of fire interval on trees in a banksia woodland in Eneabba, near the Yallalie impact crater, found that the lowest rates of mortality of the trees were associated with a fire interval of 10–14 years, which approximates the pre-human fire frequency for the region.

It is widely believed that the seeds are only released by fire. There is no doubt that many species do release their seeds immediately following fire, but less well known is the fact that many species of banksia and other species release seed over time if a fire does not occur.

A 'rule of thumb' adopted by most fire managers is that the shortest interval between burns should be double the time to flowering of the slowest obligate seeder in the community. (Note: an obligate is a plant that can only germinate from seed after fire.)


Courtesy Stephen Hopper, photographer: Ellen Hickman

FIGURE 6.11 Professor Stephen Hopper

A separate study detailed times to flowering of a variety of forest species and recorded 24 species from a total of 198 in the jarrah forest that take 6 years or more to flower from germination. This should mandate a minimum burn frequency of at least 12 years in jarrah forest, keeping in mind that this does not take into account the extra time taken between flowering to seed set and release.

If the prescribed burning rate is faster than the plant life cycle then plant species will start to disappear. Plants that have a juvenile period of more than 6 years, such as *Banksia baueri*, *B. nutans* and *B. baxteri* (all keystone, nectar-producing species) would gradually be eliminated, and species associated with late stages in the series or climax states of the ecosystem, such as tammar wallabies, quokkas and honey possums, would disappear.

To protect the biodiversity of the south-western area of WA, careful consideration of the life cycles and impacts on the plant and animal life is required. Other studies indicate that burning closer to habitation and infrastructure is more effective in protecting these assets than broad-scale burning of bushland areas that are kilometres distant. Given that projections of climate change suggest there will be more frequent and intense fires in the future, it is imperative that scientists find out the best strategy for long-term protection of our unique biodiversity.

Before taking up his current research role, Professor Hopper worked as director of two world-class botanic gardens – Kings Park in Perth and the Royal Botanic Gardens, London. In 2012 he was awarded Australia's highest civilian honour, the Companion of the Order of Australia, and was inducted into the Western Australian Science Hall of Fame.

Source: Professor Stephen D Hopper, University of Western Australia

Questions

1. In terms of biodiversity, describe the environment in the south-west of WA.
2. Evaluate the use of prescribed burning for protection of biodiversity.
3. If prescribed burning continues, describe factors that should be considered before deciding on the burning rate and location.

Question set 6.3

REMEMBERING

1 State three positive effects of fire on a community.
2 State three negative, short-term effects of fire on a community.
3 Identify evidence to show that succession has been occurring in Indonesia since the tsunami on 26 December 2004.

UNDERSTANDING

4 Describe the long-term effect on biodiversity of prescribed burning.
5 Relate the regeneration of a community after a fire to a named type of succession. Explain why this specific type of succession occurs after a fire.

Australia's first human inhabitants and traditional burning

Aboriginal and Torres Strait Islander Peoples came from the north through South-East Asia at a time when the sea level was lower than it is today. Around 50 000 years ago, they had travelled through much of Australia's inland waterways and desert areas, and inhabited coastal areas and their hinterland. The First Australians traditionally hunted and harvested food from the land and water, adapting to the various climates and resources available. They utilised their surroundings to improve their own wellbeing, modifying the environment in the process.

Throughout much of Australia, Aboriginal and Torres Strait Islander Peoples changed the existing regime of fire induced by lightning to one of fire induced by humans, so they could manage and sustain the productivity of the land. In the process, the distribution and abundance of plant species changed, and those that were more fire-tolerant increased. This in turn produced changes in the distribution and abundance of wildlife.

Aboriginal and Torres Strait Islander Peoples have for many centuries used fire for various purposes, including thinning vegetation for better access, maintaining a pattern of vegetation to encourage new growth and attract game for hunting, and encouraging the growth of useful food plants. Other than for land management, fire is important for cooking, signalling, and spiritual and ceremonial reasons.

Karla Wongi Fire Talk
Read the article about a Nyungar perspective on forest burning.

Indigenous ecological knowledge: the Gunditj Mirring Partnership Project

CASE STUDY

The Budj Bim landscape in south-west Victoria is a traditional homeland of the Gunditjmara people. Budj Bim ('High Head') is part of the 'Eccles' volcanic landform. The volcanic explosion that formed Mt Eccles is estimated to have occurred 27 000 to 30 000 years ago and was witnessed by the Gunditjmara people.

It created a complex landscape of stony rises, wetlands, swamps and adjacent low-lying land prone to flooding, and an excellent habitat for an abundance of flora and fauna that became readily available resources for the Gunditjmara people.

The Gunditj Mirring Partnership Project has produced a nine-volume literature review recording traditional and contemporary Gunditjmara land management practices, some refined over thousands of years. The sharing and use of this resource will offer valuable insights for the protection and management of the environment today and in the future.

The partnership project is designed as a way of continuing the traditional land ownership strategies, as well as their contemporary techniques, as part of a broader view that Indigenous communities have the potential to provide new and unique viewpoints on land management.

The information gathered is being collated and implemented into an extension program that will aim to test and trial land management methods. Sites on land owned and managed by Aboriginal and Torres Strait Islander Peoples will be involved in trials of certain practices, such as:

- controlled seasonal burning to encourage species for food and fibre
- strategic grazing to protect culturally significant sites through the reduction of exotic species
- revegetation near waterways to protect and maintain fishing places
- seed collection at sustainable levels
- mapping of plants used for food or medicine.

The team is also in the process of compiling a 'toolkit' of the knowledge, which will be applied to an extension program engaging with farmers who are interested in working alongside Indigenous community members to undertake on-ground works on their properties as part of the partnership.

Questions

1 Describe how the Mt Eccles volcanic explosion would have caused changes in the local ecosystem and how this may have benefited the Gunditjmara people.
2 Outline what the Gunditj Mirring Partnership Project literature review produced and how it will be used.
3 Select two of the trials described in the extension program, and explain how each will help to increase biodiversity.
4 Explain how non-Indigenous farmers in the area will benefit from the partnership.

European colonisation

Aboriginal and Torres Strait Islander Peoples have lived sustainably across Australia for tens of thousands of years. The effects of European colonisation on the landscape have been much less subtle. As they colonised more and more land, Europeans tried to impose their agricultural practices on a country that did not have the soil, water or climatic stability to sustain them. Early European farmers had no understanding of fire as a management tool, nor did they appreciate how well-adapted native animals and plants could be used as food.

FIGURE 6.12 Australia's early colonialists tried to impose their foreign agricultural practices on a country that could not cope with them, irreparably damaging the landscape.

Because of fire-stick farming, grasslands were the dominant vegetation community throughout many areas of Australia and were embraced with delight by the early colonists. This was not to last. By as early as 1853, a farmer named John Robertson wrote to Governor La Trobe of his concerns about the impacts sheep were having on the landscape. He noted that some plants had begun to disappear, clay (denuded) hills were slipping, springs of salt water were appearing and erosion from rainfall was becoming evident. Clearly, the rate of change to the environment after European colonisation had increased dramatically.

Worldwide, the effect of human activity is marked. Destruction of land habitats, changes to the atmosphere and water, the stripping of vegetation and the exploitation of wildlife have all contributed to the extinction of thousands of species. The equilibrium of ecosystems and the biosphere as a whole has been upset, irreparably in places, in what has come to be described as the sixth extinction.

6.4 ECOSYSTEM MODELS AND PREDICTING THE IMPACT OF CHANGE

Ecosystem models are very useful for simulating and analysing the long-term dynamics and properties of complex ecosystems. They allow the use of information from different disciplines, as well as providing a means to analyse, interpret and understand field observations. Models provide a basis for predictions of the impacts of changes in real ecosystems, and the development of tools for management support and policy advice.

Like all models, those designed to demonstrate ecosystem interactions are built using gathered data and the interpretation of that data. To draw on the most accurate and comprehensive data set would entail examining every part of the ecosystem, such as in a census collection. However, this is highly impractical for most ecosystems. A more practical approach is to examine parts of the ecosystem through random sampling. If all members of the population have an equal chance of being selected, simple random selection ensures that the sample is representative. The reliability of the model is determined by the representativeness of the sampling.

One of the most widely used models is that of ecological succession. The concept of secondary succession is applied to restoration ecology projects worldwide in an effort to predict how to restore ecosystems that have suffered natural or human-made disturbances, such as those at a mining site. An understanding of abiotic conditions and the roles of species can be used to predict successional outcomes.

Rainforest rescue video
A conservation group has planted over 42 000 trees to help transform a derelict farm on the edge of the Daintree into rainforest.

6.3 APPLICATION

WA mining and the environment

WA's mining boom has resulted in huge economic benefit to all Australians. However, mining has enormously changed the landscape, devastating many habitats. Over time, the government has enforced restrictions on mining development and required mining companies to have restoration plans for any affected ecosystems. Koolanooka Mine Site, an iron-ore mine 400 km north-east of Perth, is one example of an area that is in the process of being restored. It took ecological research and modelling to provide advice on how to restore vegetation communities at the nearby sites of Koolanooka, Blue Hills and Weld Range. The mining company aims to eventually restore 70% of the original species diversity.

AAP/UIG/Environmental Images

FIGURE 6.13 Ecosystem models can be useful during the ecological restoration of mining sites.

WS Chapter 6 Activity sheet

CHAPTER 6 SUMMARY

- Physical isolation allowed Australia's unique life forms to evolve.
- Australia's biodiversity is unique and globally significant, with a high number of endemic species.
- Communities change progressively over time, with one community being replaced by the next in a process of serial replacement known as succession.
- As succession progresses, local species of flora and fauna change. Such changes can interact and lead to new abiotic conditions and opportunities for different species.
- Primary succession takes place on bare sites devoid of life.
- *r*-selected species of plants are fast-growing and reproducing, and are typical of early colonising plants; they are the first to occupy unused resources and living space.
- Organisms can recolonise recently disturbed communities via secondary succession.
- The end of succession is marked by a climax community made up of slow-growing, long-living *K*-selected species.
- Natural disturbances such as tsunamis and fire are followed by succession.
- Over thousands of years, Aboriginal and Torres Strait Islander Peoples have lived using sustainable fire regimes and balanced use of biological resources from Australia's ecosystems.
- Succession models can be applied to predict changes to ecosystems, such as those undergoing rehabilitation after damage.

CHAPTER 6 GLOSSARY

Autotroph a producer; an organism that can photosynthesise to make its own food using light energy from the Sun

Climax community the stable community present at the final stage in a succession; it is stable as long as environmental factors remain unchanged (e.g. rainforests)

Endemic describes a species that is native to a particular geographic region

Fire regime the season, intensity and frequency of fire in a given area over a period of time

Gondwana the southern supercontinent that drifted apart to form present-day Antarctica, India, Africa, Australia and South America

***K*-selected species** a slow-growing, long-lived species typical of those in a climax community

Laurasia the northern supercontinent formed after Pangaea broke up; it included what is now North America, Europe, Asia, Greenland and Iceland

Nudation the development of bare sites with no organisms inhabiting the affected area

Palaeontologist a scientist who studies palaeontology, the science of the forms of life that existed over the course of Earth's history (e.g. the study of fossils)

Pangaea the supercontinent consisting of all of Earth's land masses

Pioneer plants plants that colonise (move into and establish) a newly forming community; usually autotrophic and able to attach to a new substrate

Prescribed burning the process of planning and applying fire to a predetermined area, under specific environmental conditions, to lower fuel loads and reduce the severity and size of bushfires

Primary succession when succession begins in a virtually lifeless area where soil has not yet formed

***r*-selected species** a fast-growing and reproducing organism, often the first to occupy unused resources and living space

Secondary succession a process of change in an ecosystem when a previously established community is taken over by a new group of organisms; occurs after natural disturbance (fire and flood) or through human intervention (e.g. logging and land clearing for agriculture, dramatic changes)

Soil a layer made up of a mix of organic and inorganic particles and small rocks; the organic matter forms from dead or decaying organisms, and includes water, minerals and micro-organisms

Succession a process of change in community composition and structure, usually towards the establishment of a stable ecosystem; includes changes in abiotic and biotic factors, including the populations of species present in a habitat

CHAPTER 6 REVIEW QUESTIONS

Remembering

1 Copy and complete Table 6.2 by listing the positive and negative effects of fire on an ecosystem.

TABLE 6.2 The effects of fire on an ecosystem

POSITIVE EFFECTS	NEGATIVE EFFECTS

Understanding

2 Explain how the fossil record provides evidence of past ecosystems.

3 Account for the high percentage of endemic species in Australia.

Applying

4 Dingoes occur on mainland Australia; they have never inhabited Tasmania. Identify a likely reason for their geographical distribution.

5 The dunnart is a small mammal that lives on Kangaroo Island, Australia. Its greatest threats are large, intense bushfires. However, long periods without bushfire are detrimental to its survival as well. The dunnart likes a mix of post-fire successional stages with at least some early regrowth. The vegetation at around 5–20 years post-fire has suitable structure and composition for the dunnart's habitat.

Design a suitable fire regime for Kangaroo Island that would suit the dunnart. Justify the rate of the regime.

Analysing

6 Identify the *r*-selected and *K*-selected species in the graph in Figure 6.14. Give reasons for your answer.

7 Explain why it is important for traditional owners of the land and conservation biologists to work collaboratively on land management.

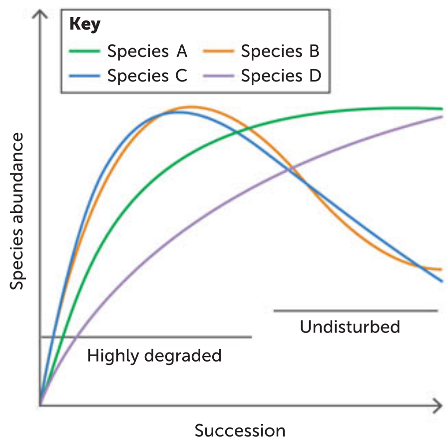
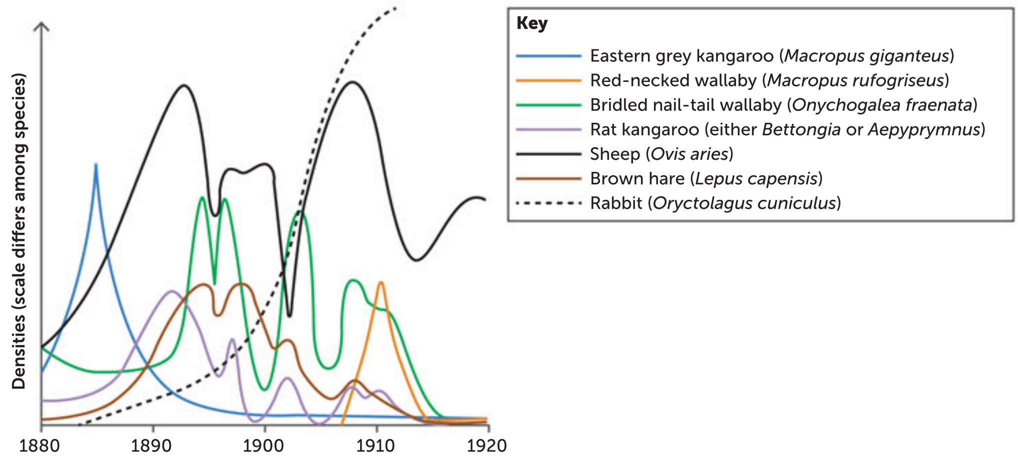


FIGURE 6.14 Change in communities in the process of succession

8 Study the graph in Figure 6.15.

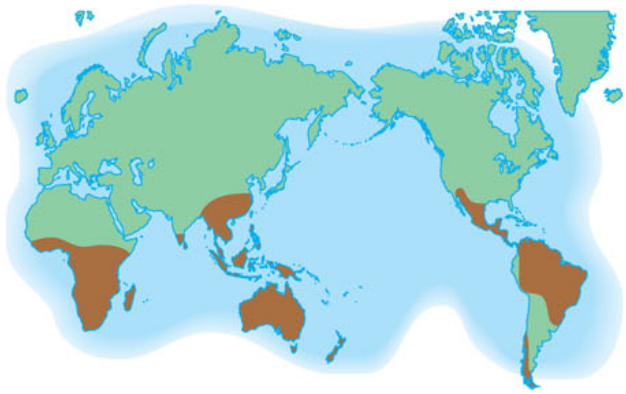
- **a** At what time was biodiversity at its highest?
- **b** How have the native herbivores fared against the exotic animals?
- **c** Describe changes in the herbivore community of the New England tablelands between 1880 and 1920. Suggest possible reasons for these changes.



Recher, H. F. et al. (eds) (1992) A Natural Legacy: Ecology in Australia, Pergamon Press, Sydney, p. 260.

FIGURE 6.15 Changes in relative abundance of native and exotic herbivorous mammals on the New England Tableland from 1880 to 1920

9 The Proteaceae family, which includes plant genera such as*Banksia*, *Grevillea*, *Hakea* and *Protea*, has a distribution as shown in Figure 6.16. Many botanists believe Proteaceae represents a family of flowering plants that evolved early. Explain the current distribution of these plants.



White, M. E. (1994) *The Greening of Gondwana*, Reed. By permission of Mary White

FIGURE 6.16 Distribution of family Proteaceae

Evaluating

10 Copy and complete Table 6.3 by stating the differences between primary and secondary succession.

TABLE 6.3 The differences between primary and secondary succession

FACTOR	PRIMARY	SECONDARY
Beginning feature		
Soil		
First signs of life		
Biomass (relative)		

11 Present arguments for and against farming native animals and plants.

Creating

12 Use the information in Figure 6.17 (a and b) to create a story about changes in the area described by the data.

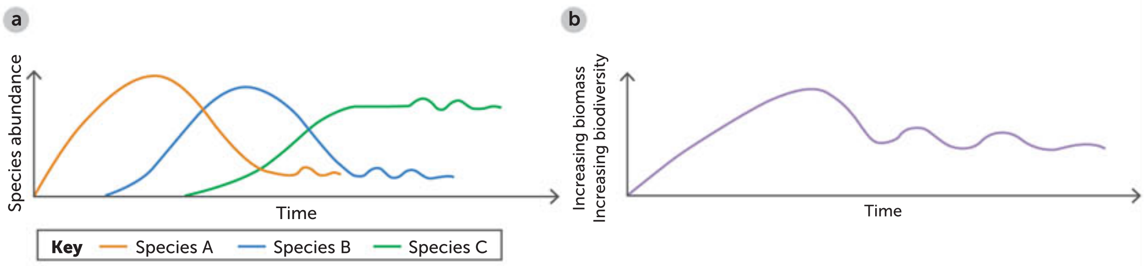


FIGURE 6.17 Graphs of changes, during succession, in **a** species abundance and **b** biomass and biodiversity

13 Describe a possible long-term change that could cause secondary succession to occur in your local community. Given the change you describe, predict the stages in succession. Present your findings as a poster.

Reflecting

14 State three things you thought you knew well before reading this chapter that you now understand better; for example, prescribed burning.

PRACTICE EXAM QUESTIONS

1 In plants, seed dispersal:
- A separates fertile from infertile seeds.
- B raises density-dependent mortality in seedlings.
- C increases competition between seedlings and parent plants.
- D allows plants to colonise new habitats.

[Q30 2014 SCSA]

2 The role of pioneer plants in primary succession is to:
- A trap moisture for higher plants.
- B attract carnivores to the area.
- C contribute to the formation of soil.
- D decompose organic material to return nutrients to the soil.

3 The most significant factor for determining the fire regime for an area should be:
- A the speed of the slowest animal.
- B duration of the life cycle of the dominant plants, including seeding and flowering.
- C availability of water.
- D reducing fuel in large areas of bushland to reduce the intensity of wild bushfires.

4 Define the term ‘climax community’. (2 marks)

5 State and explain the main stages of the process of ecological succession involved in restoring a forest environment after it was completely cleared of all life forms for a mining site. (10 marks)

James Vodicka

7 ECOSYSTEM CHANGES AND CONSERVATION STRATEGIES FOR BIODIVERSITY

CHAPTER 7 CONTENT

STARTER QUESTIONS

1 Can you list 5 of the 3000 introduced species in Australia?
2 Carbon dioxide concentration levels have cycled throughout history; what is different about the trend in levels over the last few hundred years?
3 Can you describe how climate change is impacting our biodiversity now?
4 Can you describe some free and some expensive management strategies for conserving our biodiversity?

SCIENCE UNDERSTANDING

» human activities that can affect biodiversity and can impact on the magnitude, duration and speed of ecosystem change include examples of:
  – habitat destruction, fragmentation or degradation
  – the introduction of invasive species
  – unsustainable use of natural resources
  – the impact of pollutants, including biomagnification
  – climate change

» conservation strategies used to maintain biodiversity are:
  – genetic strategies, including gene/seed banks and captive-breeding programs
  – environmental strategies, including revegetation and control of introduced species
  – management strategies, including protected areas and restricted commercial and recreational access

SCIENCE AS A HUMAN ENDEAVOUR

» identification and classification of an ecological area as a conservation reserve also requires consideration of the commercial and recreational uses of the area, as well as Indigenous Peoples' usage rights

» *Australia's Biodiversity Conservation Strategy 2010–2030* presents a long-term view of the future and the actions that need to be implemented to conserve biodiversity

» international agreements about biodiversity encourage international cooperation in the protection of unique locations, including:
  – World Heritage sites, for example, Shark Bay, Great Barrier Reef
  – biodiversity hotspots, for example, south-west WA
  – international migration routes and areas used for breeding, for example, by birds, whales, turtles, whale sharks

School Curriculum and Standards Authority (2017). Biology ATAR course: Year 11 syllabus: Science inquiry skills.

7.1 HUMAN IMPACT ON BIODIVERSITY AND ECOSYSTEMS

An ecosystem consists of a community and its environment (the biotic and abiotic factors in a given area), and the interactions between them. Stable ecosystems can be sustained over long periods of time. One sign of a healthy ecosystem is that it can sustain stress in the form of extreme conditions, such as floods, droughts, invasive species, disease and overexploitation; a healthy ecosystem shows resilience to extreme conditions. Usually, resilience is a direct result of having a substantial level of biodiversity. When the biotic or abiotic factors change, ecosystems change.

Human activities can directly or indirectly affect ecosystems. Human activities that affect the biotic and abiotic factors in ecosystems have increased dramatically since the agricultural and industrial revolutions of the 18th and 19th centuries. Land clearing and power-driven machinery increased the need for fuels: wood first, and then coal, a fossil fuel. As food, medicine and living standards improved, the human population increased, using up more natural resources. The increased demand for food and resources also led to the increased use of industrial and agricultural chemicals, fertilisers and the burning of fossil fuels, some of which caused air and water pollution. The increase in human population and activities has led to an increase in the magnitude, duration and speed of ecosystem change. These rapid changes have reduced the biodiversity of many ecosystems, which has decreased their resilience to further changes.

Human impacts have had a massive effect on some of WA's highly biodiverse ecosystems. The Southwest Australia Ecoregion is one of 36 internationally recognised biodiversity hotspots. An area is identified as a biodiversity hotspot by the US organisation Conservation International if it has high biodiversity but the species and their ecosystems are endangered. A region must meet two criteria to qualify:

- it has a minimum of 1500 vascular plants that are not found in any other region on Earth
- it has suffered at least a 70% reduction in its original natural vegetation.

The Southwest Australia Ecoregion (including Perth) and the Forests of East Australia are Australia's only two biodiversity hotspots. Many animals depend on the endemic plant species found in WA's hotspot. The small honey possum feeds on local banksias, grass trees, kangaroo paws and bottle brushes. The honey possum transfers pollen between flowers, pollinating many plant species. Bush heritage conservation groups monitor honey possums for the effects of human activities, such as harmful fire

The world of honey possums
Read about the endemic honey possum and the research conducted on it.

Protecting honey possum habitat
Watch this Bush Heritage Australia video.

FIGURE 7.1 a Lake Claremont, one of Perth's wetlands; **b** the honey possum depends on endemic trees in WA's south-west Banksia woodlands for nectar; **c** logging of timber reduces available habitat.

Shutterstock.com/Tysun
Alamy Stock Photo/Nature Picture Library
Alamy Stock Photo/Bill Bachman

regimes, habitat destruction, cat and fox predation, and the spread of disease (such as phytophthora). They also buy and manage land in partnership with Indigenous Peoples, actively protecting native species by controlling competitor pests such as rabbits, and revegetating the area with native plants.

With a relatively high number of different species of plants and animals, wetlands provide necessary resources for our wildlife. Wetlands are neither aquatic nor terrestrial, but exist as a merger of these two, changing seasonally to become more or less of each type of ecosystem. The Western Australian Museum revealed recently that only 10% of Perth's wetlands remain. The Australian Bureau of Statistics has predicted that Perth's population will increase to approximately 3.8 million by 2050. Planning for the conservation of the last 10% of wetlands is needed to ensure their survival into the future. Many important wetlands on the Swan coastal plain are being degraded by human impact because they lack protection. Species diversity is declining, as well as population numbers. Local volunteers and groups, such as Herdsman Lake Wildlife Centre, Cockburn Wetland Education Centre and Naragebup Rockingham Regional Environmental Centre, are contributing to the conservation of these wetlands, but they need more help and funding.

Worldometer
Watch the population of a country or the world change in real time.

The effects of human impact on our ecosystems can be observed locally, nationally and internationally. Australia's population is around 25 million and continues to grow. There is continued competition for both renewable and **non-renewable** resources. This parallels the effect of the global increase in population (currently 7.8 billion people and rising). Competition for land use is considerable, for a range of uses: for agriculture; for habitats for native biota; for industrial and domestic constructions; for roads, waste disposal and the spreading urban development; and for the minerals, matter and fuels that sustain a consumer society.

Human activities threaten biodiversity. Damage to ecosystems is a major global crisis because the current rate of species extinction is relatively high. The impact is observed at all three levels of biodiversity: genetic variation within a species (which reduces potential adaptation and survival), species diversity in ecosystems and ecosystem diversity. Conservation strategies that are used to maintain biodiversity can be classified into three types: genetic, environmental and management strategies. The most important conservation strategies focus on population protection, growth and habitat.

Key concept

Human activities threaten biodiversity. Damage to ecosystems is a major global crisis because of the high rate of species being made extinct.

Question set 7.1

REMEMBERING

1 Identify the signs of a healthy ecosystem.
2 Describe the ecosystems known as wetlands.

UNDERSTANDING

3 Draw a flow diagram showing a probable series of events from human population growth in Perth to the removal of 90% of wetlands.

7.2 HABITAT DESTRUCTION AND CONSERVATION STRATEGIES

Habitat destruction and fragmentation

With the rise in human population and our demands on resources, land use has changed drastically, which affects habitats. **Habitats** are environments in which a species normally lives. Habitats are destroyed as a result of urbanisation, manufacturing, agriculture, forestry, mining and fishing. **Habitat destruction** is a human activity that greatly affects ecosystems. Habitat loss has reduced species

9780170452847

richness and is the greatest threat to biodiversity. When its habitat is lost, a species is vulnerable to extinction. For example, clear-felling (a method of harvesting that removes most of the vegetation) to supply WA's timber mills is still contributing to the removal of vast areas of habitat.

Urbanisation

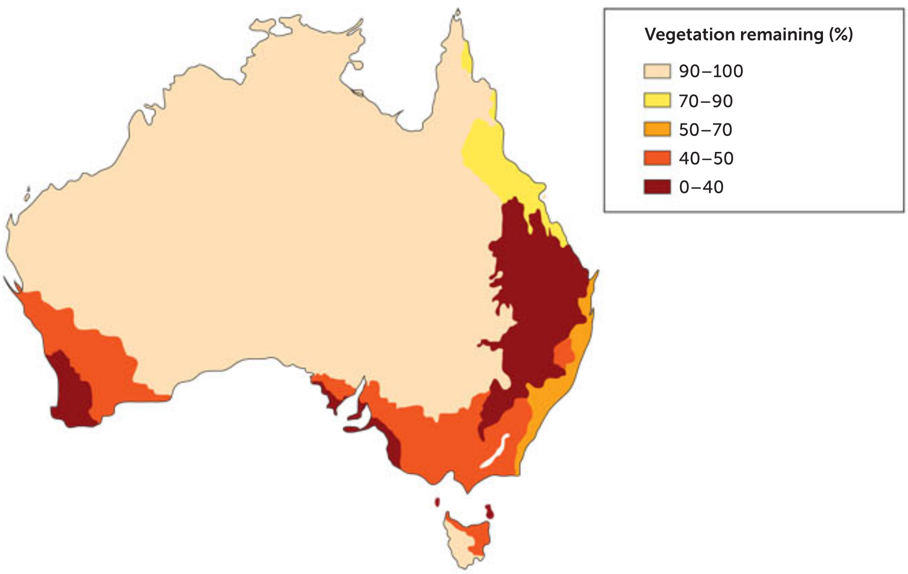
Urbanisation is the extreme modification of an ecosystem by humans to support a human population of gradually increasing density; often, this happens as more people migrate to towns and cities from rural areas. Urban ecosystems have reduced biodiversity and are dominated by people. There is little recycling of matter between the community (the living things present) and the non-living surroundings. Additional inputs of energy and matter are needed from other ecosystems to maintain modern standards of living, especially in cities. There is an increase in output of gaseous and material wastes of many kinds, and these are disposed of into our atmosphere, onto the land and into the water of other ecosystems, which in turn are also altered.

For example, scarce landfill sites are filled with materials, many of which could be recycled. Food scraps and other organic materials in landfill produce methane, a greenhouse gas that could be tapped as a fuel. Households produce vast amounts of plastic waste, and only a small proportion of it is recycled. Large volumes of recycled materials end up in landfill due to contamination. The federal government's *National Waste Report 2018* showed that only 12% of Australia's plastics are recycled.

Urbanisation can cause rapid changes of large magnitude to an ecosystem. Local biodiversity is reduced and, even though new species may potentially move into an urban area, the ecosystem is changed for a very long time, often permanently.

Agriculture

Since European colonisation, more than 20% of Australia's forests have been cleared for crops and grazing, with nearly 90% of the vegetation cleared in the more fertile areas of south-eastern Australia. The pattern of native vegetation loss shown in Figure 7.2 reflects that of European land use. The year 1750 is used by scientists as a reference point indicating pre-European vegetation. The greatest reductions in native vegetation since 1750 have been in eastern, south-eastern and south-western Australia. It has been estimated that at the turn of this century we, as a nation, were clearing the equivalent of 740 times the area of the Melbourne Cricket Ground, per day.



Hutchinson, M., McIntyre, S., Hobbs, R., Stein, J., Garnett, S. & Kinloch, J. (2005) Integrating a global agro-climatic classification with bioregional boundaries in Australia, Global Ecology and Biogeography, 14, pp. 197–212.

FIGURE 7.2 Percentage of Australian native vegetation remaining since 1750

Key concept

The rise in human population and demand for resources has changed land use. Habitats are destroyed as a result of urbanisation, manufacturing, agriculture, forestry, mining and fishing.

Identify your black cockatoo
Listen to the distinct bird call of our native black cockatoos.

CASE STUDY

Carnaby's black cockatoo

In the last 20 years, millions of hectares of habitat around Australia have been altered. Agriculture is the main reason for the land clearing, followed by native-forest logging, urban development and mining. The impact of habitat destruction on endangered species is a huge concern, and is the subject of scientific research efforts. For example, our endangered Carnaby's cockatoo has lost 56% of its habitat since European colonisation and clearing for agriculture. Researchers from the Western Australian Museum describe the specific causes of its population decline as land clearing and fragmentation of its habitat (especially in the wheatbelt); the loss of hollow-bearing trees and the impact of competitors for such trees (including galahs, corellas and feral European honey bees); bush fires; and the effects of traffic (road-kill). See Chapter 5 for more information about the impact of human activities on the Carnaby's cockatoo population.

The future of Carnaby's cockatoo in the Perth and Peel regions will continue to be affected by the growth of the greater Perth metropolitan area. In the early 2010s, there was a plan to clear an area of the Banksia woodlands ecological community to accommodate the growing human population. This development, coupled with the clearing of pine plantations for groundwater recharge, would have further reduced the feeding habitats of Carnaby's cockatoo. Fortunately, this pressure on habitats has been reduced with the listing of the Banksia woodlands as a threatened ecological community under Commonwealth legislation, so that any development has to meet strict criteria designed to protect the area.

Environmental conservation management strategies are used by Perth Zoo and Kaarakin Black Cockatoo Conservation Centre to rescue and rehabilitate sick and injured Carnaby's cockatoos, and release them back into the wild. Professor Peter Mawson is the Perth Zoo science program leader and has worked with endemic cockatoo species for more than 25 years.

Photo by Rick Dawson. Permission granted by Professor Peter Mawson.

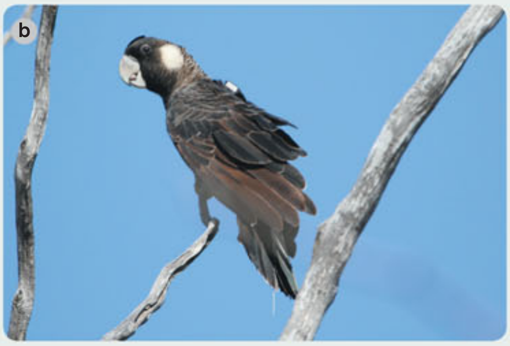
FIGURE 7.3 Some products of the breeding program at Perth Zoo: sibling Carnaby's cockatoo nestlings in an artificial nest hollow

Black cockatoo species endemic to south-west WA include Baudin's cockatoo and Carnaby's cockatoo, which are both endangered under the International Union for Conservation of Nature's Red List category, as well as the forest red-tailed black cockatoo, which is classified as vulnerable under WA's *Biodiversity Conservation Act 2016* and the federal *Environment Protection and Biodiversity Conservation Act 1999*. Numbers for their population estimates vary greatly but it is generally considered there are around 40 000 Carnaby's cockatoos, 10 000–12 000 Baudin's cockatoos and 10 000–14 000 forest red-tailed black cockatoos.

Kaarakin can care for more than 200 black cockatoos at a time, with more than 145 going through rehabilitation. In 2018, Kaarakin and Perth Zoo celebrated the release back into the wild of their 500th black cockatoo.

Scientists are using new technology to track the movement of Carnaby's black cockatoos. The Black Cockatoo Conservation Management team from Murdoch University is using data from their tracking system to make decisions about the conservation of the species. The birds are fitted with satellite PTT (platform transmitting terminal) and global position systems (GPS) tags. The PTT tag is tied and glued to the two central tail feathers. Then the solar-powered GPS tracker is attached to a small number of back feathers. Before they are released, the birds are marked for identification with passive implant transponders and individually numbered stainless steel leg bands. The PTT tag sends data eight times a day, while the GPS tag provides data every 10 minutes. Researchers are using the data to better understand how these endangered birds use their habitat (spatial studies), to improve its conservation management.

The Black Cockatoo Conservation Management Project, Murdoch University



The Black Cockatoo Conservation Management Project, Murdoch University

FIGURE 7.4 a Tagging a Carnaby's black cockatoo; **b** a tagged cockatoo, with its GPS back-mounted tracker and the antenna of the second PTT tracker visible at the end of the tail feathers

Questions

1. What are the main human activities that have affected the habitat of the Carnaby's black cockatoo?
2. What type of conservation strategies do Kaarakin and the Perth Zoo undertake to help this species?
3. How is new technology being used in conservation efforts?

Habitat fragmentation

Habitat **fragmentation** occurs when some parts of the habitat of an ecosystem are separated into isolated sections. This can be a result of land clearing for agriculture, construction of roads, urbanisation or other human activities. Habitat fragmentation isolates groups of organisms that were once part of a larger population. The smaller subpopulations cannot interbreed; therefore, they cannot share their genetic biodiversity. When faced with adverse conditions in the environment, the smaller subpopulations no longer possess the resilience to adapt or survive, which can mean they die out and become locally extinct.

Although land clearing is continuing, *Australia's State of the Forests Report 2018* has shown that the extent of forest being cleared has decreased significantly in recent years (Figure 7.5). In the report, the term 'forest' includes native forests, commercial plantations and other types of forest. Native forests are further grouped into populations based on the main genus present in the forest, with eucalypts (77%) and acacias (8%) being the most common type of native forest in Australia.

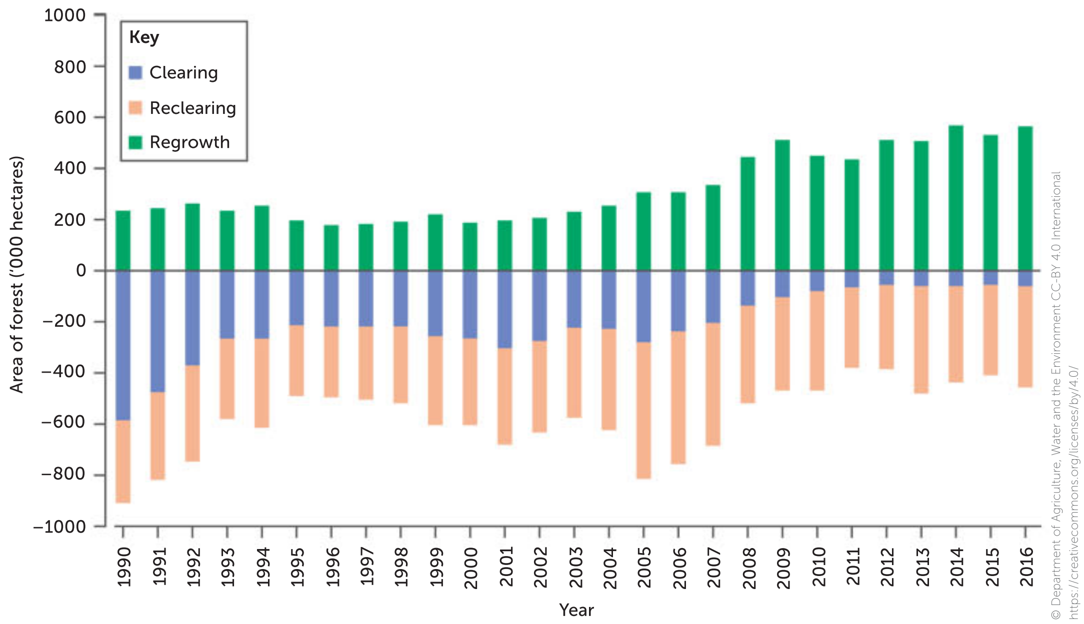


FIGURE 7.5 Annual areas of forest clearance, as reported in *Australia's State of the Forests Report 2018*

Conservation strategies

Genetic conservation strategy: seed banks

A **seed bank** is a reservoir for plant genetic material, especially for species threatened with extinction. If a population or species did become extinct, seeds from the seed bank could be used to reintroduce it to its habitat.

At the WA Seed Centre, in the Biodiversity Conservation Centre, King's Park, scientists collect, store and test native plant seeds from more than 3500 different plant species. The seeds are carefully maintained to keep them viable. Seeds are collected, cleaned and dried under controlled conditions. They are stored in freezers at −18°C and have the potential to live for decades.

Seeds are collected from all over WA, including the Kimberley coast, the Great Victoria Desert in the east, and Esperance and Cape Arid in the south-east. The Department of Biodiversity, Conservation and Attractions monitors and manages seeds at both the Seed Centre and the Threatened Flora Seed Centre, at the WA Herbarium, as part of a risk management strategy for WA's threatened flora.

Kew's Millennium Seed Bank
This video introduces the Millennium Seed Bank held by the Kew Royal Botanic Gardens at Wakehurst, UK.

As a back-up strategy, duplicate collections of seeds are transported to the UK to support the Millennium Seed Bank Partnership. Within the vaults of the Millennium Seed Bank is the largest seed collection on Earth. The Millennium Seed Bank is a collaborative global resource for the conservation and sustainable use of plants.

Gene banks are a modern and important genetic strategy used for agricultural insurance. As diversity in crop species continues to drop, with farmers selectively breeding the best strains of crop only, the risk is that the rest of a species' gene pool could be lost. To prevent the loss of genetic diversity, gene banks store seeds that contain the genetic material which may contain genes that will help species survive future changes in the environment.

Svalbard Global Seed Vault

7.1 APPLICATION

Deep inside a mountain, on a remote island between Norway and the North Pole, lies the Svalbard Global Seed Vault. It is a fail-safe, state-of-the-art seed storage facility with a combination that no single person knows in its entirety, built to withstand the test of time, and natural and human-made disasters. The vault has been likened to a Noah's Ark of plants. It aims to preserve the entire range of crop biodiversity by storing seed samples. It will secure, for centuries, millions of seeds representing every crop variety available in the world today.

Environmental conservation strategy: revegetation and bush corridors

Regeneration of land and **bush corridors** between isolated habitats can be an effective way of returning habitat to populations and enabling subpopulations to interbreed. The Gondwana Link program is an environmental strategy that has been working to reconnect bushland in the south-west of Australia since 2002 (see page 204).

Areas of the south-west of Australia were cleared many years ago for farming, roads and homes. Some landowners are now working collaboratively with scientists and farmers to restore significant areas of land, with the aim of restoring ecological resilience. As farmland is restored to bush, animals can once again move freely between populations, maintaining and increasing biodiversity. To achieve this goal, a team of people created a conservation action plan that included priority areas where focused protection of remaining habitats and restoration was needed. Eventually, three large national parks will be connected as one ecological strip. Already, over 6000 ha of land has been restored, mostly by planting in strategic locations. The environmental strategy's main goal is to restore the ecosystems to a state where they can thrive and survive changes in the environment, independent of human intervention in the future; this will represent the restoration of resilience. Native animals that will directly benefit from this program include the honey possum, malleefowl, black cockatoo and black-gloved wallaby.

Society for Ecological Restoration
Planting and other practical work has been undertaken at Monjebup North, in the south coast region of WA, to restore fragmented habitat.

Management conservation strategy: protected areas and standards

Management conservation strategies rely on controlling aspects of the environment for conservation purposes. Usually this means there is a guide or set of rules governing human activities such as the harvesting, research and use of certain species, so the negative impacts of that human activity are minimised. The goal is to maintain or improve the survival of a species.

Individual species may have management strategies assigned to them; for example, survival of a fish species that is being harvested in an unsustainable manner may be helped by the introduction of a rule only allowing it to be fished seasonally. Governing bodies have also developed strategies for the conservation of whole ecosystems. For example, the *National standards for the practice of ecological restoration in Australia* are designed to help sustain the diversity of life by outlining strategies for repairing damaged ecosystems. This manual includes a rationale for the distribution of populations and species and a description of where plant species can be planted to set up more sustainable and natural ecosystems. Following such management strategies will help to connect populations across an ecosystem.

National standards for ecological restoration
The Society for Ecological Restoration Australasia has published these national standards.

State governments have recovery plans for endangered species, such as Carnaby's black cockatoo. The national recovery plan for Carnaby's cockatoo outlines actions that are being taken to improve conservation of the species. These actions include:

- protecting important habitat, including feeding, breeding and non-breeding habitats
- regularly monitoring nest hollows and non-breeding factors (i.e. roost sites, feeding habitat), and using citizen science to count population numbers (the 'Great Cocky Count')
- conducting research into areas such as population demographics and health, movements and feeding, roosting behaviour, and modelling of climate change
- monitoring and managing the effects of car collisions, shooting, poaching and illegal habitat destruction
- promoting community awareness, understanding and involvement in conservation actions
- communicating with decision-makers to increase their understanding of conservation.

FIGURE 7.6 This new bushland was grown from direct seeding as part of habitat restoration in Ranges Link, WA.

Key concept

Genetic conservation strategies include storing seeds in a seed bank.

Environmental conservation strategies include regenerating land and bush corridors between isolated habitats, to return habitat to populations and enable subpopulations to interbreed.

Management conservation strategies include having rules governing human activities such as harvesting, research and use of certain species, so the negative impacts of such activities are minimised.

SCIENTIFIC LITERACY

Environmental conservation strategy: Gondwana Link

A satellite photograph in the early 2000s of Australia's south-west was the key factor that activated an impressive group of organisations and individuals to form the Gondwana Link program. The photograph revealed the magnitude of habitat destruction and fragmentation the south-west ecoregion had experienced since European settlement. A significant amount of land had been cleared for farming, which was needed for the growing human population. A side effect of this 200-year-old human activity is the impact on the environment. Some biodiversity has been forever lost.

The Gondwana Link program has been working to reconnect fragmented habitats across the south-west of Australia. If the Gondwana team reach their goal, 1000 km of continuous habitat will reconnect habitats from the dry woodlands of the inner region to the tall wet forests of the far south-west corner. Traditional land managers, organisations, farmers and conservation scientists have worked together to strategically revegetate gaps of cleared land to restore the fragmented habitat.

Removal of and protection from invasive and feral species such as cats and foxes is a strategy implemented to help endemic species start to repopulate the newly linked habitats. The Gondwana Link environmental strategies rely greatly on the cooperation of landowners. The gaps between habitats that need filling are located on various farms and properties. Since the beginning of the program, thousands of hectares of rural properties have been purchased. Some owners simply agreed to restore the land.

In the Great Western Woodlands, the establishment of a Ngadju Ranger program assisted in the management of 4.4 million ha of Ngadju country. Ngadju Conservation Aboriginal

Corporation now have the capacity to run the program in their own right and funding to maintain their team of 10 rangers – their country is now a nationally recognised Indigenous Protected Area.

A major aim of the program is for the resulting ecoregion to build resilience. When species are relatively high in abundance with genetic variation, changes in the environment are less likely to cause extinction. Species and ecosystems have a higher chance of surviving and adapting to change if they have a larger pool of species and genes to choose from suited to the environmental change.

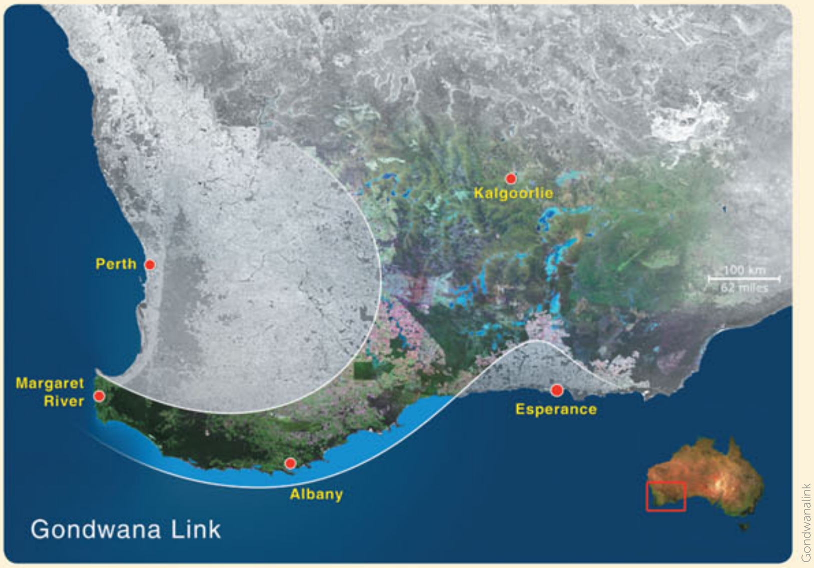


FIGURE 7.7 The 1000 km sweep of Gondwana Link, from the south-west corner of WA to the edge of the Nullarbor Plain

Questions

1. Where is the Gondwana Link project?
2. What is the main purpose of the project?
3. Describe three major achievements of the Gondwana Link project.

Land and soil degradation

In 1853, early colonialist John Robertson recorded that he had a holding of more than 11 000 sheep on his property in southwest Victoria of just under 5000 ha, a little more than two sheep per ha. This is well above the normal carrying capacity for such a large herbivore. Sheep and some other introduced domestic animals have hard hooves (unlike the soft feet of native animals), which compact the soil when they graze. This damage to the soil creates opportunities for invasive, shallow-rooted, introduced plants to grow at the expense of the deep-rooted native grasses. With significantly reduced tree cover and an increase in shallow-rooted grasses, the topsoil becomes more exposed to the effects of abiotic factors such as wind and rain. In addition, sheep are selective when they graze, taking some plants in preference to others. The vegetation gradually changes in response to these pressures. Robertson, who had a background in botany, reported that over just a few years, native grasses were being replaced and soils were eroding.

The land and soil degradation John Robertson observed on his property has been observed in many parts of Australia. While soil is the most basic of our agricultural resources, it is also finite. When measured against human lifetimes, soil is a non-renewable resource. To farmers, soil loss by wind or water means production loss (Figure 7.8). To the animals, plants and other organisms that live in that environment, it means death.

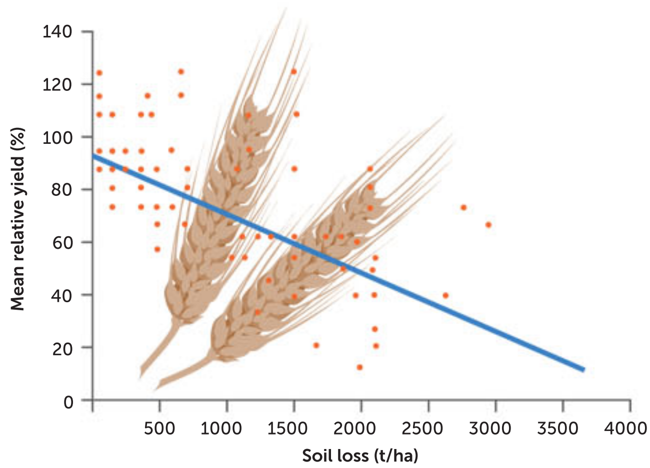


FIGURE 7.8 Graph showing soil loss and farm productivity

Past land clearance practices, the move to shallow-rooted pastoral grasses and the overuse of fertilisers that have affected soil organisms have all placed enormous pressures on the structure of the soil and the ability of the land to hold its topsoil. Farming practices that rely on large and heavy machinery for efficiency can add to the problem by compacting soil, as is evident when removal of topsoil by wind or water exposes the deep, hard ruts in paddocks. Modern agricultural practices can cause rapid changes to the abiotic components of the ecosystem, in turn rapidly changing the biotic components. If there is significant change or loss of topsoil, the ecosystem may be permanently changed. However, in recent years practices known as regenerative agriculture are beginning to be thoughtfully applied, leading to healthier nutrient recycling, increased biodiversity and more stable and resilient ecosystems. Such practices include preserving ground cover and soil stability, ground water management, land-use planning and grazing management; all of these practices reduce land and soil degradation.

Regenerative farming
Read the article and watch the videos to find out how Charles Massey (in NSW) and Ian and Di Haggerty (in WA) use regenerative farming.

Dryland salinity

Over a million hectares of agricultural land in WA's south-west is affected by dryland salinity. Dryland **salination** is the process of salts normally found under the surface of soil being transported to the soil surface by a rising watertable. In many agricultural areas of WA, the underlying reason behind the rising watertable is the removal of deep-rooted, perennial (long-lived), usually native, vegetation. Salinity refers to the concentration of salt in the soil. If the concentration of salt in soil becomes too high, plants such as crops will no longer grow and the soil is infertile.

Alamy Stock Photo/Krystyna Szulecka Photography

FIGURE 7.9 Dryland salinity caused by a combination of land clearing and irrigation practices can reduce biodiversity and devastate ecosystems.

You may wonder how the removal of deep-rooted trees may cause the watertable to rise. Deep-rooted trees help to keep the watertable depth stable by transporting water (via xylem in their vascular tissue) from the roots, through their stems and out of their leaves, by evaporation into the atmosphere. When the deep-rooted trees are removed, they no longer use water from the watertable, and it starts to rise to the surface, dissolving salt from surrounding soil as it rises. If it reaches the surface, the water evaporates due to WA's dry climate, leaving behind the salt. This is known as dryland salinity and in the southwest of WA alone, it now significantly affects more than one million hectares of land.

Groundwater map
This interactive groundwater map allows the user to view current trends in the watertable (bore water) and watertable depth in south-west WA.

Step 1
Human population increases, leading to increased food consumption and need.

↓

Step 2
Farming increases, with further clearing of deep-rooted trees.

↓

Step 3
Removal of deep-rooted native perennial species and planting of shallow-rooted annual crops. Deep-rooted native plants remove water from underground aquifers and use it in transpiration; this balances the inputs and outputs of aquifers. The roots of shallow-rooted crops do not grow down far enough to reach the watertable to access water for transpiration or evaporation.

↓

Step 4
Watertable rises. As it rises, salt from surrounding soil dissolves into the water.

↓

Step 5
Water evaporates at the soil surface, leaving behind soil that is too salty for most plants to survive.

FIGURE 7.10 The steps leading to dryland salinity

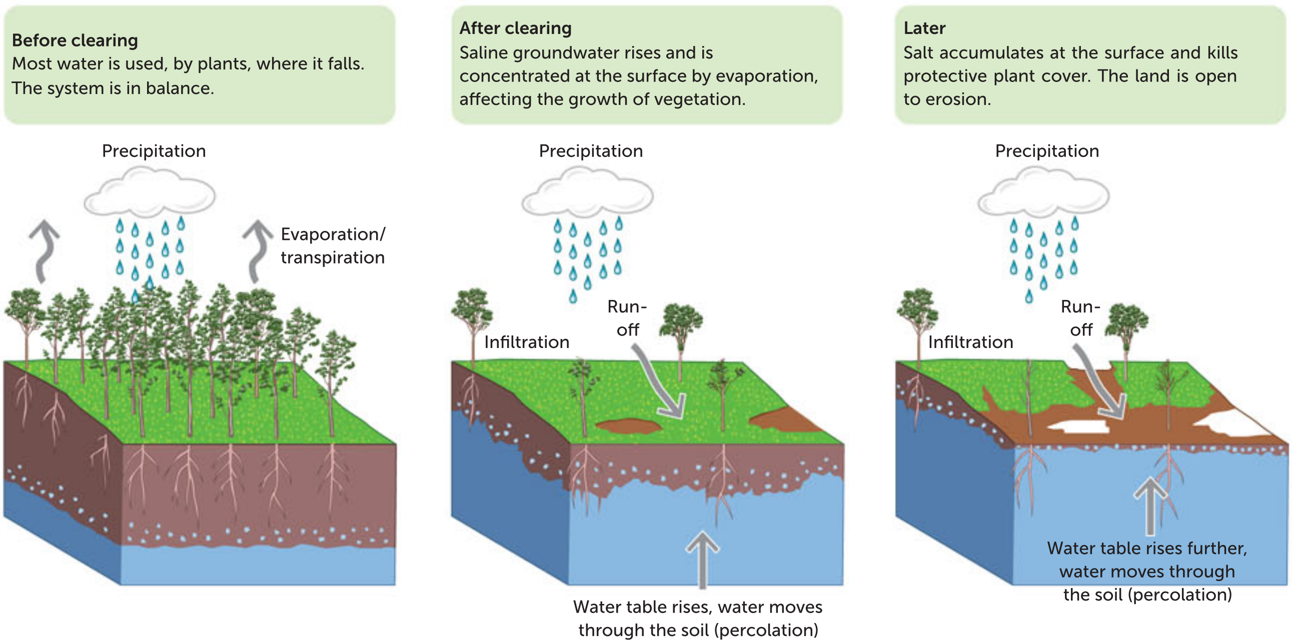


FIGURE 7.11 Dryland salinity follows the removal of deep-rooted vegetation.

To reduce dryland salinity, some farmers siphon off or pump water from the rising watertable to make it lower.

One method of avoiding dryland salinity is to plant rows of short-rooted crops adjacent to rows of deep-rooted trees. This prevents the watertable from rising and stops the salty water from entering the topsoil. This strategy reduces the amount of a crop that can be planted, but it ensures that, in the long term, the land will remain fertile.

Dryland salinity and its management
Professor David Pannell from the University of Western Australia describes dryland salinity.

Question set 7.2

REMEMBERING

1 Describe the process of urbanisation and how it affects the environment.
2 Define 'fragmentation' and explain what factors have caused habitat fragmentation in the south-west of WA.
3 Describe how habitat destruction and clearing has affected the Carnaby's black cockatoo.
4 Summarise the actions taken within the Gondwana Link project to reduce the effects of habitat fragmentation.

UNDERSTANDING

5 Draw a flow diagram showing a probable series of events for the process of dryland salinity.
6 Copy and complete Table 7.1 to organise information about each of the three types of conservation strategies for habitat destruction or fragmentation: genetic, environmental and management strategies.

TABLE 7.1 Conservation strategies

STRATEGY TYPE	EXAMPLE
Genetic	
Environmental	
Management	

7.3 INTRODUCED AND INVASIVE SPECIES

Introduced species are species that humans have intentionally or unintentionally moved from their native location to a new ecological region. In their new location, they are without the natural predators, parasites and pathogens that would usually limit their growth. Introduced species are also known as **exotic** species. The rate at which they have been introduced has increased with the increase in human travel by ship and air. Introduced species are thought to have contributed to approximately 40% of global species extinctions recorded since 1750. Introduced species become **invasive species** if they manage to establish populations in new areas. The terms invasive species and pests are interchangeable.


age-fotostock/UIG/Auscape

FIGURE 7.12 An invasive species, a feral fox

Invasive species

Because of its isolation, Australia has generally been fortunate in being able to prevent the spread of plant and animal disease from other parts of the world. Diseases cause huge financial losses to farmers in other countries. Because of the absence of diseases, such as mad cow disease, foot-and-mouth disease and various fungal diseases of plants, Australia can more easily sell its products to overseas markets.

Some wildlife are used in international trading. Australian traders need to adhere to the *Environment Protection and Biodiversity Conservation Act 1999*. However, illegal importing of exotic species is big business, and has impacted our natural ecosystems by endangering native plant and animal populations. Threatened species illegally imported without an authorised permit or exemption, such as some bird and orchid species, can attract a $110 000 fine and a 10-year jail term.

In the early days of Australia's European colonisation, many animals and plants were introduced by the British. Goats, pigs, wheat and other cereal crops were among those introduced for agriculture, and rabbits and foxes were introduced for sport. Other species arrived accidentally, such as the garden snail and black rat. Many introduced mammals, such as deer, camels, pigs, cats and dogs, have become feral pests that outcompete native mammals and reduce the health of ecosystems.

In WA, feral populations of introduced animals, including mammal, bird, reptile and amphibian species, have become invasive, causing damage to agriculture and the environment. Invasive species, especially foxes and cats, cause significant issues in WA because they prey on native species, or outcompete them for food and habitat resources. Table 7.2 lists some animals that have been declared pests in WA.

TABLE 7.2 Some of the invasive species declared pests in WA

Fox	Feral pig	Rabbit
Feral camel	Feral goat	Cane toad
Wild dog	Feral donkey	Rainbow lorikeet
Feral cat	rabbit	Red-eared slider

Cane toads are the only true toads in Australia. They became invasive after being introduced into Australia as a biological control to prey on destructive beetles in Queensland's sugarcane crops, and have spread to many areas, including northern WA. Many native Australian animals are affected by cane toads. The threat from cane toads comes in different forms. The toads have a deadly and rapidly acting toxin present in their body in all stages of their life cycle (egg, tadpole or adult stage), and as adults, they excrete it from glands around the neck. Species of frogs, reptiles, fish and mammals (such as our carnivorous quoll), especially those which normally prey on frogs, succumb to the toxin when they consume a toad. Additionally, cane toads compete with native species for food, as their diet consists of native invertebrates (mainly insects), but also native frogs, small mammals and even snakes. Because cane toads have killed so many native animals, they are a threat to Australia's genetic, species and ecosystem biodiversity.

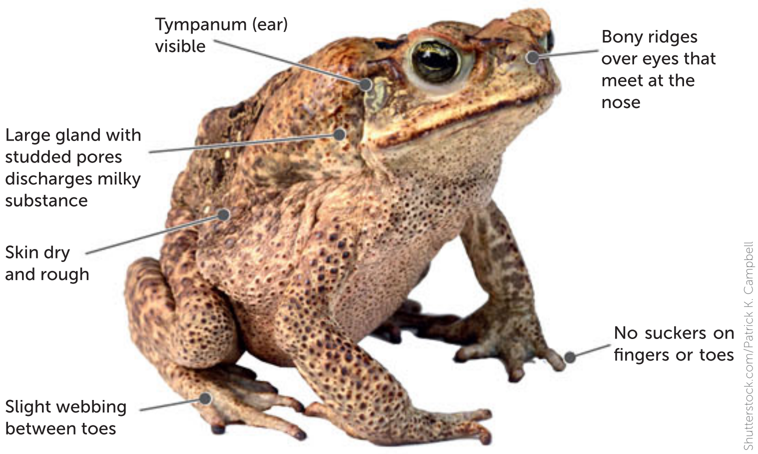


FIGURE 7.13 Cane toad, with distinguishing features labelled

Cane Toad Coalition
This group of organisations is trying to teach native wildlife to avoid eating cane toads.

7.2 APPLICATION

Cane Toad Coalition

In 2019, a collaboration between Macquarie University, WA's Parks and Wildlife Service and Indigenous rangers formed the Cane Toad Coalition and began taking action to stop the impact of cane toads on biodiversity. They began trialling a mitigation strategy that involved training native predators not to eat toads.

Normally, when an Australian native predator attacks a cane toad, the amount and toxicity of the poison rapidly kills the predator. The trial involves strategically releasing small cane toads who produce small amounts of poison, which can cause predators to become ill but not die. The hope is that this experience will teach predators to avoid the adult-sized cane toads when they encounter them. Indigenous rangers are identifying areas of high biodiversity, using their local knowledge of the ecosystems.

Australian nurseries sell some plant species that are decorative, even though they are classified as weeds. Gazania contains an attractive flower head, but due to its invasive abilities, is classed as an environmental weed in South Australia and a potential environmental weed in WA (Figure 7.13). The plant may be added to a private garden but quickly spreads through local areas and into nearby ecosystems, severely altering the vegetation structure in plant communities by replacing and suppressing native plants.

Shutterstock.com/kukuruxa

FIGURE 7.14 Gazania: one of the 10 most unwanted plants in Australia, but still for sale in many nurseries

Key concept

Introduced species are species that have been moved by humans to new ecological regions where they lack natural predators, parasites and pathogens. They are described as invasive species or pests if they establish populations and outcompete native species.

Environmental management: chemical and biological control of introduced species

The use of chemical pesticides (**chemical control**) is a quick and effective method of getting rid of pests, but there is a downside: pesticides can be ecologically damaging as well as costly. Landowners in WA use baits to protect their animals, farms and agriculture from invasive species such as foxes, rabbits and feral pigs. 1080 and strychnine are the most common active ingredients in vertebrate pest bait. There is a code of practice for the safe use of poisons and baits.

Biological control is another method of management, in which one species, a biological control agent, is used to control the population of another (pest) species. Scientists now favour the use of such biological control agents, which exploit relationships between organisms, or an integrated approach (using two or more measures) when rapid response is needed in the early stages of a pest reaching a new area. The combined approach is also known as integrated pest management. It combines the use of biological measures with the use of chemicals limited to narrow-spectrum agents that target specific species.

There are four kinds of biological control agents:

1. general predators: a species that consumes a great variety of pest species; for example, ladybirds target aphids, caterpillars, mites and small beetles
2. specialised predators: a species that targets one pest species, such as dragonflies that target a species of mosquito, at all life stages

3 parasites: species such as wasps or flies that lay their eggs in the bodies of hosts; when the eggs hatch, the larvae feed on the body of the host (moths and caterpillars), causing the host's death
4 microbial diseases: caused by bacteria, fungi and viruses that target particular species and cause death through illness; examples include the virus myxomatosis, which was introduced to Australia to control rabbit populations.

Introduced weeds, some escaped from gardens or dumped from aquariums, choke many waterways. Such plants grow freely, without any environmental control, and impact on the local animal and plant populations negatively. The overgrowth of too many weeds limits the populations of other species that native animals require for food and shelter. Biological control of weeds has had many successes. A small South American weevil, the natural predator of the water weed *Salvinia*, was released in 1980 with great success in many areas. Moths and flea beetles, introduced in 1977, are reducing the impact of alligator weed. Another beetle from South America is controlling water hyacinth. In these cases, there tends to be a balanced relationship between the control agents and the plants.

Paterson's curse (*Echium plantagineum*) is a pretty weed with purple flowers found on millions of hectares in Western Australia, South Australia, Victoria and New South Wales. Sheep and cattle producers lose around $250 million each year managing the pest species itself as well as its impact on pasture and wool production. The pest plant contains a toxin that harms livestock that consume it, eventually causing liver damage. In WA, Paterson's curse grows from Geraldton to the south coast.

Insects that have been used to control Paterson's curse include the root weevil, crown weevil, flea beetle and pollen beetle. These four biological controls attack at several stages of the pest's life cycle. For example, after feeding for a week, adult female crown weevils lay eggs which hatch within the leaf stalk. The larvae burrow into the crown (the growth point of the plant). After a feed, the larvae leave the young pest plant and mature in the soil. When they emerge as adult weevils, they feed on the leaves and flowers of the weed until it dies.

Biological control measures have their limitations. There have been ecological disasters resulting from biological control, almost all of them due to the use of general predators. As discussed earlier, cane toads were introduced in north-east Queensland to control cane sugar beetle pests, but rapidly expanded their range from the original release site and are now found in the Northern Territory, southern New South Wales and northern Western Australia.

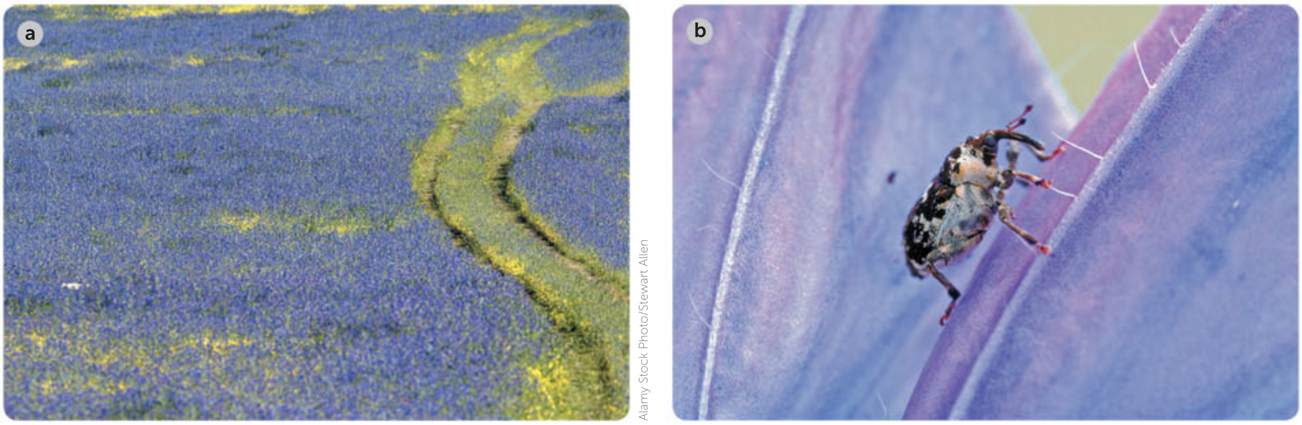


FIGURE 7.15 a Paterson's curse; **b** crown weevil, one of several species used for biological control of Paterson's curse

Scientists must take precautions before releasing a biological control into an ecosystem. Field trials must be conducted in an isolated area to discover any unexpected effects before wide release, especially to check the risk of the biological control species becoming a pest itself. To be released more widely, the biological control species must:

- only target the pest species and not impact on other populations
- decrease in number as the pest species decreases in number
- not compete with native species for a resource (e.g. food or habitat)
- be reproductively self-sustaining in the new environment.

Key concept

Chemical control of pests is effective but can be ecologically damaging and costly.

Biological control is when a species is used to control the population of a pest species. It can only be used after field trials rule out any risks.

7.3 APPLICATION

Ladybirds: ecowarriors

Ladybirds have been introduced to Australia to battle aphids on citrus trees. This reduces the use of expensive chemical pesticides and limits the impact of these chemicals on other species. Native Australian ladybirds have also been used for biological control. The Australian native vedalia ladybird was successfully released in Californian citrus orchards to control cottony-cushion scale in 1881.

FIGURE 7.16 A ladybird feeding on citrus aphids

Environmental management: culling

The thought of **culling** populations of particular species that are pushing their ecosystem beyond its carrying capacity is controversial. Populations of some species of kangaroos have increased and expanded enormously since European colonisation, which changed land use dramatically and affected many endemic species of plants and animals. The Australian red and grey kangaroos have thrived in areas where permanent water is made available for cattle. As populations of these kangaroos have increased, there has been increased competition for resources. Each year, more than 2 million kangaroos are culled under strict regulations. The kangaroo industry is worth more than $200 million each year. A small proportion of the meat is processed for human consumption, most of it for export. Culling has also been used to manage other invasive species, including camels and horses.

Reintroducing populations

Devastation of native populations has often followed from the invasion of introduced species. For example, *Galaxias* is a genus of native freshwater fish whose numbers have suffered since the introduction of the mosquitofish. Mosquitofish were introduced to Australia to reduce mosquitoes but in fact do very little to impact their numbers. The reduction in numbers of *Galaxias* has led to associated drops in the population numbers of native frogs and other aquatic species such as native insects.

Galaxias do not lay eggs – they give birth to live young, which are easily devoured by the pest species. The numbers of *Galaxias* have dropped to such low levels that some wild populations are no longer self-sustaining. However, they are relatively easy to breed in captivity. To reintroduce *Galaxias* successfully to the wild, the mosquitofish must be eradicated or absent from the release area. Eradication is a difficult process, so currently the only means of introducing *Galaxias* back into the wild is through finding uninfested waterways or artificially created ponds that have no links with infested ponds, lakes, streams or rivers.

Alamy Stock Photo/Diarmuid Toman

FIGURE 7.17 *Galaxias* is a genus of native freshwater fish whose populations decreased when mosquitofish were introduced.

Other species that have suffered similar decreases in numbers due to predation by introduced pest species face the same issues. For land animals such as bandicoots, wallabies, quolls and marsupial mice, the main threats are from feral cats, dogs and foxes. Endangered native species can be bred in captivity, but their successful reintroduction to the wild requires safe release areas such as those with pest-proof fencing, a factor that can affect the success of any such captive-breeding program.

Question set 7.3

UNDERSTANDING

1. a Under what circumstances does an organism become a pest?
   b List the advantages and disadvantages of using chemicals to control pests.
2. Compare the terms 'introduced species' and 'invasive species'.

ANALYSING

3. Draw up a table that summarises methods of biological control. Include examples of control relationships.

EVALUATING

4. Explain why cane toad populations have not been controlled yet.

7.4 UNSUSTAINABLE USE OF NATURAL RESOURCES

Unsustainable use of natural resources – using resources more quickly than they can naturally be restored – has a huge effect on biodiversity. For example, **overharvesting** means harvesting a species at a rate that exceeds the replenishing rate of the population. Organisms that have low reproductive rates, such as the African elephants (often poached for their ivory tusks), are especially vulnerable to overharvesting. This is because the sum of new individuals from births and immigration does not exceed the total individuals lost to death plus emigration. To combat this, conservation biologists have developed genetic tools and techniques to track the origin of elephant tusks. A genetic match between a tusk and a poached elephant can lead to criminal charges. Biotechnology (DNA fingerprinting) has helped conservationists and law enforcement teams in the US identify three major cartels that dominate the elephant ivory-smuggling market.

Humans historically exploit resources for short-term profit. If the resource proves to be profitable, the harvester will develop more efficient ways of harvesting the resource, depleting reserves. This is currently a major issue in the fishing and logging industries. When demand is higher than supply, and the use of the resource is not controlled, resources become unsustainable.

Key concept

Unsustainable use of natural resources means using resources more quickly than they can naturally be restored; for example, overharvesting means harvesting a species faster than the replenishment rate of the population.

Unsustainable use of natural resources has a huge effect on biodiversity.

Sustainability and fishing

More than 4000 species of fish live in the waters around the 70 000 km of Australian coastline, and about a quarter of them are found nowhere else in the world. The value of marine ecosystems has been recognised by the establishment of marine parks and reserves along stretches of the coast, but as with other kinds of ecosystems, there is competition for their use: for food, recreation, transport, commercial livelihood and as a repository for our wastes.

Commercial fishing has reduced the populations of many species, some almost to extinction, particularly by overharvesting. Shark numbers, for example, are at an all-time low. Worldwide, sharks are hunted for products such as shark-liver oil, leather, fishmeal and fertiliser. In surveys taken off the coast at Sydney and Eden, on the south coast of New South Wales, populations of small, bottom-dwelling sharks, and skates and rays that live below 200 m, showed an 80% decline between 1977 and 1997. Worldwide, one-third of the sharks, rays and skates on Earth are threatened with extinction.

The reduction in populations of these and other fish affects other species through disruptions to food chains. Penguins and seals, for example, now compete with the fishing industry for food. In the Southern Ocean, penguins account for 80% of the biomass of all sea birds, and birds are major predators on marine creatures that live in the surface layers. Tension exists between conserving penguins and sustaining fish yields.

Alamy Stock Photo/Photoshot Holdings Ltd

FIGURE 7.18 A seal entangled by marine debris

Accidental catching of other fish, birds, mammals and turtles takes its toll, and abandoned fishing lines and plastic materials also kill or maim many marine animals such as turtles, seals and marine birds, either by ingestion or by enmeshing and drowning the animal.

The **by-catch** (undersized fish, mammals, reptiles and other organisms) poses problems for species that are fished commercially. As populations of commercial fish (such as the valuable snapper) decrease, there are fewer fish reaching reproductive age to sustain population growth. Scientists and commercial fishers are trying to develop nets with meshes that will allow undersized fish to escape unharmed. Forcing fishing boats to harvest species such as leatherjackets and silver trevally at larger sizes may reduce yields in the short term, but may increase yields in the longer term.

Some fishing practices are particularly destructive to ocean ecosystems. **Bottom trawling** involves dragging a large net across the seafloor. Deep-sea fish species are targeted globally, but bottom trawling is known to also remove vast amounts of non-target species, including habitat-forming deep-sea corals and sponges. Therefore, bottom trawling poses a serious risk to the survival of deep-sea ecosystems.

Using less-destructive fishing methods and managing vulnerable areas are two measures that can help to protect lower ocean ecosystems. For example, Sweden prohibits trawling in near-shore areas, with the exception of allowing environmentally friendly trawl gear in habitats that are less sensitive. It also prohibits the use of the damaging techniques of beam trawling and shellfish dredging.

Continuous monitoring of fish stocks, water quality and indicator species over time provides the data necessary for developing effective management strategies that will conserve species and sustain commercial operations. Fishing sustainably reduces the size of a population but does not reduce biodiversity. On the other hand, overfishing to depletion changes marine ecosystems and this change will last for a long time.

Bottom trawling
See how trawling is practised and explore some ideas for how to do it with less impact on ecosystems.

The Sustainable Seafood Guide Australia
Can you guess which fish is sustainably harvested? Do you know which fish to take out of your supermarket trolley?

Management strategies: creating and monitoring protected areas

Although the rate of species loss worldwide is alarming, there are many examples of endangered populations of species being restored. Sometimes the recovery of a species is due to natural cycles of population change, but often it is the result of careful management and legal protection of species.

Whale species, for example, are staging extraordinary recoveries after being hunted to the verge of extinction. By 2050 it is predicted that the populations of southern right whales in Australian waters may approach their pre-whaling numbers. Populations of humpback whales are expanding in the north Atlantic, north Pacific and off WA.

In WA, recreational fishing licences and fishing seasons are compulsory and are used to control fishing levels. A typical licence for fishing from a boat costs around \$50. In 2020, the pink snapper fishing season was limited to 7 months. In the remaining 5 months of the year, Cockburn and Warnbro sounds were closed to provide additional protection for spawning (reproduction) of pink snapper (Figure 7.19). Some fish found in WA waters are completely illegal to catch, such as potato cod, leafy and weedy sea dragons, and humpback Māori wrasse.

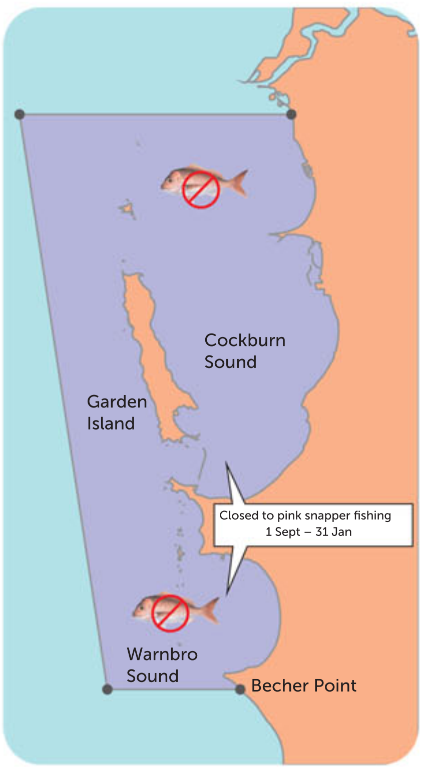


FIGURE 7.19 Sustainable management of pink snapper includes having a closed season to protect spawning fish.

Question set 7.4

UNDERSTANDING

1 Explain what it means to have unsustainable use of natural resources.

2 What is a fishing licence and why is it needed?

EVALUATING

3 Evaluate the use of bottom trawling as a fishing method.

7.5 THE IMPACT OF POLLUTANTS: EUTROPHICATION, BIOMAGNIFICATION AND PLASTICS

Eutrophication

Rain and floods move salt and other substances, such as fertilisers, off the land and into waterways. In the summer of 1991, the world's largest toxic blue-green algal bloom (from cyanobacteria) occurred along a 1000 km stretch of the Darling River in NSW, gaining world attention. Algal blooms are also increasingly common along coastal areas where streams and rivers enter the sea.


age-fotostock/UIG/Auscape

FIGURE 7.20 Eutrophication of a river, showing the algal bloom completely covering the surface of the water

Eutrophication is a process that occurs when excess nutrients, particularly nitrogen and phosphorus, enter a body of water and become highly concentrated, leading to excess growth of organisms such as algae. A summary of the process is as follows.

1 Fertilisers are used on nutrient-poor farmland, parks and gardens.
2 Fertiliser compounds are usually rich in nitrogen and phosphorous, which are nutrients for algae.
3 When fertiliser dissolves in rainwater or excess irrigation water, known as 'run-off', it can flow into local water bodies such as lakes and cause algal blooms.
4 Excess nitrogen and phosphorous not absorbed by roots are often leached from the soil by run-off and may enter the watertable.
5 An **algal bloom** is a rapid increase in the population of algae or other micro-organisms (such as cyanobacteria) at the surface of a water body that blocks sunlight from entering. When this happens, autotrophs that live under the surface die.
6 Algae die and are decomposed by bacteria.
7 As bacteria consume the dead algae, they use large amounts of oxygen from the water, which depletes oxygen levels. The water can become **hypoxic** (low in oxygen) and possibly **anoxic** (completely devoid of oxygen).
8 The low oxygen levels do not meet the respiration needs of aquatic organisms, and fish and other populations die.

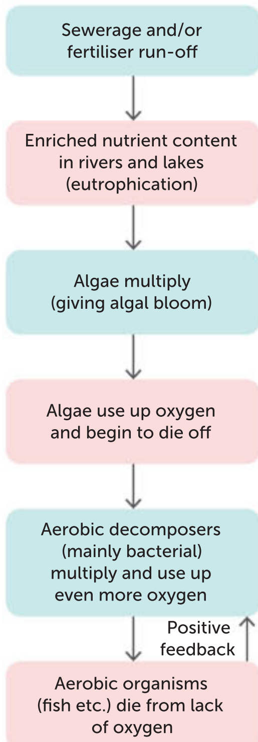


FIGURE 7.21 The steps in eutrophication

Conditions of high light (aided by tree removal around streams) and reduced flow (aided by diversion of water for irrigation practices) increase the likelihood of algal blooms. Some blooms are toxic, affecting the nervous system, but others are relatively harmless.

Biomagnification

Biomagnification occurs when successively higher concentrations of non-biodegradable chemicals build up in the tissues of organisms in the higher trophic levels of a food chain. Human activities release many toxic chemicals into the environment. Organisms acquire toxins from their environment, along with nutrients and water. Some toxins are excreted; others are stored in tissue because the organism is unable to excrete or metabolise them. Often such substances are stored in fat cells. When these organisms are consumed, the chemical accumulates in the next trophic level, becoming more concentrated. This is repeated for each trophic level. Each trophic level needs to consume relatively large amounts of matter compared to the level below, leading to increasing concentrations of the chemical.

DDT is an insecticide that was widely used in the 1900s to kill mosquitoes, in order to combat malaria. The persistence of DDT in the environment and the biomagnification of this compound through trophic levels has led to serious health effects in many organisms. In humans, studies have shown that DDT may be associated with higher incidences of cancer, infertility, miscarriage and diabetes. DDT has been linked to the population decline of bird species high on the food chain in the US, such as the bald eagle and peregrine falcon, because it causes affected individuals to produce thinner eggshells. Both species rebounded after the US put limits on the use of DDT in 1972.

Biomagnification simulation
See how biomagnification can concentrate chemicals in living things.

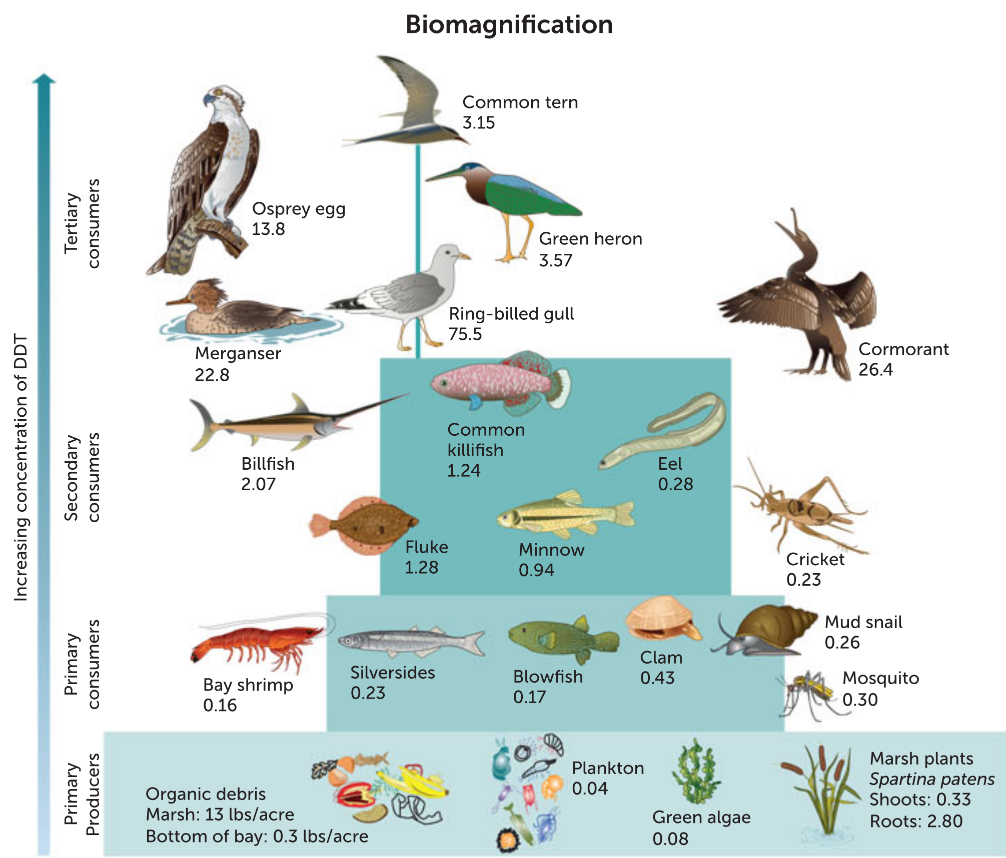


FIGURE 7.22 An early US study of the biomagnification of DDT

Plastic

Large amounts of the world's plastic rubbish enter waterways, where many aquatic animals sometimes mistake plastic for food. Turtles frequently ingest plastic bags, confusing them with their prey, jellyfish. Scientists have found at least 56 species of sea birds confuse fish eggs and crustaceans with polystyrene balls and plastic buoys. Animals such as seabirds can die from stomach or intestinal blockages from ingested plastic or from injuries received when pierced by sharp plastic. Plastic rubbish has been found in many groups of animals, ranging from whales, to sea turtles, to tiny crustaceans.

How much plastic is in the ocean?
Find out some history about plastic in a very humorous but smart delivery.

Alamy Stock Photo/Science Photo Library

FIGURE 7.23 Plastic can be consumed by wildlife, causing disease and death.

Question set 7.5

REMEMBERING

1 Define 'eutrophication'.

UNDERSTANDING

2 Draw a flow diagram to represent the steps leading to eutrophication.

EVALUATING

3 Draw an annotated diagram for biomagnification by drawing a pyramid of biomass, showing the concentrations of a named chemical at different trophic levels.

7.6 CLIMATE CHANGE

Climate, weather and climate change vocabulary

Climate is the average, long-term, predictable atmospheric weather conditions at a site over a period ranging from months to many thousands of years. Climate is made up of variables such as rainfall (precipitation), temperature, intensity of sunlight, and wind. **Weather** is the atmospheric conditions in an area over a short time, usually 2–3 days. Weather forecasts or predictions can be very unreliable. Weather is not a gauge for climate change, because it is short term. Experiencing an unusually cool week in the summer month of February in WA is not evidence for climate change.

Climate change is a significant change in the global climate that can be identified by changes in the average and the variability of such features as temperature and precipitation, and that lasts for a long time, typically decades or longer.

Key concept

Climate change is a significant long-term change in global climate that includes changes in the average and variability of, for example, temperature and precipitation.

Evidence for global warming

Comparing past and present climates is the best way to find evidence for a change in climate. In lieu of being present to measure atmospheric conditions thousands of years ago, scientists are able to analyse samples from ancient ice cores extracted from polar ice. The layers of ice in the ice core contain bubbles of gas trapped long ago that reveal data about past carbon dioxide levels and temperature. As scientists measure variables in each layer, they compare these variables and track changes over relative time. The lower the layer, the earlier the time period. Scientists have been able to collect and analyse data from Antarctic ice cores to calculate estimates of average global temperatures and carbon dioxide levels spanning 400 000 years.

Antarctic ice core research
Watch the video to learn about how the study of ice core samples can provide clues to climate change patterns.

FIGURE 7.24 An ice-drilling site, Antarctica

Figure 7.25a shows that there have been periodic cycles of increasing and decreasing temperature over the past 400 000 years. Figure 7.25b shows that the atmospheric concentration of carbon dioxide has also risen and fallen in cycles, between 180 and 300 parts per million (ppm) by volume. Note that the cycles in carbon dioxide concentration and temperature appear to coincide.

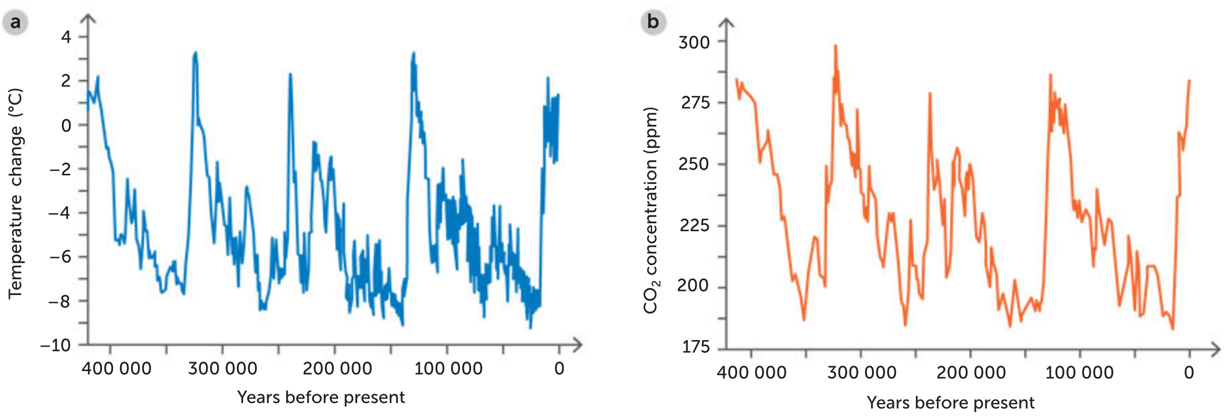


FIGURE 7.25 a Average global temperature over the last 400 000 years; **b** carbon dioxide concentrations over the same period

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The Industrial Revolution began around 1750, and involved increasing levels of human activity and use of resources, including the combustion of fossil fuels. Agricultural advances added to this growth in human activity and its impact on the environment. As the food supply increased, so did the human population. Advances in technology and improved food led to a higher standard of living, more employment opportunities and cheaper goods. The new forms of technology required the burning of fossil fuels, with coal being the most commonly combusted fossil fuel during the last 200 years. A product of the combustion of fossil fuels is carbon dioxide. Since the Industrial Revolution began, the rate of burning of fossil fuels has increased dramatically, resulting in a significant overall increase in atmospheric carbon dioxide.

There is evidence to support a relationship between the relatively sudden rise in concentration of carbon dioxide in the atmosphere in the last few hundred years and the rise in average global temperature. Scientists have concluded that it took around 50 000 years for the atmospheric carbon dioxide level to increase from its previous minimum concentration to its maximum concentration. The current increase in atmospheric carbon dioxide happened very quickly – in a matter of hundreds of years rather than thousands of years. Figure 7.26 shows the rapid rise, in the concentration of atmospheric carbon dioxide, from below 340 ppm in 1980 to more than 410 ppm in 2020.

The magnitude of the increase in atmospheric carbon dioxide that we have seen recently is different from that of past increases. Many scientists hypothesise that the increase is causing relatively rapid climate change and having an impact on our biodiversity.

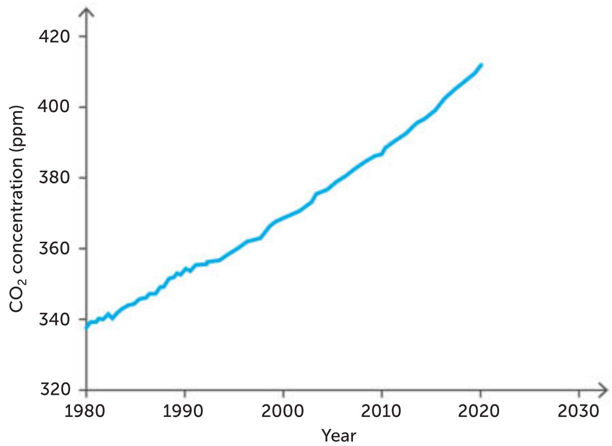

FIGURE 7.26 Global atmospheric concentration of carbon dioxide

The enhanced greenhouse effect and global warming

Variation in the Sun's intensity and volcanic eruptions have been identified as some of the factors that have caused climate to change. However, **greenhouse gases** (gases that trap heat) are probably the most significant drivers of our climate. Climate variables affect the geographic distribution of organisms and therefore any significant change in climate has a significant effect on the biosphere. The human activities of burning fossil fuels and deforestation are increasing the concentrations of carbon dioxide and other greenhouse gases in the atmosphere.

Greenhouse gases are released from natural sources (e.g. living things, volcanoes, fires) and industrial processes. They are gases that trap heat in Earth's atmosphere. Greenhouse gases include the major gases carbon dioxide, nitrous oxide, water and methane, as well as industrial products such as perfluorocarbons, hydrofluorocarbons and sulfur hexafluoride. The **greenhouse effect** is the insulating effect of these gases in the atmosphere. Incoming solar radiation is in the form of shortwave ultraviolet (UV) radiation and visible light. This radiation heats Earth and its atmosphere, and is

The greenhouse effect
Read the information and watch the video to reinforce your knowledge and understanding of the greenhouse effect and its link to temperature and climate change.

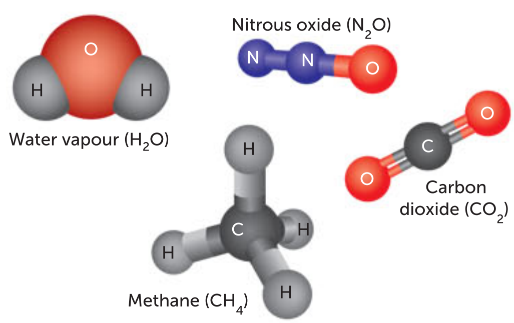

FIGURE 7.27 Some major greenhouse gases

re-emitted as long-wave, infrared radiation (heat) (Figure 7.28). The greenhouse gases trap and absorb some of the heat originating from the Sun, keeping Earth warm. The natural greenhouse effect is essential for maintaining Earth's average global temperature within a range that is warm enough for life on Earth to survive.

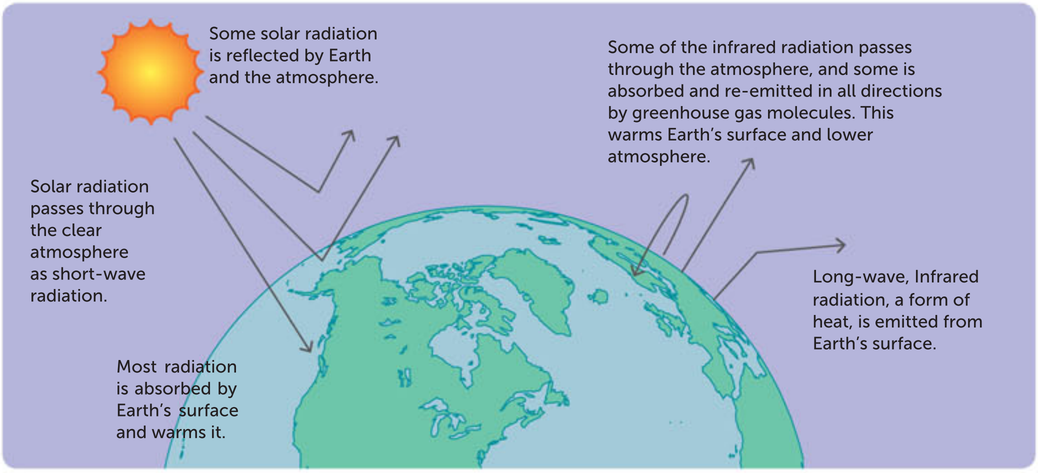

FIGURE 7.28 The greenhouse effect

The **enhanced greenhouse effect** is occurring because the concentrations of greenhouse gases have increased and too much heat is being retained. Human activities such as fossil fuel combustion, the release of methane and other gases from agricultural practices, and deforestation have increased the concentration of greenhouse gases in the atmosphere. It is the enhanced greenhouse effect that is causing an increase in average global temperatures. **Global warming** is the steady rise in global average temperature in recent decades, which experts believe is largely caused by human-generated greenhouse gas emissions. The long-term trend in global temperatures continues upwards.

Fossil fuels are natural energy sources, such as coal, oil and natural gas, which contain hydrocarbons (organic compounds). Fossil fuels are formed from fossilised living things, usually in sedimentary rock, over millions of years. They produce carbon dioxide when burned. They are burned for fuel and food to meet human demands, which are increasing as the human population increases. An alternative energy source that emits much less greenhouse gas is wind energy. Wind energy systems are found in a few areas of WA, such as the Coral Bay Wind-Diesel System.

Deforestation is the permanent removal of standing forests and it can lead to significant levels of carbon dioxide emissions. Forests are cut or burned for human benefit; to clear land for agriculture and to make various products. Forests usually act as carbon sinks (they store carbon). When they are removed, the carbon dioxide that they would normally use for photosynthesis remains in the atmosphere. Intense wildfires can also remove forests and release carbon. Fires such as the Australian bushfires of 2019–20 have made scientists deeply concerned. With a hotter, drier climate in the future, intense bushfires may cause forests like the Amazon to become carbon sources instead of carbon sinks.

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FIGURE 7.29 Coral Bay wind turbine

Agriculture also contributes significantly to greenhouse gas emissions because it produces methane and nitrous oxide (14% of WA's greenhouse gas emissions). However, farmers can use strategies known as carbon farming that help reduce greenhouse gas emissions and hold carbon in vegetation and soils. Carbon farming includes changing tillage practices (how soil is treated prior to planting) to increase the organic carbon in soil; revegetation and reforestation; and changing the fire management of savanna regions. Farmers benefit not just because they contribute less to climate change, but by reducing soil erosion and improving soil structure and fertility.

1. Sunlight hits the surface of Earth as visible light (short-wave radiation). Some of it is absorbed, and some is reflected.
2. It is converted to infrared/long-wave radiation or heat energy.
3. Some of the radiation is normally radiated back into the atmosphere towards space.
4. Humans burn fossil fuels and cause deforestation, adding greenhouse gases to the atmosphere.
5. The reflected long-wave radiation (heat) is absorbed/trapped by greenhouse gases such as carbon dioxide, nitrous oxide, water vapour and methane.
6. Some of the heat transforms into kinetic or potential energy.
7. Some of the heat is re-emitted/re-reflected by greenhouse gas molecules.
8. More heat is retained in the atmosphere.
9. The surface of Earth and troposphere increase in temperature, causing an increase in the average global temperature. The United Nations reports that from 1880 to 2012, the average global temperature increased by 0.85°C.
10. There is a correlation between rising atmospheric concentrations of carbon dioxide since the Industrial Revolution began more than 200 years ago and average global temperatures (global warming).

FIGURE 7.30 A summary of the processes involved in the enhanced greenhouse effect

Key concept

The enhanced greenhouse effect is when higher concentrations of greenhouse gases in the atmosphere cause excess heat to be retained, causing an increase in average global temperatures.

Observable factors related to climate change

Sea levels
Is an increase in sea levels inevitable?

Melting ice
How do scientists measure how much melting ice adds to sea levels?

Climate change is observed in changes to various long-term weather variables. Wind and precipitation patterns are shifting and extreme weather events, such as drought, floods and storms, are occurring more frequently. Climate change is causing increased melting of glaciers and polar ice sheets, resulting in a gradual increase in sea levels. Greenland has lost almost 4 trillion tonnes of ice since 2002. Mountain ranges from the Himalayas to the Andes to the Alps are also losing ice rapidly as glaciers shrink. Plants and animals are also affected by global climate change when the timing of seasonal events, such as flowering or pollination, is affected by global warming.

Key concept

Climate change is increasing the frequency of extreme weather events, including heat waves, high rainfall, drought and storms.

As the abiotic and then biotic factors change in an ecosystem, some species experience different selective pressures affecting their survival. These could include habitats becoming unsuitable, not enough food or conditions that require fast migration. As we lose individuals and species, biodiversity declines and the result is a decline in the resilience of ecosystems.

TABLE 7.3 Some possible effects of climate change

EVENTS INCREASED BY CLIMATE CHANGE	POSSIBLE CONSEQUENCE TO HUMANS
Heat waves	Increase in death rate in elderly and poor Increase in heat stress in livestock Change in tourist destinations
Rainfall	Increase in floods Increase in soil erosion
Drought	Decrease in crop and livestock production Decrease in quantity and quality of water Increase in forest fires
Storms	Increase in property and infrastructure loss Increase in infectious disease epidemics Increase in risk to human life

Mixed effects of global warming
Discover the mixed effects of global warming on plant growth. While warmer temperatures in the 1980s and 1990s caused an increase in plant productivity, this advantage has since been counteracted by more frequent droughts.

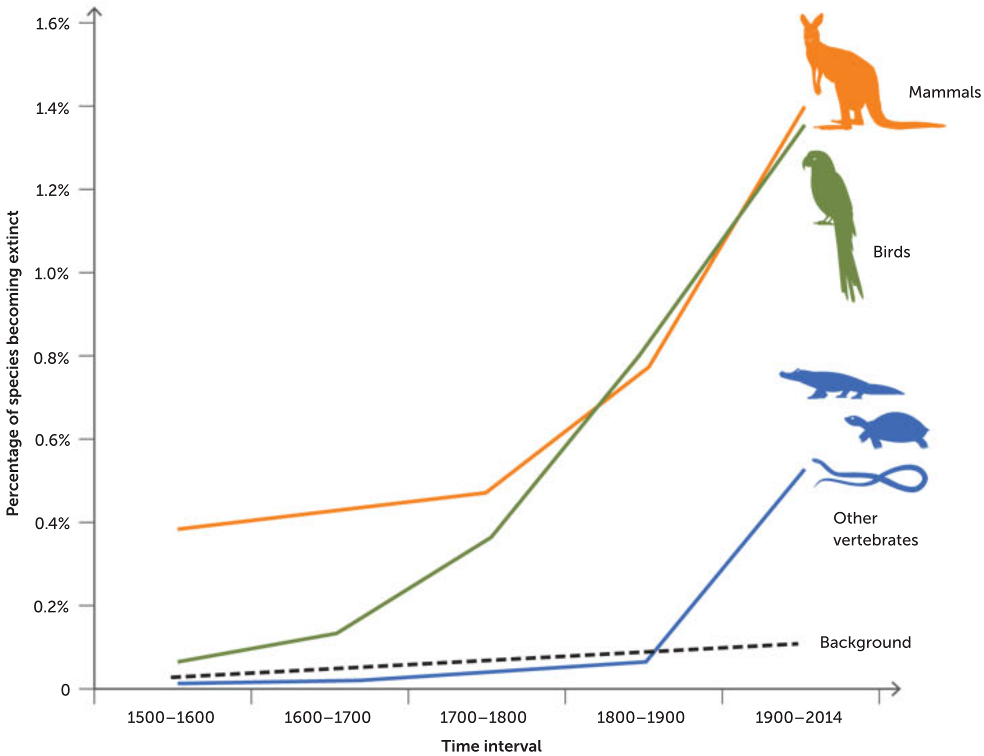

FIGURE 7.31 Vertebrate extinction rates since 1500. The background line shows the amount of extinction expected without human influence.

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Climate change in WA wetlands

Climate change is making large areas of WA hotter and drier. Many species and ecosystems are enduring abiotic conditions that are changing faster than they are able to adapt, increasing their risk of becoming endangered or extinct.

Wetland ecosystems such as those in Perth are some of the most vulnerable to climate change, because higher temperatures and decreased rainfall cannot be tolerated by many wetland species. Wetlands are important because they can help reduce both the level of greenhouse gas emissions and the adverse effects of global warming. Some wetlands hold large stores of carbon; they are carbon sinks. Protecting them from damage and destruction can prevent the release of a significant store of greenhouse gases into the atmosphere.

There is other evidence that WA animals are being affected by climate change. Birds such as the red-tailed tropicbird are expanding their range by flying further south because of changes in ocean temperatures and climate. Some migratory birds are arriving at feeding sites earlier in the season compared to a decade ago.

TABLE 7.4 The major ways that humans are causing extinctions

CAUSE	EFFECT
Climate change	Alters habitat (availability of food and water, presence of other species)
Hunting and fishing	Makes removal rate of individuals from a population faster than the replenishing rate
Introduced species	Increases competition for resources with and predation on native species
Agriculture	Alters habitats and pollutes environment
Pollution	Alters the chance of survival and reproduction of species
Large human populations	Intensifies all other factors

TABLE 7.5 A summary of conservation issues associated with human activities. Note that each issue may have multiple solutions, which may be classified differently.

HUMAN ACTIVITY (BROAD CONSERVATION ISSUE)	SPECIFIC EXAMPLES AND DESCRIPTIONS	CONSERVATION STRATEGIES AND SOLUTIONS
Habitat destruction: urbanisation, agriculture or landfill	Clear-felling for timber mills (to make paper towel, flooring, decking, etc) Habitat loss for endangered animals such as Carnaby's black cockatoo	Environmental: Bush Heritage buys and manages protected land Management: Perth Zoo and Kaarakin Black Cockatoo Conservation Centre rescue, rehabilitate and release cockatoos
Habitat fragmentation	Sections of a large area are split into smaller, isolated regions, creating subpopulations with smaller gene pools that can't interbreed and can't share genetic biodiversity	Genetic: Seed banks are used for storage of seeds, for insurance against extinction and to conserve the gene pool in crop and other species Management, environmental: Protection, revegetation and bush corridors; e.g. Gondwana Link
Habitat degradation	Dryland salinity: Salts normally found deep below the surface of soil are transported to the surface by a rising watertable, often caused by the removal of deep-rooted, perennial (long-lived), usually native, vegetation	Environmental: Plant rows of short-rooted crops alternating with rows of deep-rooted trees to keep the watertable deep Management: Siphoning, draining or pumping of a rising watertable to lower it back down

HUMAN ACTIVITY (BROAD CONSERVATION ISSUE)	SPECIFIC EXAMPLES AND DESCRIPTIONS	CONSERVATION STRATEGIES AND SOLUTIONS
Introduction of invasive species	Introduced or invasive species such as feral cats and foxes have no natural predators, parasites or pathogens to limit their growth; Paterson's curse is a toxic weed found on millions of hectares in WA. Queensland fruit fly was detected in Perth in March 2020. If it spreads to agricultural areas, WA could lose access to international markets	Management: Australian wildlife traders must comply with the *Environment Protection and Biodiversity Conservation Act 1999*; other measures include culling and chemical control; e.g. baiting of foxes Genetic: Breeding programs such as the Perth Zoo numbat breeding program Management: Biological control; e.g. insect species including the root weevil, crown weevil, flea beetle and pollen beetle have been used to control (not eradicate) Paterson's curse Management: To control Queensland fruit fly, methods include surveillance, quarantine, baiting and release of sterile male fruit flies.
Unsustainable use of natural resources	Unsustainable use includes overharvesting of commercial fish, bycatch and bottom trawling (which destroys marine ecosystems) Whales have been hunted to the brink of extinction	Management: Using less destructive fishing methods and managing vulnerable areas are two measures that can help to protect lower ocean ecosystems. Recreational fishers must have fishing licences and comply with fishing seasons. Some species are protected under the *Fish Resources Management Act 1994* Whale hunting is banned in Australian waters
Impact of pollutants	Plastics: Large amounts of the world's plastic rubbish end up in waterways. Many aquatic animals are harmed when they ingest or become entangled in plastic	Management: Recycle waste; dispose of rubbish appropriately
Biomagnification	Successively higher concentrations of a non-biodegradable substance (e.g. DDT) can be found in the tissue of organisms as you move up the trophic levels of a food chain	Management: The Australian Government banned the use of DDT in 1987
Eutrophication	Process that occurs when excess nutrients, particularly nitrogen and phosphorus, enter a body of water and become highly concentrated, leading to excess growth of organisms such as algae	Environmental: Prevent run-off from entering waterways; redirect run-off; plant vegetation alongside water bodies to act as a barrier, absorbing some of the fertiliser nutrients in run-off
Climate change	Combustion of fossil fuels increases greenhouse gas concentration in the atmosphere, leading to the enhanced greenhouse effect. Deforestation is the permanent removal of standing forests (e.g. in the WA clear-fell industry), and can lead to significant levels of carbon dioxide emissions	Environmental: Use cleaner energy sources such as wind turbines to create electricity (e.g. Coral Bay Wind-Diesel System) Management: Bush heritage buys and manages land for conservation Management: Government quota on amount and rate of land clearing
Agriculture	Agriculture causes greenhouse gas emissions: methane and nitrous oxide (14% of WA's greenhouse gas emissions)	Environmental: Carbon farming practices such as changing tillage practices (how soil is treated prior to planting) reduce carbon emissions by increasing organic carbon in soil Environmental: Revegetation and reforestation Environmental: Savanna fire management

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Question set 7.6

REMEMBERING

1 Define the term 'fossil fuel'.

UNDERSTANDING

2 Compare and contrast the terms 'weather' and 'climate'.
3 Explain why ecosystems change when the climate changes.
4 Describe the difference between global warming and climate change.

ANALYSING

5 Describe the change in the trend (the last couple of hundred years compared to the last few thousand years) of carbon dioxide concentration in the atmosphere by analysing the graphs in this chapter.
6 Draw an annotated diagram to represent the greenhouse effect.
7 Explain the difference between the greenhouse effect and the enhanced greenhouse effect, and why we need the former but not the latter.

7.7 INTERNATIONAL COLLABORATION ON BIODIVERSITY

World Heritage List
Sites of unique cultural, natural and mixed importance are shown on an interactive map.

International efforts to protect biodiversity are emerging at an increasing rate. Organisations from different regions and nations are collaborating on conservation projects and agreeing on strategies and standards of protection and prevention. Biodiversity, in terms of genetic variation, species diversity and ecosystem diversity, is still flourishing in many parts of the world. We can all contribute in our own way to the protection of biodiversity and prevention of further loss.

TABLE 7.6 Some international biodiversity projects

TYPE OF PROJECT	DESCRIPTION	EXAMPLES	FURTHER INFORMATION
World Heritage sites	The United Nations Educational, Scientific and Cultural Organization (UNESCO) globally supports the identification, protection and preservation of cultural and natural heritage that is of outstanding value to humanity.	Ningaloo Coast, Great Barrier Reef	Sites are nominated then listed, and site managers and local authorities work to manage, monitor and preserve these World Heritage sites.
Biodiversity hotspots	This program targets regions that are rich in unique biodiversity (with at least 1500 endemic vascular plant species) and at high risk of destruction (with 30% or less of its original natural vegetation). There are 36 hotspots around the world in need of conservation. Hotspot listing means funding can be acquired for the protection of the region and for scientific support.	South-west WA	The Southwest Australia ecoregion is one example.
Protection of international migration routes and areas used for breeding; e.g. the Conservation Management Plan for the blue whale	Projects are undertaken to protect migrating species, such as whales. Several whale species migrate north from the Southern Ocean into the warm tropical waters off northern Australia to breed during the winter months. Whale sharks follow a migration route along the northern WA coastline to the waters of neighbouring countries, thousands of kilometres away. The greatest threat to whale sharks is a 'ship strike'. Conservation strategies include minimising offshore developments and limiting large vessels in areas of whale shark migration and breeding sites, such as Ningaloo Reef, Christmas Island and the Coral Sea.	Birds, whales, turtles, whale sharks	Ningaloo Coast has two major breeding sites where turtles come ashore between December and March to lay their eggs: Dirk Hartog Island in the Ningaloo Coast (Shark Bay) World Heritage Area, and the Muiron Islands in Ningaloo Marine Park. It is estimated there are up to 6000 sea turtles living in Shark Bay.

When an ecological area is identified for classification as a conservation area, many factors are considered, such as commercial and recreational uses of the area, as well as Indigenous Peoples' usage rights. Before Ningaloo Reef was given the status of a World Heritage site by UNESCO in 2011, all of these factors were considered. There was consultation, communication and collaboration between local owner/operators and Indigenous stakeholders. Ningaloo Reef already had high protection measures from the Australian, state and local governments, giving UNESCO confidence that the management plan to conserve or improve the biodiversity in the area could be effective. For example, commercial users of the marine area are bound by certain criteria when they take tourists on a 'swim with the humpback whale' tour. Tour guides keep their vessels outside a 'no approach zone' of 50 m either side of the migration path. Negotiation of native title claims and pastoral leases were prioritised. Tourists who enjoy recreational fishing are permitted to fish only in the designated recreational zones.

Australia's Biodiversity Conservation Strategy 2010–2030
Conservation is everyone's responsibility. Read pages 22–9 to reinforce what you have learnt about habitat loss, invasive species, unsustainable use of natural resources, fire regimes and climate change.

FIGURE 7.32 Ningaloo Coast World Heritage site: **a** Exmouth; **b** Coral Bay

Numbat captive-breeding program at Perth Zoo

CASE STUDY

Numbats (*Myrmecobius fasciatus*) once ranged across the southern third of the Australian continent west of the Great Dividing Range. Intensive agriculture and the associated fragmentation of habitat, pastoralism, altered fire regimes (which affect habitat quality and the availability of termites), and the introduction of foxes and feral cats have all contributed to the decline of numbats. Our drying climate influences the frequency and severity of fires and also reduces the availability of termites in the wild. Numbats are now restricted to two small wild populations in south-west WA, at Dryandra Woodland and the Tone-Perup Nature Reserve. The species is listed as endangered and there may be as few as 1000 numbats left in the wild.

Perth Zoo has been involved in the captive breeding for release of numbats since 1992. During that time, 268 captive-bred numbats have been released into the wild at nine locations in two states, resulting in the establishment of four new self-sustaining populations: three in Western Australia and one in New South Wales. Some releases have

Photo credit: Professor Peter Mawson, Perth Zoo

FIGURE 7.33 Alex the numbat

been to unfenced habitat, where baits have been laid for foxes and cats, while other releases have been to fenced predator-proof enclosures. The breeding colony at the zoo is supported with the regular introduction of wild-born numbats to maintain the genetic integrity of the breeding program.

Captive numbats are fed a diet of fresh or frozen termites (~30% of daily food intake) and an artificial diet developed specially for numbats. Captive-bred numbats are released at 6 weeks of age, with females commencing breeding 2–4 weeks after release, but males not breeding until they are aged 2 years. Numbats produce a maximum of four young each year and have a reproductive life of 2–4 years in the wild, and longevity of a similar duration.

The numbat **captive-breed-for-release** program is designed to provide additional animals for release into the wild to establish new populations or to augment existing ones. Numbat populations in the wild are seldom large enough to sustain the capture and relocation of animals in a wild-to-wild **translocation** (transport and release of animals in another location). Captive breeding provides the numbers of animals required without adversely affecting wild populations. It also allows animals of known age with known genetics to be used in translocations.

Dr Peter Mawson, Science Program Leader, Perth Zoo, Department of Biodiversity, Conservation and Attractions

Questions

1 Describe the change in distribution of numbats in Australia over time.
2 Identify the major factors that have caused the decline in population numbers and habitats.
3 State the definition and purpose of a breeding program.


Photo credit: Professor Peter Malston, Perth Zoo

FIGURE 7.34 Numbat keeper at Perth Zoo

CHAPTER 7 SUMMARY

- Human activities affect biodiversity and can cause rapid change in ecosystems.
- Urban ecosystems are dominated by humans and biodiversity is low.
- Urbanisation causes major changes to ecosystems very rapidly and for a very long time.
- Clearing of land for agriculture and urbanisation causes habitat destruction and fragmentation.
- Clearing of native vegetation reduces biodiversity and can lead to habitat fragmentation.
- Land and soil degradation encourages shallow-rooted plants at the expense of deep-rooted plants including trees, and this increases the risk of topsoil being blown or washed away.
- Dryland salinity can be caused by a combination of land clearing and irrigation practices. It can reduce biodiversity and devastate ecosystems because the abiotic changes it causes lead to damaging biotic changes.
- Humans have changed the distribution of water for their own use, changing ecosystems in the process; changes to water quality and quantity have resulted.
- Widespread use of fertilisers, and the run-off of water enriched with these fertilisers, causes algal blooms and eutrophication.
- The regulation of various species' populations may involve human interference using methods such as culling and pest control through either chemical or biological means.
- Unsustainable harvesting of natural resources, such as by commercial fishing, has reduced the populations of many species, some almost to extinction.
- Biomagnification is the sequence of processes in an ecosystem by which higher concentrations of non-biodegradable chemicals accumulate in the tissues of organisms higher up the trophic levels.
- Global warming is happening because of human-generated increases in atmospheric greenhouse gases. As a result, climate is changing more rapidly than in previous cycles of change.
- Conservation strategies are categorised as genetic, environmental or management strategies. These strategies include seed banks such as the one at Kings Park, captive breeding programs such as Kaarakin, biological control programs such as weevils for Paterson's curse, Gondwanaland revegetation program and recreational fishing licences.
- International agreements about biodiversity help to protect local environments. For example, Ningaloo Reef is a World Heritage site; the south-west of WA is a global biodiversity hotspot; and migration routes such as that of the whale sharks along the WA coast are protected and managed.

WS

Chapter 7 Activity sheet

CHAPTER 7 GLOSSARY

Algal bloom a rapid increase in the population of algae or other micro-organisms (such as cyanobacteria), at the surface of a water body, that blocks sunlight from entering

Anoxic completely devoid of oxygen

Biological control a method of pest control in which another species is introduced that can control the population of the pest species

Biomagnification the sequence of processes in an ecosystem by which higher concentrations of a particular non-biodegradable chemical accumulate in the tissues of organisms higher up the trophic levels

Bottom trawling a destructive method of fishing which involves dragging a large net across the seafloor

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Bush corridors the strips of regenerated land between isolated habitats that reconnect subpopulations, returning habitat to populations and enabling subpopulations to interbreed

By-catch the unwanted fish and other marine creatures trapped by commercial fishing nets during fishing

Captive-breed-for-release describes a program designed to provide additional animals for release into the wild to establish new populations or to augment existing ones

Chemical control a chemical, such as a pesticide or poison, that is used to control the population of a pest or invasive species

Climate the average, long-term, predictable atmospheric weather conditions at a site over a period of many years, ranging from months to many thousands of years; made up of such variables as rainfall (precipitation), temperature, intensity of sunlight, and wind

Climate change a significant change in the global climate that can be identified by changes in the average and the variability of such features as temperature and precipitation, and that lasts for a long time, typically decades or longer

Culling a conservation management strategy involving the killing and removal of individuals in a population in order to reduce the negative impact the animal is having on an ecosystem

Deforestation the permanent removal of standing forests

Enhanced greenhouse effect the intensified version of the natural greenhouse effect; caused by increased concentrations of greenhouse gases in the atmosphere, resulting from human activities such as fossil fuel combustion and agricultural practices (which release gases) and deforestation (which reduces carbon storage)

Eutrophication the process that occurs when excess nutrients, particularly nitrogen and phosphorus, enter a body of water and become highly concentrated, leading to excess growth of organisms such as algae

Exotic not indigenous; non-native

Fossil fuels natural energy sources, such as coal, oil and natural gas, containing hydrocarbons; formed from fossilised living things, usually in sedimentary rock, over millions of years; they produce carbon dioxide when burned

Fragmentation the separation of some parts of the habitat of an ecosystem into isolated sections; can be a result of habitat destruction for land clearing for agriculture, roads or urbanisation; results in isolated groups of organisms that were once part of a larger population

Global warming the steady rise in global average temperature in recent decades, which experts believe is largely caused by human-generated greenhouse gas emissions

Greenhouse effect the insulating effect of greenhouse gases in the atmosphere, which prevent some of the solar radiation from escaping Earth's atmosphere; the gases trap and absorb some of the heat originating from the Sun, which keeps Earth warm

Greenhouse gases the gases that trap heat from the Sun and keep Earth's surface warm; they include carbon dioxide, nitrous oxide, water and methane, and industrial chemicals such as perfluorocarbons, hydrofluorocarbons and sulfur hexafluoride

Habitats the environments in which a species normally lives

Habitat destruction the total degradation of a habitat, a human activity that greatly impacts ecosystems

Human activities the actions of humans that alter trophic structures, energy flow, cycling of matter and biodiversity; they are also described as the 'human impact on the environment'

Hypoxic low in oxygen

Introduced species the species that humans have intentionally or unintentionally moved from their native location to a new ecological region; also known as exotic species

Invasive species introduced species that are able to establish populations in new areas

Non-renewable describes a resource with a long replacement time (usually longer than a human lifetime), which we use faster than it can be replaced; the rate of use/death is higher than the replenishing /reproductive rate; once it is used, it will take thousands or millions of years to replenish

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Overharvesting harvesting a species at a rate that exceeds the rate at which the population can replenish itself

Salination the process of increasing the salt concentration (e.g. in soil)

Seed bank a collection of plant seeds that have been carefully prepared for long-term storage

Translocation the transport and release of animals in another location

Unsustainable use the overuse or overharvesting of natural resources, including species, at rates that exceed the replenishment rate of the population or resource

Urbanisation the extreme modification of an ecosystem by humans to support a human population of gradually higher density

Weather the atmospheric conditions in an area over a short time, usually 2–3 days

CHAPTER 7 REVIEW QUESTIONS

Remembering

1 Define ‘deforestation’.
2 Name an invasive species in Australia and describe the impact it has had on the ecosystem it entered.
3 There are only 36 regions in the world that qualify as international biodiversity hotspots. State the criteria for gaining this protection.
4 Describe three ways you could reduce your use of fossil fuels.
5 Some scientists are concerned that if we do not reduce our carbon emissions now, the impact will be irreversible. Describe what changes may be ‘irreversible’.
6 State UNESCO’s purpose for establishing World Heritage sites.
7 Describe the role of greenhouse gases in the greenhouse effect.
8 Explain the effect of deforestation on the level of greenhouse gases in the atmosphere.

Applying

9 A population of producers contained 0.3 ppm of a non-biodegradable substance. They were consumed by primary consumers, who were consumed by secondary consumers in a food chain. Calculate the concentration of the non-biodegradable substance present in the third trophic level (secondary consumers) if the concentration multiplied by 9.5 at each trophic level.
10 Explain how an algal bloom in a water body can lead to the death of an ecosystem.
11 ‘Short-term pain for long-term gain’: apply this principle to companies considering changing from fossil fuels to alternative energy sources.

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12 Figure 7.35 shows some of the interaction conditions for boats providing whale-spotting tours. How do each of these conditions protect whales?

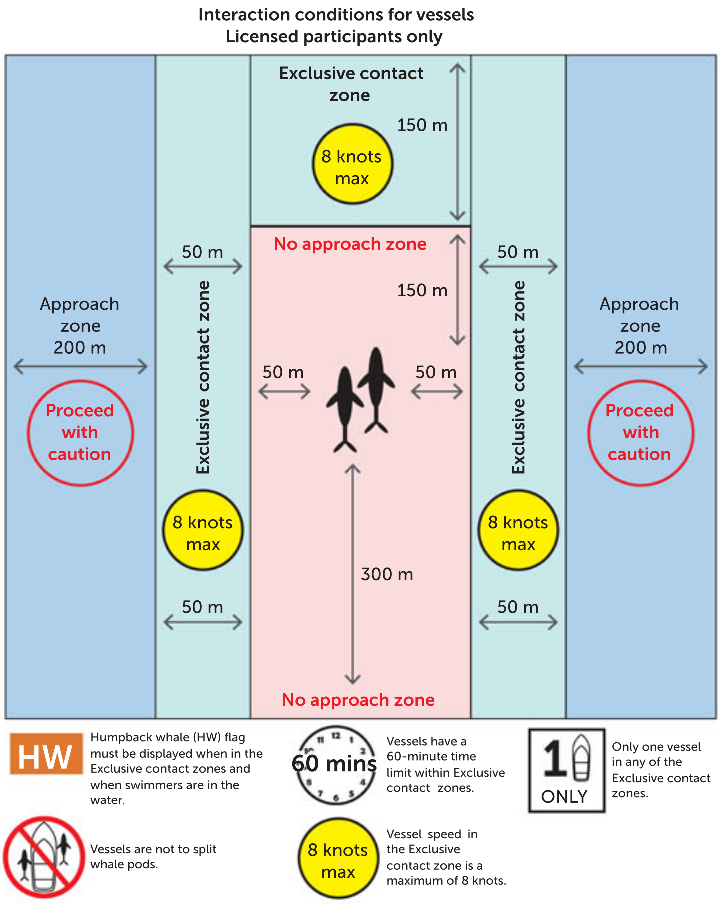

FIGURE 7.35 Conditions for whale-watching tour boats

Creating

13 Copy and complete Table 7.7 and give an example of each type of change. Make a comparative note about the scope and duration of each change.

TABLE 7.7 A summary of types of change to ecosystems

CHANGE	EXAMPLE	DURATION	MAGNITUDE	SPEED
Flood				
Fire				
Urbanisation				

Evaluating

14 A brown moth, so small it is barely visible and with a preference for chardonnay, threatened to become the Victorian wine industry's greatest scourge. The light brown apple moth caterpillar is capable of devouring up to 10 shoots out of every 100 throughout the growing season. Winemakers in the past resorted to chemical spraying, but they now rely on the native *Trichogramma* wasp. The wasps lay their own eggs inside the moth eggs and, as they hatch, the wasp larvae eat the moth caterpillars.

a What are the advantages and disadvantages of chemical spraying?

b What kind of relationship is being made use of to control the moths? Identify the partners.
c Draw a simple graph to show what happens to the population of apple moths and the population of *Trichogramma* wasps over time. Label your graph carefully.

Reflecting

15 Increases in human populations have placed pressure on resources. Identify three resources you consider are essential for human survival and suggest strategies for managing their sustainability.

16 Investigate and describe an example of habitat destruction that has affected species in your local or regional area.

17 Reflect on how the knowledge and skills you have gained by studying this unit of biology have increased your awareness of the costs of decreasing biodiversity. Refer to the local examples you investigated.

PRACTICE EXAM QUESTIONS

1 In pre-industrial times, the concentration of carbon dioxide in the atmosphere was 280 parts per million (ppm). In 2010 it was 395 ppm. What has been the percentage increase in carbon dioxide in the atmosphere over that time?
A 41%
B 71%
C 141%
D 35%

2 Which of the following strategies would a conservation scientist be likely to use to re-join fragmented bushland in a local area?
A build fencing to prevent animal species from migrating
B plant native trees next to invasive weed species
C conduct surveys of the area's vegetation using capture–recapture
D collaborate with farmers, local Indigenous landowners, other landowners and local government to gain permission and support for the project

3 Grass weeds, such as the invasive species Coolatai grass, occur in many areas of WA.
a Define 'invasive species'. (2 marks)
b Coolatai grass is controlled by chemical herbicides and by physically grubbing it out (pulling out the whole plant including roots). Explain why it is too risky to use a biological control. (3 marks)

4 Algal blooms in the Swan-Canning Estuary look like a layer of scum and are a nuisance. Describe the general cause of these blooms. (4 marks)

5 Define 'dryland salinity', and describe its cause and the effect it has on agricultural land. (10 marks)

6 Copy and complete Table 7.8 by providing a reasonable conservation strategy for each conservation issue. Note that each issue may have multiple solutions, and solutions may belong to more than one category of conservation strategy. (8 marks)

TABLE 7.8 Some conservation issues and solutions

CONSERVATION ISSUE	SOLUTION	CLASSIFICATION OF CONSERVATION STRATEGY
Dryland salinity		
Habitat fragmentation		
Biomagnification		
Invasive species		

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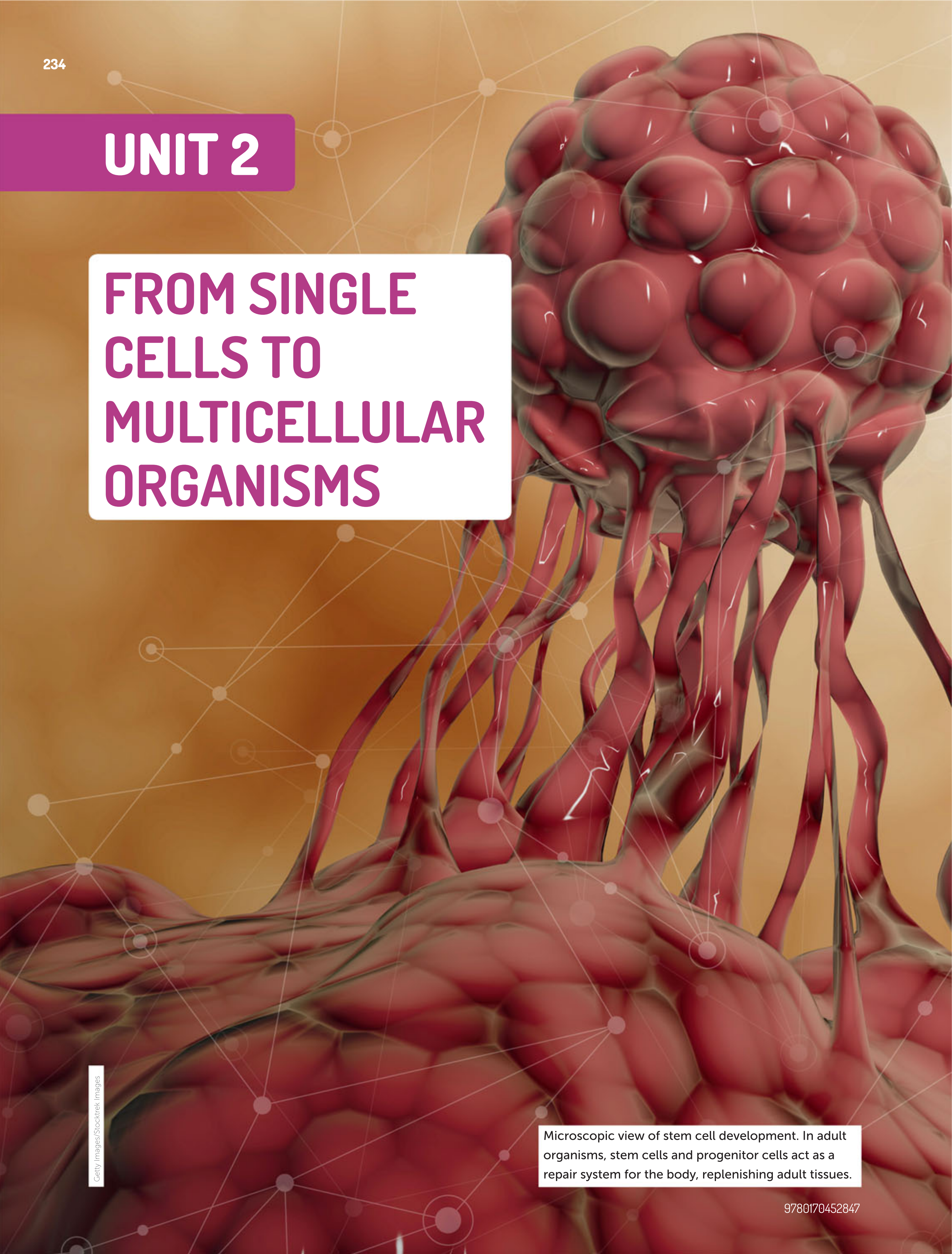
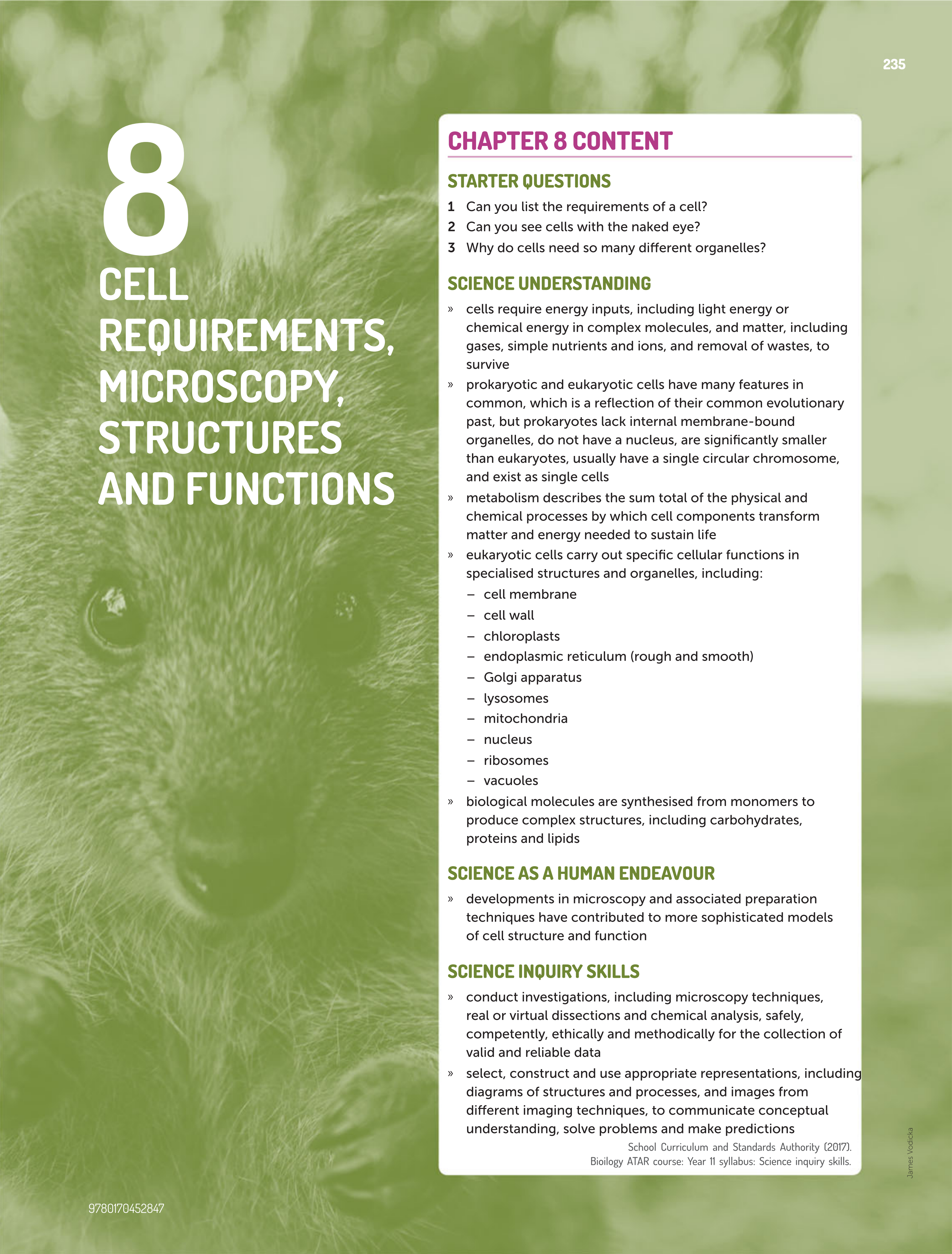
UNIT 2

FROM SINGLE CELLS TO MULTICELLULAR ORGANISMS



Getty Images/Stocktrek Images

Microscopic view of stem cell development. In adult organisms, stem cells and progenitor cells act as a repair system for the body, replenishing adult tissues.


James Vodicka

8 CELL REQUIREMENTS, MICROSCOPY, STRUCTURES AND FUNCTIONS

CHAPTER 8 CONTENT

STARTER QUESTIONS

1 Can you list the requirements of a cell?
2 Can you see cells with the naked eye?
3 Why do cells need so many different organelles?

SCIENCE UNDERSTANDING

» cells require energy inputs, including light energy or chemical energy in complex molecules, and matter, including gases, simple nutrients and ions, and removal of wastes, to survive
» prokaryotic and eukaryotic cells have many features in common, which is a reflection of their common evolutionary past, but prokaryotes lack internal membrane-bound organelles, do not have a nucleus, are significantly smaller than eukaryotes, usually have a single circular chromosome, and exist as single cells
» metabolism describes the sum total of the physical and chemical processes by which cell components transform matter and energy needed to sustain life
» eukaryotic cells carry out specific cellular functions in specialised structures and organelles, including:
  – cell membrane
  – cell wall
  – chloroplasts
  – endoplasmic reticulum (rough and smooth)
  – Golgi apparatus
  – lysosomes
  – mitochondria
  – nucleus
  – ribosomes
  – vacuoles
» biological molecules are synthesised from monomers to produce complex structures, including carbohydrates, proteins and lipids

SCIENCE AS A HUMAN ENDEAVOUR

» developments in microscopy and associated preparation techniques have contributed to more sophisticated models of cell structure and function

SCIENCE INQUIRY SKILLS

» conduct investigations, including microscopy techniques, real or virtual dissections and chemical analysis, safely, competently, ethically and methodically for the collection of valid and reliable data
» select, construct and use appropriate representations, including diagrams of structures and processes, and images from different imaging techniques, to communicate conceptual understanding, solve problems and make predictions

School Curriculum and Standards Authority (2017). Bioilogy ATAR course: Year 11 syllabus: Science inquiry skills.

8.1 CELLS AND THEIR REQUIREMENTS

The millions of species living on Earth are extremely diverse but they all share some characteristics to be defined as living. They are all made up of one or more **cells**. Furthermore, for cells to function, they require energy, in the form of either light energy or the chemical energy in complex molecules; matter, including gases (such as oxygen and carbon dioxide), simple nutrients and **ions**; the ability to respond to stimuli; and the removal of wastes.

FIGURE 8.1 The organisms on Earth can look very different, but they are all made up of cells: **a** water flea; **b** octopus; **c** palm tree.

An organism's cells either capture light energy from sunlight (photosynthesis) or use chemical energy they gain from food to produce a usable form of energy during a process called **cellular respiration** (often just called respiration). Respiration is the conversion of energy from carbohydrates and fats into a form of energy that cells can use. Energy is required for the metabolic activities of all cells. One small group of bacteria is able to create sugars (organic molecules) from inorganic compounds without sunlight. This process is known as **chemosynthesis** and the organic matter synthesised provides energy for respiration. These bacteria are found where there is no sunlight, such as in nitrogen-fixing bacteria in the soil and chemotrophs in the deep-sea ocean trenches.

Metabolism is the term used when referring to all of the chemical reactions that take place inside a cell or organism; the total sum of the reactions. Cellular processes such as building and breaking down of complex molecules occur through chemical reactions. Some of these chemical reactions release energy, whereas others absorb energy. Both types require energy to proceed. Some groups of organisms use metabolic processes to maintain constant internal conditions (such as temperature) within a narrow range.

Living things, whether they are autotrophs or heterotrophs, require nutrients. **Autotrophs** use photosynthesis or chemosynthesis to create the nutrients they require. **Heterotrophs** consume autotrophs or other heterotrophs to gain their nutrients. Nutrients can be gained via eating or absorption (through the roots in the case of plants).

Key concept

Metabolism is all of the chemical reactions that take place inside a cell or organism: the total sum of the reactions. Cellular processes such as building and breaking down complex molecules occur through chemical reactions.

Once inside an organism, nutrients can be assimilated. **Assimilation** is the process through which an organism incorporates nutrients from outside its body into more complex molecules needed in its fluid or solid parts. **Absorption** is the transport of the nutrients into the organism and assimilation is the conversion of the nutrient into part of the organism.

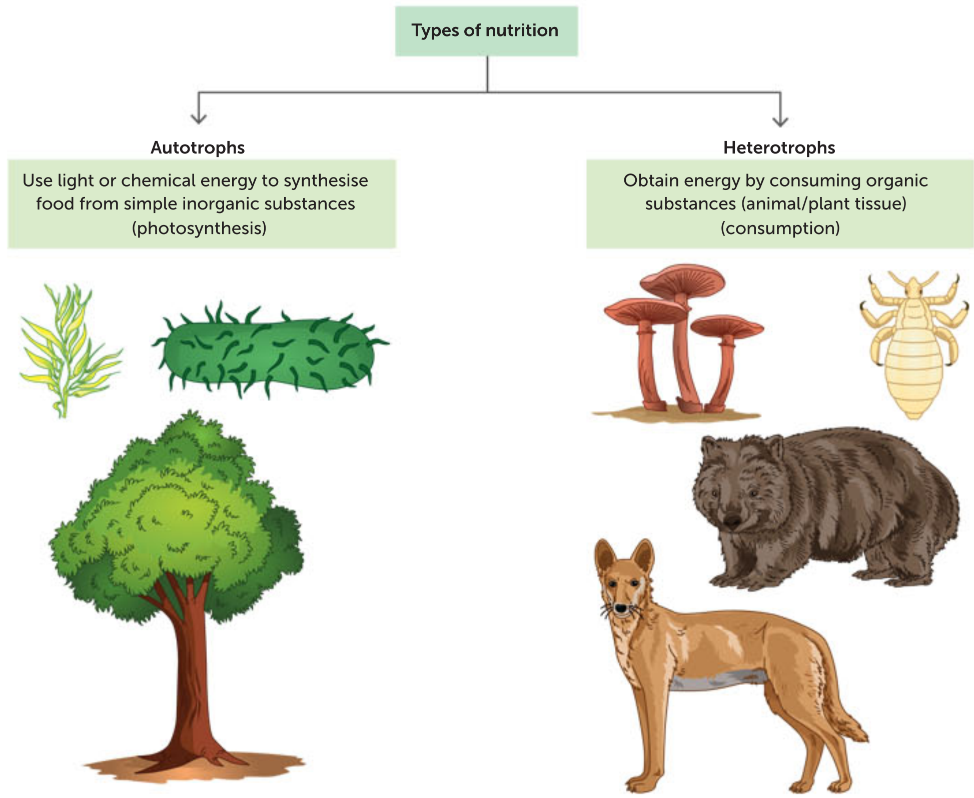


FIGURE 8.2 Autotrophs (e.g. bacteria, algae and plants) and heterotrophs (e.g. fungi and animals) acquire energy and nutrients differently.

Growth involves an offspring developing into an adult member of the species. Single-celled organisms, called **unicellular** organisms, reproduce by first duplicating their genetic material, DNA, and then dividing it equally before the cell splits to form two new identical daughter cells. This is known as asexual reproduction. Organisms that reproduce sexually produce specialised reproductive male and female cells that can fuse with like cells from another member of the species to form new individuals. Multicellular organisms may reproduce sexually, asexually or by both methods.

Many organisms possess specialised cells that are sensitive to environmental stimuli. Organisms detect changes in the environment such as light, temperature, water, gravity and chemical substances. Worms, for example, contain light-receptor cells that detect changes in light intensity and move away from brighter light. Plants respond to water availability by growing roots towards a water source.

All organisms must get rid of waste products. Metabolic processes produce potentially toxic wastes that need removal for cells to remain healthy. Carbon dioxide and nitrogenous wastes such as urea (a substance excreted in urine) are removed from cells and organisms in a variety of ways, such as by exhalation and excretion.

In addition to the above features, living things also contain non-cellular features; for example, the slime on the back of a frog, the exoskeletons of insects, the bark of trees, the skin of grapes and the fingernails of your hands.

TABLE 8.1 Major forms of energy and matter that enter or exit cells

ENERGY	MATTER
• Light energy from the Sun and/or • Chemical energy stored in complex molecules	• Gases such as O_2 and CO_2 • Simple nutrients, ions and water • Wastes

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Key concept

Cells require inputs (energy and matter) and produce outputs (wastes), in order to function, reproduce, respond to stimuli and grow.

The discovery of cells and cell theory

Over the past 150 years, we have come to understand that all organisms are made up of cells, the basic structural and functional units of an organism. A cell is considered the basic unit of life because it is an easily recognised package, surrounded by a membrane. This cell membrane (also called the plasma membrane) is a clear boundary between the internal and external environment of the cell.

All cells arise from pre-existing cells. Some organisms consist of single cells (unicellular organisms), while others consist of millions upon millions of cells organised into functional groups of tissues, organs and systems (multicellular organisms).

In 1838, Matthias Schleiden suggested that each cell within a plant developed as an independent unit. He thought that the nucleus probably had something to do with the development of each cell. In 1839, Theodor Schwann used his extensive knowledge of zoology and animal tissues to theorise that 'Animals as well as plants consist of cells and cell products – and even though the cells are part of a whole organism, they have, to some extent, an individual life of their own'.

An introduction to cells
Take a tour through different cell types in this introductory video.

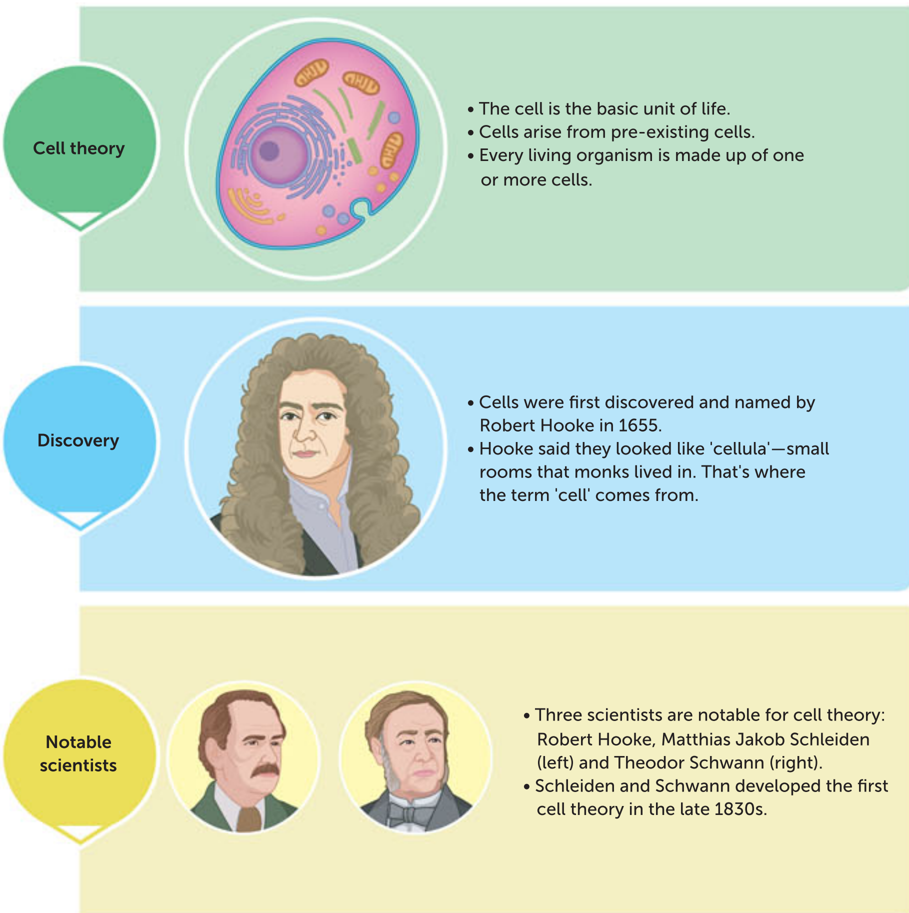


FIGURE 8.3 Cell theory, and the scientists whose discoveries helped to develop it

These observations, along with microscopic examinations of a great variety of different materials, led Schleiden and Schwann to the belief that most organisms are composed of cells. This belief is embodied in cell theory, which was proposed by these two scientists in 1839. Cell theory states that all living things are composed of one or more cells. The cell is the smallest entity that retains the properties of life.

Cell division was observed by several scientists in the mid-19th century, and in 1859, Rudolf Virchow proposed the new idea that all cells come from pre-existing cells.

Key concept

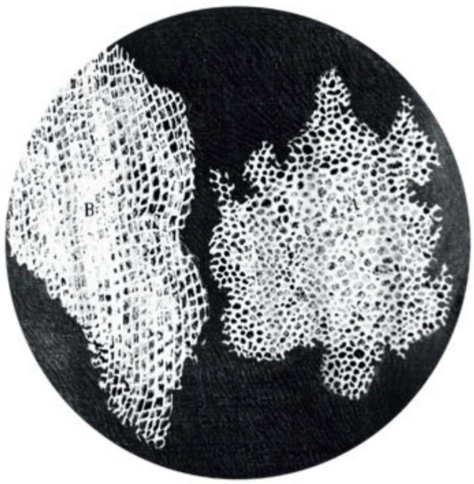
Cell theory states that:
- The cell is the basic unit of life.
- Cells arise from pre-existing cells.
- All living things are composed of cells or cell products.

Microscopy and cell size

We are indebted to the early microscopists for our knowledge of cell structure and function. In the early 1600s, Galileo Galilei improved on the idea of Dutch lens makers by putting together some glass lenses in a cylinder and using this to magnify objects. By the middle of the 17th century, a curator of experiments for the Royal Society of London, Robert Hooke, used a microscope to observe thinly sliced cork from a mature tree. When you look at Figure 8.5 you might be able to see a resemblance to what Hooke described as 'small rooms'. He used the Latin name 'cellula' (small room) for these structures, not realising that they were actually living components of the tree.


Alamy/Artokoloro

FIGURE 8.4 An early compound microscope from Italy



Getty Images/Oxford Science Archive/Print Collector

FIGURE 8.5 Robert Hooke's drawing of cork cells

How small are cells?

Advances in technology over the last decades have enabled scientists to view smaller and smaller objects. Centimetres, millimetres and even micrometres or microns (μm) are often too large to measure the objects we can examine: we are now in the 'nano age'.

1 metre (m) = 10^2 centimetres (cm)
= 10^3 millimetres (mm)
= 10^6 micrometres or microns (μm)
= 10^9 nanometres (nm)

$$1\text{ cm} = \frac{1}{100}\text{ m}$$

$$1\text{ mm} = \frac{1}{1000}\text{ m}$$

$$1\ \mu\text{m} = \frac{1}{1\,000\,000}\text{ m}$$

$$1\text{ nm} = \frac{1}{1\,000\,000\,000}\text{ m}$$

Biodifference
Examine the differences between light microscopes and electron microscopes.

Microscopy equipment and use

Microscopy is the technical field of using microscopes to view samples and objects that cannot be seen with the unaided eye. The type of microscope you use in your school laboratory is a light (or optical) microscope. If you look at material with a simple light microscope, fine structures will not be visible. Light rays from a light source beneath the stage are transmitted through two glass lenses in series: the objective and the ocular (eyepiece) lenses. Depending on their strength, these two lenses together provide magnifications of up to 400 times. The ocular lens usually has 10 times magnification. More sophisticated technology is needed to view the smallest parts of cells.

Light microscopes

Light microscopes can magnify objects effectively to approximately 1000 times the actual size. To increase the contrast between structures in a specimen, various dyes (such as methylene blue) can be used. You may be able to see a nucleus, chloroplast, cytoplasm, cell membrane and cell wall under a light microscope, but most of the **organelles** will not be visible. An advantage of light microscopes is that a specimen can be kept alive while being viewed.

The quality of an image depends on magnification and resolution. **Magnification** is a scaling up of the object's size. It is a measure of the degree of enlargement of the observed object, for example in multiples such as 4×, 10×, 40× and 100×. **Resolution** is the measure of the clarity of the image. It can be described as the minimum distance between two distinguishable but separate points. You can view a diverse range of cells of different sizes under the light microscope but to view a more comprehensive diversity, an electron microscope is needed.

Interactive cell size
Use these interactive websites to compare the range of sizes of different types of cells.

Key concept

Magnification is a measure of the enlargement of an object viewed through a microscope; for example, 4×, 10×, 40× and 100×.

Resolution is the measure of the clarity of an image, described as the minimum distance between two distinguishable but separate points.

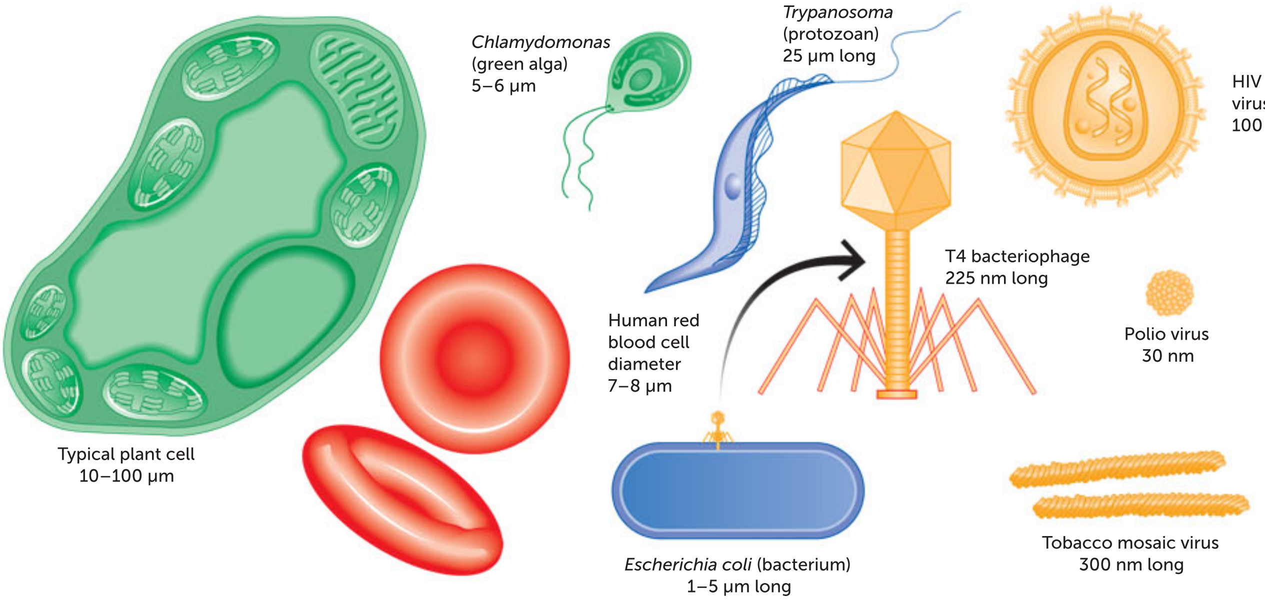


FIGURE 8.6 Some sizes of biological specimens (not drawn to scale)

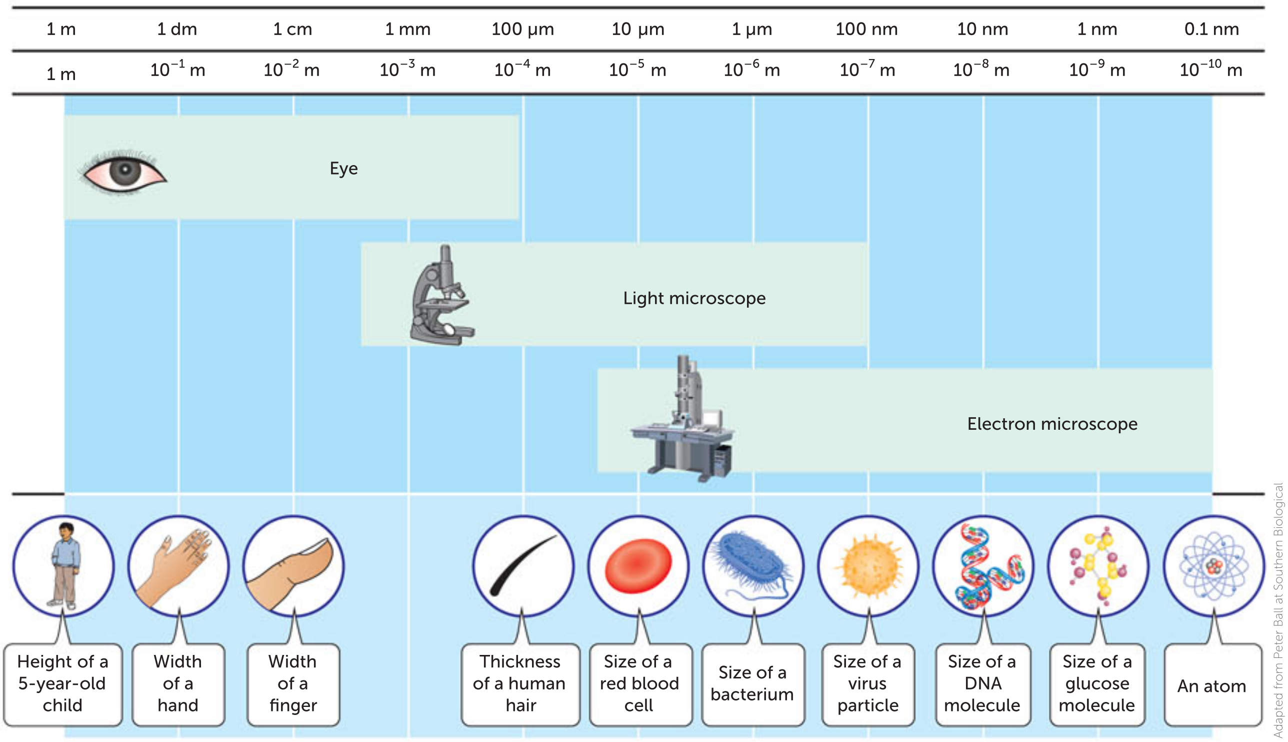


FIGURE 8.7 The resolving power of microscopes compared to what can be seen by the naked eye

Electron microscopes

Since the 1950s, microscopic studies have been revolutionised by the development of the **electron microscope**. This instrument uses an electron beam instead of light, and electromagnets instead of glass lenses. The interactions between the electrons and the object are recorded on a photographic plate, which then forms an image on a screen.

The electron microscope can give clear pictures that are magnified 1 000 000 times or more. A cell with a diameter of 10 μm can be magnified up to a diameter of 5 m. Features as small as one-tenth of a nanometre (one ten-billionth of a metre) can be seen, including individual atoms. Organelles that can be viewed under electron microscope include ribosomes, vacuoles, Golgi bodies, rough endoplasmic reticulum, smooth endoplasmic reticulum, mitochondria, nuclear membranes, nuclear pores and nucleoli.

The electron microscope has had a profound effect on biology. Materials that were formerly believed to have little or no structure have been shown to have an elaborate internal organisation.

The electron microscope shown in Figure 8.8 is called a transmission electron microscope (TEM) because the electrons used to create the image pass through the specimen. In the scanning electron microscope (SEM), solid specimens are bombarded with a beam of electrons, which causes secondary electrons to be emitted from the surface layers of the specimen. The TEM is the most common form of electron microscope and has the best resolution. It can magnify up to 1 500 000 times. The SEM has poorer resolution, but gives excellent three-dimensional images of surfaces. A disadvantage of electron microscopes is that the methods used to prepare the specimen kill the cells being viewed.

FIGURE 8.8 A transmission electron microscope (TEM) used in biological research

Developing cell models

Through a long history of experimentation and observation using increasingly sophisticated technologies, we have come to know much more about the roles of cells in living things and what cells are composed of. We now have a better understanding of how their composition relates to their function, and what they require to function.

Each cell can be thought of as a 'chemical factory', in which production is controlled by information stored within the organism's genetic material, the **nucleic acid** molecule called **DNA (deoxyribonucleic acid)**. Like any factory, the cell has inputs – the variety of raw materials that are processed by specialised **enzymes** or '**protein** machines' – and outputs – the products of such activities. Some of the products are used within the cell, whereas others are packaged and exported for use elsewhere.

The development of sophisticated computer technologies has further advanced our knowledge of cells, and in many cases taken the place of live modelling, due to the speed with which a computer model can test different scenarios compared with relying on natural life cycles. Programs have been

FIGURE 8.9 Bacterial cells take in materials from their environment, such as water and nutrients. They produce wastes and, in some cases, products such as toxins.

designed to model how molecules interact at the cellular level in complex networks of chemical reaction pathways. Computer models can predict how a cell's immediate environment can affect its functioning.

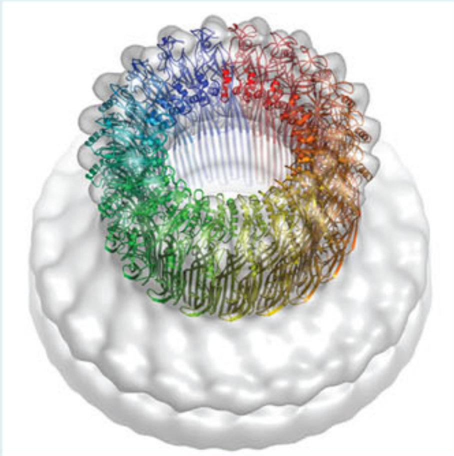
8.1 APPLICATION

Particle accelerators

The uses of particle accelerators, such as synchrotrons, have added to our knowledge of structural biology. Three-dimensional images of **biomacromolecules** (large molecules such as proteins that play a role in the structure and function of cells) are being investigated through this area of particle physics. Findings from these investigations are having an impact on many areas of health and science.

Questions

1 Describe a technique that researchers use to view a biomacromolecule, such as a protein.
2 How is finding the structure of a biomacromolecule helpful to scientists?



Australian Synchrotron (Helen Saibil, Birkbeck College)

FIGURE 8.10 A perforin protein (rainbow colours) is shown attached to a cell wall (white). This image was created using data produced by the Australian Synchrotron.

Question set 8.1

REMEMBERING

1 List five requirements of cells and briefly describe what they are used for.

UNDERSTANDING

2 'Living things are made up of cells and the products of cells.' Explain what this means.
3 Draw a scaled line to show the relative sizes of cells.

EVALUATING

4 Evaluate the advantages and disadvantages of using these two different types of microscopes.
   a light microscope
   b SEM

CALCULATING

5 If the magnification of the ocular lens of your microscope is 10×, calculate the magnification at:
   a low power (magnification of objective lens is 5×)
   b medium power (magnification of objective lens is 10×).

8.2 TYPES OF CELLS

Microscopes have revealed the common anatomical features of all cells, which are:

- The contents of the cell are enclosed in a cell membrane.
- There is a semi-fluid substance inside the cell membrane called the cytosol.
- Cells contain chromosomes, which contain genes.
- All cells have ribosomes, which function to make proteins.

Cells can be classified into two main groups: prokaryotes and eukaryotes. **Prokaryotes** are single-celled organisms (unicellular organisms) that lack internal membrane-bound organelles, do not have a nucleus, are significantly smaller than eukaryotes and usually have a single, circular chromosome. **Eukaryotes** can be unicellular or multicellular organisms. Their cells possess internal membrane-bound organelles, including a nucleus, are relatively larger than prokaryotes and usually have linear chromosomes.

Prokaryotic cells: structures and their functions

The simplest type of cell is a prokaryotic cell. These cells are very small, typically ranging from 1–10 μm (1–10 $\times$ 10^{-6} m) in length and 0.2–2.0 μm in diameter with a simple internal structure. Unlike more complex cells, prokaryotic cells have difficulty performing several different functions at the same time. It is the lack of membrane-bound organelles that limits the versatility of these simple cells.

Prokaryotic cells live as single-celled organisms and are grouped within two major classification domains: the Bacteria and the Archaea (see Chapter 2).

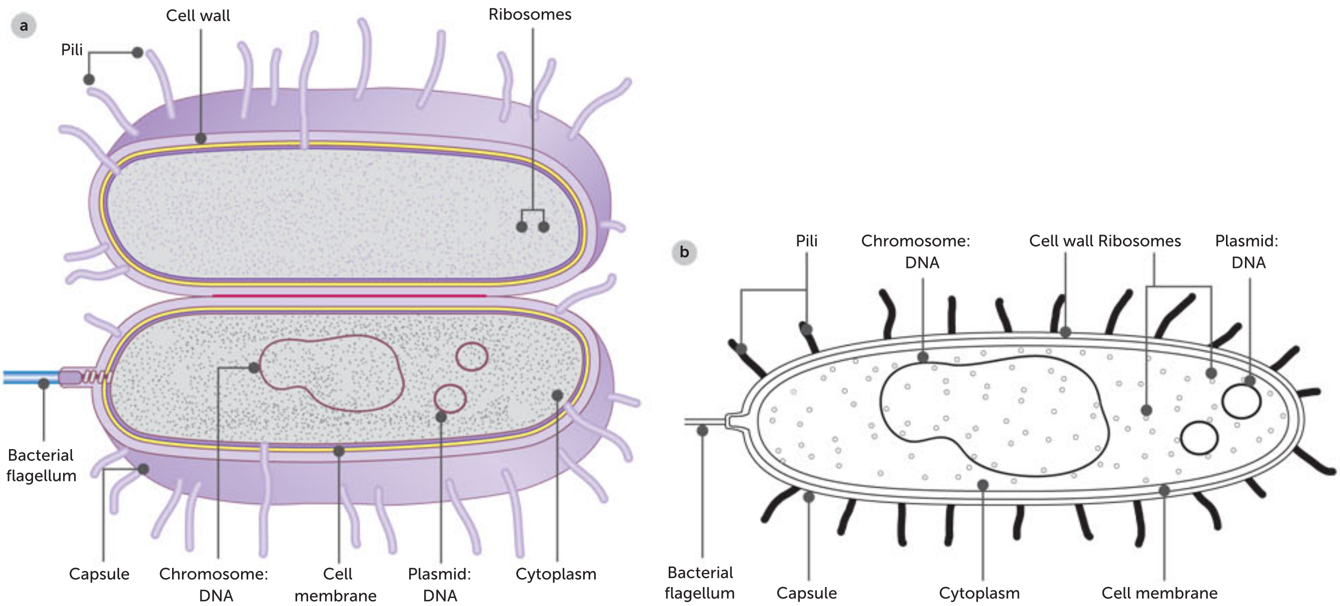


FIGURE 8.11 a A generalised diagram of a prokaryotic cell; **b** a line drawing of the cell

Cytoplasm

If you use a light microscope to observe prokaryotic cells such as bacteria, the granular or 'spotty' substance making up the internal bulk of the cell is visible. This is the **cytoplasm**. The chemical reactions that enable the cell to live are carried out here. The **cytosol** is the semi-fluid part of the cytoplasm. It's often described as the 'soup' of the cell because it contains many dissolved substances. Collectively, the cytoplasm is made up of cytosol together with the other internal structures (e.g. the circular chromosome, plasmids and ribosomes).

Ribosomes

All cells contain **ribosomes**. In prokaryotes, such as bacteria, ribosomes are scattered freely throughout the cytosol. Ribosomes are the only distinguishable organelles in prokaryotic cells. However, they are so small that they are only visible by electron microscope and they are not bound by a membrane.

As all cell types, including prokaryotes (bacteria), contain ribosomes, they are clearly very important for cell functioning. Ribosomes are the site of protein synthesis: this is where **amino acids** are joined together to form proteins. Proteins are needed for cell growth, repair and general cell functioning, so it makes sense that ribosomes are found in even the simplest prokaryotic cell.

Genetic material

The genetic code in DNA differs between different species of bacteria. Most bacteria contain a single, circular chromosome, not visible using a light microscope. It lies in direct contact with the cytoplasm and carries instructions for making the different types of proteins that are synthesised in the ribosomes. Numerous small rings of DNA, called **plasmids**, may also be present in the cytoplasm. These can reproduce independently of the main chromosome.

Cells alive: bacteria cells
Explore the structure of a bacterial cell.

Key concept

Prokaryotes have ribosomes but lack membrane-bound organelles, do not have a nucleus, are significantly smaller than eukaryotes, usually have a single, circular chromosome made of DNA and exist as single cells.

Eukaryotic cells: structures and their functions

Eukaryotic cells are found in the kingdoms Protista, Fungi, Plantae and Animalia. The internal structure of eukaryotes includes various organelles, many of which can be viewed as membrane-bound compartments (Figure 8.12, page 246). A membrane-bound organelle is a structure that has membranes enclosing it, suspended in the cytosol of a eukaryotic cell, and performs a specialist function. Organelles facilitate particular biochemical processes, such as cellular respiration and photosynthesis. By separating different processes into different organelles and maximising the surface area through the folding and stacking of internal membranes, a greater number of chemical reactions can occur at the same time. Organelles also facilitate the synthesis of complex molecules and the entry and exit of substances into and out of the cell. Membrane-bound organelles enable a cell to carry out hundreds of different chemical reactions simultaneously, without the reactions interfering with each other. Organelles may also store substances for use in chemical reactions at a later time.

Nucleus

One of the most prominent organelles in a eukaryotic cell is the nucleus (plural nuclei). This is clearly visible using both light and electron microscopes. The main molecule found within the nucleus is the same nucleic acid that makes up the prokaryotic chromosome – DNA.

Similarly to prokaryotic cells, in eukaryotic cells DNA is bundled into chromosomes that code for the production of proteins. These proteins carry out a variety of activities within the cell. In eukaryotes, chromosomes are not circular but are rod-shaped or linear when visible during cell division. The number of chromosomes within the nucleus is characteristic of the species. For example, humans have 46 chromosomes in each of their body cells, whereas dogs have 78.

The nucleus controls the activities of the cell. By coding for different proteins at different times, the nucleus can coordinate the activities of a cell. The membrane around the cell nucleus keeps the DNA of eukaryotic cells separate from the chemical reactions of the cytoplasm. The membrane also makes it easier for DNA to be copied and organised before cell division.

Bioflix tour of an animal cell
Take a virtual tour of an animal cell.

Bioflix tour of a plant cell
Take a virtual tour of a plant cell.

Eukaryotic cells interactive plant and animal cell models
Explore the structure of a membrane-bound organelle.

Biology: cell structure
View the video twice. The first time, just watch it. The second time, make summary notes.

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Bioman Games and Labs

Play the 'Cell Explorer: The animal cell' game to test your knowledge of animal cells.

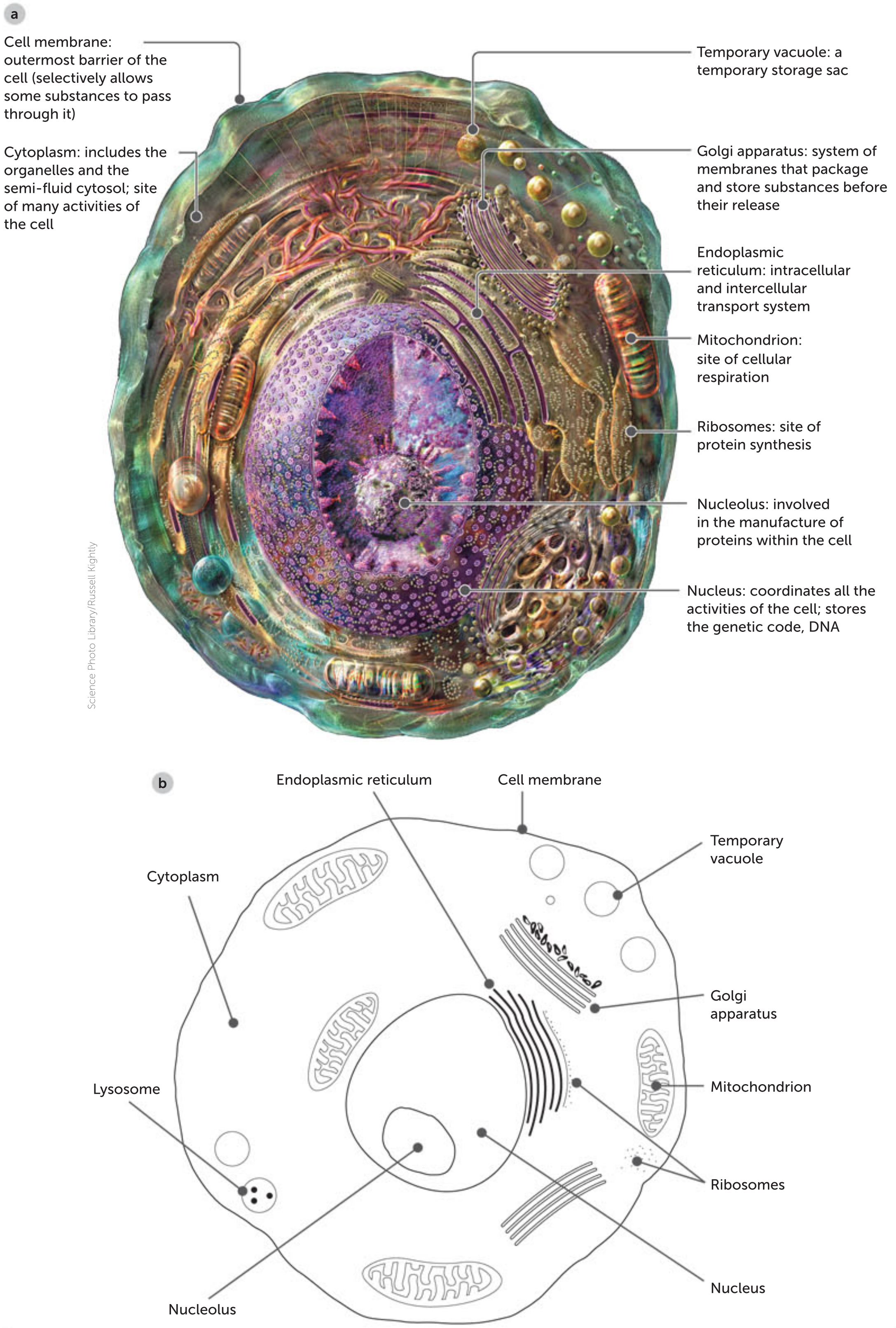

FIGURE 8.12 a A eukaryotic cell from an animal, showing its cell membrane and other organelles; **b** a line drawing of the cell

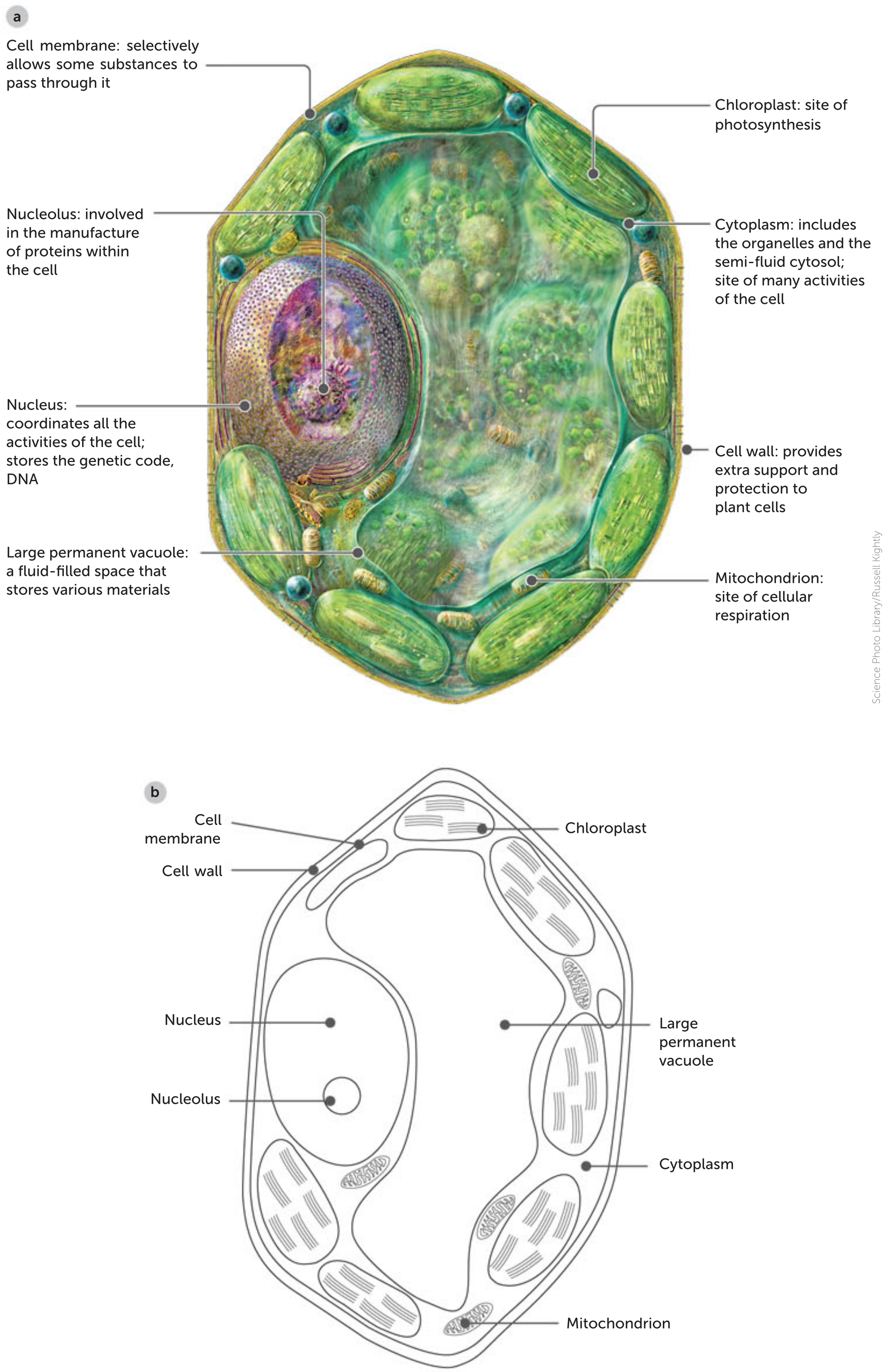

FIGURE 8.13 a A eukaryotic cell from a plant, showing its cell membrane, cell wall and other organelles; **b** a line drawing of the cell

TABLE 8.2 Cell structures and their functions

ANIMAL AND PLANT STRUCTURES	FUNCTIONS
Cell membrane	A flexible phospholipid bilayer that controls the entry and exit of substances and encloses the cell; also known as the plasma membrane
Cytoplasm and cytosol	The cytoplasm is all of the cell contents (including organelles) between the nuclear membrane and the cell membrane. The cytosol is the semi-liquid (jelly-like) part of the cytoplasm and does not include the organelles. Metabolic activity occurs both in the organelles (in the cytoplasm) and in the cytosol.
Endoplasmic reticulum (ER) (rough and smooth)	A network of channels and flattened sacs that extends almost everywhere in the cytoplasm. It transports materials such as proteins throughout this region. It is continuous from the nuclear envelope. There are two types: • smooth ER, which does not have ribosomes attached; it has a unique set of enzymes and carries out many functions, such as the production of membrane phospholipids • rough ER, which does have ribosomes attached and therefore is a site for protein synthesis
Golgi apparatus	A structure of flattened sacs which collect, package, modify and distribute materials such as proteins synthesised in the cell. It: • modifies products of the ER such as proteins • manufactures certain macromolecules • sorts and packages materials into transport vesicles
Lysosomes	A sac of enzymes that can digest (break down) foreign substances, including bacteria, and macromolecules, including lipids, carbohydrates, nucleic acids and proteins
Mitochondria	The site of aerobic cellular respiration, a metabolic process that generates large quantities of a usable form of energy known as ATP (adenosine triphosphate)
Nucleus	The structure that contains most of the cell's DNA. It includes: • a nuclear membrane (envelope), which has pores to allow communication between the nucleus and the rest of the cell • a nucleolus, which is involved in the production of ribosomes • chromatin, which is the loose form of DNA and its proteins, and which only becomes visible as chromosomes during cell division
Ribosome	A non-membranous structure that carries out protein synthesis in two locations: • in the cytosol • on the outside of the rough ER
Centrosomes and centrioles	Two structures that play a major role in cell division (which is discussed in more detail in Units 3 and 4). The centrosome is located at one end of the cell, close to the nucleus. In many cells microtubules (spindle fibres) grow out from a centrosome. In animal cells, the centrosome has a pair of centrioles
PLANT-ONLY STRUCTURES	**FUNCTIONS**
Chloroplast	The site of photosynthesis in plant (and algae) cells. Inside these, the light energy from the Sun is converted into chemical energy and stored in carbohydrates
Cell wall	A structure made of tough cellulose fibres which protects the plant cell, maintains its shape and prevents excessive uptake of water. Prokaryotes, fungi, and some protists also have cell walls; however, their cell walls are made of different substances from plants
Large vacuole	A plant cell (or fungal cell) may have one or several large vacuoles which can store water, nutrients, metabolic wastes and toxins (ready for their removal and also to protect the rest of the cell). In plants, full vacuoles can provide rigidity for the whole organism

Bioman Games and Labs
Play the 'Cellcraft' game to review your knowledge of cell organelles and their functions.

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Key concept

Eukaryotes may be unicellular or multicellular. Their cells are much larger and more complex than prokaryotes, with many different membrane-bound organelles, including a nucleus that contains linear chromosomes.

Specialised and unspecialised cells

Most of the cells of our body (e.g. blood, liver, brain and nerve cells) are specialised to perform particular functions. **Stem cells** are unspecialised cells that have the potential to develop into many different kinds of cell. Unlike most specialised cells, they also have the capacity to keep dividing.

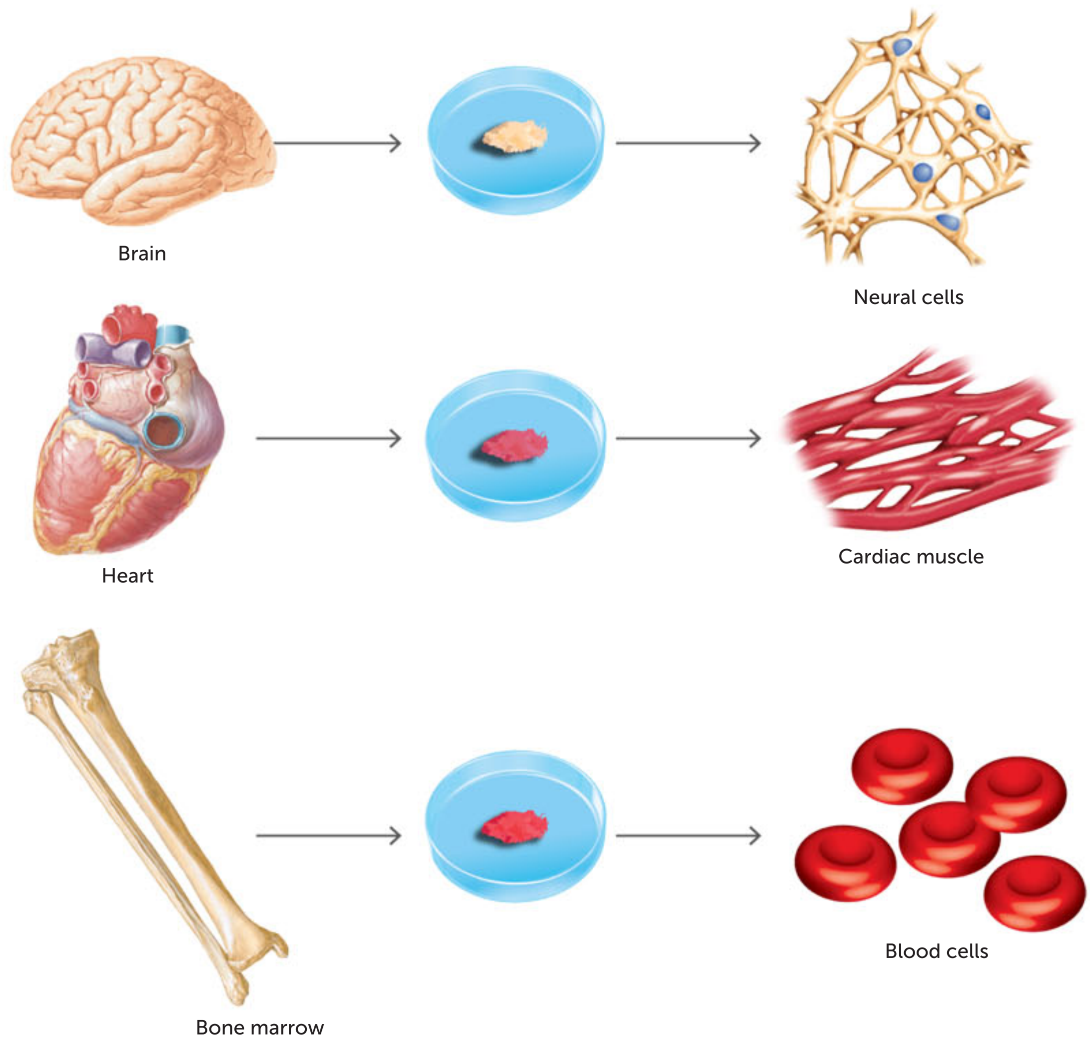

FIGURE 8.14 Examples of adult stem cells, unspecialised cells that have the potential to develop into many kinds of cells

CASE STUDY Virtual plant cell: immersing in biology using virtual reality

The University of Western Australia is host to one of the series of Plant Energy Biology Centres in Australia. Plant cells can be viewed in three dimensions (3D) using new virtual reality (VR) technology. Previously, cell modelling using two-dimensional (2D) imagery led some students to believe cells themselves are 2D. A 3D model is a more accurate representation of a real cell and its 3D organelles. VR is the computer-generated simulation of a 3D image that can be interacted with in a realistic way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors.

Virtual Plant Cell (VPC) uses the novelty of VR technology to enhance learning. It connects students with plant science and its application to real-world challenges through immersive experiences. VPC was created by a world-leading plant science centre, the Australian Research Council Centre of Excellence in Plant Energy Biology. Students can explore and interact with the sub-microscopic inner world of a plant, learning about the key organelles and structures of a cell or discovering how global agricultural challenges can be tackled through science innovation.

When students view the VPC video they can learn about the organelle structures and their specialist functions. For example, they will find out that the vacuole can swell to fill up to 90% of the cell, making the cell, and the whole plant, rigid. When the vacuole loses fluid, it shrinks, causing the cell to shrink and the plant to wilt.

Plant energy website
Select 'VPC: Cell explore (360° video package)' then click on the video to watch it.

Questions

1 Describe the purpose of a model.
2 Define the term 'virtual reality'.
3 Evaluate whether you think VR cell modelling will result in a better understanding of cells and their organelles.

Question set 8.2

REMEMBERING

1 a State where in cells you would find the cytoplasm.
  b Describe the relationship between the cytoplasm and cytosol.
2 Describe what plasmids are.

UNDERSTANDING

3 Using a named example, explain how the structure of an organelle relates to its function.
4 Compare the structure of chromosomes found in prokaryotic and eukaryotic cells.

APPLYING

5 If you were given images of an unknown cell, explain how you would be able to tell if it was:
  a eukaryotic or prokaryotic
  b from a plant or from an animal.

ANALYSING

6 State the function of ribosomes. Explain why you would expect to find more ribosomes in a protein-producing cell than a skin cell.

EVALUATING

7 A large cell, of diameter 0.3 mm, was observed. Ribosomes were present in the cytoplasm but no other organelles. Could this be a prokaryotic or eukaryotic cell? Justify your answer. Identify further evidence that would be useful in your argument.
8 Discuss the impact on the functioning of the cell of having a large number of organelles with folded and stacked membranes.

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8.3 CELLS REQUIRE ENERGY

Wherever life exists, it depends on a source of energy and a supply of matter. Provision of energy is vital to ensure that all essential life processes take place. These life processes include respiration, growth and repair of damaged tissue, reproduction, digestion, excretion of wastes and synthesis of new proteins. Organisms can obtain energy from a variety of sources. Some organisms are able to directly harness energy from the Sun. They use this energy to drive the chemical reactions involved in **photosynthesis**. Some organisms are able to harness the energy released by chemical reactions, in chemosynthesis. Both groups are autotrophs. Other organisms rely on autotrophs to provide their energy for them, usually by consuming them. These organisms are heterotrophs. Even though we describe the energy needs of whole organisms, it is important to consider cells within these organisms.

Photosynthesis

Photosynthesis is a metabolic process that converts the Sun's light energy into stored chemical energy in the form of carbohydrates. Carbon dioxide and water combine in the presence of light and chlorophyll to produce sugars and oxygen. Most life depends on the Sun's energy, but not all cells can harness this energy. Cells that convert solar energy into chemical energy, such as green plant cells, use the pigment **chlorophyll**. Chlorophyll absorbs light energy to make it available for photosynthesis. Some eukaryotic cells contain oval-shaped organelles called **chloroplasts**, which contain chlorophyll.

Photosynthesis is a series of reactions that occur in the **stroma** and **thylakoid membrane** system of the chloroplast (Figure 8.15). During these photosynthesis reactions, carbon dioxide and water are combined to produce glucose, oxygen and water. The internal membranes of a chloroplast are folded many times. This provides more surface area on which the chemical reactions of photosynthesis can occur. Chloroplasts have their own genetic material – DNA and **RNA (ribonucleic acid)** – and ribosomes that are similar to those found in prokaryotes, reflecting an evolutionary link between chloroplasts and a prokaryotic cell.

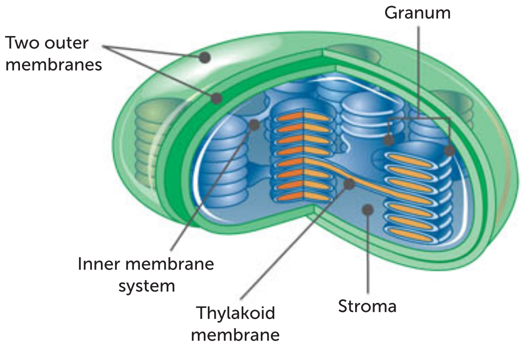

FIGURE 8.15 A generalised sketch showing the grana and stroma of a chloroplast

Cellular respiration

All organisms, with the exception of those in the Domain Archaea, use glucose as the primary source of energy to drive the thousands of chemical reactions that occur constantly in each living cell. The chemical bonds in glucose are broken, providing energy in a form the cell can use. Cellular respiration is a metabolic process that converts stored chemical energy (such as that in glucose) into a usable form of energy stored in **ATP (adenosine triphosphate)**. Cellular respiration is a series of chemical reactions that use glucose and oxygen and produce carbon dioxide and water. During certain stages of these chemical reactions, energy is released. This energy is used to build up molecules of ATP. ATP is an energy-storage molecule that is used to power cellular processes.

In eukaryotic cells, the first stage of cellular respiration takes place in the cytoplasm. The final stage occurs in mitochondria. **Mitochondria** are small, oval-shaped organelles found scattered throughout the cytosol of the cell. Each mitochondrion consists of a smooth outer membrane and a highly folded inner membrane (Figure 8.16, page 252). The folds in the inner membrane are called **cristae**, and they protrude into the inner space of the mitochondrion, a protein-rich fluid called the matrix. These cristae provide two important features that support cellular respiration: the enzymes for cellular respiration are located mainly on the cristae, and the numerous folds of the cristae provide a large surface area on which the chemical reactions can occur.

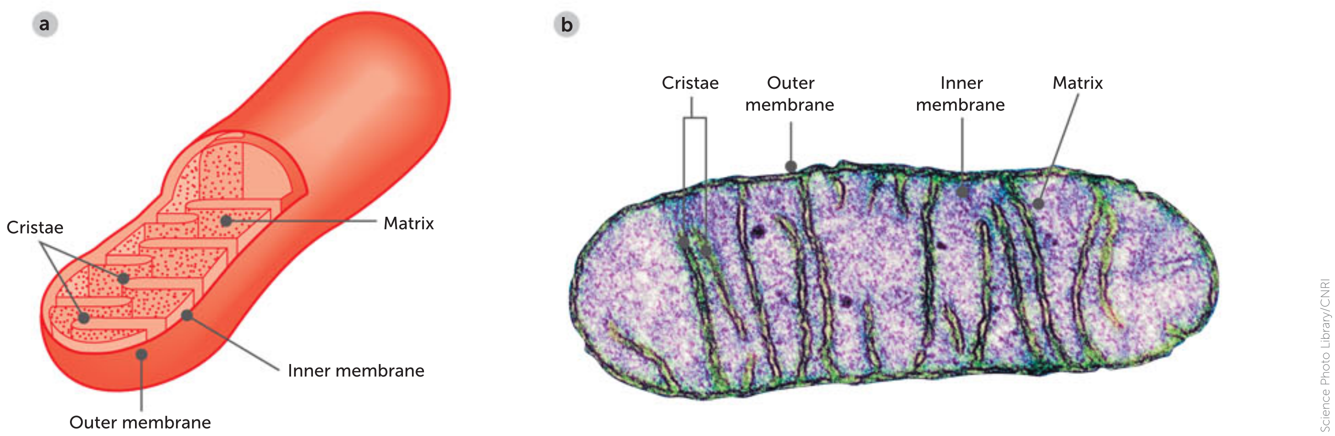

FIGURE 8.16 a A generalised sketch and **b** electron micrograph of a mitochondrion in longitudinal section. The stalked particles on the surface of the cristae are the sites of ATP synthesis.

Prokaryotes and eukaryotes have a common evolutionary past

Scientists theorise that the first eukaryotes evolved around 2 billion years ago. The **endosymbiotic theory** proposes that eukaryote cells were formed when a bacterial cell was ingested by another primitive prokaryotic cell. The theory suggests that the larger prokaryotic cell ingested the smaller bacterial cell by engulfing it in a process known as phagocytosis. The bacteria escaped being digested and instead formed a symbiotic relationship with its host.

It is proposed that mitochondria and chloroplasts evolved through this process of endosymbiosis, where one species lives inside another. Mitochondria and chloroplasts can make copies of themselves and split in two, like bacteria do when they reproduce. Both mitochondria and chloroplasts can arise only from pre-existing mitochondria and chloroplasts. They cannot be formed in a cell that lacks them. Both mitochondria and chloroplasts have two membranes, said to be remnants of the outer original host cell and the inner, engulfed bacterial cell. They also have their own genetic material (DNA).

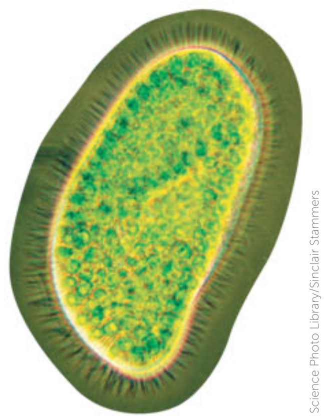

FIGURE 8.17 Light micrograph of *Paramecium bursaria*, a single-celled protozoan. The smaller green cells within the *P. bursaria* are unicellular green algae, which live symbiotically inside this organism.

Question set 8.3

REMEMBERING

1 List five life processes that require energy.

2 Recall the requirements of:
  - a photosynthesis
  - b respiration.

UNDERSTANDING

3 Distinguish between the energy sources used by autotrophs and heterotrophs.

4 Name the organelle that allows cells to access energy so they can carry out activities. Explain how it does this.

5 Draw and label the structural features of the following:
  - a chloroplast
  - b mitochondria.

6 Distinguish between:
  - a chemosynthesis and photosynthesis
  - b cellular respiration and photosynthesis
  - c heterotrophic and autotrophic.

APPLYING

7 Explain why you would expect human bicep muscle cells to contain more mitochondria than a cell in your big toe.

8.4 SPECIALISED ORGANELLES SYNTHESISE COMPLEX MOLECULES

Every living cell is involved in synthesising large molecules that are needed not only to build the body parts of organisms but also to maintain the biochemical processes that keep them living: communication, transformation of energy and the relay of genetic information. These biological molecules are synthesised from monomers to produce complex structures, including carbohydrates, proteins and lipids. A **monomer** is a small molecule, many copies of which are linked together to form a larger molecule known as a **polymer**. Large biomacromolecules are synthesised inside the cell. Proteins, nucleic acids and complex carbohydrates are built up by linking monomers. Even though lipids are large biomacromolecules, they are not polymers; they are composed of distinct chemical groups of atoms. Biomacromolecules are any large organic, complex molecules found in living things. **Organic molecules** are large, complex carbon compounds usually derived from a living thing. Examples include glucose and starch.

Biomacromolecules are grouped into four main classes based on their chemical composition and structure. The four classes are complex **carbohydrates**, **lipids**, proteins and nucleic acids. Each of these groups is further subdivided according to their slight differences in structure and, therefore, in function.

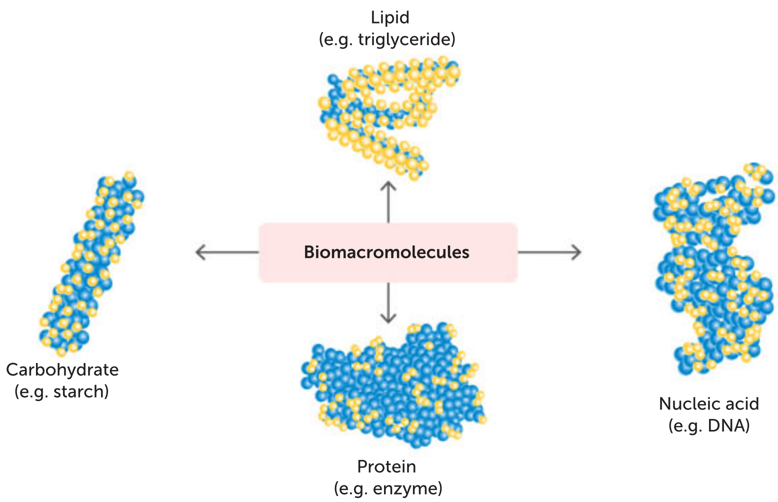

FIGURE 8.18 The major groups of biomacromolecules

Some organisms are able to synthesise their own biological macromolecules from inorganic substances. **Inorganic compounds** are small, simple compounds which do not contain both carbon and hydrogen; for example, water and carbon dioxide. Others build them from organic compounds that they have ingested. Autotrophs build their own organic compounds from the inorganic materials that they take in from their surroundings. For example, seaweeds, eucalypts, grasses and microscopic algae all produce simple sugars (the basic building unit) through the process of photosynthesis, using the inorganic materials water and carbon dioxide. Using these simple sugars, autotrophs then build the other organic compounds (such as sucrose, starch and cellulose) that they need.

Some autotrophic organisms, such as certain kinds of bacteria, are able to build or synthesise their organic requirements through chemical processes other than photosynthesis. This is referred to as chemosynthesis. These chemosynthetic autotrophs, or chemotrophs, are typically found in extreme conditions, such as in the depths of the ocean near hydrothermal vents, in thermal springs or in places deprived of oxygen or light.

Heterotrophs, such as humans, have to synthesise their own biomacromolecules from existing organic compounds. They use the chemical energy in the food they ingest. Heterotrophs must take in a range of organic compounds, such as protein, in their food. They then break this food down into simpler substances, such as amino acids, in the process of digestion. These smaller substances are then used to synthesise all the other organic compounds that are required by the organism.

Carbohydrates

Carbohydrates are the most common compounds in living things. We hear about them constantly in relation to our diet. Their name gives a clue to the composition of carbohydrates. Each molecule consists of carbon, hydrogen and oxygen atoms in the ratio of 1:2:1, giving the general formula for carbohydrates as $n\text{CH}_2\text{O}$.

Carbohydrates are classified as **monosaccharides** (or simple sugars [Figure 8.19a]), **disaccharides** (Figure 8.19b) and **polysaccharides** (Figure 8.19c) depending on the complexity of the linkages of the monomers. The product of photosynthesis, glucose, is a monosaccharide.

Organisms use carbohydrates as an energy source and for structural components. Carbohydrate molecules can combine with other atoms or groups to form important compounds; for example, **glycoproteins**, which are a combination of carbohydrate and protein molecules.

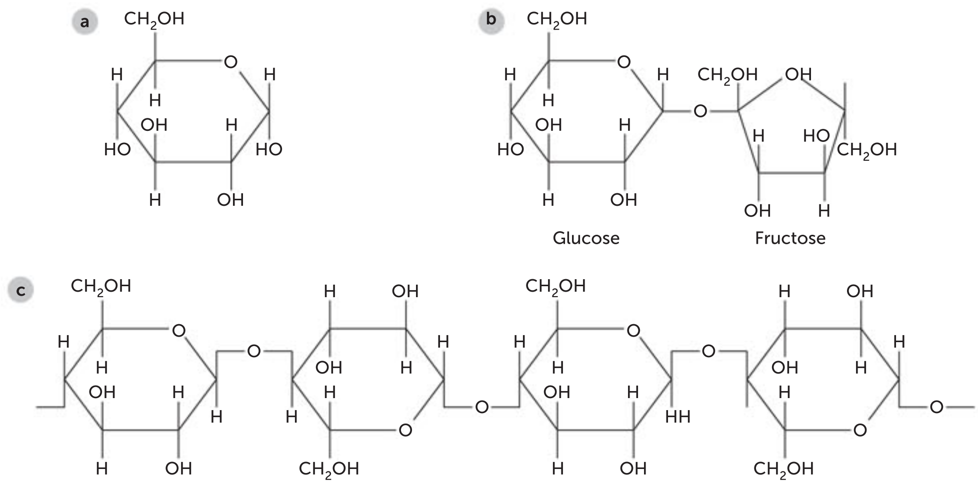

FIGURE 8.19 a Glucose is a monosaccharide. **b** Sucrose is a disaccharide, made up of a glucose and fructose sugar joined together. **c** Cellulose is a polysaccharide, with many glucose units joined together.

Lipids

Lipids
View the animation to assist your understanding of lipids.

Lipids are a diverse group of molecules and include fats and oils, phospholipids, glycolipids and steroids. They all contain the elements carbon, hydrogen and oxygen, and are insoluble in water. In cells, lipids have three important functions:

1. energy storage (they have approximately twice the amount of energy as carbohydrates)
2. structural component of membranes
3. specific biological functions (e.g. transmission of chemical signals both within and between cells).

Cells also excrete lipids that function to protect the cell or the whole organism.

The fats and oils of plants and animals are typically composed of **triglyceride** molecules (Figure 8.20). Their name gives a clue to their composition ('tri' means three), by referring to the number of fatty acid chains attached to a glycerol backbone.

Lipids that are required for particular purposes, such as the phospholipids and cholesterol used for making membranes, are synthesised in the tubular cavities of the **endoplasmic reticulum (ER)**.

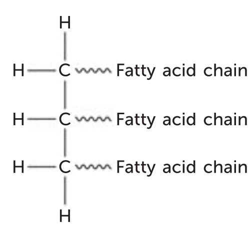

FIGURE 8.20 A triglyceride molecule contains a glycerol unit and three fatty acid chains.

Proteins

Virtually everything a cell is, or does, depends on the proteins it contains. They contribute to building many different cellular structures and parts and, as enzymes, control the thousands of chemical reactions that maintain life processes.

Your body produces more than one million new red blood cells each second. A range of different proteins is found embedded within the membranes of these cells. For example, channel proteins penetrate through the membrane and allow select substances to pass through the membrane. This means that your red blood cells need to produce proteins for one million cell membranes and organelle membranes each second.

Like lipids, proteins are made up of the elements carbon, hydrogen and oxygen. However, they are different from lipids in that they always contain nitrogen. In addition, sulfur is often present, and sometimes phosphorus and other elements. These elements combine to form the building blocks of proteins, amino acids. Amino acids are assembled into proteins in the ribosomes.

More than 100 different kinds of amino acids can be found in cells, but only 22 join together to form a protein or polypeptide. Of these amino acids, 20 are 'standard' and are found in eukaryotes, including humans. The other two 'non-standard' amino acids are found only in some simple microbes. It is the order and number of amino acids that make each type of protein different. The order of amino acids in proteins is determined by the DNA code within the genes located on our chromosomes.

Plants can synthesise their own amino acids, but animals must obtain some of them from their diet. Of the 20 standard amino acids, 9 are called 'essential' because they cannot be synthesised by cells in your body; for example, phenylalanine and tryptophan. Others may be conditionally essential for people at some ages or with medical conditions. Essential amino acids may also differ between species.

Nucleic acid

The nucleic acids DNA (deoxyribonucleic acid) and one type of RNA (ribonucleic acid) are found in the nucleus. A molecule of DNA is composed of two long strands of subunits called **nucleotides**. The strands of nucleotides are wound around each other to form a double helix (Figure 8.22). The DNA code guides the production of proteins that carry out and control the many activities within a cell. When a cell divides, new DNA is synthesised.

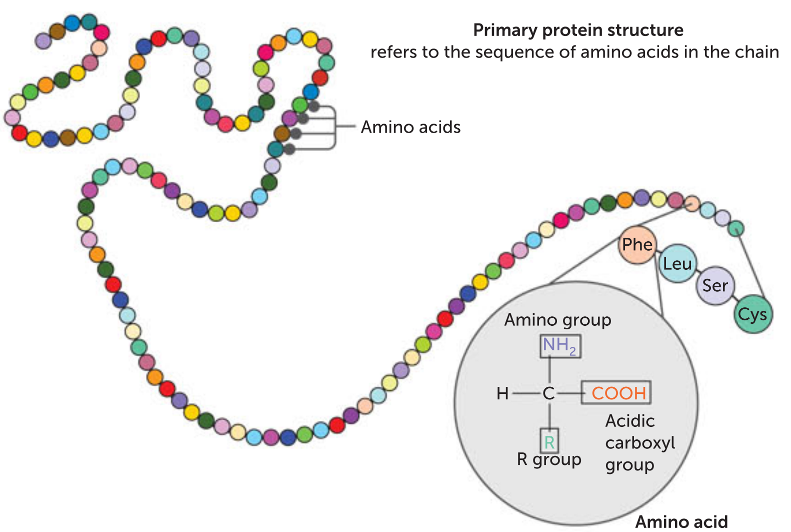

FIGURE 8.21 A chain of amino acids forms a polypeptide, which folds to form a protein.

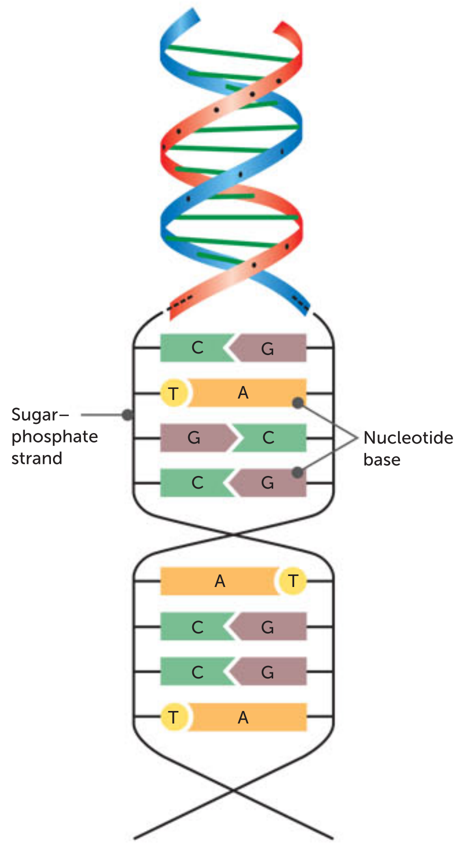

FIGURE 8.22 DNA is a double-stranded molecule made of a sequence of four different kinds of nucleotides.

DNA molecules are large. They are too large to move through the nuclear membrane. It is the job of one type of nucleic acid, **messenger RNA (mRNA)**, to transfer the instructions in the DNA code to the ribosomes so it can guide protein synthesis. The order of nucleotides in mRNA is determined by the order of nucleotides in a section of DNA. When a strand of mRNA has been synthesised, it moves out of the nucleus to the ribosomes in the cytoplasm. The order of nucleotides in the mRNA determines the order of amino acids in the protein that is synthesised.

Key concept

Organisms contain large, complex organic molecules called biomacromolecules, which are made of simpler units. Proteins are made of amino acids, carbohydrates are made of monosaccharides, lipids are made of triglyceride molecules and nucleic acids are made of nucleotides.

DNA and RNA
Watch the video to solidify your understanding of nucleic acids: DNA and RNA.

A dark-staining structure within the nucleus is called the **nucleolus**. One or more of these can be seen in cells when they are not dividing. The nucleolus is responsible for the synthesis of a type of nucleic acid called ribosomal RNA (rRNA) and the assembly of ribosomes from rRNA and proteins.

TABLE 8.3 Biological macromolecules and their basic units

TYPE OF MACROMOLECULE	SMALLEST UNIT OR MONOMER	SOME MAJOR FUNCTIONS	SOME FOOD SOURCES
Carbohydrate	Monosaccharides; e.g. glucose	Energy for metabolism, building blocks for larger molecules	Pasta, rice, potatoes
Lipid	Glycerol, fatty acids	Storage of energy, cell membrane structure	Avocado, olive oil
Proteins	Amino acids	Used as coenzymes, internal defence	Meat, egg
Nucleic acid	Nucleotides	Store and transmit genetic information	Beef, spinach

Question set 8.4

REMEMBERING

1 Name the four main types of biomacromolecules found in all organisms.
2 Define 'organic compounds'.
3 State which biomacromolecules are polymers.
4 Describe the chemical composition of a carbohydrate.
5 State where in a cell you would expect to find DNA and RNA.

UNDERSTANDING

6 Explain why lipids are also called triglycerides.
7 Distinguish between:
  a monosaccharides, disaccharides and polysaccharides
  b DNA and RNA
  c monomers and polymers.

APPLYING

8 Explain why there are so many different kinds of protein.

ANALYSING

9 Plants contain more carbohydrate but less fat than animals. Explain possible reasons why they differ in this way.

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8.5 SPECIALISED ORGANELLES REMOVE CELLULAR PRODUCTS

Cellular products are often produced in one part of the cell and used in another part of the cell. Sometimes these products are required for use in other cells. Wastes need to be removed and are transported out of the cell. Through observations and experiments such as labelling protein cell products with fluorescent dyes or tracking radioactively labelled atoms, specialised cell organelles that facilitate the transport of wastes have been identified.

Endoplasmic reticulum

How do proteins produced in ribosomes move to other parts of the cell? This happens via the endoplasmic reticulum (ER). The ER is an interconnecting system of thin membrane sheets dividing the cytoplasm into compartments and channels. The membrane of the ER is able to pinch off into small sacs called **vesicles** and deliver proteins to all parts within the cell. The ER is therefore an **intracellular** transport system.

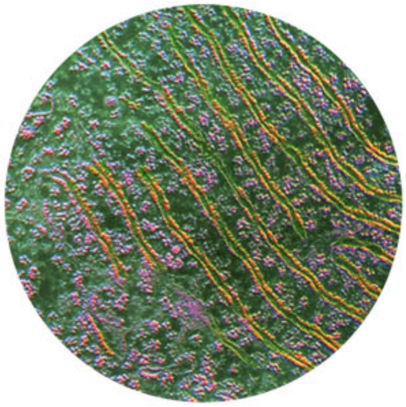


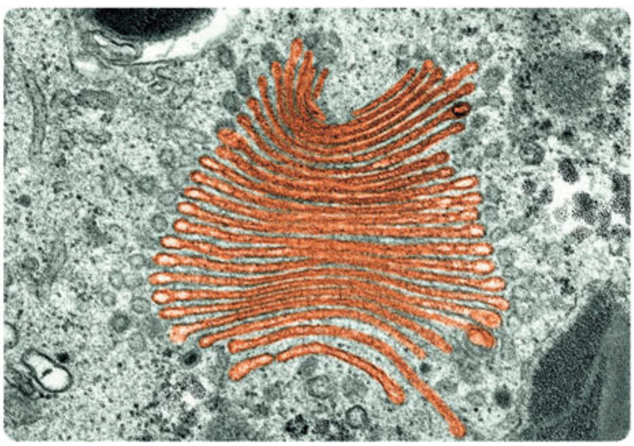
FIGURE 8.23 Rough ER studded with ribosomes

Most of the ER in cells is studded with ribosomes, and thus is known as **rough endoplasmic reticulum (rough ER)**. The proteins produced by the ribosomes can move directly into the ER and be moved about the cell. Some proteins are not required by the cell in which they are made, and are exported or secreted into other cells. Such proteins include enzymes and hormones. Therefore, the ER is also an **intercellular** (between cells) transport system, helping to move proteins from one cell to another.

In certain parts of some cells, the ER has no ribosomes attached to it and is known as **smooth endoplasmic reticulum (smooth ER).** The amount and function of this smooth ER depends on the type of cell it is in. Its main role is to transport proteins, synthesise lipids and to assist in the manufacture of cell membranes. In liver cells, it also detoxifies drugs, and in adrenal cortical cells, it produces the steroid hormone. Some carbohydrates are produced on smooth ER. It is also a place for storage of calcium ions, which are necessary for muscle contraction and interactions between some membrane proteins.

Golgi apparatus

Consider a grass-eating animal, such as a kangaroo. The cells in grass have a tough cell wall. For the kangaroo to be able to digest and absorb the nutrients from inside the grass cell, the cell wall must be broken down by enzymes. Cells in the digestive glands of the kangaroo produce such enzymes. Being proteins, these digestive enzymes are produced initially by the ribosomes on the rough ER. They move through the channels in the ER within the cytoplasm of the cell. From



Science Photo Library

FIGURE 8.24 Electron micrograph of the Golgi apparatus (magnification 80 000×)

there they move into the **Golgi apparatus** (also known as a Golgi body) where they are packaged and stored before being secreted from the cell to move to the intestines of the kangaroo. This is where they can begin their work digesting the cellulose in the cell wall of the grass.

The Golgi apparatus consists of a system of membranes within the cytoplasm. Parts of the Golgi apparatus membrane are able to pinch off into small vesicles. It is these vesicles that move to the cell membrane, where they join to the membrane and discharge their contents to the outside of the cell.

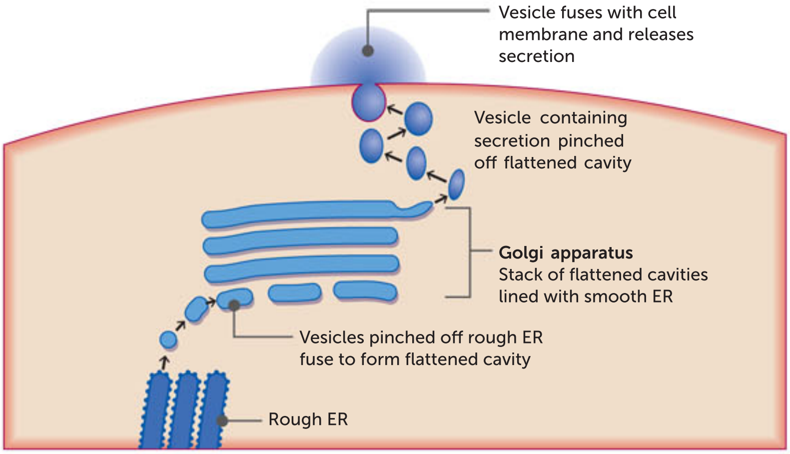


FIGURE 8.25 How the Golgi apparatus secretes a substance from a cell

Lysosomes

Inevitably, organelles within the cytoplasm of cells reach their 'use-by date' and wear out. Instead of wasting the raw materials that make up these organelles, the cell has a clever method of recycling them. This is the job carried out by **lysosomes** ('lysis' means to break apart), one of the special organelles found within the cytoplasm of animal cells. Lysosomes are formed by the Golgi apparatus. They contain digestive enzymes that are responsible for splitting complex chemical compounds into simpler ones; for example, breaking proteins down into amino acids. These simpler substances can then be used as building blocks for new compounds and organelles.

Sometimes lysosomes may destroy the entire cell. This happens when the lysosome membrane ruptures, releasing the enzymes, which then digest the contents of the cell, killing it in the process. This is known as **apoptosis** or programmed cell death.

Cell membrane

Some molecules must be able to move in and out of cells. Many molecules are too large to move passively through the cell membrane, so there must be another way. The cell membrane has an ingenious solution to this problem. It can engulf large particles and liquids in its environment in a process known as **endocytosis**. It surrounds and encloses the material to form an endocytic vesicle within the cell, which it then uses to store or transport the material within the cytoplasm.

Conversely, exocytic vesicles function to transport large molecules and particles across the cell membrane and out of the cell. During **exocytosis**, a small membrane-bound vesicle moves through the cytosol, joins with the cell membrane and then releases its contents to the exterior of the cell. You will learn more about cell membrane transport in Chapter 9.

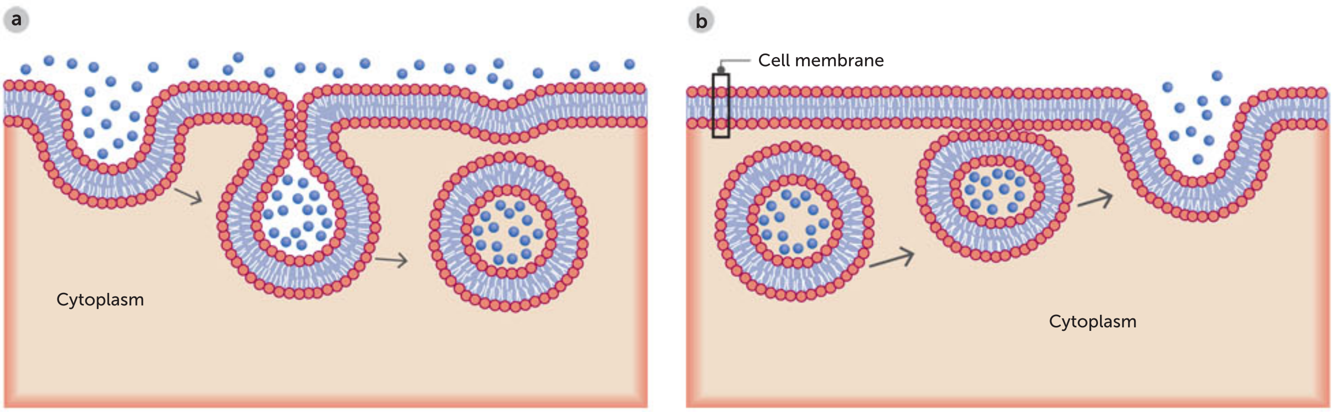


FIGURE 8.26 The processes of **a** endocytosis and **b** exocytosis

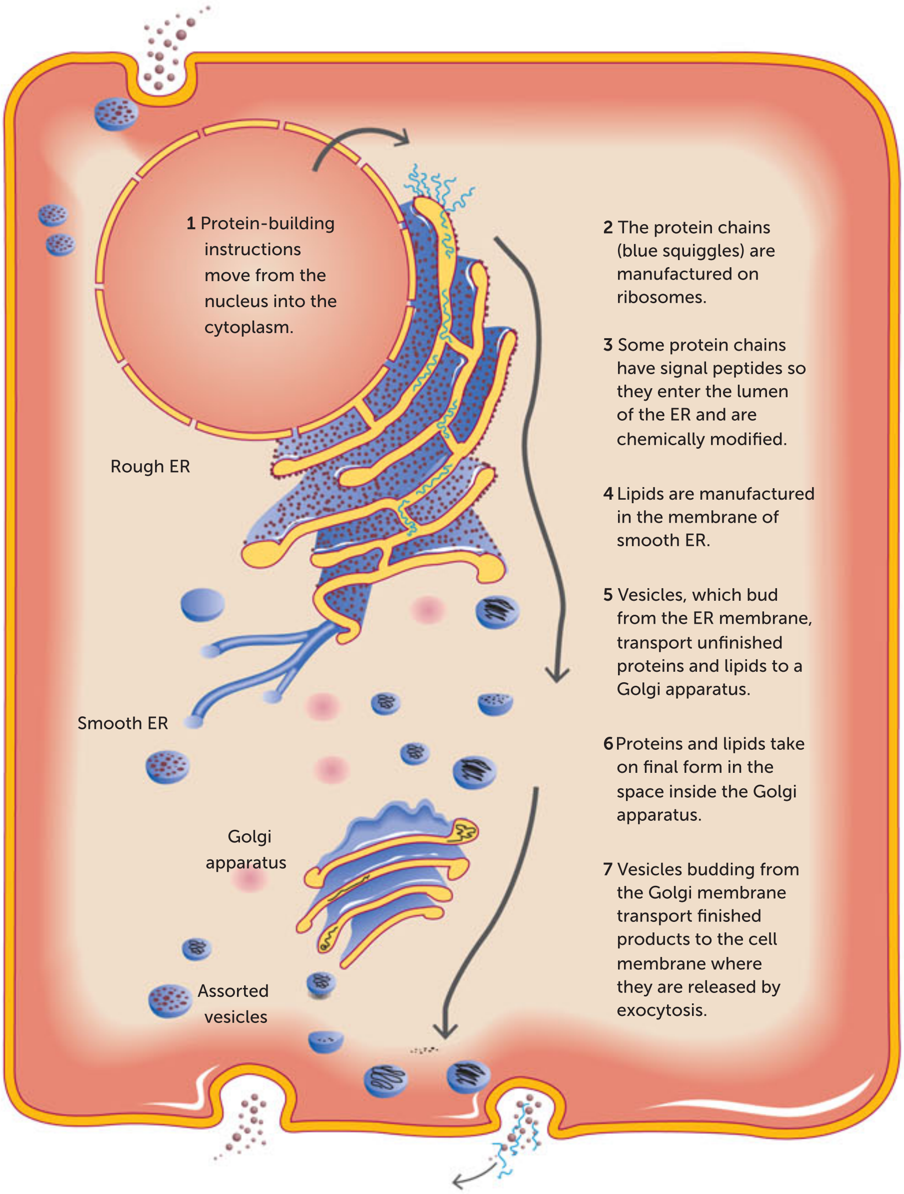


FIGURE 8.27 Protein pathways, showing the production, transport and secretion of proteins

Key concept

Some cellular products move through the endoplasmic reticulum, are packaged in the Golgi apparatus, and are then released from the cell through the cell membrane via exocytosis.

Question set 8.5

REMEMBERING

1 Describe the main roles of the endoplasmic reticulum.

2 Outline one similarity and one difference between endocytosis and exocytosis.

UNDERSTANDING

3 Explain the role of the Golgi apparatus in the transport of materials out of the cell. Describe the kinds of materials it packages.

APPLYING

4 Predict the function of a cell that contains more rough ER than smooth ER.

5 Describe how lysosomes are like cell 'recycling stations'.

ANALYSING

6 Using an electron microscope, a scientist observes small, sac-like vesicles joining and detaching from cell membranes.
 a Name these vesicles.
 b Describe the function of these structures.
 c Name the process described.
 d Another observer describes these structures as lysosomes. What would you say to argue against this observation?

CHAPTER 8 ACTIVITY AND INVESTIGATIONS

8.1 ACTIVITY

Microscopes and field of view

When you look through a light microscope, a circular area is illuminated by a light source. The distance across the centre, or diameter, is known as the field of view (FOV). The FOV can be measured using a transparent ruler called a minigrid (or stage micrometer). To use the minigrid, place it on the stage under the low magnification. Align the left edge of the grid with the left side of the FOV. Count the number of 1 mm squares across the diameter of the circle and this is your FOV. As magnification increases, FOV decreases, in proportion: in other words, there is an inverse relationship between magnification and FOV. As you increase magnification you see fewer cells and they appear larger. The cells are not actually changing in size, just appearing larger. The diameter that can be observed gets smaller by the same proportion. For example, if the magnification increases by 10×, the FOV decreases by 10×.

Cell size can also be calculated using a minigrid:

Cell size = diameter of FOV ÷ number of cells

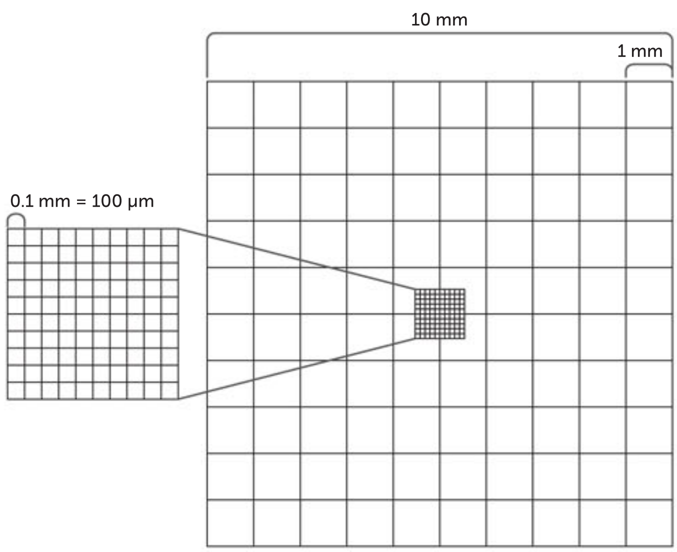


FIGURE 8.28 As magnification increases, the field of view decreases.

1 To practice calculating the FOV as magnification changes, copy and complete Table 8.4. The first two rows are worked examples for you to follow. For the last two rows you can use your own method to calculate FOV or you can use this ratio:

$$FOV_1 \times magnification_1 = FOV_2 \times magnification_2$$

TABLE 8.4 Calculating field of view (FOV)

OBJECTIVE MAGNIFICATION (×)	TOTAL MAGNIFICATION (×)	FOV CALCULATION	FOV (mm)	FOV (µm)
4	40	–	4.5	4500
10	100	$40 \times 4.5 = 100 \times FOV_2$	1.8	1800
40	400	$100 \times 1.8 = 400 \times FOV_2$		450
100	1000			
32	320			

2 A student could see six cells across the diameter of a 4.5 mm field of view at 40× magnification.
   a Calculate the length of one cell.
   b Calculate the magnification if the field of view changed to 1.8 mm.
   c Calculate the magnification if only two cells can fit across the field of view.

8.1 INVESTIGATION

Microscopes and cells

One of the main characteristics of living things is that they are made up of cells. However, it was not until the late 1600s, with the invention of the light microscope, that cells could be seen and studied in detail. As microscopes have become more refined and powerful, we have been able to see more and more of the structures that make up cells.

Aims

- To revise and refine microscope use
- To explore some of the structures of unicellular and multicellular organisms

Materials

- light microscope
- prepared microscope slides, such as red blood cells, liver cells, striated muscle, *Paramecium*, *Euglena*, pollen
- plastic ruler marked in millimetres or minigrid (optional)

WHAT ARE THE RISKS IN DOING THIS EXPERIMENT?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
If you drop the microscope it could hurt you or damage the lenses.	Handle the microscope with two hands.
A glass slide could break and cut you.	Clean up any broken glass using protective gloves and put glass into a safety container.

Procedure

1 Place a plastic ruler or minigrid onto the stage so that you can see it when you look through the microscope. Work out the diameter across the fields of view of the different magnifications.
2 Select at least four different prepared slides. Examine each one carefully, first under low power and then under high power.

Results

1 Create a table and record the diameter of the fields of view for each of the magnifications you used.
2 Draw each of the specimens as seen under high power. Make sure the magnification is shown and each specimen is labelled with its name. For each specimen, state whether it is a unicellular organism or part of a multicellular organism.

Discussion

1 When a specimen is viewed through a microscope, it appears larger than it really is. Explain how you can determine exactly how much it has been enlarged.
2 State how many micrometres there are in a millimetre.
3 Choose three specimens that you viewed and describe at least three structural differences between them.

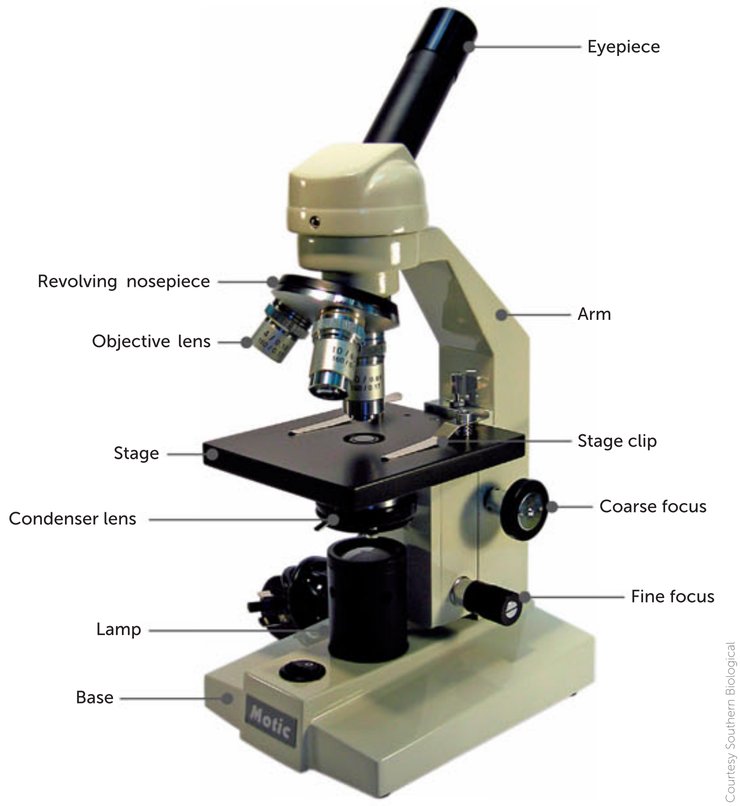


FIGURE 8.29 The parts of a light or optical monocular microscope

4 Copy and complete Table 8.5.

TABLE 8.5 Magnifications of a microscope

OBJECTIVE LENS	TOTAL MAGNIFICATION EYEPIECE LENS 10×	TOTAL MAGNIFICATION EYEPIECE LENS 5×
4×		
10×		
40×		

5 Copy and complete Table 8.6 to list the parts and functions of a light microscope.

TABLE 8.6 Parts of a microscope

PART	FUNCTION
Ocular lens	
Revolving nose piece	
Coarse focus	
Fine focus	
Condenser lens	

Biological drawings of objects viewed by microscope – guidelines

1. Draw what you observe only.
2. Start with enough space – allow half a page.
3. Using a sharp pencil, draw four or five neighbouring cells.
4. Draw and label only the structures a light microscope allows you to view.
5. Indicate and label a cell wall and cell membrane and any other details such as a nucleus that can be observed.
6. Indicate a title for the specimen viewed, the magnification and field of view (FOV). You may need to use a minigrid to measure the FOV.

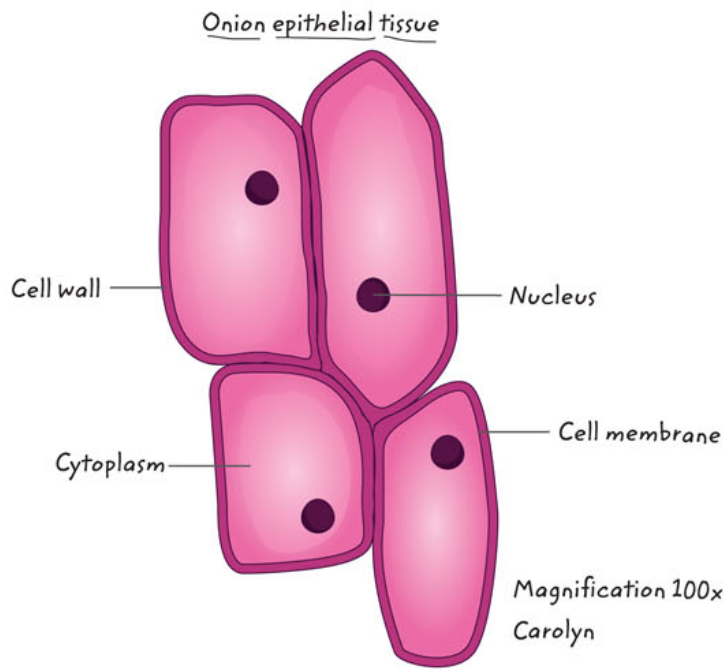


FIGURE 8.30 Correct style for biological drawing

8.2 INVESTIGATION

Investigating cells

Living cells have a range of different structures that enable them to meet their needs for energy production and to carry out their specialised tasks. How do prokaryotic organisms, such as bacteria, compare in their basic structure to plant and animal cells?

Aim

1. To compare and contrast the structure of eukaryotic and prokaryotic cells, and plant and animal cells
2. To prepare your own onion cells slide, known as a wet mount.

Materials

- light microscope
- microscope slides
- coverslips
- minigrid
- onion
- knife or single-edged razor blade

The Homeschool scientist
Find out the method for making a wet mount of onion cells.

- tweezers or mounted needles
- eye dropper (optional)
- methylene blue stain with eye dropper
- paper towelling
- large beaker of water for used microscope slides and coverslips
- *Elodea* plant (or an alternative freshwater oxygenator available from the local aquarium or biological supplier)
- prepared slide of human cheek cells
- prepared slide of bacteria
- prepared slides of plant and animal tissues
- oil immersion lens
- oil immersion

WHAT ARE THE RISKS IN DOING THIS EXPERIMENT?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
The knife or razor blade is very sharp.	Take care when using the knife or razor blade and handle it carefully.
Coverslips break easily and can cut.	Take care with coverslips and do not push hard when placing them.
Elodea is a noxious weed.	Dispose of *Elodea* safely, away from waterways.

Procedure

Plant cell: onion

1. Prepare a microscope slide with a drop of cold water on it.
2. Cut a piece off the onion provided. Peel a section of 'membrane' from between the two layers of onion. The membrane will be about as thin and flexible as plastic wrap. Use the knife or razor blade to carefully cut the membrane until it is about a quarter the size of a fingernail.
3. Place the small piece of membrane in the drop of water, making sure that it stays flat. You can stop it from curling or doubling over on itself by using tweezers or mounted needles.
4. Carefully place a coverslip on top of the onion membrane on an angle to push out any air bubbles. This is known as a 'wet mount'. Check that there is enough water to surround the onion membrane (which should sit well within the boundaries of the coverslip). The water will seep under the coverslip by itself.

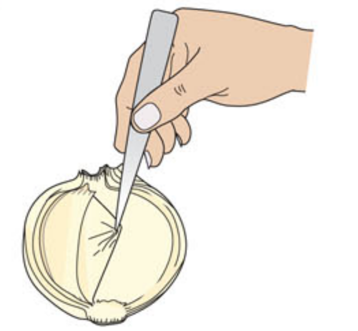


FIGURE 8.31 Preparing onion tissue

5. Focus on onion cells under low power and then switch to high power. Draw a diagram of a few cells, labelling the nucleus, cell wall and cytoplasm.
6. Put one drop of methylene blue stain next to one side of the coverslip (Figure 8.32, page 266). Use some paper towelling on the other side of the coverslip to absorb liquid and so draw the stain across under the coverslip.
7. Focus on the cells again and identify whether the stain has made any structures more visible.
8. Make a careful diagram of a few cells. Label the nucleus, cell wall and cytoplasm.
9. Use a minigrid to measure the dimensions of an onion cell.

Plant cell: Elodea (or alternative)

10. Repeat steps 1 to 5 in the procedure using an *Elodea* leaf from the tip of the plant instead of the onion membrane. Float the tissue in warm water instead of cold water.
11. View the *Elodea* leaf on low and then high power. Watch it for a few minutes. What do you see happening to the cell contents? What does this suggest?

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12 Make a careful diagram of one cell. Label the cell wall, nucleus, chloroplasts and cytoplasm.
13 Stain the *Elodea* cell using methylene blue by following the instructions in step 6. What differences do you see occurring within the *Elodea* cell? What does this suggest?

Animal cell

14 Examine the prepared slide of a cheek cell under low power then high power. Make a careful diagram of one of the cells. Label the cell membrane, nucleus, cytoplasm and any other structures that you can identify.
15 Your teacher may have prepared other animal and plant tissue slides for you. Take a look at each slide using the light microscope and see if there are any different cell structures that you can identify.

Prokaryotic cell

16 Place a prepared slide of bacterial cells onto your microscope stage.
17 An oil immersion objective lens may be used to give a higher magnification (useful for observing bacteria). A drop of oil is placed on the coverslip above the specimen and the oil immersion objective lens is centred over the oil. Only use the fine adjustment for focusing.
18 Draw a bacterial cell.

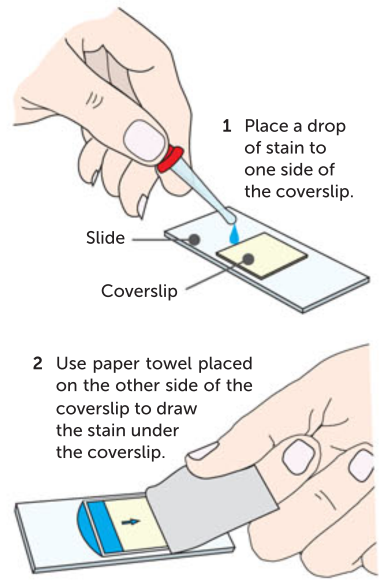

FIGURE 8.32 Staining a slide

Results

1 Draw labelled diagrams of onion cells, an *Elodea* cell and a bacterial cell. Include the magnification used and size of the cell (in micrometres, μm).
2 Describe the similarities in and differences between the three types of cells.

Discussion

1 Describe what effect adding the methylene blue stain had on your ability to see different parts of the onion cell.
2 List what sorts of substances would need to be able to pass through the walls of onion cells.
3 Describe what you observed happening to the chloroplasts inside the *Elodea* cell. Name this process and explain why it is happening.
4 Note any differences you noticed in the *Elodea* cell once the cell had been stained with methylene blue. Account for these differences.
5 Compare the size of a bacterial cell to the sizes of the plant and animal cells you have seen so far.
6 Outline what cell detail you can see inside the bacterial cells.
7 State two limitations of using a light microscope.
8 From your observations, suggest two differences between prokaryotic and eukaryotic cells.
9 Describe how the prepared slides that you used in this activity compare to the ones that you had to prepare using fresh materials. Explain whether one was better to use than the other.
10 Describe how the oil immersion technique assisted you in seeing the internal structure of the cell.

CHAPTER 8 SUMMARY

WS Chapter 8 Activity sheet

- Living things are characterised by their ability to move, grow, and replicate or reproduce.
- Cells have requirements. Living things can use the energy from sunlight or in food for their activities and they are able to remove wastes.
- All living things are made of cells and the products of cells, and new cells arise only from previously existing cells.
- Organisms can be single celled or multicellular.
- The development of different kinds of microscopes has advanced our understanding of cell structure.
- The simplest type of cell is a prokaryote. Prokaryotes exist as single cells. Prokaryotic cells belong to the domains Bacteria and Archaea.
- Circular chromosomes and ribosomes are found in the cytoplasm of prokaryotic cells.
- Eukaryotic cells are complex cells containing membrane-bound organelles with specific metabolic functions.
- Autotrophs are able to use energy from the Sun or from chemical reactions to provide their energy needs.
- Chemotrophs are a small group of bacteria that are able to create sugars (organic molecules) from inorganic compounds without sunlight.
- Heterotrophs rely on autotrophs to provide their energy needs.
- Chloroplasts, containing the pigment chlorophyll, are organelles in eukaryotic cells that use the energy in sunlight to convert carbon dioxide and water to glucose and oxygen.
- Cellular respiration is a series of chemical reactions that breaks down glucose and uses oxygen to produce carbon dioxide and water. The energy released by this process is used to build up the energy-storage molecule ATP.
- Mitochondria are the organelles in eukaryotic cells where cellular respiration takes place.
- Carbohydrates, lipids, proteins and nucleic acids are the main biomacromolecules of living things.
- Cells assemble biomacromolecules from small organic compounds, including simple sugars, fatty acids and glycerol, amino acids, and nucleotides.
- The most complex carbohydrates are polysaccharides, such as starch. The simplest are monosaccharides, such as glucose. Glucose is synthesised in chloroplasts.
- Lipids are insoluble in water. They have many important cellular functions. Lipids are synthesised in the endoplasmic reticulum.
- Proteins are made up of one or more polypeptide chains of amino acids. Proteins are synthesised in ribosomes.
- DNA and RNA are polymers of nucleic acids. The nucleus has an important role in their synthesis.
- Many proteins are modified and lipids are assembled in the endoplasmic reticulum and the Golgi apparatus.
- Vesicles package compounds ready for storage, intracellular movement or secretion out of the cell.
- Large molecules and particles can move into and out of the cell via endocytosis and exocytosis.

CHAPTER 8 GLOSSARY

Absorption the movement of substances from the external environment across the cell membranes into the internal environment of a cell or organism

Amino acid a nitrogen-containing compound that is a building block of proteins

Apoptosis the programmed series of events that leads to cell death as a result of the dismantling of internal contents of the cell

Assimilation the process through which an organism incorporates nutrients from outside its body into the more complex structures needed in its fluid or solid parts

ATP (adenosine triphosphate) a high-energy compound composed of adenine, ribose and three phosphate groups; it releases energy for cellular reactions when its last phosphate group is removed and it is converted to ADP (adenosine diphosphate)

Autotroph an organism capable of making its own food from inorganic substances using light energy (through photosynthesis) or chemical energy (through chemosynthesis); includes green plants, algae and certain bacteria

Biomacromolecule a molecule that has an important structural or functional role in cells

Carbohydrate an organic compound that is a structural component of cells and a major energy source in the diet of animals; includes sugars, starches, celluloses and gums

Cell the basic structural unit of all life forms on Earth

Cellular respiration a series of cellular biochemical reactions and processes that use glucose and oxygen and produce carbon dioxide and water; the energy released is used to convert ADP to ATP

Chemosynthesis the synthesis of organic substances using energy from chemical reactions

Chlorophyll the green pigment found in chloroplasts; it is able to absorb light energy, making it available for photosynthesis

Chloroplast a membrane-bound organelle found in the cytoplasm of plants and algae containing the green pigment chlorophyll; its main function is to be the site of photosynthesis and storage of carbohydrates

Cristae the folded inner membranes in the matrix of the mitochondria, which provide increased surface area for cellular respiration

Cytoplasm all the fluid, dissolved materials and organelles between the cell membrane and the nuclear membrane

Cytosol the part of the cytoplasm containing highly organised fluid material with dissolved substances; excludes the organelles

Disaccharide two linked monosaccharide molecules

DNA (deoxyribonucleic acid) an information molecule that is the universal basis of all organisms' genetic material; it contains instructions, written in a chemical code, for the production of proteins by each cell

Electron microscope a microscope that uses an electron beam instead of light, and electromagnets instead of glass lenses; interactions between the electrons and the object are recorded on a photographic plate, which then forms a viewable image on a screen

Endocytosis the movement of solids or liquids into a cell from the environment via vesicle formation

Endoplasmic reticulum (ER) an organelle in eukaryotic cells consisting of an interconnecting system of thin membrane sheets dividing the cytoplasm into compartments and channels; lipid synthesis occurs here

Endosymbiotic theory the theory suggesting that chloroplasts and mitochondria arose from ancient prokaryote cells that were ingested by other prokaryote host cells

Enzyme a specific biological catalyst that increases the rate of a chemical reaction without being altered itself by lowering the amount of energy required for the reaction to proceed

Eukaryote a complex type of cell with a nucleus and membrane-bound organelles; a member of Domain Eukarya

Exocytosis the movement of solids or liquids from a cell to the environment via vesicle formation

Golgi apparatus a collection of membranes that package and store substances into vesicles in preparation for their release from the cell

Glycoprotein a protein molecule with an attached carbohydrate chain

Heterotroph an organism that cannot synthesise its own organic compounds from simple inorganic materials; it depends on other organisms for nutrients and energy requirements

Inorganic compounds small, simple compounds which do not contain both carbon and hydrogen; for example, water and carbon dioxide

Intercellular occurring between cells

Intracellular occurring within a cell

Ion an atom or molecule that has an electrical charge due to losing or gaining electrons; used by cells as reactants for many cellular processes

Lipid a type of organic molecule that includes fats and oils; insoluble in water

Lysosome an organelle within the cytoplasm containing digestive enzymes

Magnification the scaling up of an object's size; a measure of the degree of enlargement of an observed object, measured by multiples such as 4×, 10×, 40× and 100×

Messenger RNA (mRNA) a ribonucleic acid formed in the nucleus that has a sequence complementary to DNA; it travels to the cytoplasm where its information is read by ribosomes to determine which amino acids are joined together to form proteins

Metabolism the sum of all the biochemical reactions in an organism; can be divided into two types, catabolic reactions and anabolic reactions

Microscopy the technical field of using microscopes to view samples and objects that cannot be seen with the unaided eye (objects that are not within the resolution range of the eye)

Mitochondrion an organelle within the cytoplasm that is the site of cellular respiration, releasing energy for the cell

Monomer a small molecule that acts as a building block for macromolecules

Monosaccharide a simple sugar, such as glucose, which cannot be broken down into smaller sugar molecules

Nucleic acid a large organic molecule made up of nucleotides; DNA and RNA are the information-carrying molecules of the cell

Nucleolus a site for assembling protein and RNA that will later form ribosomes; visible in a non-dividing cell

Nucleotide an organic compound composed of a sugar, a phosphate group and a nitrogenous base; a subunit of DNA and RNA

Organelle a structure, most often membrane-enclosed, that is suspended in the cytosol of a cell and that performs a specialist function; only eukaryotes have membrane-bound organelles

Organic molecules large, complex carbon compounds usually derived from a living thing; for example, glucose and starch

Photosynthesis a metabolic process that converts the Sun's light energy into stored chemical energy in the bonds of carbohydrates; carbon dioxide and water combine in the presence of light and chlorophyll to produce sugars and oxygen

Plasmid a small, circular piece of DNA that is found in bacteria and is able to replicate independently of the cell's main chromosome

Polymer a large molecule built up from linking smaller molecules together

Polysaccharide a type of complex carbohydrate that is made up of linked simple sugars

Prokaryote a simple type of cell that lacks a nucleus and membrane-bound organelles; a member of domains Archaea or Bacteria

Protein a large organic molecule, built up of amino acids, with specific structural and functional roles in living things; includes enzymes

Resolution the measure of the clarity of the image; can be described as the minimum distance between two distinguishable but separate points

Ribosome a small structure present in high numbers in all cells that builds amino acids into complex proteins; this organelle is not bound by a membrane

RNA (ribonucleic acid) the single-stranded nucleic acid that functions in transcribing and translating information from DNA into proteins

Rough endoplasmic reticulum (rough ER) endoplasmic reticulum with ribosomes attached

Smooth endoplasmic reticulum (smooth ER) endoplasmic reticulum with no ribosomes attached

Stem cell an unspecialised, immature cell capable of giving rise to different kinds of specialised, differentiated cells

Stroma the jelly-like semi-fluid interior of a chloroplast

Thylakoid membrane the interconnected folded membranes within chloroplasts

Triglyceride a simple lipid formed by linking glycerol with three fatty acids

Unicellular having a single cell

Vesicle a small, membrane-bound sac in the cytoplasm that transports, stores or digests substances

CHAPTER 8 REVIEW QUESTIONS

Remembering

1 Match each structure with its function.

ORGANELLE/STRUCTURE		FUNCTION	
a	nucleus	i	collecting and packaging centre of the cell
b	endoplasmic reticulum	ii	photosynthesis and storage
c	lysosome	iii	transport of substances around the cell
d	mitochondria	iv	stores chromatin (DNA and its proteins) and is the control centre of the cell
e	Golgi apparatus	v	aerobic respiration, which releases energy to the cell
f	chloroplast	vi	breakdown of materials

Understanding

2 Distinguish between:
- a structure and function
- b a chloroplast and chlorophyll
- c organic and inorganic
- d rough and smooth endoplasmic reticulum.

3 Compare the structure and function of mitochondria and chloroplasts.

Applying

4 a Describe features that are common to all cells.
- b Describe features that are unique to:
  - i prokaryotic cells
  - ii eukaryotic cells.

5 Certain cells have densely packed mitochondria and the cristae (infolded projections of a mitochondrion) are very close together. What would you predict about the function of such cells? Explain your reasoning.

6 Explain why some organisms are able to live without light but others cannot.

7 A cell has been likened to a factory or an office. This type of analogy is useful when considering the structures and functions of cells. A factory is a place where products are made, exported from the factory and distributed for sale. Raw materials and energy are needed for the manufacture of the products.
- a Using the following components of a factory, describe a structure or function of a cell that is similar. For example, a factory has outside walls; all cells have a membrane and some types of cells also have cell walls.

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Factory: goods manufactured; business plans; photocopying room; manufacturing area; warehouse; management offices; assembly workers, warehouse packers; doors; hallways; power source

b Outline one difference between a factory and a cell.

c Suggest another analogy for a cell.

Analysing

8 a State whether the cell shown in Figure 8.33 is from a prokaryote or eukaryote. Give reasons for your answer.

b Identify whether this photograph was taken using an electron microscope or a light microscope. Give your reasons.

c Some organelles may be present in this cell but are not shown in the photograph. Suggest why this might be the case.

d Name the organelles that have arrows pointing to them.

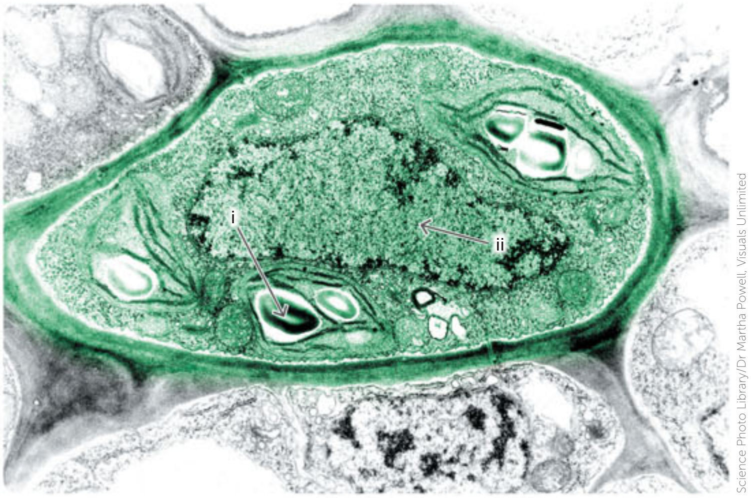

FIGURE 8.33 An unidentified cell

9 One of the jobs of our white blood cells is to engulf potentially dangerous bacteria and destroy them. Explain why there are a large number of lysosomes present in white blood cells.

10 If you were asked to classify a particular type of cell, name the structures you would look for. Suggest whether the structures present would allow you to predict the function of the cell.

Evaluating

11 The freshwater bacterium *Gemmata obscuriglobus* has its DNA packaged in a membrane envelope. Recently, Australian scientists showed the bacterium 'swallows' large particles in a process similar to endocytosis. Explain why scientists are now questioning whether *G. obscuriglobus* is classified correctly as a bacterium.

12 If plant cells can make their own food, explain why they need mitochondria.

13 Radioactively labelled amino acids were supplied to a pancreatic cell that produces digestive enzymes to be released into the digestive system.

a In which organelles of the cell would they be subsequently detected? List them in order.

b In what form would they appear in these organelles? You might like to present your answer as a diagram.

Creating

14 Suggest why it is said that carbon is the element on which all life depends.

Reflecting

15 Predict what our world would be like today if electron microscopes had not been developed. Suggest how your life would be different.

PRACTICE EXAM QUESTIONS

1 The element nitrogen always occurs in which of the following organic compounds?
A proteins
B carbohydrates
C lipids (fats)
D starches

[Q3 2011 SCSA]

Questions 2–4 relate to a student viewing a smear of red blood cells under a microscope.

[Q5-7 2011 SCSA]

2 The microscope is set with an ocular of 10× and an objective of 10×. To increase the magnification to 400×, the student should set the:
A ocular to 20× and objective to 40×.
B ocular to 20× and the objective to 15×.
C objective to 20× and leave the ocular unchanged.
D objective to 40× and leave the ocular unchanged.

3 When the magnification is increased to 400×, which of the following will increase?
A resolution of the image
B number of cells visible
C diameter of the field of view
D depth of the field of view

4 The student estimated the average diameter of the red blood cells to be 7.6 µm. What is the average diameter of these cells in millimetres (mm)?
A 0.76
B 0.076
C 0.0076
D 0.000 76

5 DNA contains the genetic code for the production of:
A carbohydrates.
B lipids (fats).
C proteins.
D starches.

[Q20 2011 SCSA]

6 Mitochondria are the sites of:
A photosynthesis.
B chemosynthesis.
C respiration.
D transpiration.

[Q25 2011 SCSA]

7 Lipids are organic molecules that are:
A found in animals but not in plants.
B the main components of chromosomes.
C products of cellular respiration.
D used for energy storage.

[Q28 2011 SCSA]

8 Distinguish between the terms ‘autotroph’ and ‘heterotroph’. (2 marks)

[Q31 2010 SCSA]

9 a Draw a plant cell and label 6 features (6 marks)
b Name two features that are present in plant cells but not in animal cells. (2 marks)
c Name two differences between prokaryotic and eukaryotic cells. (2 marks)

[Q38 2011 SCSA]

10 Examine the cell drawing in Figure 8.34.

a Name the structures A to D. (4 marks)

b State and describe briefly one (1) function of structures A and C. (4 marks)

[Q32 a and b 2010 SCSA]

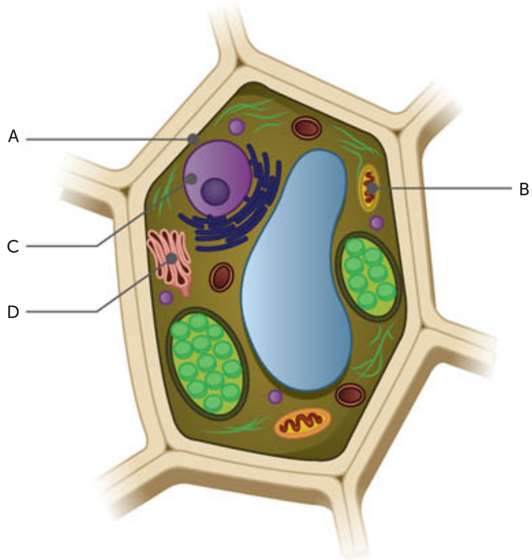

FIGURE 8.34 A cell drawing

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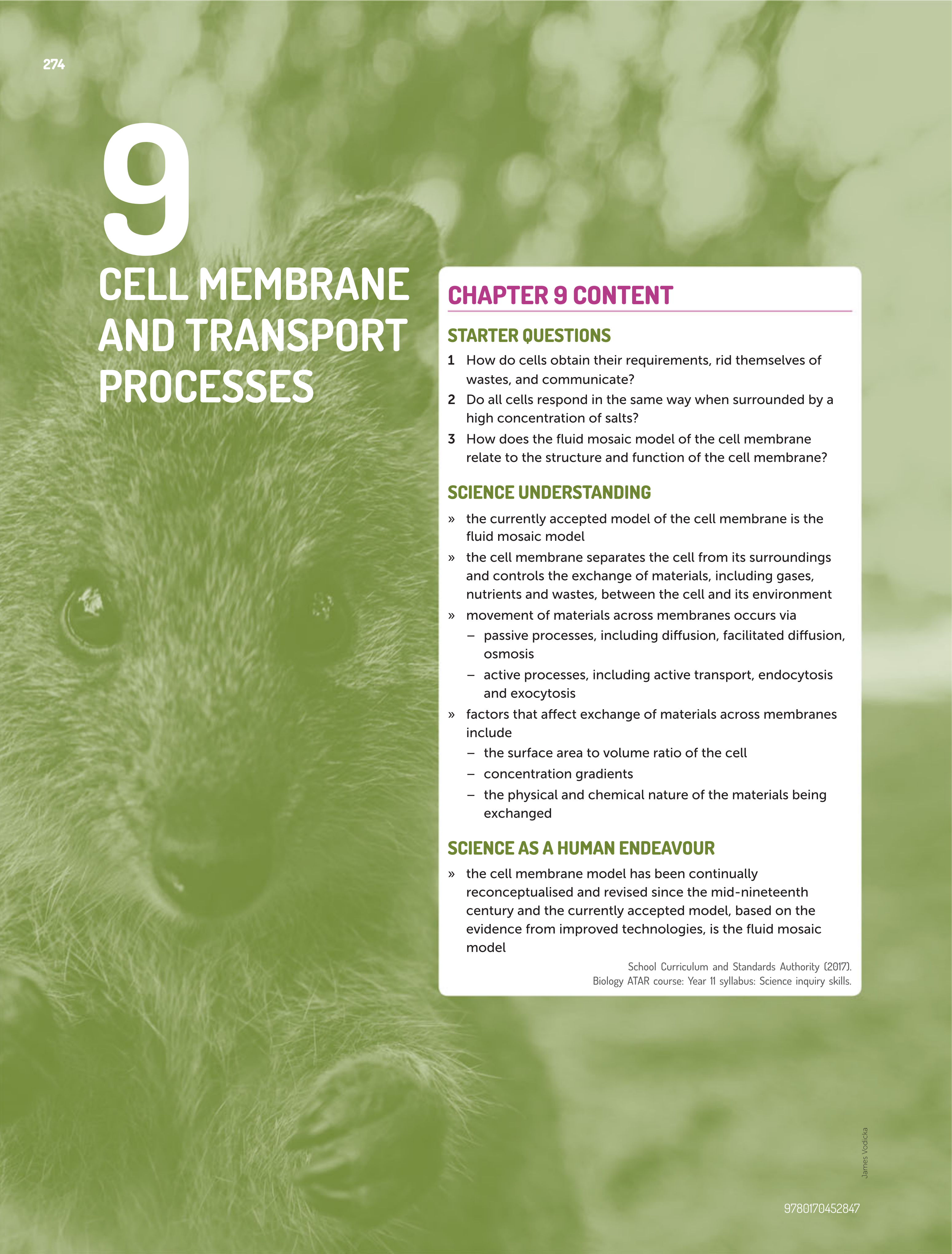

9 CELL MEMBRANE AND TRANSPORT PROCESSES

CHAPTER 9 CONTENT

STARTER QUESTIONS

1 How do cells obtain their requirements, rid themselves of wastes, and communicate?
2 Do all cells respond in the same way when surrounded by a high concentration of salts?
3 How does the fluid mosaic model of the cell membrane relate to the structure and function of the cell membrane?

SCIENCE UNDERSTANDING

» the currently accepted model of the cell membrane is the fluid mosaic model
» the cell membrane separates the cell from its surroundings and controls the exchange of materials, including gases, nutrients and wastes, between the cell and its environment
» movement of materials across membranes occurs via
  – passive processes, including diffusion, facilitated diffusion, osmosis
  – active processes, including active transport, endocytosis and exocytosis
» factors that affect exchange of materials across membranes include
  – the surface area to volume ratio of the cell
  – concentration gradients
  – the physical and chemical nature of the materials being exchanged

SCIENCE AS A HUMAN ENDEAVOUR

» the cell membrane model has been continually reconceptualised and revised since the mid-nineteenth century and the currently accepted model, based on the evidence from improved technologies, is the fluid mosaic model

School Curriculum and Standards Authority (2017). Biology ATAR course: Year 11 syllabus: Science inquiry skills.

James Vodicka

9.1 THE CELL MEMBRANE: SELECTIVELY PERMEABLE

In both multicellular and unicellular organisms, each cell is an independent unit enclosed by a **cell membrane** (also known as a plasma membrane). The cell membrane forms the boundary between the **internal environment** of the cell – the **cytoplasm** – and its **external environment**. Its functions include the recognition of other cells, the transportation of materials into and out of the cell, the provision of attachment sites for enzymes and hormones, and in nerve cells, the transmission of neural impulses. Both the physical and chemical properties of the cell membrane enable it to control the exchange of materials and messages. Organelle membranes have the same general structure as cell membranes.

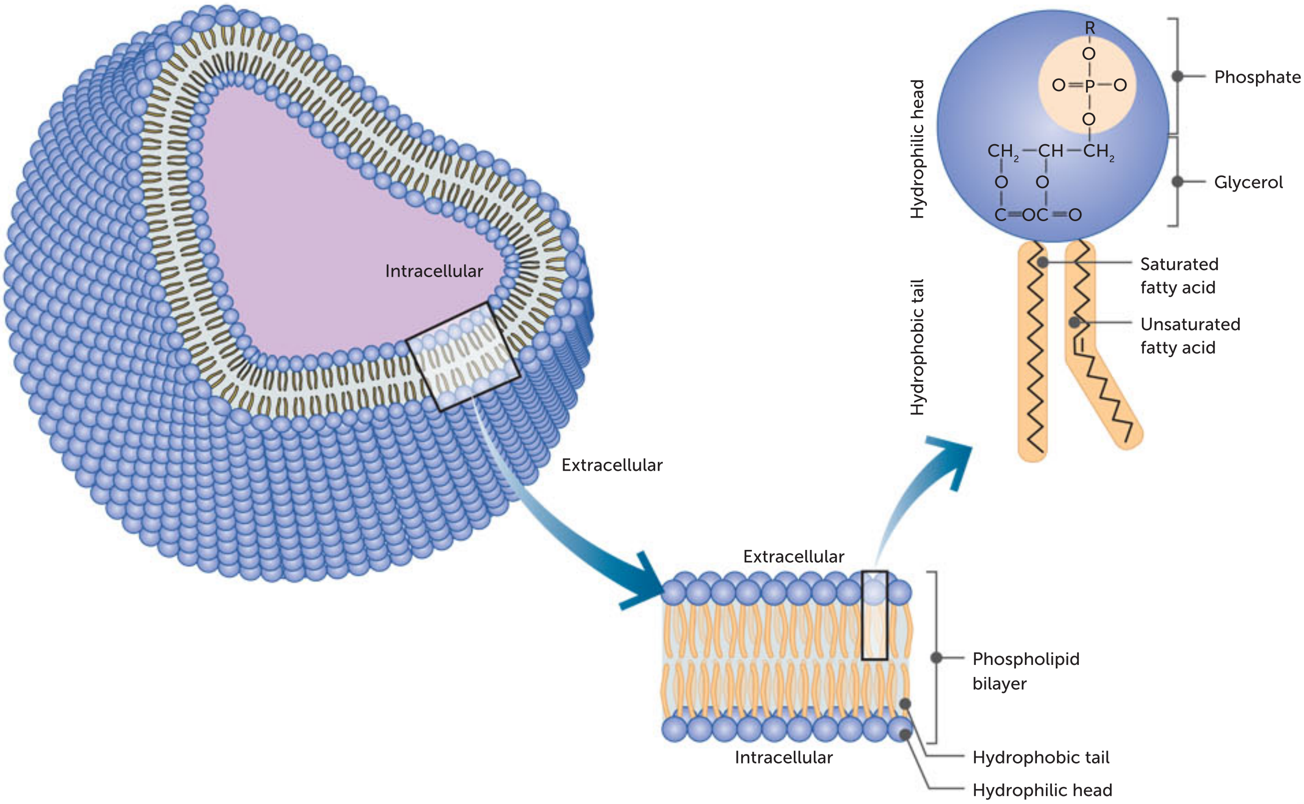

FIGURE 9.1 A simplified model of the cell membrane and its intracellular and extracellular environment

In plants, bacteria, fungi and many algae, a cell wall surrounds the cell membrane and adds strength and support. It is **permeable**, allowing the passage of almost all materials. It is not the cell wall, but the **selectively permeable** cell membrane that controls the movement of substances into and out of cells.

Key concept

Cell membranes (plasma membranes) have a structure that enables them to carry out many functions, including recognising other cells; transporting materials; providing attachment sites for enzymes and hormones; and in nerve cells, enabling transmission of nervous impulses.

An amoeba is a **unicellular** freshwater organism, meaning the whole organism consists of a single cell. It is continuously interacting with its pond environment via its cell membrane. When feeding, an amoeba can sense food particles, ignoring silt and other indigestible material. As a protective boundary, the membrane allows the entrance of some molecules, such as oxygen, but excludes others, some of which could damage the cell's contents. The cell membrane is a very flexible structure, flowing like a liquid when the amoeba moves or engulfs food (Figure 9.2).

Multicellular organisms, whether they are plants or animals, are made up of many cells, each surrounded by a cell membrane. These cells also exchange substances with their external environment, which for most cells is the **extracellular fluid**. Extracellular fluid is all body fluid outside the cells of any multicellular organism. Extracellular fluid bathes the outside of the cell membrane, providing the liquid medium through which nutrients are supplied and wastes are removed. Each of the cells in **tissues** communicates via the cell membrane with many other types of cells. This communication can cause cells to grow or differentiate into a specialised cell or die.

FIGURE 9.2 A scanning electron micrograph of an amoeba surrounding its prey *(Tetrahymena)* demonstrates the flexibility of the cell membrane.

Key concept

The cell membrane controls the exchange of material between the internal and external environments of the cell.

The internal and external environments of cells

The internal environments of cells are distinct and very different from their external environments. For example, almost 99% of the mass of an average human body is made up of only six elements: carbon, oxygen, hydrogen, nitrogen, calcium and phosphorus. Table 9.1 shows that the proportions of these elements are very different in the human body compared with the external environment in the earth, seawater and atmosphere.

TABLE 9.1 A comparison of the proportion of different elements in the human body, earth, seawater and the atmosphere

ELEMENT	SYMBOL	PERCENTAGE IN HUMAN BODY	PERCENTAGE IN EARTH	PERCENTAGE IN SEAWATER	PERCENTAGE IN ATMOSPHERE
Carbon	C	18	0.03	0.0028	0.039455
Oxygen	O	65	47	86	21
Hydrogen	H	10	0.14	11	0.000055
Nitrogen	N	3	trace	negligible	78
Calcium	Ca	1.5	3.6	0.04	negligible
Phosphorus	P	1.1	0.07	negligible	negligible

Unicellular organisms often live in dynamic environments, such as freshwater ponds, where conditions may change quickly. An amoeba living in a freshwater pond could experience a significant increase in salinity if run-off from the land carries minerals into its pond environment. An organism living in brackish (slightly salty) water could have the opposite problem after heavy rain. Unicellular organisms must control the movement of substances across their cell membrane to cope with rapid changes like these.

The cells in multicellular organisms are more protected from swings in environmental conditions because they are surrounded by extracellular fluid. In humans, the contents of this liquid are kept fairly constant by the workings of various organs such as the lungs, kidneys and liver. Nevertheless, the internal cellular environment has very different concentrations of some substances compared with the extracellular environment (Table 9.2).

TABLE 9.2 A comparison of the concentration of various ions inside and outside the cell in multicellular organisms

TYPE OF ION	EXTRACELLULAR CONCENTRATION (mmol/L)	INTRACELLULAR CONCENTRATION (mmol/L)
Sodium	145	15
Potassium	4.5	120
Chloride	116	20
Calcium	1.2	10

Table 9.2 shows that the level of potassium **ions** is more than 26 times greater inside a cell compared with the level in extracellular fluid. Other ions are significantly more concentrated outside the cell. The cell membrane is responsible for maintaining this concentration difference. It can do this because it is selectively permeable, allowing some substances through the membrane, but not others.

Depending on its activities, a cell will need to take in certain useful molecules and ions from the external environment and excrete others. For example, a cell that is producing protein needs to take in a variety of amino acids. When substances such as calcium ions are used as signals for cell communication, their levels inside cells need to be controlled.

Many cellular reactions need specific conditions in order to occur efficiently and effectively. Cellular processes such as photosynthesis and respiration use **enzymes** to speed up chemical reactions to a point where each step proceeds smoothly to the next. Enzymes can only perform their tasks within narrow temperature and pH ranges. Hydrogen ion concentrations must be kept within strict limits to maintain suitable pH levels in the **cytosol**. Toxic waste products need to be removed to ensure they do not interfere with chemical reactions in the cytoplasm. For all these reasons, the cell membrane must regulate the internal environment of the cell.

Question set 9.1

REMEMBERING

1 Draw an animal cell and label the following parts:
  - **a** cytoplasm
  - **b** cell membrane
  - **c** an organelle membrane
  - **d** intracellular fluid
  - **e** extracellular fluid.

2 Refer to Figure 9.1. What is the main component of cell membranes and how many layers are there of this component?

UNDERSTANDING

3 Contrast the terms permeable, semipermeable and impermeable.

4 Analyse Table 9.2. Name:
  - **a** one ion that is more highly concentrated in the extracellular environment than the intracellular environment
  - **b** one ion that is more concentrated in the intracellular environment than the extracellular environment.

Development of the cell membrane model

SCIENTIFIC LITERACY

Although cells were named and described by Robert Hooke and Antonie van Leeuwenhoek in the 17th century, it wasn't until the late 19th century before scientists began to understand the nature of the cell membrane. An important reason for this delay was that the membrane is so thin that it cannot be seen through a light microscope. This means if a typical cell of 30 micrometres (μm) was enlarged 10 000 times to the size of a watermelon (30 cm), the cell membrane would still only be equal to the thickness of a piece of paper.

Scientists had to take an indirect approach to model the structure of the cell membrane, making predictions from its physical and chemical properties decades before it could be seen. In the mid-1890s, Charles Ernest Overton demonstrated that lipid-soluble substances such as ether and chloroform readily enter cells. This suggested that the cell membrane was composed of lipid.

A series of pioneering experiments in 1925 indicated that the membrane consisted of a double layer of lipids, referred to as a lipid **bilayer**. A decade later, to account for the

observation that up to half of the mass of cell membranes was protein, Hugh Davson and James Danielli proposed a model in which the lipid bilayer was coated on either side with a layer of proteins, rather like a lipid sandwich. In the 1950s, direct observation of the membrane with the newly invented electron microscope appeared to confirm this model, which became widely accepted and was extended to all cell and organelle membranes.

Not all experimental observations made over the next decade fitted neatly with predictions made based on the Davson–Danielli model. The model did not explain the fluidity of the membranes observed in living cells and why different membranes differ in composition and function. In 1972, S.J. Singer and Garth Nicolson proposed a new model that was able to explain all the physical and chemical properties of membranes known at that time. This **fluid mosaic model**, as they called it, hypothesised that discrete, globular protein molecules were embedded in the lipid bilayer, not overlying it. Furthermore, they proposed that these proteins moved around within the flexible lipid bilayer, and that many of them penetrated from one side to the other. With some modifications, this model is still used today. It colourfully describes membrane proteins as 'icebergs floating in a sea of lipids'.

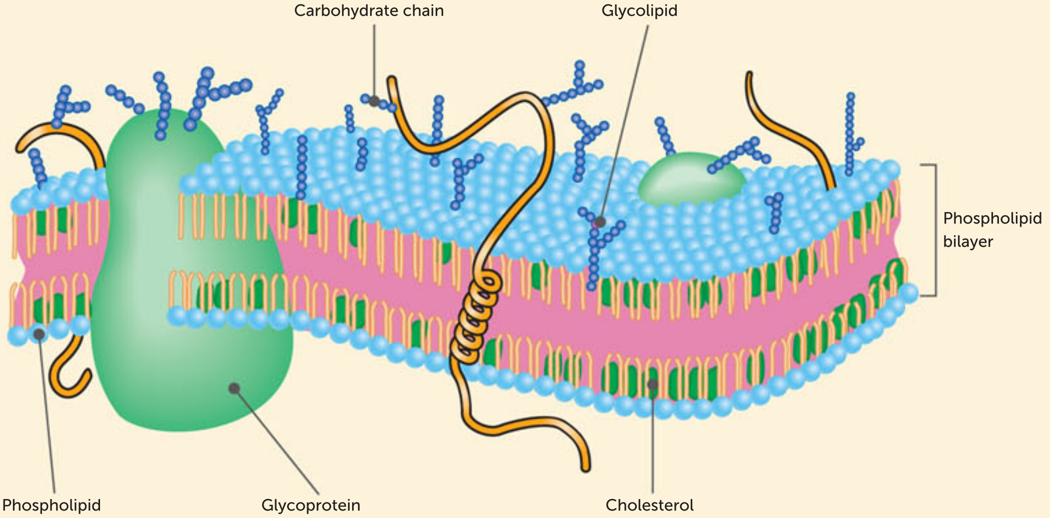

FIGURE 9.3 A three-dimensional view of a cell membrane based on the fluid mosaic model

The determination of the structure of the cell membrane gives a fascinating insight into the nature of scientific models and the way scientific concepts progress. Scientists develop models based on the available evidence, communicating their ideas by publishing their work for scrutiny by other scientists. As more evidence becomes available, often through technological advances such as the invention of the electron microscope, the model may be modified, revised or even replaced.

The Davson–Danielli model of membrane structure survived for decades before major revision. This makes it an important contribution to our understanding of the cell membrane, even though it was ultimately shown to be an inaccurate representation. It is important to understand that models are proposed as a hypothesis. They are used to organise and explain existing knowledge, as well as to generate predictions that can be tested with further research. Ongoing research, such as investigating the structure of these proteins, continues to refine the fluid mosaic model. Therefore, it is possible that substantial modifications or even a new model could be seen in the future.

Questions

1 Explain why Singer and Nicolson used the words 'fluid', 'mosaic' and 'model' to describe their ideas.

2 In a table, describe the similarities and differences between the Davson–Danielli and Singer–Nicolson models.

3 A technique called freeze-fracture electron microscopy has been used to investigate the structure of membranes. Research the technique and briefly summarise:

  a the way images are obtained

  b what those images show.

4 Using an example, construct an argument to support the statement: 'Advances in science understanding in one field can influence other areas of science, technology and engineering.'

5 It has been said that the development of complex models often requires a wide range of evidence from multiple individuals and across disciplines. Use the example of modelling the structure of membranes to either support or refute this statement.

9.2 MEMBRANE STRUCTURE AND THE FLUID MOSAIC MODEL

The structure of a cell membrane is complex, and it is easier to describe and explain the structure with the use of a model. The currently accepted model of the cell membrane is the fluid mosaic model. Like all models, the fluid mosaic model is our best representation of a real phenomenon, and is refined as new research reveals more about membrane structure and function.

The fluid mosaic model describes membranes as a double layer of lipids, a lipid bilayer, with the ability to flow and change shape, like a two-dimensional fluid. Specialised protein molecules are embedded in the lipid in various patterns, like a mosaic. Some of these proteins can move laterally, and others are fixed in position. Both proteins and phospholipids help to control the exchange of materials between the external and internal environments. The ability of the cell membrane to keep the concentration of substances inside cells fairly constant and very different from the external environment depends on its structure.

Fluid mosaic model
This resource describes the cell membrane as a tapestry of several types of molecules.

Bozeman Science: Cell membranes
Watch this video to gain an overview of cell membrane structure and function.

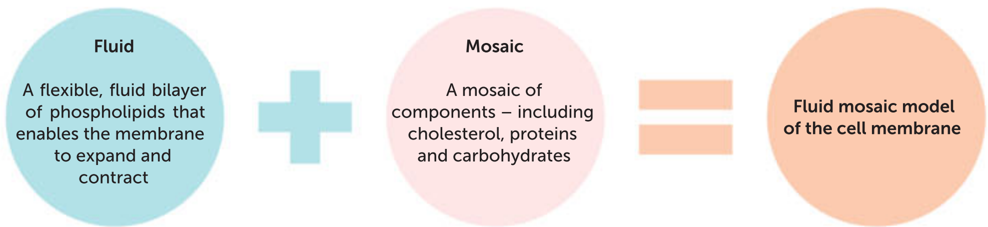

FIGURE 9.4 The combination of the flexible and fluid phospholipid bilayer, with its mosaic of proteins, cholesterol and carbohydrate chains

Key concept

The fluid mosaic model describes membranes as a double layer of lipids (a lipid bilayer), which can flow and change shape, with specialised protein molecules embedded in various patterns.

Phospholipid bilayer

The lipid bilayer is composed of subunits called phospholipids. Each phospholipid can be represented by a head and two tails (Figure 9.5). A phosphate group on the head makes this end **hydrophilic** (able to absorb water or dissolve in water), while the fatty acid tails are **hydrophobic** (water-avoiding

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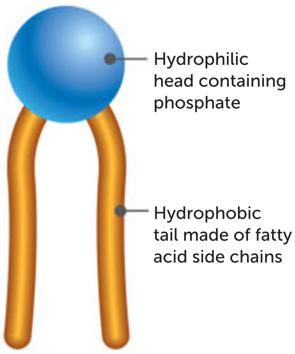

FIGURE 9.5 A phospholipid molecule. The hydrophilic head is attracted to water, whereas the hydrophobic tails repel water.

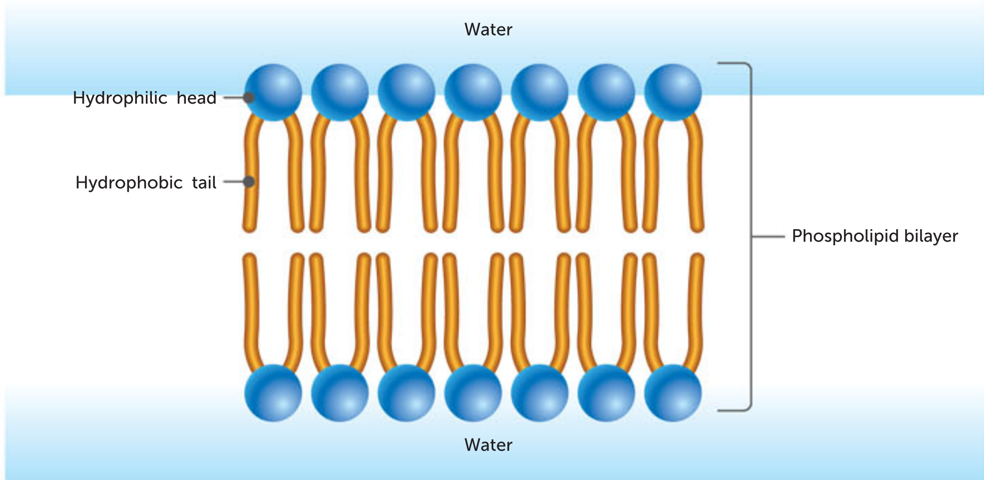

FIGURE 9.6 A representation of the way phospholipids form a bilayer in membranes

or unable to dissolve in water). This means that while the heads are attracted to water, the tails are repelled. These molecules spontaneously form a bilayer, with the fatty acid tails turned inwards, away from the watery environment of the cytosol, and towards each other (Figure 9.6), rather like salad oil forming a film on the surface of water.

In animal cells, another type of lipid called **cholesterol** is interspersed among the phospholipid molecules. Cholesterol is an important lipid in the membrane as it helps to maintain cell membrane stability at varying temperatures. When the temperature changes, the cholesterol present between the phospholipids maintains the right level of fluidity in the membrane. In plants and bacteria, it is phytosterol (not cholesterol) that stabilises membrane flexibility.

The lipid components of all membranes, whether from plants, animals or bacteria, provide membranes with the unique properties of being flexible and able to repair themselves. This allows cells to change shape and grow. During cell division and vesicle formation, membranes can break and reassemble themselves. Additionally, if the cell membrane is punctured, some of the cytoplasm will leak out but the hole will quickly seal. Some techniques used in biotechnology make use of this property when the inside of a cell needs to be accessed (Figure 9.7).

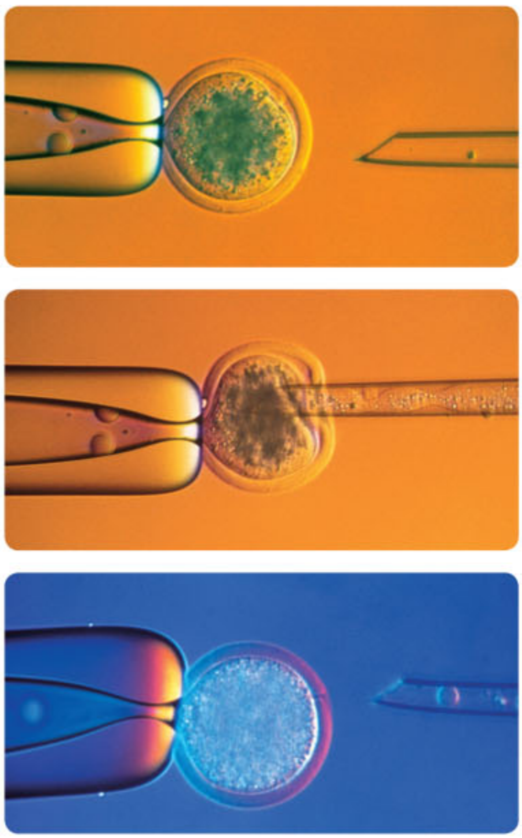

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FIGURE 9.7 Puncturing and resealing the membrane of a cell: this sequence of micrographs shows the removal of the nucleus of an egg cell.

Cell membrane proteins

A range of proteins is embedded in the phospholipid bilayer. Transmembrane proteins are those proteins that extend across the entire membrane, past the hydrophilic heads and hydrophobic tails. They function as **transport proteins** by controlling the entry and exit of substances to and from the cell (Figure 9.8). These proteins have evolved to enable interaction and communication between cells, and the exchange

Active cell membranes
Watch the video, noting the fluid and flexible cell membranes.

of substances between cells and the external environment. Transport proteins act as passageways that allow specific substances to move across the membrane. An example is the rapid movement of ions across the membrane when a nerve is stimulated. This causes a dramatic change in the electric potential difference (the difference in positive and negative charges) across the membrane and explains how the electrical charge of a nerve impulse is transmitted along nerve cells. In contrast, peripheral proteins do not extend into the middle region of the phospholipid bilayer (containing the hydrophobic tails). Instead, they sit bound to the surface of the cell membrane.

Transport proteins assist the movement of ions, small molecules and macromolecules across the membrane, to enter or exit the cell. There are two main types of transport proteins: channel proteins and carrier proteins.

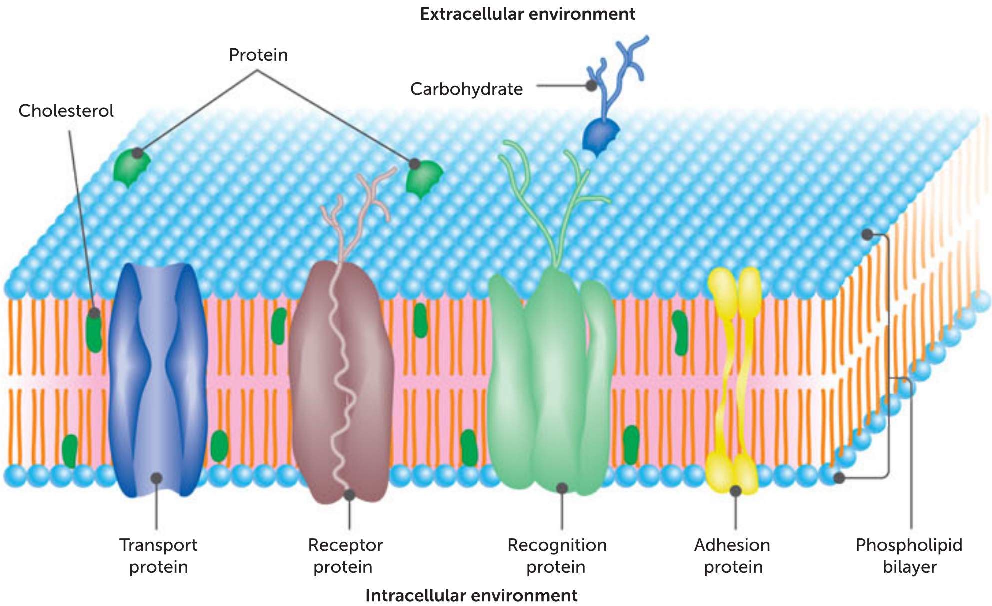

FIGURE 9.8 A view of part of the cell membrane, showing embedded proteins

Channel proteins (ion channels)

channel proteins catalyse the movement of specific ions and some simple molecules (such as water) down each substance's own electrochemical gradient. They help these substances across the membrane via **passive transport**, in a process called **facilitated diffusion**. Passive transport and facilitated diffusion are **passive processes** because they do not require energy to move substances. They are also generally referred to as **diffusion**. An example of a protein channel is the calcium channel, which can only facilitate the transport of calcium in and out of the cell. Channel proteins that facilitate the transport of water are called **aquaporins**. Aquaporins selectively allow water to pass along its **concentration gradient**.

Carrier proteins (transporters)

carrier proteins have to change shape to pass a molecule across the membrane. Many of these use energy from **ATP (adenosine triphosphate)** to transport specific small molecules or ions *against* their concentration gradient. For example, the **sodium–potassium pump** maintains the electrochemical gradient (and the correct concentrations of sodium and potassium ions) in living cells. The sodium–potassium pump moves potassium ions into the cell while at the same time moving sodium ions out, at a ratio of three sodium ions for every two potassium ions moved in.

In addition, some carrier proteins facilitate movement of ions or molecules (i.e. glucose) along their concentration gradient, which does not require energy and is therefore an example of passive transport.

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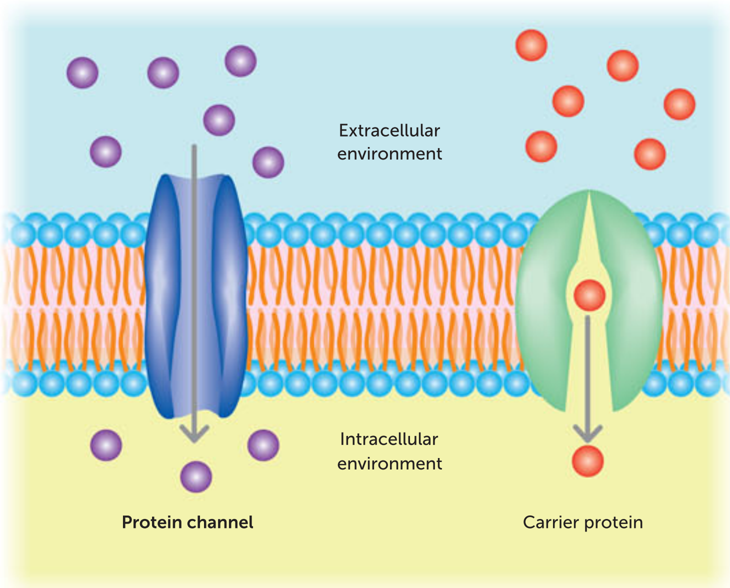

FIGURE 9.9 Channel proteins versus carrier proteins

Visualising the cell membrane
Work through the animation and complete the quiz.

Cell membrane structure
Explore this full summary of transport across cell membranes.

Cell membrane rap
Membrane structures are explained in a rap lecture.

Tutorial
See how the structure and functions of cell membranes are related.

Other membrane proteins

Other examples of membrane proteins in multicellular organisms include **adhesion proteins**, which link cells together to maintain both the three-dimensional structure and the normal functioning of tissues.

Membrane proteins are also involved in cellular communication. **Receptor proteins** bind hormones and other substances that cause changes to the cell's activities. Different types of cells have different receptor proteins, enabling them to respond to only certain signals and so carry out specific functions.

Key concept

The cell membrane forms the boundary between a cell and its external environment. Its phospholipid bilayer and embedded proteins control the movement of substances into and out of the cell (between the internal and external environments).

Question set 9.2

REMEMBERING

1 Describe the fluid mosaic model of the cell membrane.
2 Describe the double-layered cell membrane.
3 State the types of molecules responsible for each of the following features of the cell membrane.
  a ability to bind hormones
  b flexibility
  c movement of ions into cells
4 Describe the functions of cholesterol in a cell membrane.

UNDERSTANDING

5 Compare channel proteins with carrier proteins.
6 Describe the different properties of phospholipid molecules in relation to water molecules.
7 Using the data in Table 9.2 (page 277), name one substance that would require passive transport and one substance that would require active transport along a concentration gradient for movement into a cell.

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9.3 PASSIVE MOVEMENT ACROSS MEMBRANES

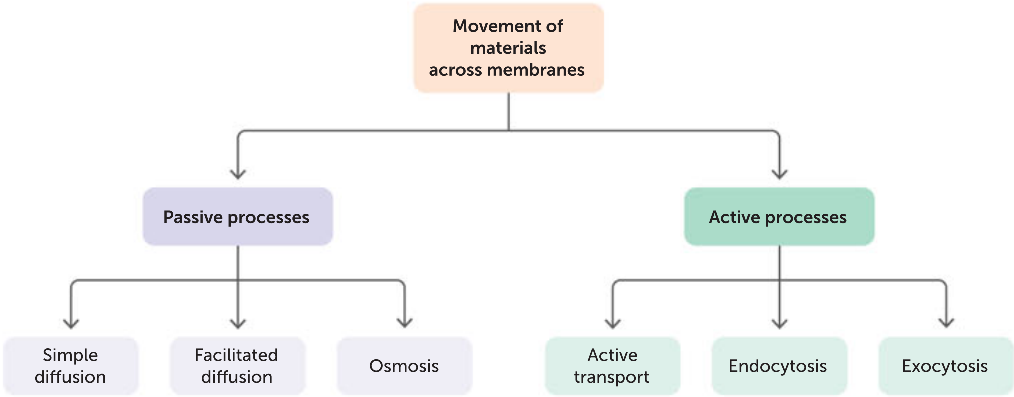

FIGURE 9.10 An introduction to different types of movement across membranes

Movement of substances that does not require energy is called passive transport. Passive transport is a spontaneous process where materials move down a concentration gradient, from an area of high concentration to an area of low concentration.

A simple analogy to explain passive transport is riding a bicycle. Riding uphill requires you to use energy in your leg muscles. You are actively peddling. Once you are at the top, you can coast passively down the hill, without using energy. Many molecules move across the cell membrane passively, without using energy. This type of movement relies on a process called diffusion.

Simple diffusion

If you drop a crystal of potassium permanganate ($KMnO_4$) into a beaker of water, and you do not stir the contents or move the beaker, what happens? You will find that, over time, the purple colour of the permanganate spreads through the water until eventually it is evenly distributed. As the crystal dissolves, the potassium and the permanganate ions from the crystal separate and move through the water (Figure 9.11).

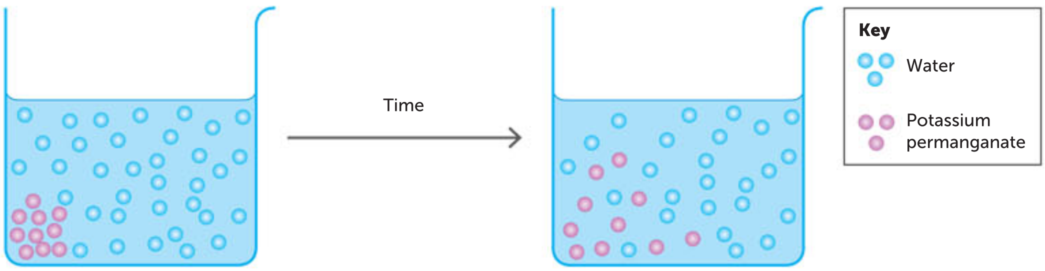

FIGURE 9.11 The diffusion of potassium permanganate in water over a period of time

What causes the particles in the potassium permanganate crystal to behave in this way? The particles dissolving from the crystal are in a state of continuous random motion. They can move in any direction. To start with, there are far more of them near the crystal, increasing the probability that they will move away from the crystal. This causes a net (overall) movement of potassium permanganate particles away from the crystal. This is the process of diffusion.

Diffusion
View the animation.
What is the end result of diffusion?

Diffusion is the net movement of particles from a region of high particle concentration to a region of lower particle concentration. The difference in particle concentration between the two regions is called the concentration gradient. Diffusion occurs because of the random kinetic movement of the particles, and its effects are seen when a concentration gradient exists until the particles are evenly distributed throughout the system. When that happens, **equilibrium** is said to be reached. Particles will continue to move randomly, but at equilibrium they move at equal rates in all directions.

Diffusion is a **passive process** as it does not require additional energy to make it happen. It takes place in gases and liquids, and in both living and non-living systems. Increasing the concentration gradient or heating the particles to make them move faster will increase the rate of diffusion. The **particle theory** (also referred to as the kinetic theory of matter) says that the particles that make up matter are in constant motion, and the higher the temperature, the faster the speed of the particles.

Key concept

A concentration gradient exists when a substance is at a higher concentration in one region compared with its concentration in another region.

Movement of particles down a concentration gradient, from where they are in high concentration to where they are in low concentration, is passive and does not require energy.

Movement of particles up a concentration gradient, from where they are in low concentration to where they are in high concentration, is active and requires energy.

Diffusion across membranes

Small, uncharged molecules such as oxygen, water and carbon dioxide move easily through the cell membrane by simple diffusion. Figure 9.12 shows the simple diffusion of small particles passing between the phospholipid molecules from a high to a low concentration. Oxygen always tends to diffuse into cells because cells use oxygen in cellular respiration, which maintains a low concentration of oxygen in the cytoplasm.

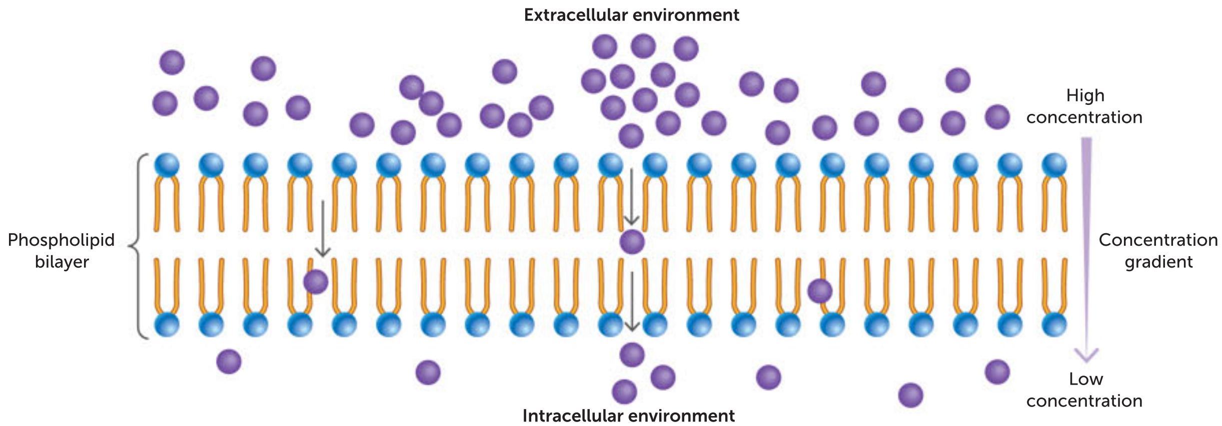

FIGURE 9.12 The simple diffusion of small molecules through the cell membrane is dependent on the concentration gradient.

Alcohols such as ethanol can easily pass through the phospholipid bilayer because they are non-polar and consequently soluble in lipids (unlike water and glucose molecules) (Figure 9.13). This means that they are uncharged molecules that are not repelled by the non-polar tails and they are not soluble in water. Water (which is a polar molecule) can pass through the membrane, but not as easily as alcohols.

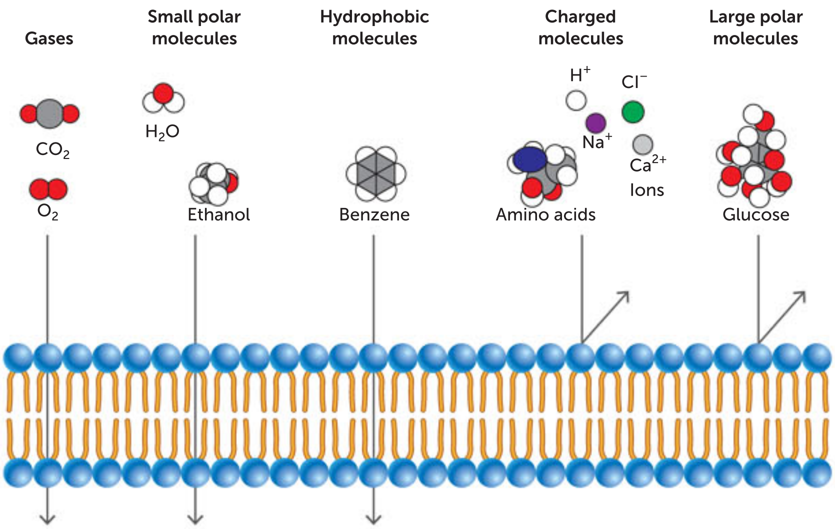

FIGURE 9.13 Some molecules and ions that can and cannot cross the membrane by simple diffusion

Facilitated diffusion

Charged particles (such as sodium and chloride ions) and relatively large molecules (such as glucose and amino acids) do not readily pass through the phospholipid bilayer. In the cell membrane, certain proteins assist such particles to diffuse into the cell. This process is called facilitated diffusion.

Two types of protein are involved in facilitated diffusion: carrier proteins and channel proteins. Carrier proteins bind to specific molecules on one side of the membrane, change shape and release the substance on the other side (Figure 9.14). An example is the glucose transporter protein, which is located in the cell membrane of all types of mammalian cell and carries glucose passively in either direction, depending on the direction of the concentration gradient.

Channel proteins include aquaporins, for facilitated diffusion of water, and ion channels that open and close in response to a stimulus (gated channels). Facilitated diffusion is classified as passive because no energy is needed for the solute particles to move down the concentration gradient from an area of high concentration to an area of low concentration.

Facilitated diffusion
Explain how facilitated diffusion differs from simple diffusion.

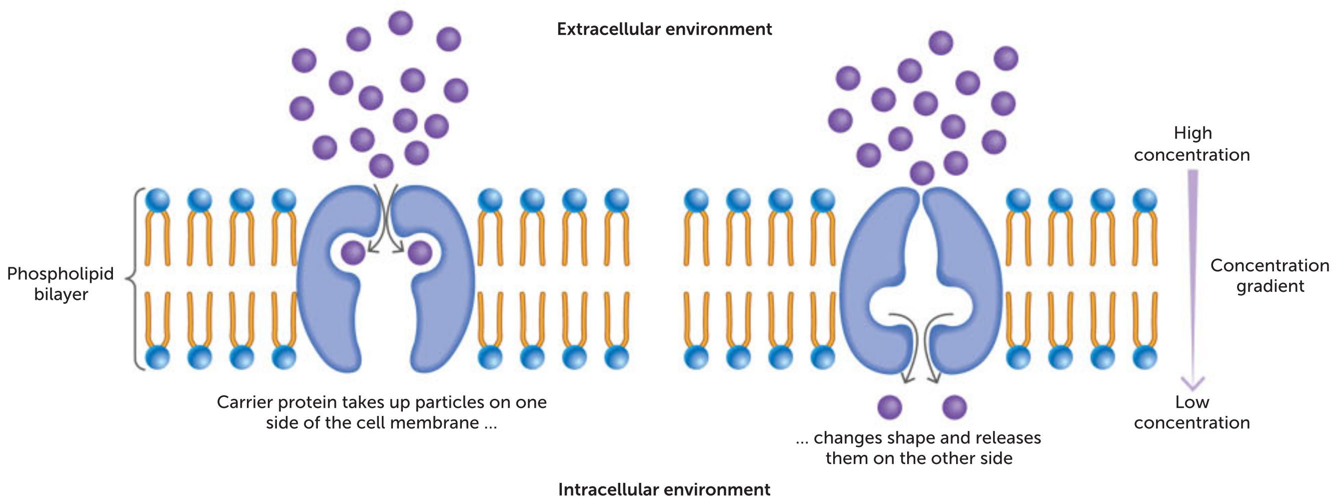

FIGURE 9.14 Facilitated diffusion using a carrier protein in the cell membrane moves particles such as glucose down the concentration gradient.

Channel proteins form narrow passageways through which small ions can diffuse rapidly from a high ion concentration to a lower ion concentration (Figure 9.15). Only ions of a specific size and shape can pass through a particular channel protein.

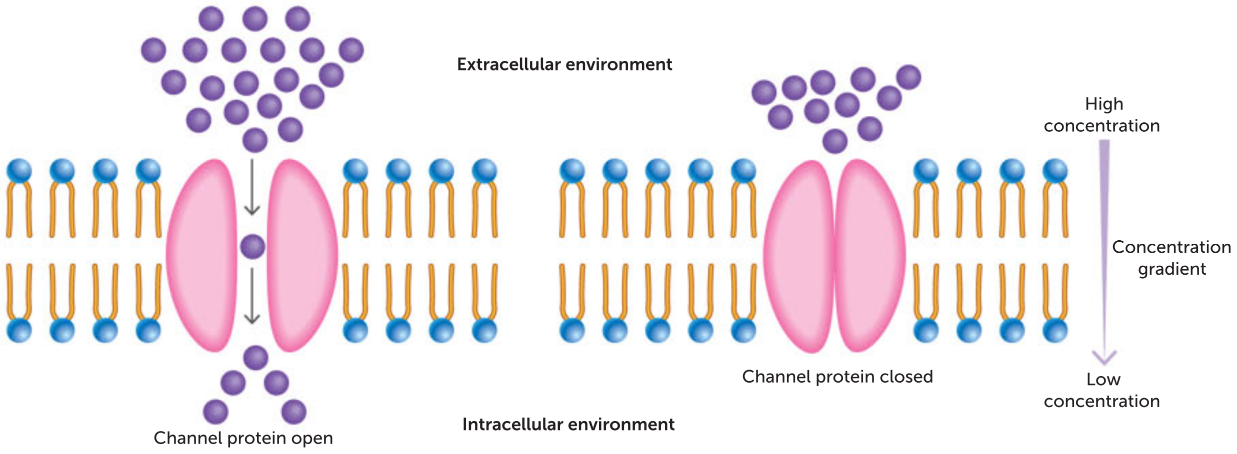

FIGURE 9.15 Facilitated diffusion through a channel protein in the cell membrane. Particles move down the concentration gradient.

Osmosis and diffusion
Further explore osmosis and diffusion by viewing this video.

Osmosis

Osmosis is the diffusion of water through a semipermeable membrane and down its concentration gradient. Water is the medium in which biochemical processes take place. Water also transports materials in **solution**, helps keep cells in shape and forms the fluid that bathes tissues. Water is described as the universal **solvent**. If you add sugar or salt to water, you are adding **solute** to solvent and making a solution. A dilute solution has a relatively high concentration of water molecules compared to solute particles dissolved in it, whereas a concentrated solution has a low concentration of solvent molecules and a high concentration of solute particles (Figure 9.16).

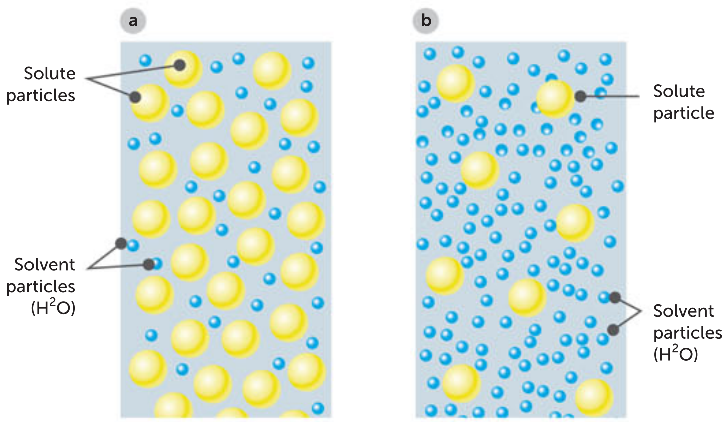

FIGURE 9.16 Making solutions: **a** a concentrated solution; **b** a dilute solution

Key concept

Solution (mixture of particles) = solvent particles + solute particles
High-concentration solution = low concentration of solvent + high concentration of solute
Low-concentration solution = high concentration of solvent + low concentration of solute

Cell membranes are selectively permeable, meaning that water molecules pass through them easily but solutes do not. If the concentration of water molecules inside a cell is lower than the concentration outside, water will diffuse into the cell until a balance or equilibrium is reached (where the net overall movement is zero).

The process of water molecules moving across a membrane is called osmosis. By definition, osmosis is the diffusion of water across a selectively permeable membrane from an area of high water concentration (low solute) to an area of low water concentration (high solute). Osmosis is a special type of diffusion in which water molecules move passively via small gaps between phospholipids and through aquaporins. Similar to diffusion, osmosis requires no input of energy, because water is moving down its concentration gradient (Figure 9.17).

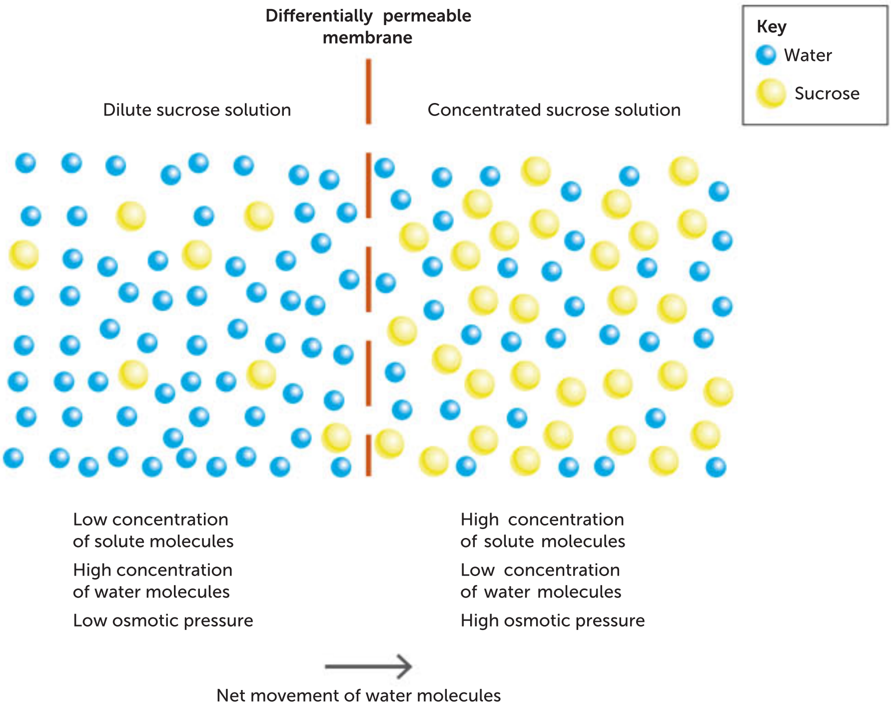

FIGURE 9.17 Osmosis occurs when there are different conditions on the two sides of a differentially permeable membrane.

When two solutions have the same concentration of solutes, they are said to be **isotonic** ('iso' means same) to each other. If the two solutions are separated by a selectively permeable membrane, water will move between the two solutions by osmosis, but there will be no **net change** in the amount of water in either solution (equal numbers of particles cross the membrane in both directions). If cells are placed in solution, and the external solution is isotonic to the cells, the water molecules jostle on both sides of the membrane, moving in both directions equally. Even at equilibrium (when there is the same concentration of solution on both sides), particles do not stop moving across the cell membrane.

When cells are surrounded by a solution that contains a lower solute concentration than their cytoplasm, the external solution is said to be **hypotonic** ('hypo' means lower) to the cells. Water molecules will diffuse through the membrane into the cells because the cells have a lower concentration of solvent (less water). The reverse applies if the cells are surrounded by a solution of higher solute concentration; the external solution is described as **hypertonic** ('hyper' means higher) to the cells, and water molecules will diffuse out.

TABLE 9.3 A summary of hypotonic, isotonic and hypertonic solutions

HYPOTONIC SOLUTION	ISOTONIC SOLUTION	HYPERTONIC SOLUTION
Lower solute concentration in extracellular fluid compared with intracellular fluid	Same concentration of solutions inside and outside the cell	Higher solute concentration in extracellular fluid compared with intracellular fluid
Water moves into cells	No net movement of water	Water moves out of cells

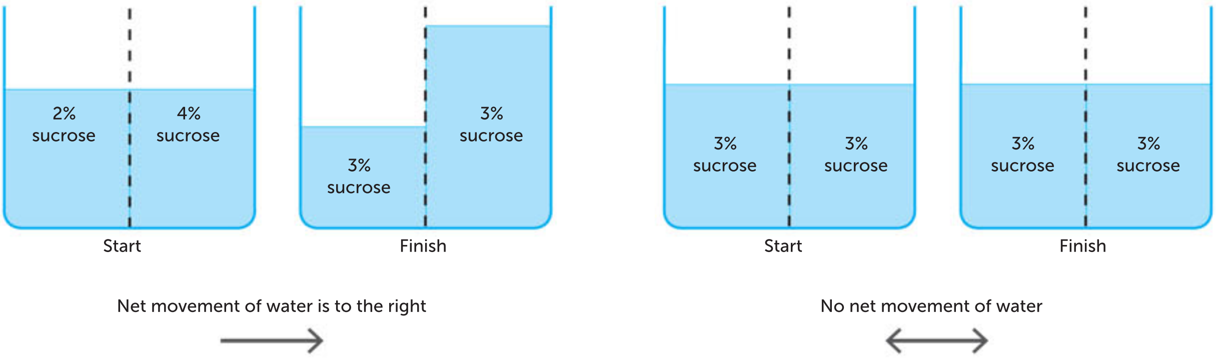

FIGURE 9.18 These diagrams show the net movement of water molecules between solutions separated by a differentially permeable membrane that is impermeable to sucrose.

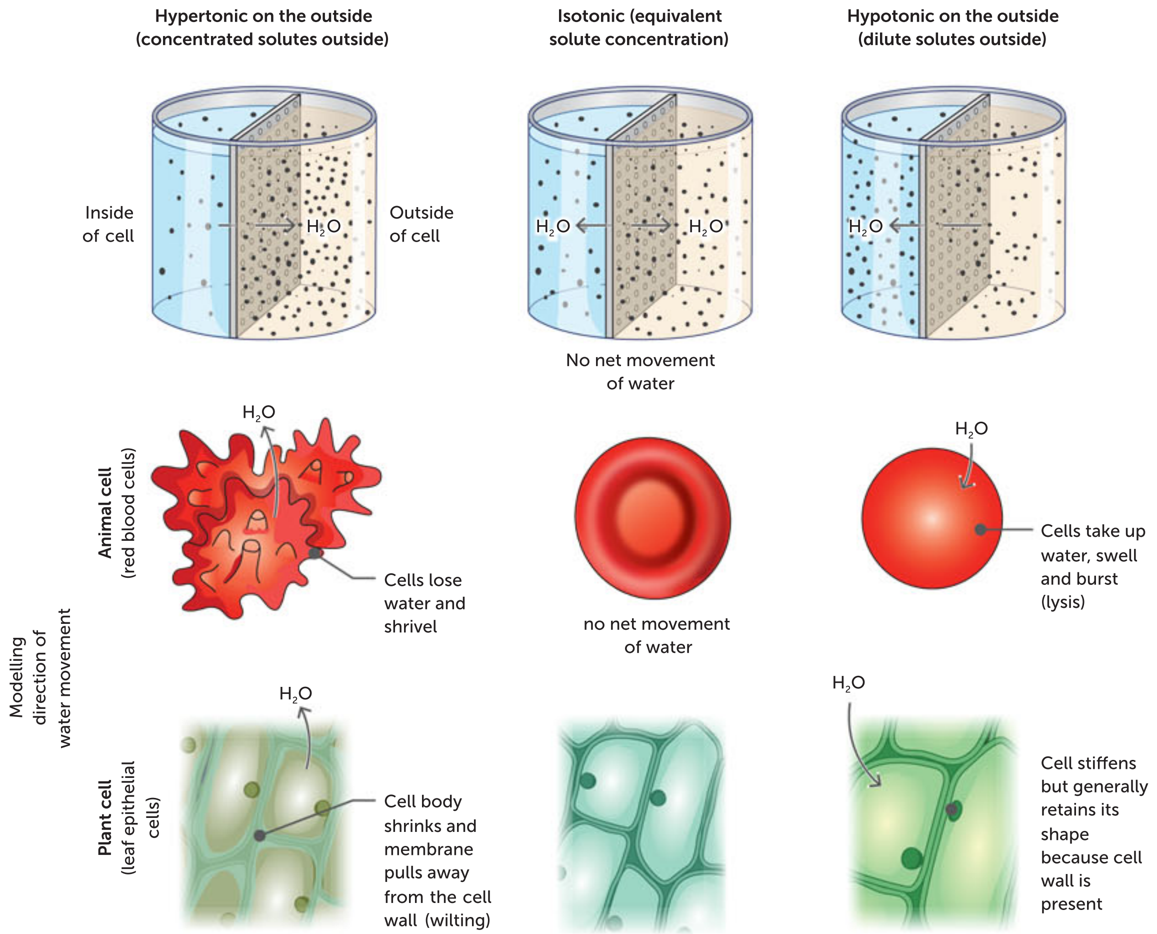

FIGURE 9.19 A comparison of hypertonic, isotonic and hypotonic solutions in animal and plant cells

Osmosis in animal cells

The cells of unicellular eukaryotes and multicellular organisms such as animals are surrounded only by a cell membrane, unlike the cells of plants, fungi and bacteria, where a cell wall surrounds the cell membrane. Hypertonic solutions, such as fresh water, pose a special problem for these organisms. Water moving into their cells by osmosis can cause the fluid cell membrane to swell and eventually burst, killing the organism. Unicellular organisms such as amoebae that live in fresh water have important regulatory mechanisms to combat these problems. They are able to remove excess water by forming little pools of water in organelles called **contractile vacuoles** (Figure 9.20) in the cytoplasm. When these vacuoles stretch to a certain point, they contract and expel the water.

In multicellular animals, cells are bathed in isotonic extracellular fluid. This means that cells can function efficiently because water diffuses equally in both directions, resulting in no net movement of water into or out of cells. To keep the internal environment of your body in isotonic balance, the solute concentration in the extracellular fluid is controlled by the concentration of solutes in blood plasma, which in turn is controlled by the kidneys.

You may have been in hospital and seen patients hooked up to an intravenous drip. This drip is connected directly to their circulatory system, adding fluid to their blood plasma. It is important that fluid in the drip has a solute concentration equal to blood plasma (it is isotonic). In this situation, water will enter and leave blood cells at the same rate, so that the cells maintain their ideal water concentration.

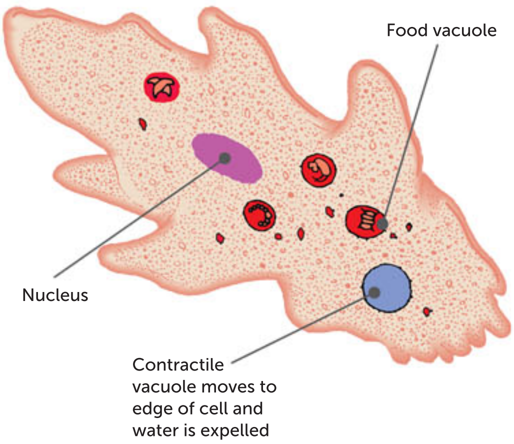

FIGURE 9.20 Amoebae are able to remove fresh water using organelles called contractile vacuoles.

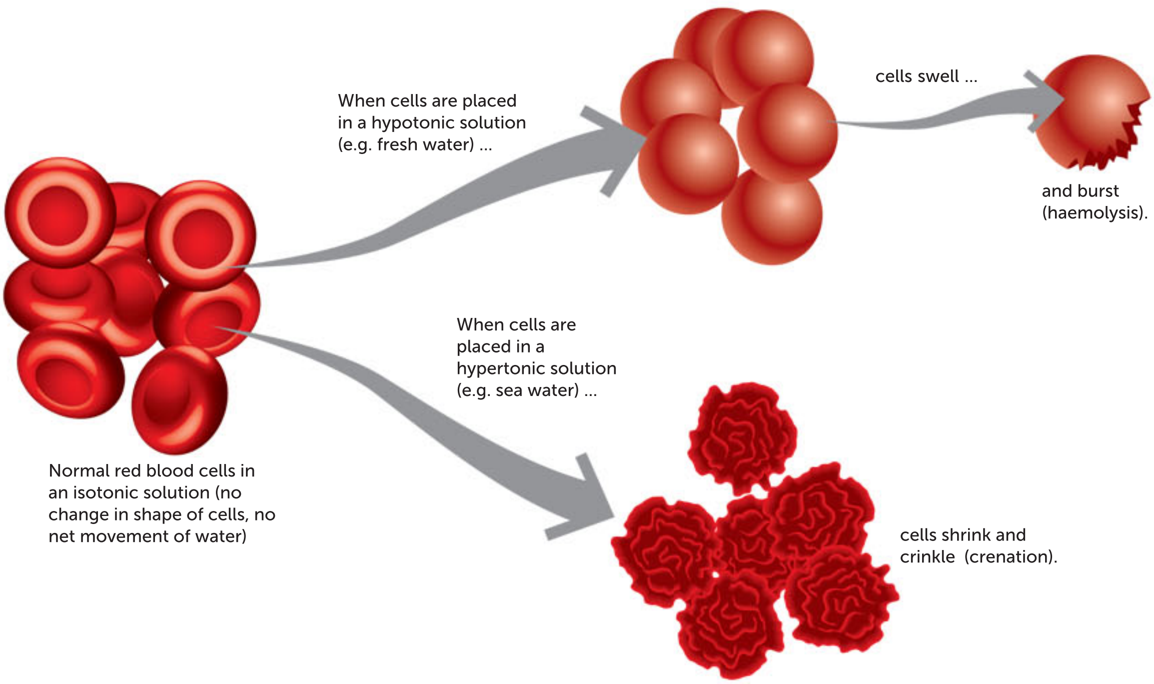

FIGURE 9.21 Damaged blood cells. Human red blood cells swell or shrink in solutions of varying solute concentrations.

9.1 APPLICATION

Osmosis in the laundry

Consider the case of a blood-stained piece of clothing. If a cut spills blood onto some clothing, you should soak the blood-stained material in water to remove the stain. In this case, the concentration of water in the solution around the clothing is higher than that in the red blood cell's interior and there is a net movement of water into the cell. This causes the blood cells to swell and become so full of water that they eventually burst. This releases the red pigment and helps to remove it from your clothing. By taking this action, you are using the process of osmosis.

Osmosis in red blood cells
View the animation and draw diagrams to show the direction of water movement in haemolysis and crenation.

Questions

1. How does a change in the shape of red blood cells, such as having sickle cells, affect the rate of osmosis across the membranes of red blood cells?
2. How do haemolytic diseases, such as thalassemia and hereditary spherocytosis, result in changes in the rate of osmosis across the membranes?

Osmosis in plants

Unlike animal cells, plant cells with intact cell walls will not burst when soaked in fresh water (hypotonic solution), even though water moves into them by osmosis. How can you explain this difference?

Think about the differences in plant and animal cell structure. Animal cells lack cell walls and rarely contain large vacuoles. Plants commonly have large, fluid-filled vacuoles and firm but permeable cell walls that surround the cell membrane. Like the cell membrane, the vacuole membrane is selectively permeable. Plant cell vacuoles contain cell sap that is rich in solutes: it is a solution of high concentration. When a hypotonic solution surrounds a plant cell, water molecules diffuse by osmosis, first into cytosol and then into the vacuole. The vacuole swells, pushing the cytoplasm and cell membrane against the cell wall. The tough cell wall prevents the cell from bursting. When the cell wall stretches as much as possible, no more water can enter and the cell is said to be **turgid** (Figure 9.22).

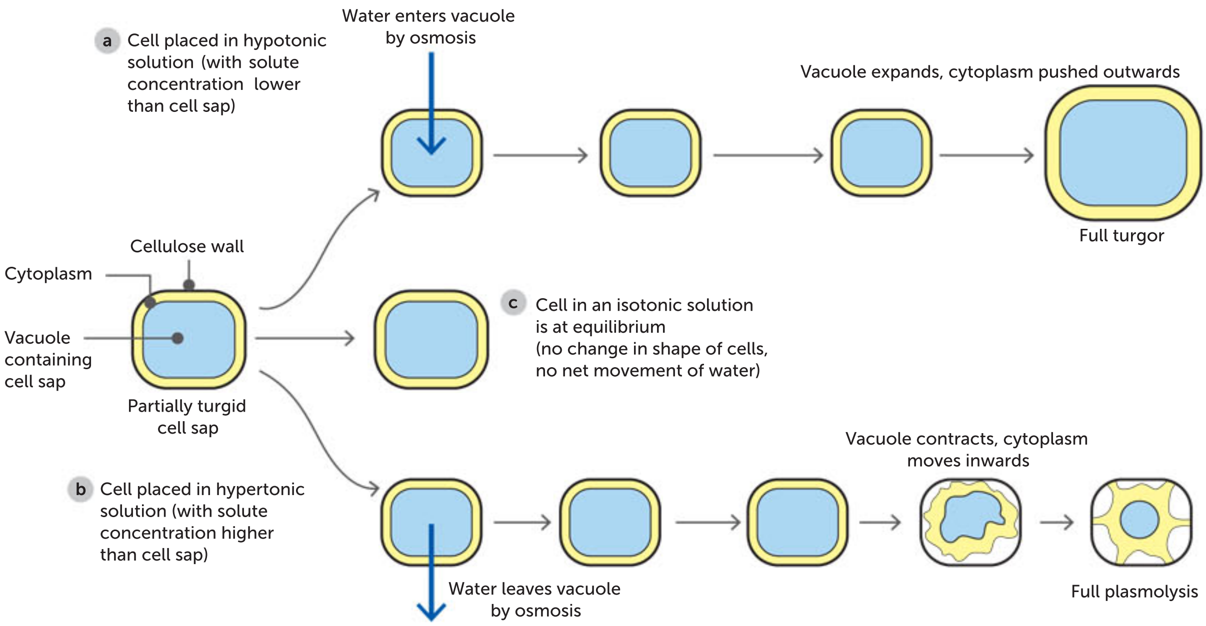

FIGURE 9.22 The effect of immersing a partially turgid plant cell in **a** pure water (a hypotonic solution), **b** a high solute concentration (a hypertonic solution) and **c** an isotonic solution

Turgor is very important for plants. It supports them and maintains their shape and form. The stems of non-woody plants are kept erect by the turgid, tightly packed cells that fill them. Turgor is also responsible for holding leaves in a flat, opened-out position. Certain plant cells are able to undergo quite rapid changes in their solute concentration with consequent changes in turgor. This allows such cells to change their shape. Stomatal guard cells behave this way, as do cells responsible for the leaf movements of insectivorous plants (such as the Venus flytrap).

On a hot, dry day, you may see some plants **wilt**. When significant quantities of water evaporate from the plant, the external concentration of water molecules becomes less than in the vacuole. Water molecules diffuse out, reducing the volume of the vacuole and causing the cells to become limp or **flaccid** and the plant to wilt (Figure 9.23a). If enough water is lost, the cell membrane pulls away from the cell wall in a process called **plasmolysis** (Figure 9.23b).

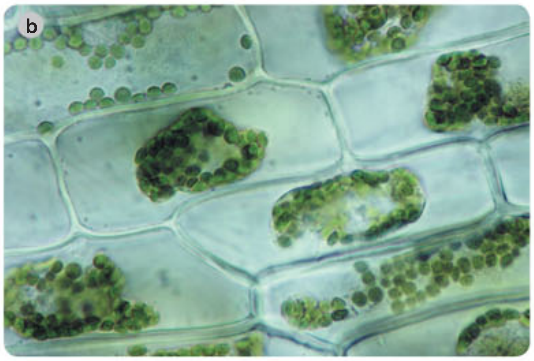

FIGURE 9.23 a In hot conditions, a plant loses water and wilts as its cells lose turgor pressure. **b** Plasmolysis in *Elodea* cells. Water has diffused out of the cells, causing the volume of cytoplasm to shrink. Gaps between the cytoplasm and cell wall are filled by solution from outside the cells.

Question set 9.3

REMEMBERING

1 A salt solution is a mixture of salt and water. Which substance is the solvent and which is the solute?
2 List the factors that increase the rate of diffusion.
3 What is facilitated diffusion? What substances enter the cell by this process?
4 Give one reason why plant cells do not burst when placed in a hypotonic solution.

UNDERSTANDING

5 Explain why red blood cells are stored in saline (salt) solution rather than pure water.
6 If salad greens such as lettuce are left for a period of time, they become limp. To restore their crispness they can be soaked in cold water. Explain the reason this works.

APPLYING

7 Explain why the juice comes out of strawberries if you sprinkle sugar on them.
8 Animal cells are placed in three different solutions. After a period of time, cells in solution X burst. Cells in solution Y remain the same and cells in solution Z become shrivelled.
   a Which solution was hypertonic compared with the animal cells?
   b Which cell sample was isotonic compared with the surroundings?
   c How would plant cells look in these solutions?

9.4 ACTIVE TRANSPORT ACROSS MEMBRANES

The processes of diffusion and osmosis do not require the input of energy. However, there are occasions when energy is needed to move substances across membranes. **Active transport** and bulk transport are some examples where energy is needed to transport materials from an area of low concentration to an area of high concentration. Active transport is performed by specific proteins embedded in the membranes. Active transport enables cells to maintain reverse concentration gradients of substances that the cell requires.

After you eat a meal, nutrients such as glucose are absorbed into the cells lining the inside of the small intestine. If diffusion alone was involved, once the concentration of glucose inside and outside the cell became equal, there would be no net movement. Some of the glucose available from digestion would be excreted along with wastes and undigested food. However, this is not what happens. Glucose continues to move into cells lining the small intestine even when its concentration is lower outside the cell. Cells appear to pump glucose in through their cell membranes.

In this and other similar situations, molecules or ions move up their concentration gradient, from a region where they are in low concentration to a region of higher concentration. Because this

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movement of molecules or ions through a membrane against a concentration gradient requires the input of energy, it is called active transport.

How does active transport take place? Membrane transport proteins, similar to those responsible for facilitated diffusion, use energy from ATP to move molecules or ions up their concentration gradient (Figure 9.24). As these carrier proteins work in only one direction, they effectively act as one-way valves. The importance of these pumps becomes apparent when people with certain diseases, such as those suffering from cystic fibrosis, cannot produce them in adequate amounts.

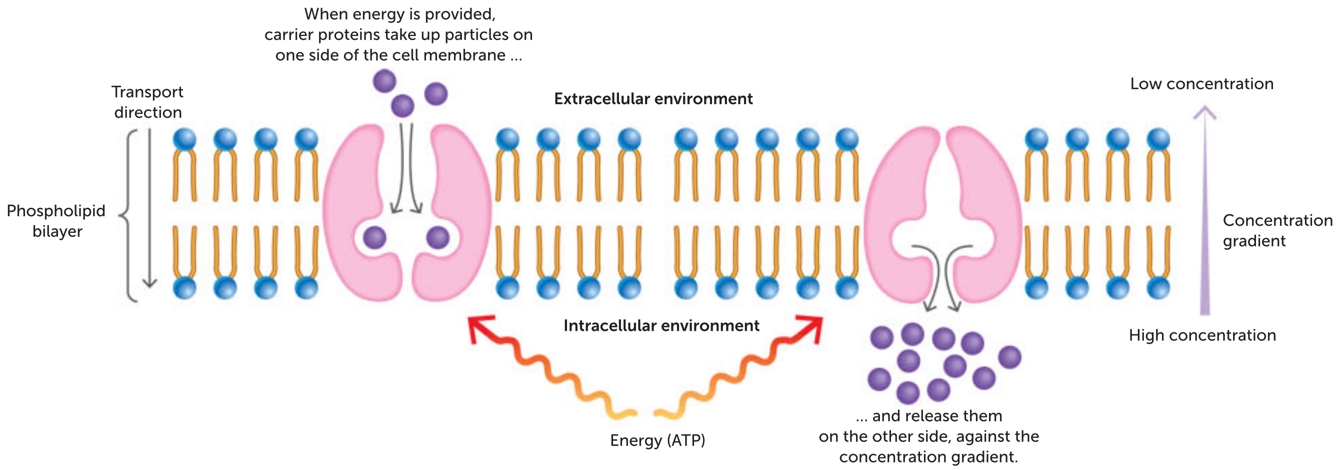

FIGURE 9.24 Active transport via a carrier protein in the cell membrane. Energy is transferred to the carrier protein, enabling it to move the particles against a concentration gradient.

Without active transport the kidneys could not reabsorb useful materials, muscles would not contract and impulses would not be able to travel along nerves. As we saw in Table 9.2 (page 277), animal cells contain high concentrations of potassium ions but low concentrations of sodium ions. The mechanism responsible for this is the sodium–potassium pump, which moves these two ions in opposite directions across the cell membrane. The sodium–potassium pump has a particular significance for excitable cells, such as nerve cells, which respond to stimuli. Other substances such as amino acids and hydrogen ions are also pumped across membranes by active transport.

The energy demands of these processes are significant. It has been estimated that while a person sleeps, as much as 40% of the total energy budget is used for active transport. Cells engaged in active transport have huge numbers of mitochondria. These organelles build up the ATP that is used as the energy source in these cells.

TABLE 9.4 The types of transport of relatively small molecules across cell membranes

TRANSPORT CLASSIFICATION	ENERGY REQUIRED?	TYPE	MECHANISM
Passive transport	No	Simple diffusion	Small, hydrophobic (e.g. lipids) or uncharged (e.g. carbon dioxide, oxygen gas) molecules move through the membrane unassisted, from a high to low area of concentration
		Osmosis	Diffusion of water, through a semipermeable membrane, from an area of low solute concentration (high water content) to an area of high solute concentration (low water content). Water may move unassisted, but some membranes have proteins called aquaporins, which facilitate osmosis
		Facilitated diffusion	Small, hydrophilic substances (e.g. sodium ions, glycerol) move through special integral proteins, called channel proteins, from an area of high concentration to an area of low concentration. Each type of channel protein allows only one type of molecule to diffuse
Active transport	Yes (ATP)	Active transport	Relatively small hydrophilic or hydrophobic particles are pumped in or out of the cell by specific membrane proteins, called carrier proteins or protein pumps, up (against) the concentration gradient from area of low to area of high concentration

Question set 9.4

REMEMBERING

1 State the main difference between active and passive transport.

2 List one or two substances that pass through the cell membrane by each of the following transport mechanisms:

- **a** simple diffusion
- **b** osmosis
- **c** facilitated diffusion
- **d** active transport.

UNDERSTANDING

3 Describe how carrier proteins work.

9.5 ACTIVE MOVEMENT OF LARGE SUBSTANCES ACROSS MEMBRANES

Endocytosis

At times, very large particles or even whole cells have to be moved into a cell across the cell membrane. In other circumstances, relatively large molecules have to be exported from a cell. The large size of these particles makes their movement through the membrane by passive or active transport impossible. Large molecules, such as polysaccharides and proteins, cross the cell membrane in bulk via vesicles using **endocytosis** and **exocytosis**. These are active processes, requiring energy to move vesicles around the cytoplasm and to change the shape of the cell.

Figure 9.2 (page 276) shows a unicellular amoeba feeding on a smaller organism, illustrating the process of endocytosis. The amoeba changes shape by sending out projections that surround the prey. When the cell membrane of the projections meet, membrane fusion occurs. This results in the formation of a vesicle, which then stores or transports the material within the cytoplasm (Figure 9.25). The two types of endocytosis discussed in this chapter are named according to the type of material consumed. The process of engulfing solids, like when an amoeba feeds, is called **phagocytosis**; and the process of engulfing droplets of liquid is **pinocytosis**.

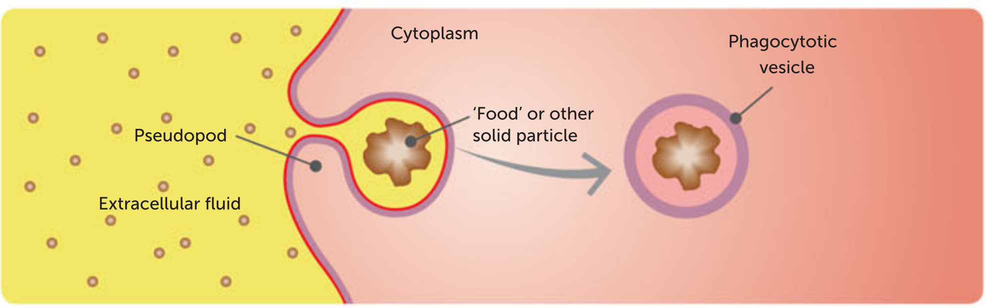

FIGURE 9.25 The process of phagocytosis

Human macrophages (a type of white blood cell) are called phagocytes because, in defending the body against disease, they engulf bacteria by phagocytosis (Figure 9.26). Macrophages use **recognition proteins** in the cell membrane of the cells they encounter to discriminate between invading bacteria and body cells, demonstrating that phagocytosis is a selective process.

Pinocytosis occurs when the cell membrane engulfs a drop of extracellular fluid in much the same way as phagocytosis (Figure 9.27). Fat droplets found in the small intestine after a meal move into cells by means of pinocytosis.

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FIGURE 9.26 A macrophage engulfing cells by phagocytosis

Key concept

ATP energy is required to move substances across membranes by active transport and bulk transport.

Exocytosis

Specialised animal cells produce a variety of substances, such as hormones, mucus, milk proteins and digestive enzymes, which have important functions elsewhere in the organism. This is also true for plants, where particular cells are specialised to produce products that need to be relocated. These include growth regulators, toxins to ward off predators and macromolecules for use elsewhere. In all these cases, exocytosis is involved.

Exocytosis is the process by which large molecules held in vesicles within the cell are transported to the external environment. It is essentially the reverse of endocytosis. During exocytosis, a membrane-bound vesicle moves to the cell membrane, fuses with it and then releases its contents to the exterior of the cell (Figure 9.28).

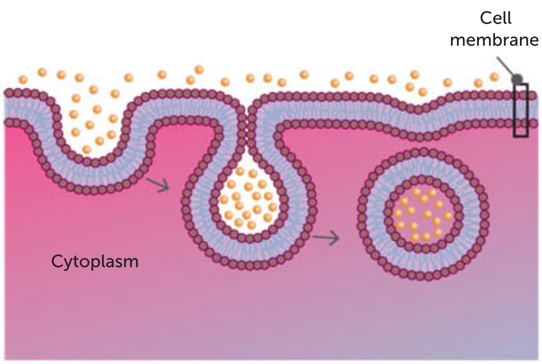

FIGURE 9.27 The process of pinocytosis, a type of endocytosis

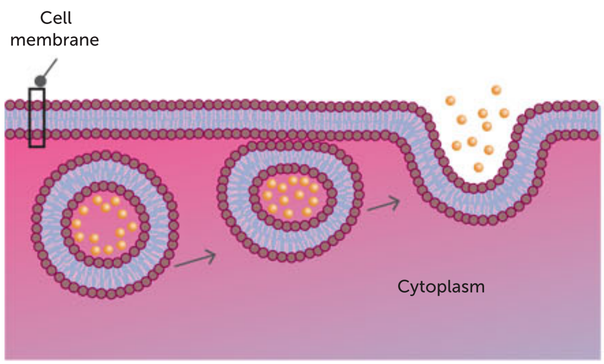

FIGURE 9.28 The process of exocytosis

Key concept

The exchange of materials (including gases, nutrients and wastes) between the cell and its environment across membranes occurs via:

- passive processes, including diffusion, facilitated diffusion and osmosis
- active processes, including active transport, endocytosis (movement of large particles into a cell) and exocytosis (movement of large particles out of the cell).

Endocytosis includes phagocytosis (engulfing solids) and pinocytosis (engulfing droplets of liquid).

Aquaporins

CASE STUDY

Plants are sources of food (for humans and animals), fibre and fuel. Plants are able to generate products that serve humans in these ways because of their plant energy systems. They can use the energy in sunlight to transform water and carbon dioxide into high-energy organic substances. The efficiency of a plant's energy system determines its yield. Humans need plant products but the environment has limiting factors that affect the efficiency of such energy systems.

A plant's system of energy production involves metabolic processes that require several reactants, including water. Water enters plants cells via the cell membrane, either by osmosis or through facilitation by aquaporins.

Aquaporins are tiny protein channels in the cell membranes of plant cells. Protein channels facilitate diffusion, the movement of substances across membranes. Aquaporins facilitate the movement of water from an area of high concentration to an area of low concentration. They are also called water channels or major intrinsic proteins.

Plant cells can create more aquaporins when they are needed. Aquaporins are proteins and, like all proteins, they are coded for by genes. When an aquaporin is need by a cell, the aquaporin gene is expressed and a protein is made that has a specific structure that helps it perform its function.

Scientists at the Australian Research Council Centre of Excellence in Plant Energy Biology have been researching how to regulate the production of aquaporins. Knowledge of how plants produce more aquaporins can be used to produce high-yielding crop plants, capable of surviving challenging environmental conditions. The scientists' aim is to improve the security of the food supply for humans, by developing more efficient and resilient crops.

As well as facilitating the transport of water, aquaporins assist movement of a variety of solutes. They are present in members of all the biological domains, but plants have the highest diversity. Scientists have found that modifying aquaporins is an important way to improve plant performance during drought.

One study was conducted on aquaporins in tomato plants (*Solanum lycopersicum*), an important vegetable crop that is also a model for fleshy fruit development. Scientists found 47 genes that coded for aquaporins in the tomato genome and then analysed their structural features. They found that the aquaporin genes were expressed in tissue-specific and development-specific patterns. They interpreted this as a first step towards showing how aquaporins help to transport water and solutes in leaves and during fruit development. They suggested that aquaporins are involved in water movement into developing fruit. Their next plan was to study the functions of aquaporins during fruit development.

Questions

1. State where you would find aquaporins.
2. Describe the function of an aquaporin.
3. Discuss the benefit for humans of studying aquaporins.

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Question set 9.5

REMEMBERING

1 Explain why certain white blood cells are known as phagocytes.
2 Identify two types of cells in which active transport would occur.
3 Distinguish between active transport and simple diffusion.
4 List four types of substances that are secreted from cells.

UNDERSTANDING

5 Draw two annotated diagrams to explain how the cell membrane is involved in the processes of endocytosis and exocytosis.

9.6 FACTORS THAT AFFECT EXCHANGE OF MATERIALS

Whether or not a substance crosses a membrane, and the method by which it crosses, are determined by characteristics of the selectively permeable membrane, and the physical and chemical properties of the substance itself. The rate of movement is determined by the size and shape of a cell and the concentration gradient of the substance being exchanged.

Chemical properties of a substance

The chemical properties of a substance indicate how it will behave in the extracellular environment and affect its transport across cell membranes. As mentioned earlier, alcohols (e.g. ethanol) are able to easily penetrate and cross membranes because they are uncharged molecules. This allows them to dissolve in the phospholipid bilayer. Charged ions such as sodium (Na^+), potassium (K^+) and calcium (Ca^{2+}), which are hydrophilic, cannot cross the hydrophobic interior of the membrane (Figure 9.29). They move across membranes through membrane transport proteins, called ion channels, which are specific for the substance they carry.

Physical properties of a substance

The physical properties of size and shape affect whether or not a substance moves across the cell membrane, how it is transported and how quickly it moves. Small molecules like water, oxygen and carbon dioxide are able to slip between the phospholipids. They cross the membrane easily and quickly, diffusing passively from a high concentration to a low concentration.

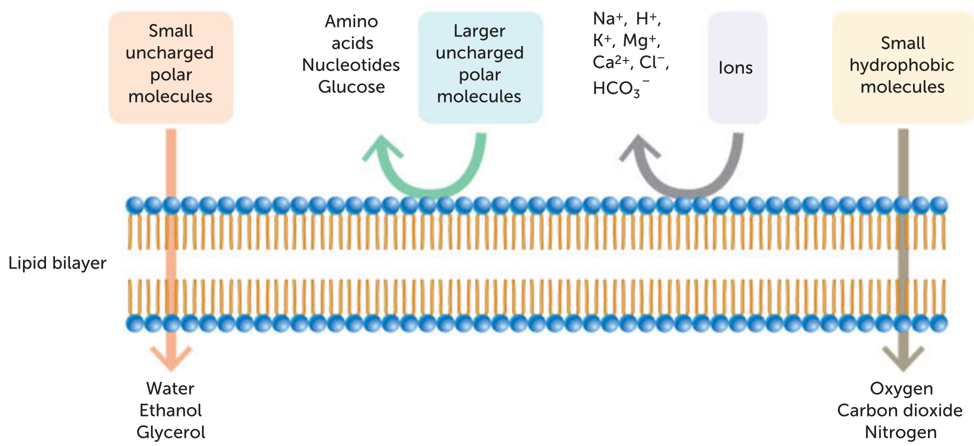

FIGURE 9.29 The relative permeability of a lipid bilayer to different classes of molecules

Earlier in this chapter, you learned that molecules that are physically too big to move in this way are transported by specific membrane proteins that span the cell membrane. The specificity of transport proteins depends on the physical shape of the molecule fitting into the carrier protein, much like an enzyme fitting its substrate. Very large molecules, such as proteins that are too large to fit into membrane transport proteins, are taken up by cells in vesicles in the process of endocytosis. Similarly, very large molecules, such as the hormone insulin, are secreted out of the cell in vesicles by exocytosis.

Concentration gradient

The rate of diffusion of any substance is affected by the relative concentration of the substance on either side of the membrane. If the concentration gradient is high, then the substance will diffuse rapidly. As the concentrations become more similar, the rate of diffusion will be slower. There are various ways that cells can increase the concentration gradient across their membranes in order to maintain a rapid rate of diffusion.

In multicellular animals, one way of maintaining a steep concentration gradient is for the circulatory system to remove the diffused substance, such as carbon dioxide, away from the tissues. Another is to convert the diffused substance into something else, thus lowering its concentration. For example, when glucose molecules diffuse into liver cells, some are used up and others are converted to glycogen, maintaining a steep glucose concentration gradient.

Size and shape of cells

There are many different cell types in your body, each carrying out a specialised function. Yet unicellular organisms survive successfully with only one type of cell. No matter where they are from, almost all cells are very small. Why are there no large unicellular organisms? Why is it that cells divide rather than continue to increase in size? There must be an advantage for multicellular organisms to consist of many, smaller, specialised cells. This advantage relates to the ability of a cell to obtain its nutrients and remove its waste products.

The greater the distance that a substance must travel, the slower the rate of diffusion. This places an upper limitation on cell size. A large, spherical cell will die because nutrients or wastes cannot reach or leave the centre of the cell fast enough to satisfy the organism's requirements. If nutrients do not arrive in time, important metabolic processes cannot proceed. If wastes do not exit the cell fast enough they can reach toxic levels, interfering with metabolic processes. Therefore, unicellular cells must be either small in size, as in the case of many prokaryotes, or flat, as are many single-celled eukaryotes.

Another factor is that the thickness of cell membranes can vary, and diffusion through a thicker membrane is slower than diffusion through a thinner one.

Surface-area-to-volume ratio

An important concept related to exchange across membranes and the movement of substances into and out of an organism is the **surface-area-to-volume (SA : volume) ratio**. It represents an important relationship between the surface area of the membrane surrounding a cell and the volume of its cytoplasm.

Cell surface area versus volume
Use the applet to explore the relationship between cell surface area and volume.

As we have seen, the uptake of materials from the external environment into a cell occurs via its cell membrane. These materials are then used to fuel the chemical reactions that occur throughout the volume of the cytoplasm. For a cell to be able to supply the cytoplasm with its metabolic requirements and remove wastes, it needs a large surface area in relation to its volume. That is, it needs a large surface-area-to-volume ratio, where the surface area is the area of membrane around the cell and the volume is the amount of cytoplasm.

As a cell grows larger, both its surface area and volume increase, but its volume grows faster than its surface area. This is shown in Table 9.5 (page 298). Cell A has a volume of 0.52 cm^3 and a surface area of 3.14 cm^2 to service it. This is a surface-area-to-volume ratio of 6:1. Cell C, however, has a volume of 14.14 cm^3 and a surface area of 28.28 cm^2 to service it, a surface-area-to-volume ratio of only 2:1.

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TABLE 9.5 The surface-area-to-volume ratios of three hypothetical cells

	CELL A	CELL B	CELL C
Diameter (cm)	1.0	2.0	3.0
Surface area (cm_2)	3.14	12.57	28.28
Volume (cm_3)	0.52	4.19	14.14
SA : volume ratio	6:1	3:1	2:1

As cell size increases, the surface-area-to-volume ratio decreases. This is because its volume increases more rapidly than its surface area. This means the efficiency with which a cell obtains its nutrients and removes its wastes is reduced as its size increases. A cell may increase in size until it reaches a point where the inward movement of essential substances and the outward movement of wastes across the surface area by diffusion are not fast enough to meet the cell's needs. For this reason, individual cells tend to be very small.

Key concept

Factors that affect exchange of materials across membranes include:
- the surface-area-to-volume ratio of the cell
- concentration gradients
- the physical and chemical nature of the materials being exchanged.

How big can cells grow?

Because of the restrictions of the surface-area-to-volume ratio, most cells are too small to see without the aid of a microscope. Red blood cells, for example, are about 8 millionths of a metre wide; approximately 2000 of them would fit across your thumbnail. However, some eukaryotic cells can be observed with the unaided human eye, such as the yolks of bird eggs, cells in some algae, and the eggs of fish and frogs (spawn).

Such cells have special ways to offset the low surface-area-to-volume ratio that comes from their large size. In giant algal cells, an inert vacuole fills the majority of the cell (Figure 9.30). This pushes the metabolically active cytoplasm to the outside of the cell, just beneath the cell membrane. This has two benefits. It means that the distance materials need to diffuse when moving into or out of the cell is much less. It also has the effect of reducing the active volume of the cytoplasm and so reducing the amount of exchange that must occur across the membrane.

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FIGURE 9.30 Bubble algae *(Valonia ventricosa)* is one of the largest known unicellular organisms. Its single cell can grow up to 5 cm in diameter, and has multiple nuclei and a large central vacuole.

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Key concept

Cells with a larger surface-area-to-volume ratio can obtain nutrients and remove wastes more efficiently.

Shape of cells

In a multicellular organism, some cells need to be of a certain size in order to perform their specific function. For example, nerve cells that connect your spinal cord to your toes are more than 1 m long. To explain how large cells overcome issues associated with their increased size, we need to look at the relationship between shape and surface-area-to-volume ratio.

The shape of an object can significantly change its surface-area-to-volume ratio. A sphere has the least surface area for the volume it encloses. This explains why soap bubbles are perfect spheres. The thin elastic membrane made by the soap mixture contracts to the smallest area that can enclose the volume of air blown into it when the bubble was made. Spherical cells have a relatively small surface-area-to-volume ratio compared with cells of other shapes. In the case of the nerve cell, its long, thin shape gives it a large surface area compared to its volume.

Cells often have specific features that ensure they have the highest surface-area-to-volume ratio possible. Long, thin or flat cells have relatively more membrane for a certain volume compared with spherical cells. A good example of this is seen in the root hairs that cover the root tips of most plants. The long, thin extensions of the single cells that form root hairs significantly increase the surface area over which water and mineral salts can be absorbed (Figure 9.31).

Alamy Stock Photo/Science Photo Library

FIGURE 9.31 Scanning electron micrograph of root hairs in oregano (*Origanum vulgare*). These hairs greatly increase the surface area for absorption of water.

Worked example 9.1

Calculate the surface-area-to-volume ratio of a cube 1 cm × 1 cm × 1 cm. (3 marks)

ANSWER	LOGIC	
Surface area of a cube = 6 × length of side^2 Surface area = 6 × 1 × 1 = 6 cm^2	Calculate surface area. Insert correct formula. Insert numbers into formula. Calculate answer.	1 mark
Volume of a cube = length × width × height Volume = 1 × 1 × 1 × 1 cm^3	Calculate volume. Insert correct formula. Insert numbers into formula. Calculate answer.	1 mark
Surface area : volume = 6 ÷ 1 = 6	Calculate SA : volume ratio. Insert numbers into formula.	
	Calculate answer.	1 mark

Try these yourself

1 Calculate the surface-area-to-volume ratio of a cube 2 cm × 2 cm × 2 cm. (3 marks)
2 Calculate the surface-area-to-volume ratio of a cube 3 cm × 3 cm × 3 cm. (3 marks)

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Surface area of a sphere
Explore changes in the surface area of a sphere as it increases in size.

Volume of a sphere
Explore changes in the volume of a sphere as it increases in size.

Question set 9.6

REMEMBERING

1 List two examples of physical factors and two examples of chemical factors that affect the movement of substances across cell membranes.

2 Describe the effect of differing concentration gradients on the rate of diffusion of oxygen into a cell.

3 State two ways that cells can increase the concentration gradient of a substance.

UNDERSTANDING

4 Explain how the shape of a cell affects its surface-area-to-volume ratio.

5 Explain how increasing the size of a cell affects the cell's ability to gain and lose substances by diffusion.

APPLYING

6 To compare cell surface area and volume as they increase, calculate the surface area and volume of three spheres with radii of 2 cm, 5 cm and 8 cm. Copy and complete Table 9.6 to organise your data. You may use the maths interactives found in the weblinks to calculate the data. State the trend that you observe as cell size (sphere radius size) increases.

TABLE 9.6 The surface area and volume of three cells

CELL	RADIUS (cm)	SURFACE AREA ($A = 4\pi r^2$) (cm^2)	VOLUME ($\frac{4}{3}\pi r^3$) (1 DECIMAL PLACE) (cm^3)	SA:VOL RATIO (1 DECIMAL PLACE)
1	2	50.3	33.5	1.5:1
2	5			
3	8			

ANALYSING

7 Analyse the data in Table 9.6 and discuss whether there is a linear relationship between size and surface-area-to-volume ratio.

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CHAPTER 9 ACTIVITY AND INVESTIGATIONS

9.1 ACTIVITY

Observing diffusion of a solid in a liquid

Aim

To explore the passive movement of particles within a liquid

You will need

- 250-mL beaker
- warm water
- potassium permanganate
- straw or filter funnel

What to do

1. Fill the beaker with warm water.
2. Add several crystals of potassium permanganate by carefully lowering the straw or funnel until it nearly touches the bottom of the beaker, then dropping several crystals so that they settle to the bottom of the beaker without disturbing the water. (By doing this, you can attribute the spread of the solid to the passive process of diffusion instead of any further energy you add to the system.)
3. Record the changes you observe over the next 10 minutes.

What did you discover?

1. Describe the change in colour over the 10 minutes.
2. Explain your observations, ensuring you use the term 'concentration gradient'.
3. Predict what difference you would observe with hot water rather than warm water. If you have time, test this prediction.

NOTE: To observe a gas diffuse in a gas, pour peppermint oil to cover an evaporating dish and ask students to raise their hand once they detect its smell.

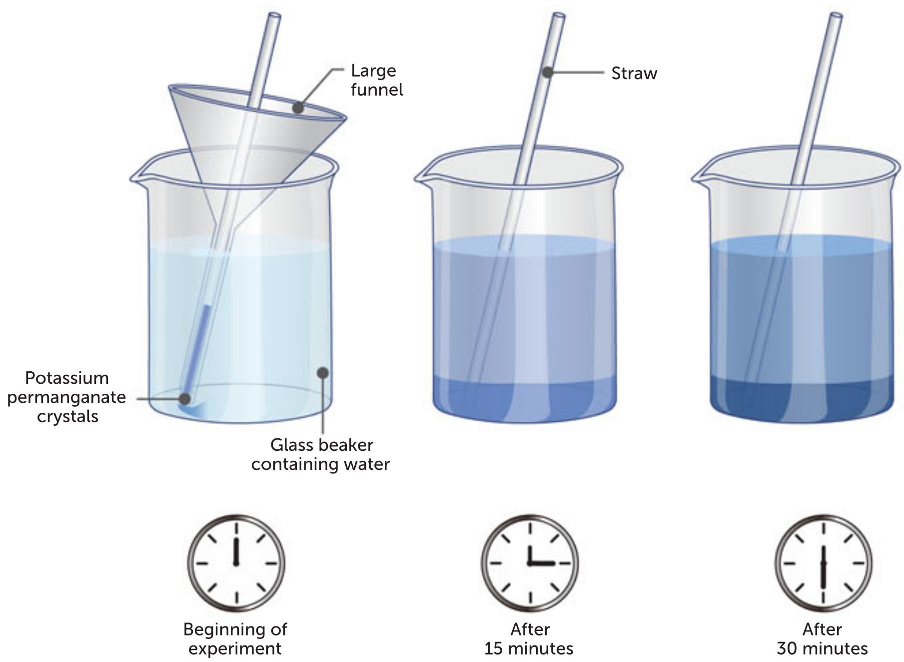

FIGURE 9.32 Test to observe diffusion

9.1 INVESTIGATION

Investigating the rate of osmosis

Potato tissue provides a simple model of a cell to test the factors that affect the rate of osmosis across a semipermeable membrane.

Aim

To design an experiment to test how one of the following factors affects the rate of osmosis:
- 'cell' size
- 'cell' shape
- salt concentration of solution

Materials

- stopwatch
- two potatoes, raw, peeled
- table salt
- 30-cm ruler
- any extra materials you will need for your chosen investigation

Procedure

1. Select the factor that your team will test.
2. List your materials. Include a risk assessment box and add a procedure.
3. Perform your investigation.
4. Record and analyse your results. Discuss and draw a conclusion.

9.2 INVESTIGATION

Investigating cell size using agar cubes

The relatively small size of cells allows the diffusion of many substances through their membranes to be sufficient for the cells' needs. However, if a cell gets too large then the rates at which substances can move into and out of the cell may not be high enough. As the size of an object increases, its volume increases at a greater rate than its surface area. For a cell, this means that it may be unable to take in enough nutrients, and toxins may be retained for too long.

Using agar cubes with indicator and vinegar, we can see how much effect a small increase in surface area has on volume.

Aim

To determine the relationship between surface-area-to-volume ratio and diffusion rates.

Materials

- prepared agar cubes with bromothymol blue indicator (1 × 1 cm, 1 × 2 cm, 1 × 3 cm)
- 150 mL vinegar (acetic acid)
- 250 mL beaker
- plastic or metal spoon
- timer
- ruler
- calculator
- paper towel
- disposable gloves

WHAT ARE THE RISKS IN DOING THIS EXPERIMENT?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Glass beaker may break or have chipped edges.	Inspect and discard any chipped or cracked beakers, no matter how small the damage. Sweep up broken glass with brush and dustpan; do not use your fingers.
Disposable gloves may pose allergy risk.	Use a type of glove that does not have an allergy risk and is suitable for the chemicals being used.
Acetic acid may impose an irritant vapour.	Ensure investigation is performed in a well-ventilated space.

Procedure

1. Propose a hypothesis for this investigation.
2. Put on disposable gloves and measure each cube in height (h), width (w) and length (L) to calculate surface area (SA) and initial volume (V_i). Record your data in a table like Table 9.7.
3. Fill the beaker with enough vinegar to ensure that the largest cube can be submerged, and place one cube of each size into the beaker and start the timer for 4 minutes.
4. After 4 minutes, remove the cubes and pat them dry with paper towel. Measure the portion of each that is still blue. Try to minimise the time the cubes are out of the vinegar. Record your data in a table like Table 9.8.
5. Replace the cubes and then repeat the procedure, leaving them in for 4 minutes at a time and measuring the dimensions of the blue portion after each 4-minute interval, for a total of 20 minutes.
6. Calculate the volume of the portion of the cube that is still blue (V_f) after each 4-minute interval and the percentage of the whole cube that the vinegar has penetrated (% P).

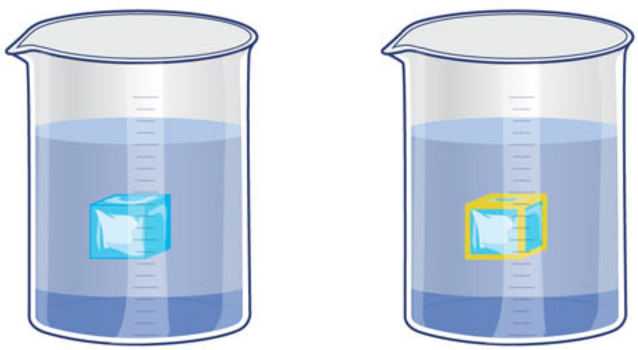

FIGURE 9.33 a A cube of agar in vinegar; **b** the same cube after several minutes

Results

1. Copy and complete Table 9.7, recording your initial measurements of surface area (SA) and initial volume (V_i) for each cube.

TABLE 9.7 Initial measurements and calculations for cubes

CUBE	HEIGHT, *h* (cm)	WIDTH, *w* (cm)	LENGTH, *l* (cm)	SA (cm^2)	V_i (cm^3)	RATIO (SA/V) (cm^{-1})
A						
B						
C						

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2 Copy and complete Table 9.8 for each cube by measuring and recording the volume of the part of the cube that is still blue (V_f), then using the initial volume (V_i from Table 9.7) to calculate the penetration of the vinegar into the cube (*P*). Next, convert this to a percentage.

TABLE 9.8 Penetration of vinegar into cubes

Size of cube:

TIME (min)	*h* (cm)	*w* (cm)	*l* (cm)	V_f (cm^3)	P ($V_i - V_f$) (cm)	PERCENTAGE PENETRATION ($P/V_i \times 100$) (%)
0						
4						
8						
12						
16						
20						

Discussion

1 Explain why the agar cubes change colour when placed in the vinegar solution.
2 Describe the relationship between the surface-area-to-volume ratio and the rate at which diffusion occurs.
3 Create a graph of time in minutes (*x* axis) against the percentage penetration (*y* axis) of each cube. Comparing them all on one graph will demonstrate the differences in each graph line.

Conclusion

Summarise your findings by commenting on your hypothesis. Explain the advantages and disadvantages of various cell sizes and list some real-life examples.

Taking it further

Create a graph of initial surface-area-to-volume ratio (*x* axis) against the total time in minutes (*y* axis) to demonstrate that as the ratio increases, the time taken to completely penetrate a cube will decrease non-linearly.

Chapter 9 Activity sheet

CHAPTER 9 SUMMARY

- The surface membrane of the cell is called the cell membrane but is also referred to as the plasma membrane.
- The cell membrane forms a boundary between the internal and external environments of cells.
- The cell membrane is composed of a phospholipid bilayer in which proteins are embedded.
- The currently accepted model of the cell membrane is the fluid mosaic model.
- The cell membrane regulates the internal environment by allowing some molecules but not others to pass across it. It is semipermeable.
- The main substances embedded in the phospholipids of a cell membrane are proteins, carbohydrates and cholesterol.
- Transport across membranes can be active or passive.
- Different types of proteins are involved in transport. Channel proteins do not require energy and facilitate the movement of substances along a concentration gradient. Some protein carriers and all protein pumps require energy. Transport mechanisms that use energy can transport substances up (against) the concentration gradient.
- Simple diffusion, facilitated diffusion and osmosis are ways that molecules can cross membranes by passive transport (which does not require energy).
- Energy in the form of ATP is required to move substances across membranes by active transport, endocytosis and exocytosis.
- Solutions can be compared using the terms hypertonic, isotonic and hypotonic.
- The physical and chemical nature of a substance determines the way in which it will be transported across membranes by cells.
- The size, shape and surface-area-to-volume ratio of a cell affect the rate of supply of nutrients and removal of wastes.
- The greater the concentration gradient of a substance across a membrane, the faster it will diffuse.

CHAPTER 9 GLOSSARY

Active transport the process whereby cells actively transport substances across a membrane from a low concentration to higher concentration of the substance; characterised by the fact that the process consumes energy

Adhesion protein a membrane protein that helps link cells together

Aquaporins water channels that are intrinsic membrane proteins and that selectively allow water or other small uncharged molecules to pass along the concentration gradient

ATP (adenosine triphosphate) a high-energy compound composed of adenine and ribose with three phosphate groups attached; it stores a usable form of energy; it releases energy for cellular reactions when its last phosphate group is removed and it is converted to ADP (adenosine diphosphate)

Bilayer a double layer

Carrier protein a protein within membranes that assists other molecules to cross the membrane; in facilitated and active transport, carrier proteins have to change shape to pass a molecule across the membrane; with the use of energy in the form of ATP, they can transport specific small molecules or ions against their concentration gradients

Cell membrane (plasma membrane) the selectively permeable boundary of all living cells that maintains the contents of the cell and regulates movement of substances in and out of the cell

Channel protein a protein that forms channels within membranes to allow the passive passage of hydrophobic substances across the membrane; they catalyse movement of specific ions (or water) down their electrochemical gradient via passive transport, a process called facilitated diffusion

Cholesterol a type of lipid embedded in cell membranes that provides stability and allows fluidity

Concentration gradient the difference in concentration of a substance between two different regions

Contractile vacuole the vacuole found in some freshwater unicellular organisms that maintains osmotic balance by collecting water and emptying it from the cell

Cytoplasm all the fluid, dissolved materials and organelles between the cell membrane and the nuclear membrane

Cytosol the fluid part of the cytoplasm, containing highly organised fluid material with dissolved substances; excludes the organelles

Diffusion the passive movement of particles from a high to a low concentration of that substance

Endocytosis the movement of solids or liquids into a cell from the environment via vesicle formation

Enzyme a biological catalyst that speeds up biological reactions without undergoing any change itself; most enzymes are proteins; all enzymes are macromolecules

Equilibrium the state reached when two solutions have the same concentration of solutes and the net movement is zero across a selectively permeable membrane

Exocytosis the movement of solids or liquids from a cell to the environment via vesicle formation

External environment the environment surrounding a cell, outside the cell membrane

Extracellular fluid the fluid that bathes the outside of cells in multicellular organisms

Facilitated diffusion a form of diffusion that requires a substance to be attached to a specific carrier molecule to move across a membrane

Flaccid floppy; describes the condition of a plant cell that has lost water

Fluid mosaic model a model which describes membranes as a double layer of lipids, a lipid bilayer, with the ability to flow and change shape, like a two-dimensional fluid; specialised protein molecules are embedded in the lipid in various patterns, like a mosaic

Hydrophilic describes a substance that tends to interact with and dissolve in water

Hydrophobic describes a substance that avoids association with water

Hypertonic describes a solution with a higher solute concentration compared with another solution

Hypotonic describes a solution with a lower solute concentration compared with another solution

Internal environment (of a cell) all material contained within the cell membrane

Ion an atom or molecule that has an electrical charge due to losing or gaining electrons; used by cells as reactants for many cellular processes

Isotonic describes a solution with an equal solute concentration to another fluid

Multicellular describes an organism consisting of more than one cell

Net change the amount of change after considering the movement of particles across a membrane in both directions; the result after subtracting movement in one direction from movement in the other is the net change

Osmosis the movement of water across a selectively permeable membrane from regions of low solute concentration to high solute concentration

Particle theory (also known as the kinetic theory of matter) the theory stating that matter consists of tiny particles in constant motion; the motion of particles increases when they have higher energy

Passive process a process that take place without any input of energy

Passive transport the movement of molecules, across a membrane, that does not require the input of energy

Permeable describes a membrane through which substances can pass

Phagocytosis the bulk transport of solids into a cell by engulfment and formation of a vesicle

Pinocytosis the bulk transport of liquids into a cell by engulfment and formation of a vesicle

Plasma membrane see *cell membrane*

Plasmolysis the cytoplasm pulling away from the cell wall because of water loss from the cell

Receptor protein a protein in a cell membrane that binds hormones and other signal molecules

Recognition protein a protein that acts as a marker on membranes

Selectively permeable describes a membrane that allows some substances but not others to pass across it

Sodium–potassium pump a membrane protein that uses energy to transport sodium ions out of, and potassium ions into, cells, against their concentration gradients

Solute a substance that can be dissolved in another substance

Solution a mixture of solute and solvent

Solvent a substance in which another substance can be dissolved to create a solution

Surface-area-to-volume (SA : volume) ratio the mathematical ratio of the size of the surface area (in two dimensions) compared to the volume of an object (in three dimensions)

Tissue a group of specialised cells working together to perform a specific function

Transport protein a protein that carries molecules across membranes

Turgid describes a cell that is tight and rigid from absorbing water

Unicellular describes an organism made up of a single cell

Wilt to become limp and floppy

CHAPTER 9 REVIEW QUESTIONS

Remembering

1 List two natural conditions that might cause plant cells to become plasmolysed.

2 Draw a diagram of a unicellular freshwater organism in seawater, labelling the direction of the net movement of water between the cell and its environment.

3 When human cheek cells are studied under a microscope, they are mounted on a slide in a drop of 'normal' saline (salt) solution, rather than tap water. Explain why this is the best method of preparing these cells.

4 Describe the structure of the cell membrane, according to the fluid mosaic model.

Understanding

5 A student places a living cell into a drop of liquid containing a 5% sugar solution. After 30 minutes, the liquid contains less than 5% sugar. Explain what has happened.

6 Write a few sentences to explain the process by which carbon dioxide might move from the external environment into a cell.

7 Explain why red blood cells become crenated (crinkled) in a hypertonic solution.

Applying

8 When plants do not have enough water, they wilt. Once watered, they will stand up straight again. Apply your knowledge of membrane transport to explain the role of vacuoles in this process.

Analysing

9 Two cells have the same internal concentration of sugar solution when they are placed in distilled water. Even though both cells expand over time, one expands faster than the other. Discuss some possible reasons for this observation.

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10 Three duck eggs with their shells removed all weigh 50 g. They are placed in different concentrations of salt solutions: 1.0, 1.5 and 2.0 mol/L (molar) concentration, respectively. After 2 hours, the eggs are reweighed. The egg placed in the 1.0 mol/L salt solution weighed 54 g, the egg placed in the 1.5 mol/L salt solution weighed 50 g and the egg in the 2.0 mol/L salt solution weighed 46 g.
  a Construct a line graph showing probable change in egg mass over a 2-hour period.
  b Explain, for each concentration, why the eggs gained or lost mass or stayed the same.

Evaluating

11 There is a great deal of concern about rising levels of salt in many parts of Australia. Evaluate which is worse for a citrus farmer: a lack of available fresh water or to have saline soils. Discuss reasons for your answer.

12 Evaluate whether a round cell with a diameter of 5 mm will have a greater chance of survival than a round cell of 2 mm.

Creating

13 Xenophyophores are giant unicellular organisms found more than 10 km below the sea surface. They are the largest individual cells known to exist; they can grow up to 10 cm across. Reflect on the issues facing these organisms and describe three adaptations that you would expect them to display.

14 A student made the comment that ‘The formation of vesicles by endocytosis should reduce the size of the cell membrane’. Apply your knowledge of both endocytosis and exocytosis to critically examine this comment.

15 A person marooned on a desert island surrounded by seawater must look for fresh water to drink. There are plants on the island.
  a Suggest how they might find enough water to stay alive.
  b Discuss what would happen to the person if he or she drank the seawater.

PRACTICE EXAM QUESTIONS

1 Algal cells are common in the surface waters of the ocean. Cells with a high surface-area-to-volume ratio sink more slowly than cells with a low surface-area-to-volume ratio. Which of the following cells will sink at the slowest rate?
  A a small cell with long spines
  B a small cell with short spines
  C a large cell with long spines
  D a large cell with short spines

[Q16 2011 Stage 2 SCSA]

2 A living cell was placed in a dilute salt solution in a dish. The cell expanded until it eventually burst. The cell burst because the:
  A cell membrane was damaged by salt crystals.
  B cell membrane was not permeable to water.
  C salt concentration of the solution was higher than that of the cell.
  D salt concentration of the solution was lower than that of the cell.

3 A biology student made an artificial cell using a balloon that was permeable to water but not to sucrose. The student filled the balloon with 10% sucrose solution and placed it in a tank of 5% sucrose solution. The apparatus was then left overnight. A likely outcome the next day would be that the balloon would:
  A gain water.
  B lose water.
  C gain sucrose.
  D lose sucrose.

[Q29 2010 Stage 2 SCSA]

4 Distinguish between diffusion and osmosis (2 marks)

[Q31e 2011 Stage 2 SCSA]

5 Draw a diagram to show the structure of the cell membrane, including proteins, phospholipids and cholesterol (limit your diagram to show a short section of the membrane). (3 marks)

6 State two functions of the proteins in the cell membrane. (2 marks)

7 Explain how the following substances cross the cell membrane: (4 marks)
  a carbon dioxide
  b glucose.

8 Define plasmolysis and draw a labelled diagram to show cell structure before and after plasmolysis. (5 marks)

9 Describe four different types of cell membrane transport, including one named substance that is carried by each mechanism. (8 marks)

10 Analyse Figure 9.34, which represents an experiment a Year 11 student conducted to try to observe osmosis and diffusion into or out of a cell. Discuss the relative concentration of the solution compared to the cell, and the structures and processes of cell membrane transport being modelled in the diagram. (10 marks)

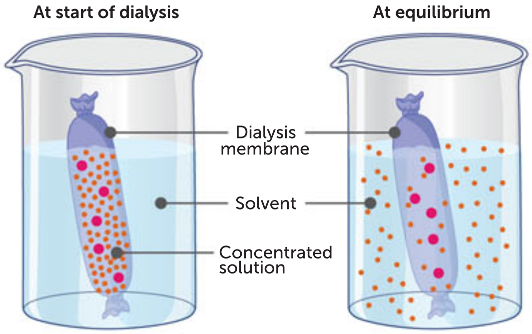
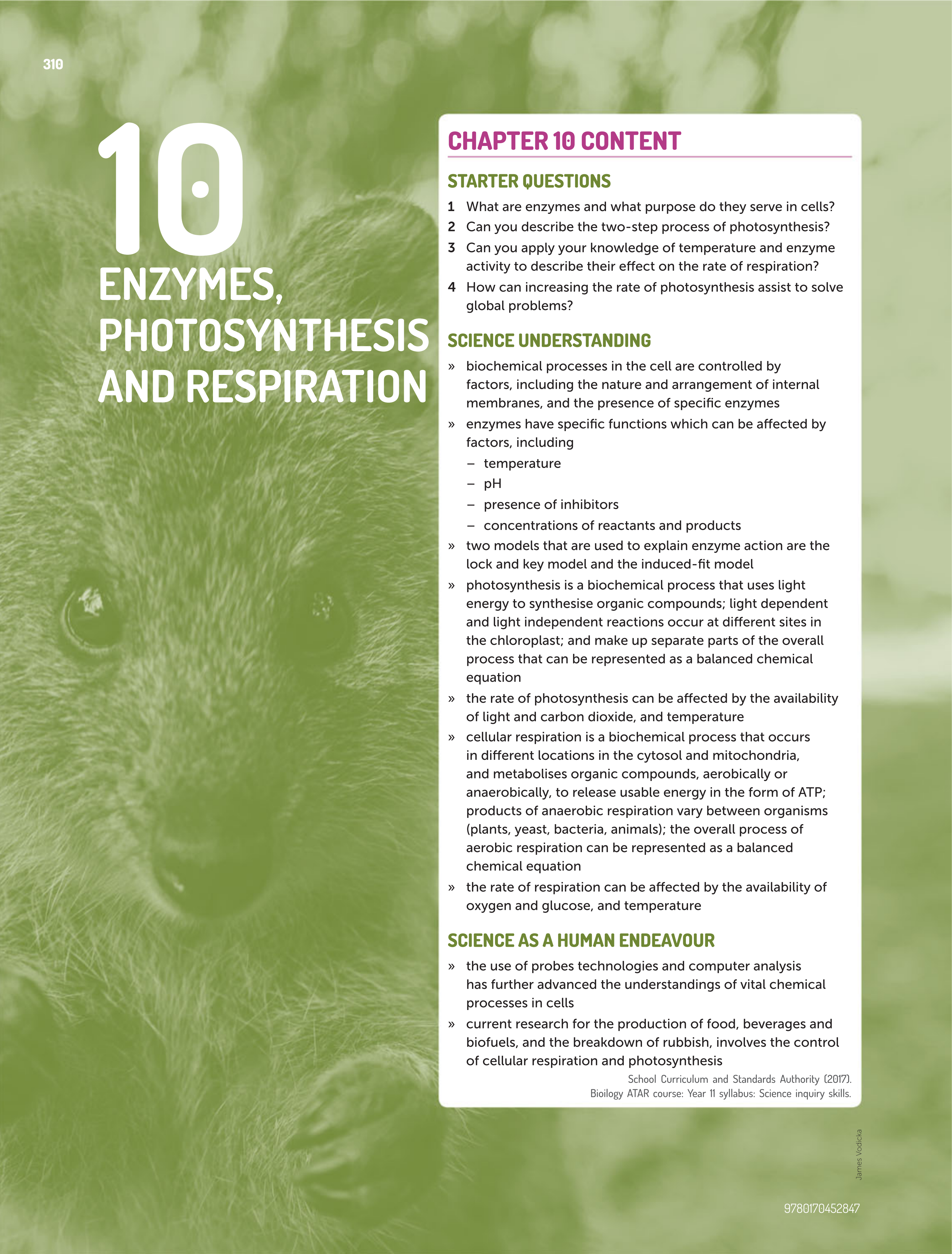


FIGURE 9.34 A model of diffusion



10 ENZYMES, PHOTOSYNTHESIS AND RESPIRATION

CHAPTER 10 CONTENT

STARTER QUESTIONS

1 What are enzymes and what purpose do they serve in cells?
2 Can you describe the two-step process of photosynthesis?
3 Can you apply your knowledge of temperature and enzyme activity to describe their effect on the rate of respiration?
4 How can increasing the rate of photosynthesis assist to solve global problems?

SCIENCE UNDERSTANDING

» biochemical processes in the cell are controlled by factors, including the nature and arrangement of internal membranes, and the presence of specific enzymes
» enzymes have specific functions which can be affected by factors, including
  – temperature
  – pH
  – presence of inhibitors
  – concentrations of reactants and products
» two models that are used to explain enzyme action are the lock and key model and the induced-fit model
» photosynthesis is a biochemical process that uses light energy to synthesise organic compounds; light dependent and light independent reactions occur at different sites in the chloroplast; and make up separate parts of the overall process that can be represented as a balanced chemical equation
» the rate of photosynthesis can be affected by the availability of light and carbon dioxide, and temperature
» cellular respiration is a biochemical process that occurs in different locations in the cytosol and mitochondria, and metabolises organic compounds, aerobically or anaerobically, to release usable energy in the form of ATP; products of anaerobic respiration vary between organisms (plants, yeast, bacteria, animals); the overall process of aerobic respiration can be represented as a balanced chemical equation
» the rate of respiration can be affected by the availability of oxygen and glucose, and temperature

SCIENCE AS A HUMAN ENDEAVOUR

» the use of probes technologies and computer analysis has further advanced the understandings of vital chemical processes in cells
» current research for the production of food, beverages and biofuels, and the breakdown of rubbish, involves the control of cellular respiration and photosynthesis

School Curriculum and Standards Authority (2017). Bioilogy ATAR course: Year 11 syllabus: Science inquiry skills.

James Vodicka

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10.1 BIOCHEMICAL PROCESSES IN CELLS

Biochemical processes are chemical processes that occur in all cells. Biochemical reactions result in **products** needed by cells. Most chemical changes in a cell result from chains and cycles of biochemical reactions, with each step controlled by a separate, specific enzyme. The sum of all the biochemical reactions in an organism is called **metabolism**, and this can be divided into two types of reactions.

Anabolic reactions involve the synthesis of complex molecules from simpler ones and usually require energy to form new chemical bonds.

Catabolic reactions involve the breakdown of complex molecules into simpler ones and usually release energy from breaking chemical bonds.

For cells to continue functioning, enough energy must be provided to maintain the process of generating products from reactants. To achieve this, chemical reactions in cells occur in a series of regulated steps collectively called biochemical processes. The product of one step becomes the reactant for the next step (Figure 10.1). In this way, a product from one reaction is continually removed by being the reactant for the next reaction.

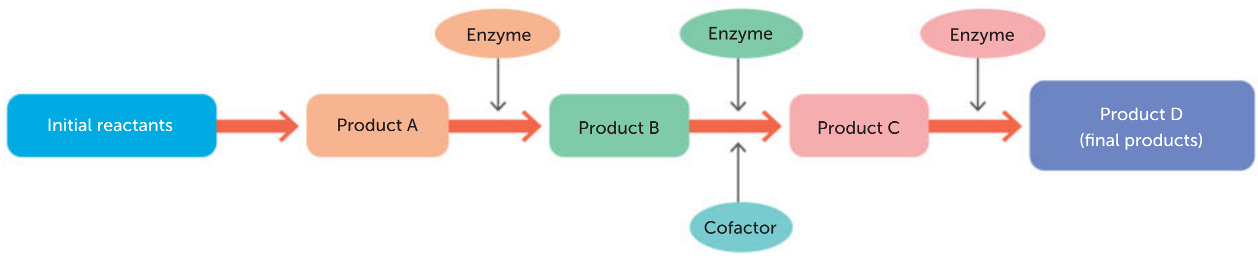


FIGURE 10.1 A model of a biochemical pathway. The products or outputs of the first step become the reactants or inputs for the next step, until the final products are reached. Each step is regulated by a specific enzyme. Cofactors may be involved.

Cells have a number of ways of removing the final product from solution so that a biochemical pathway keeps operating in the required direction. In a plant cell, the final product of photosynthesis is glucose. Glucose, a soluble substance, can be converted into an insoluble polysaccharide, starch, which is stored by the plant. Thus, the plant is able to continue to produce and store glucose. Alternatively, glucose may be used as a reactant in cellular respiration. In cellular respiration, the product carbon dioxide diffuses from cells and is expelled into the atmosphere. Alternatively, carbon dioxide may be used as a reactant in photosynthesis. Each step in the biochemical pathways of photosynthesis and cellular respiration is controlled and regulated by specific enzymes.

Key concept

Metabolism is all of the biochemical reactions in an organism. It comprises:

- anabolic reactions, which synthesise complex molecules from simpler ones and usually require energy to form new chemical bonds
- catabolic reactions, which break down complex molecules into simpler ones and usually release energy by breaking chemical bonds.

Internal cellular membranes control biochemical processes

A cell has compartments called organelles. Compartmentalising a cell by having membrane-bound organelles creates specialised micro-environments for specific functions. A large number of activities can occur at the same time in a very limited space and under different conditions. For example, chemical reactions in lysosomes break down compounds brought into the cell by using strong digestive enzymes in an acidic environment. Enclosing them in a membrane prevents them destroying the cell. Membrane-bound structures can also concentrate reactants and store products for later use.

Some organelles, such as mitochondria, increase their internal surface area by having internal membranes that are folded and stacked. The folded membranes of mitochondria (cristae) are studded with enzymes needed for cellular respiration. Enzymes are arranged in order of the steps involved in cellular respiration. The internal membranes of chloroplasts are also studded with enzymes necessary to keep photosynthetic reactions continuing.

Question set 10.1

REMEMBERING

1 Define 'metabolism'.

2 Define 'biochemical pathway'.

UNDERSTANDING

3 Compare anabolic and catabolic reactions and give an example of each.

APPLYING

4 Interpret Figure 10.1 in your own words.

10.2 ENZYMES

Specific enzymes control biochemical pathways

Towards the end of the 19th century, the German chemist Eduard Buchner was experimenting to find a way of preventing yeast extracts from going bad. In one trial he added sugar to yeast extract and, rather than preventing change, he found that the sugar was fermented and converted to alcohol. Louis Pasteur had already demonstrated that yeast was responsible for the fermentation of sugar but Buchner took the research further. He showed that the juice extracted from living yeast cells was responsible for fermentation, not the yeast cells themselves. To describe the active ingredient in the juice that caused the fermentation he coined the term 'enzyme', from the Greek word 'zyme' meaning leavened. This is now the collective term for the thousands of organic protein molecules extracted from cells and found to act as organic **catalysts**.

An **enzyme** is a biological catalyst that speeds up biological reactions without undergoing any change itself. Most enzymes are proteins; all enzymes are macromolecules. Enzymes lower the activation energy required for a reaction to proceed. Without enzymes, chemical reactions would take much longer to occur.

The sum of the thousands of chemical reactions that occur constantly in each living cell is known as **cellular metabolism**. The rate of cellular metabolism varies among organisms. The metabolic reactions that occur in cells do not take place randomly; all are controlled and regulated to maintain cell functions and to meet the energy needs of the cell. These reactions need to occur at a rate that allows the cell to function. What is it that controls the type and duration of these reactions? Each step in the pathway is controlled by an enzyme.

Enzyme
Biological catalyst
Usually a protein
Speeds up chemical reactions in cells
Lowers the activation energy
Unchanged and reusable
Each is specific to one type of reaction

FIGURE 10.2 Enzyme definition and function

Enzymes are one of the most important groups of proteins. Without enzymes, the reactions that occur in living organisms would be so slow as to hardly proceed at all; this would be incompatible with the maintenance of life.

Enzymes do more than merely speed up the reactions; they also control them. Over 1000 different reactions can take place in an individual cell. The functional organisation that this demands is achieved by a specific enzyme in a particular place within the cell acting as a catalyst for each individual reaction.

There are as many enzymes in living organisms as there are types of chemical reactions. They are divided into two broad groups: intracellular and extracellular. Intracellular enzymes speed up and control metabolic reactions inside cells. Extracellular enzymes are produced by cells but achieve their effects outside the cell. They include digestive enzymes, which break down food in the small intestine.

Key concept

An enzyme is a biological catalyst (usually a protein) that speeds up a specific reaction without undergoing any change itself.

The enzyme-regulated chemical reactions that occur in cells are also known as biochemical pathways.

Biochemical processes: catabolic and anabolic reactions

The main metabolic pathways that transfer energy through living systems are **photosynthesis** and **cellular respiration**. These reactions transform energy in order to keep an organism alive.

Consider the case of starch breaking down into sugar. This is a type of chemical reaction where a complex molecule breaks down into a simpler one. Reactions such as this are termed catabolic reactions. When amino acids are joined together to form proteins, small molecules build up into larger molecules. These are anabolic reactions. You may have heard the term 'anabolic' before, with reference to anabolic steroids and body building.

Now consider the energy changes of chemical reactions. **Exergonic reactions** ('exo' means out) are those that release energy. They are sometimes referred to as 'downhill' reactions. When molecular bonds are broken, energy is released. It makes sense that when a large molecule is broken down to smaller molecules, a large amount of energy is released. The opposite type of reaction, when molecular bonds are formed, is called an **endergonic reaction** ('endo' means in). These are sometimes referred to as an 'uphill' reaction.

For example, when starch breaks down to sugar, energy is released. Catabolic reactions always release energy, so they are always exergonic. In another example, when proteins are built up from amino acids, energy is used. These types of anabolic reactions are always endergonic. Cells use the available energy released from catabolic reactions to fuel anabolic reactions (Figure 10.3).

Biochemical reactions: catabolic and anabolic reactions
Find out how catabolic and anabolic reactions occur in living cells.

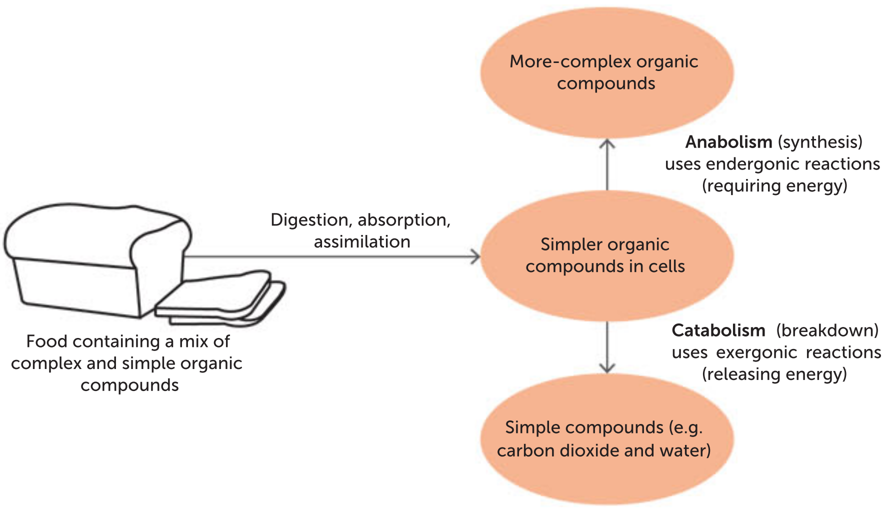


FIGURE 10.3 The relationship between catabolic and anabolic reactions in a typical animal cell. The ingested organic compounds are first reduced to smaller compounds that can enter cells, then may be either built up into more-complex compounds or broken down into even simpler compounds.

The energy released from catabolic reactions, such as cellular respiration, is 'shuttled' into anabolic reactions, particularly those that recharge molecular 'cell batteries'. To understand how this works we need to understand the role of biological reactions in making and breaking molecules.

A biochemical process or reaction occurs when the chemical bonds of inputs or reactants are broken and the atoms recombine to form a new substance or substances: the output or products. In endergonic reactions, a total net amount of energy is absorbed and locked up in the bonds of the products, which have more stored energy than the reactants. In exergonic reactions, a total net amount of energy is released from the bonds of the reactants and the products have less energy than the reactants.

Activation energy

Energy is the capacity to cause change. It is measured in joules or kilojoules. Chemical reactions require energy to start. The **activation energy** is the minimum amount of initial energy required to start a chemical reaction. Activation energy is usually supplied in the form of heat energy (thermal energy) that the reactant molecules absorb from their surroundings. Enzymes catalyse reactions in cells by lowering the activation energy required. They do not provide energy; instead, they weaken bonds within reactants to speed up the reaction. Enzymes are able to destabilise existing chemical bonds in reactants.

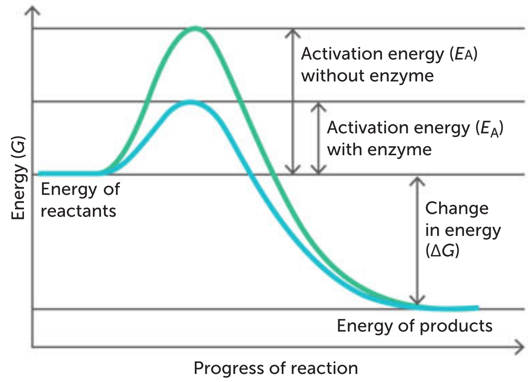


FIGURE 10.4 A generalised activation energy graph

The progress of a metabolic reaction can be represented in graph form. Two lines can be drawn to compare the effect of an enzyme on the progress of the reaction.

Activation energy
These two videos show the concept of reverse reactions.

One of the fastest enzymes is catalase. This enzyme is found in several organs and tissues, including the liver, where its job is to speed the breakdown of hydrogen peroxide (H_2O_2) into oxygen and water, according to the reaction:

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

Hydrogen peroxide is a toxic by-product of metabolism, so it is essential that the cell removes it as fast as possible. Hydrogen peroxide has a high activation energy, which means that the energy input required before it will break down into oxygen and water is high. The decomposition of hydrogen peroxide in the presence of catalase can proceed up to 100 million times faster than without it! The action of enzymes in reducing the activation energy of reactions is represented in Figure 10.5.

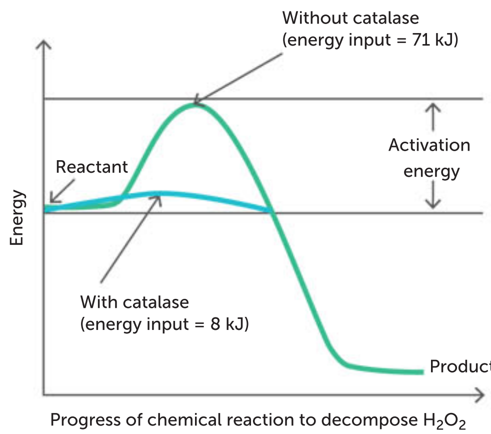


FIGURE 10.5 Catalase reduces the activation energy needed to break down hydrogen peroxide. Enzymes are powerful because they reduce the activation energy for chemical reactions.

Key concept

The activation energy is the initial energy needed to start a chemical reaction. It is usually supplied by the heat energy that reactants absorb from their surroundings. Enzymes catalyse reactions by lowering the activation energy required for a reaction to occur.

Enzymes are not destroyed or altered by reactions

Because enzymes are not destroyed or altered by the reactions they catalyse, they can be used again. The product molecules are not specific to the **active site** of an enzyme, so when they are released, the active site becomes available for another **substrate** molecule. This is not to say that a given molecule of an enzyme can be used indefinitely, because the action of an enzyme depends critically on its shape, which is readily affected by changes such as temperature and acidity.

Question set 10.2

REMEMBERING

1 Define 'activation energy'.
2 Define 'enzyme'.
3 Compare intracellular and extracellular enzymes.

UNDERSTANDING

4 Draw an energy profile diagram to show the effect of an enzyme on the activation energy of a reaction.
5 Compare the terms 'reactant' and 'enzyme'.

APPLYING

6 Explain how enzymes lower the activation energy in a reaction.

10.1 APPLICATION

Special enzymes

Besides requiring these molecules to live, some organisms rely on enzymes to glow. Bioluminescent species of fish, jellies, fungi and insects can produce 'cold light' in a chemical reaction involving the enzyme luciferase. In the presence of oxygen and energy packets of ATP (adenosine triphosphate) produced in cells, luciferase oxidases luciferin to produce light. In the black of night or deep in the ocean, bioluminescent abilities help organisms to find both mates and prey.

Alamy Stock Photo/Science Photo Library

FIGURE 10.6 Ocean dwellers such as this comb jelly can produce bioluminescent light as a result of the enzyme luciferase, which converts chemical energy to light energy.

Questions

1 Why are so many animals in the ocean bioluminescent?
2 Is the light of the glow-worm produced in the same way as that of a firefly?
3 What is the function of bioluminescence?

10.3 MODELLING ENZYME SPECIFICITY

Most enzymes are types of proteins and, like all proteins, they have a specific shape. It is an enzyme's shape that allows it to bind with a specific reactant. The reactant the enzyme acts on is called the enzyme's substrate. Enzymes are generally named according to the substrate they catalyse, or the reaction, and they usually end in '–ase'; for example, sucrase, lipase and maltase. We can explain the properties of enzymes by suggesting that, when an enzyme-controlled reaction takes place, the enzyme and substrate molecules become joined together for a short time to form an **enzyme–substrate complex**. The substrate is converted to the end product by the catalytic action of the enzyme. The enzyme is unchanged by the reaction and can be used again. This means enzymes are often only needed in small quantities within a cell.

It is thought that each enzyme has a precise region on its surface to which the substrate can become attached. This is called the active site (Figure 10.7). All enzymes are substrate-specific. For instance, sucrase can only catalyse the substrate sucrose.

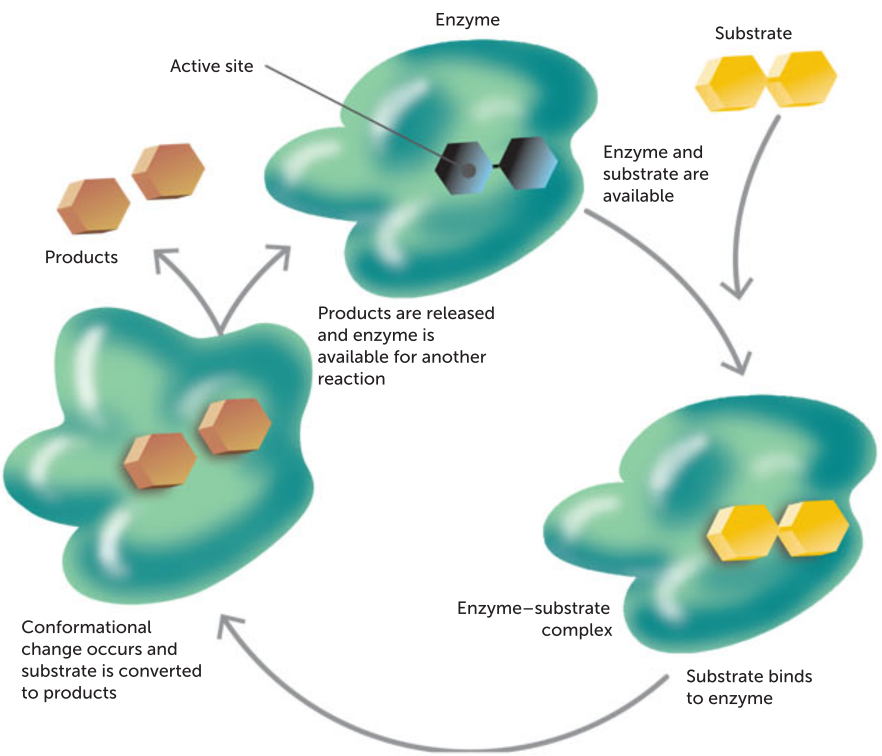


FIGURE 10.7 Enzymes are highly specific molecules. A small part of the enzyme, called the active site, has the correct shape, or conformation, to bind with a specific reactant (substrate). The conformational change that results prepares the substrate for reaction.

There are two models for how an enzyme–substrate complex is formed at the active site. A **model** is a representation that describes, simplifies, clarifies or provides an explanation of the workings, structure or relationships within an object, system or idea.

One model of enzyme action is known as the **lock-and-key model** (Figure 10.8a). The folding of an enzyme protein forms a fixed groove or pocket-shaped active site. The active site is highly specific for a particular substrate. The substrate must be of a compatible shape for binding to occur. The substrate fits the active site of the enzyme like a key fits into a lock.

The other model is known as the **induced-fit model** of enzyme action (Figure 10.8b). This model is more widely accepted. In this case, the enzyme shape is not fixed. The bonds that form between an enzyme and its substrate are thought to slightly modify the shape of the enzyme so that the

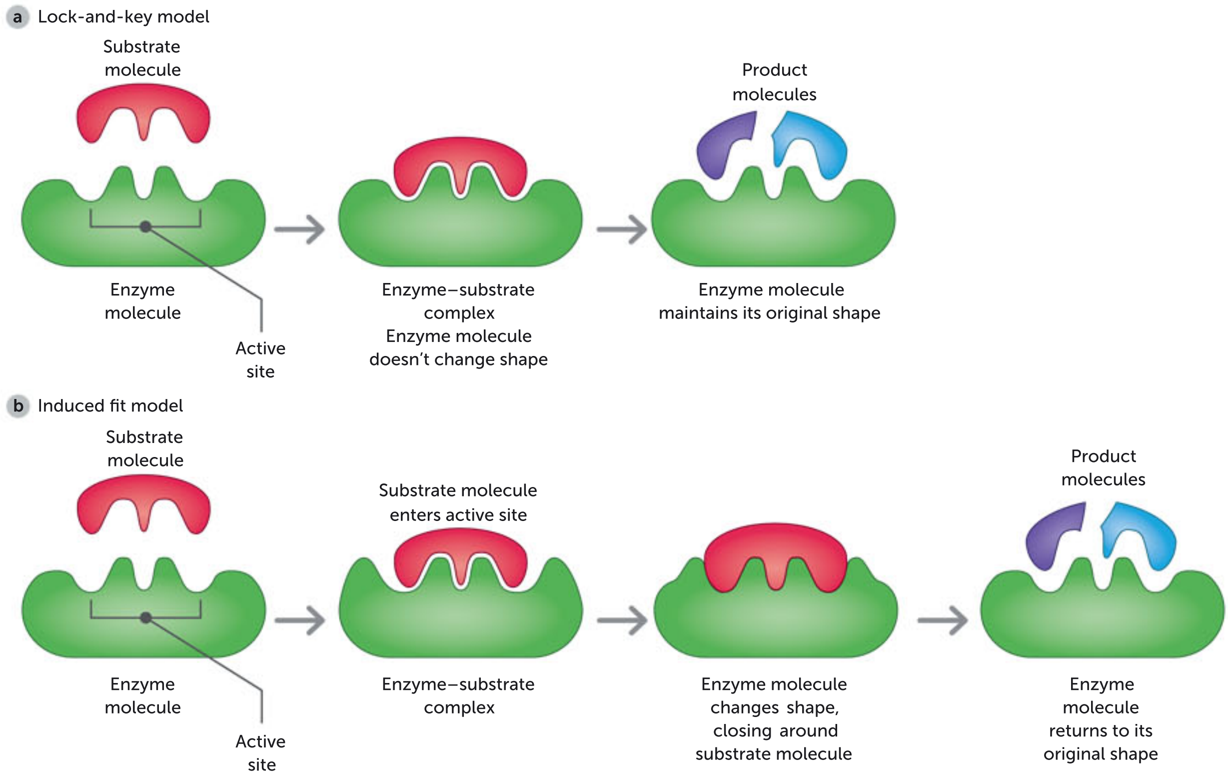


FIGURE 10.8 A generalised catabolic reaction. **a** With the lock-and-key model, the substrate fits into a specific active site on the surface of the enzyme, where the reaction takes place. **b** With the induced-fit model, the substrate molecule enters the enzyme's active site, causing the enzyme molecule to change its shape so that the two molecules fit together more closely.

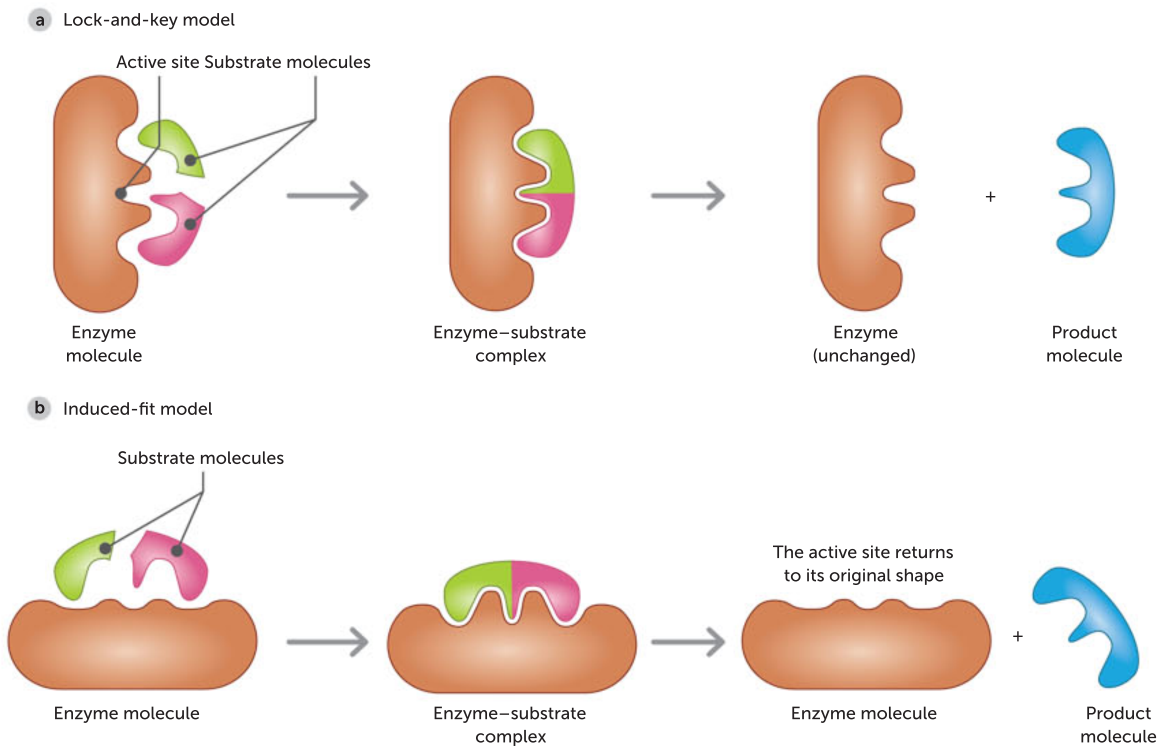


FIGURE 10.9 A generalised anabolic reaction, shown by **a** lock-and-key modelling and **b** induced-fit modelling

substrate can be accommodated by the enzyme. Enzymes in this model have broad specificity (e.g., lipase can bind to a variety of lipids). This means they still only bind to few enzymes of similar shape but there is some conformational shape change in the active site. In this situation, the bonds within the substrate molecule are stretched and bent by the molecular interactions with the amino acid groups that line the active site. As a result of these stresses on the substrate, the activation energy required to kick-start the reaction is dramatically lowered and new product molecules are formed at a faster rate. After a product is released, the active site returns to its original shape. Catabolic and anabolic reactions can be demonstrated using both models.

Key concept

Two models that are used to explain enzyme action are the lock-and-key model and the induced-fit model, which is more widely accepted.

Enzymes can work in either direction

Enzyme-controlled reactions can work in either direction because metabolic reactions are generally reversible. The direction in which the reaction proceeds at any given time depends on the relative concentrations of substrates and products.

If there is a high concentration of reactants present compared with products, an enzyme-controlled reaction will synthesise more of the reactants into products until equilibrium is reached.

Question set 10.3

REMEMBERING

1 Summarise the features of an enzyme.
2 Describe what happens to an enzyme after it has catalysed a reaction.

UNDERSTANDING

3 List the main properties of enzymes, then relate each property to the lock-and-key model.
4 Explain why there are thousands of different types of enzymes in the human body.

APPLYING

5 Explain the induced-fit model of enzyme action. Describe how this is different to the lock-and-key model.
6 Copy and complete Table 10.1 to show the differences between the two models of enzyme action.

TABLE 10.1 The differences between models of enzyme action

FEATURE	LOCK-AND-KEY MODEL	INDUCED-FIT MODEL
Active site	Rigid	
Specificity	Highly specific	
Shape	Perfect fit	
Effect on activation energy	Not applicable	
Action of active site after reaction	Not applicable	

10.4 FACTORS THAT AFFECT ENZYME ACTIVITY

The intracellular and extracellular environments are regulated to ensure that enzymes are able to perform and meet the cell's needs. Enzymes are sensitive to changes in temperature, pH, substrate and product concentrations, and other substances that may compete with a substrate for an active site. Changes in any of these factors will affect the enzyme's ability to function.

Temperature

Enzymes have an optimal temperature range in which they operate. The temperatures that enzymes work best in are the temperatures of the environment they can be found in. For example, enzymes operating in the human body work best at temperatures of around 37°C, which is the relatively constant core temperature of the body. The enzymes of **psychrophiles** (or cryophiles), micro-organisms that live in near-freezing environments such as the wind-blasted rocks of snow-covered mountain summits, can operate at very low temperatures. The micro-organism *Pyrodictium* exists in geothermal-heated areas of the sea floor. It is a **thermophile** and its enzymes operate best at temperatures of around 95–105°C.

Enzymes from another thermophile, *Thermus aquaticus,* are utilised in biotechnology. The enzyme Taq polymerase (used to make millions of copies of DNA in a technique called the polymerase chain reaction, PCR) is utilised because it operates at the required reaction temperature of 70°C and is not **denatured** at elevated temperatures of 90°C.

So how does a change in temperature affect enzyme activity? As the temperature increases, molecules become more active and collide more often. This increase in collisions increases the opportunity for a substrate to bump into its enzyme so that it binds at the active site. The rate of reaction therefore increases. However, if the temperature gets too high, the enzyme starts to denature. It loses its functional shape so that the substrate can no longer bind with the active site and the reaction rate decreases (Figure 10.10). If the shape has changed enough to break the bonds between the connecting units of amino acids, enzymes cannot return to their original shape when conditions revert to normal. In this case, the enzyme is destroyed.

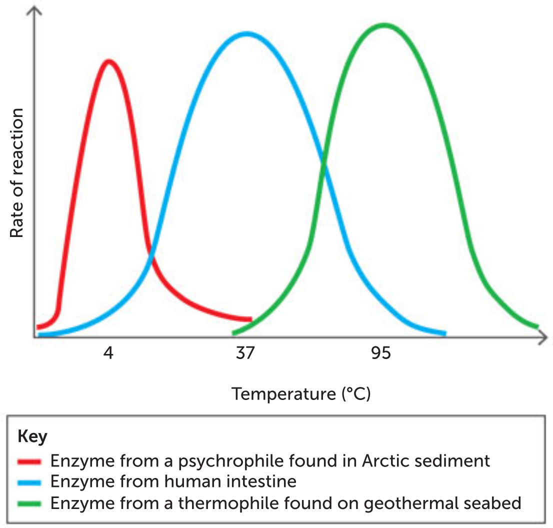


FIGURE 10.10 The temperature range (not to scale) for three different enzymes. Activity gradually increases until the optimum temperature for enzyme activity is reached. As temperature continues to increase, enzymes become denatured and the reaction rate decreases.

This has repercussions for us that can be both dangerous and useful. If our body temperature rises too much during an infection, critical enzymes in our brain could denature, leading to seizures and possible death. On the other hand, we are able to chew and digest meat more easily after it is cooked. Raw meat is difficult to chew because of fibrous proteins contained in the muscle cells. By heating and cooking the meat, the proteins are denatured, making it easier to chew and digest.

Consider the boiling of a lobster. Living lobsters obtain their blue-purple colour from the pigment astaxanthin. These pigment molecules are an orange colour until they bind to a protein in the lobster shell, which alters their shape and their light-absorbing properties. This protein denatures when exposed to high cooking temperatures. As a result, the pigment molecules can no longer bind to the protein so the pigment returns to its free form and the lobster appears orange (Figure 10.11). Cooling the lobster after cooking does not make it blue–purple again, because the effects of denaturing proteins are irreversible. It is important to note that enzymes are not denatured at low temperatures. Like all chemical reactions, a lower temperature means a lower rate of enzyme activity and therefore a lower rate of reaction.

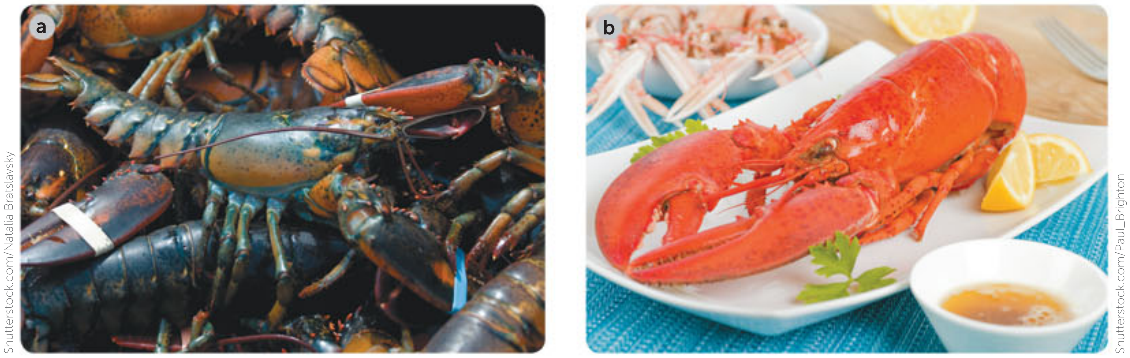


FIGURE 10.11 The change in colour from **a** blue–purple to **b** orange when a lobster is cooked is caused by a pigment-binding protein in the shell, which denatures on cooking. As the lobster stays orange when it cools, it is apparent that the action of denaturing this protein is not reversible.

pH

The pH of the solution surrounding enzymes, whether it is acidic, basic or neutral, can have a profound effect on the structure and activity of the active site of an enzyme and its interactions with a substrate. Each enzyme has an optimum pH at which it works (Figure 10.12). Some enzymes can work in a broad range of pH environments, while others are very sensitive and will only work in a narrow pH range. Most enzymes work most effectively around a neutral pH of 7. Again, the optimal pH of an enzyme relates to the environment in which it is found. Some work in environments of extreme pH, such as the enzyme pepsin, which operates in acidic gastric juices. It has an optimal pH of 1.5. Catalase, which works in the neutral environment of cells in the liver, has an optimal pH of 7. Alkaline phosphatase, which is found in the relatively alkaline environment of the bone, has an optimal pH of 9.5.

Some enzymes change shape in response to changes in pH. In some cases, such as excessive acidity or alkalinity, the active site shape can alter so much that the enzyme becomes denatured and can no longer catalyse a reaction, or the substrate may change shape so it no longer fits into an active site.

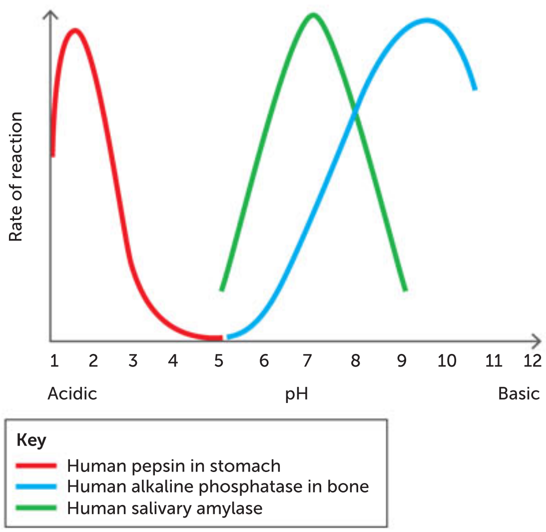


FIGURE 10.12 The optimum pH range for three different enzymes. The enzyme pepsin digests proteins in the acidic juices of the stomach, the enzyme alkaline phosphatase catalyses reactions in the relatively alkaline environment of the bone and the enzyme salivary amylase digests carbohydrates in the mouth at a neutral pH.

Key concept

Enzymes work best within a limited temperature and pH range.

Substrate and enzyme concentration

The amount of substrate and enzyme present in a reaction mix can limit the amount of product produced. Increased amounts of substrate will result in more products being made, until all the enzyme molecules are working at their maximum capacity (Figure 10.13).

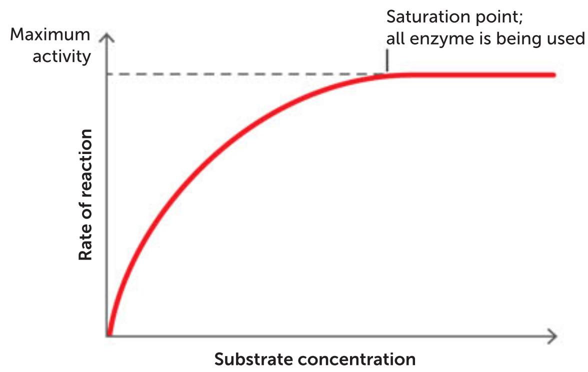


FIGURE 10.13 The effect of increases in substrate concentration on the rate of an enzyme-catalysed reaction. At saturation, further increases in substrate concentration do not increase the rate of the reaction.

When the amount of enzyme in a system is increased, the amount of product increases exponentially. This keeps on happening until the product starts to inhibit enzyme action or the substrate is depleted. The rate of reaction is proportional to the enzyme concentration, provided there is excess substrate present.

Enzyme concentrations are regulated in response to the needs of cells. This regulation is achieved by controlling the production of the protein, breaking down the enzyme or activating the enzyme in response to a stimulus. For example, pepsinogen is an inactive form of the enzyme pepsin. When it enters the acidic environment of the stomach, it is activated to catalyse the digestion of proteins.

Inhibitors

Some enzymes have two or more active binding sites. These enzymes can move between their active and inactive states when **inhibitor** or activator molecules bind with them. The activity of almost every enzyme in a cell is regulated by feedback inhibition, in which the product of a reaction can inhibit enzyme activity. If a large amount of product is present in the cell, it will act as an inhibitor by binding to a site on the enzyme, other than the active site, thus slowing the rate of reaction. When the inhibitor binds to the enzyme, the active site of the enzyme changes shape so that it no longer has an affinity for its substrate. If the product is removed, inhibition will be reduced and the product will be produced again. This helps cells keep the concentration of products within a certain range. Examples of inhibitors include toxins, poisons and antibiotics.

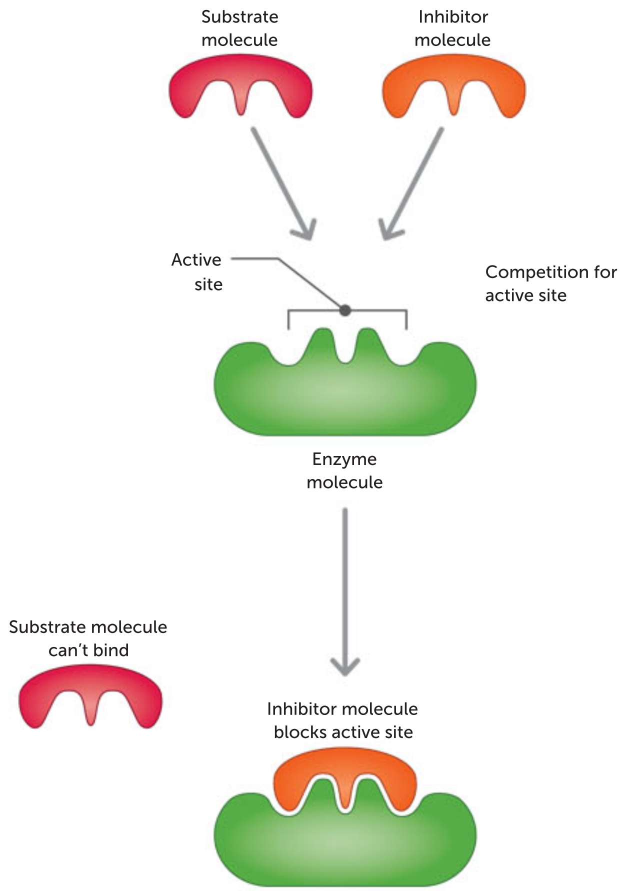


FIGURE 10.14 An enzyme inhibitor blocks the active site of an enzyme so that the substrate can no longer fit in. Some inhibitors (poisons) bind irreversibly so the enzyme can no longer perform its specific function.

Key concept

Enzymes are affected by factors that include:
- temperature
- pH
- presence of inhibitors
- concentrations of reactants and products.

Cofactors and coenzymes

Some enzymes are inactive until they bind with other molecules or ions that change their conformation. This alters the shape and the charge of the enzyme's active site so that it can capture substrate molecules and catalyse reactions more efficiently. Two classes of substances bind to enzymes, or to the substrate, to activate the enzyme: cofactors and coenzymes. **Cofactors** are small inorganic substances, such as zinc ions and magnesium ions. **Coenzymes** are non-protein organic substances that are required for enzyme activity, and are relatively small molecules compared to the enzyme. Many are made by organisms from dietary vitamins and act as carriers of substances to and from reactions that are catalysed by enzymes. Coenzymes play a major role in metabolic pathways.

Question set 10.4

REMEMBERING

1. Outline two factors that can affect the activity of an enzyme.
2. Compare the function of an inhibitor with those of a cofactor and a coenzyme.

UNDERSTANDING

3. Explain what has happened to an enzyme when it becomes denatured.
4. Describe how the amount of product produced in a reaction can affect an enzyme's activity.
5. How might a shortage of zinc or magnesium affect the enzyme activity of some organisms?

APPLYING

6. Explain why doctors get worried if a patient develops a temperature in excess of 42°C.
7. Sketch a graph to show the effect of temperature on enzyme activity. Include labels such as 'optimum temperature', 'slow enzyme activity', 'fast enzyme activity' and 'enzyme denatures'.

10.5 ATP

Living cells require energy to do their work. **ATP (adenosine triphosphate)** is the main energy-carrying molecule used in metabolism. It is used in both energy-consuming reactions (endergonic reactions) and energy-releasing reactions (exergonic reactions, which need a small amount of activation energy).

Energy enters ecosystems in the form of light energy. Producers convert light energy into chemical energy by building organic molecules and storing energy in their bonds. This process is called photosynthesis. Cells in producers and consumers use the energy stored in organic molecules to make the usable form of energy, ATP. In this process, known as cellular respiration, some energy is lost as heat and escapes from cells into the surrounding environment.

As reactions do not always occur in the same place within the cell, energy has to be transferred between reactions. This transfer is achieved by the energy-carrying molecule ATP, which is readily moved around the cell. ATP is a nucleotide containing adenosine attached to a sugar group (ribose), which is bound to a chain of three phosphate groups.

ATP functions well as a renewable energy source. When a cell requires energy to do work, the high-energy chemical bonds attaching the last phosphate group to ATP are broken, thus releasing stored energy. This energy is now available to fuel a cellular reaction. The remaining molecule now has only two phosphate groups and is called **ADP (adenosine diphosphate)**.

$$\text{ATP} \rightleftarrows \text{ADP} + \text{P} + \text{energy}$$

Free energy obtained from respiration can also be used to add a phosphate group to ADP, converting it to ATP. The ATP–ADP cycle is the cell's way of shuttling energy between reactions (Figure 10.15). It provides an efficient linking or coupling of energy-yielding processes to energy-requiring processes within the cell by conserving, transferring and releasing energy. There are other energy storage molecules in the cell, like NADH and $FADH_2$, but the ATP system is the most common, and the most important. You can think of the others as different brands of rechargeable batteries that have the same function.

When a bond forms between an available phosphate group and ADP, resulting in ATP, the process is called **phosphorylation**.

NADH and $FADH_2$ are other energy-carrying molecules. NADH and $FADH_2$ function as coenzymes during cellular respiration. Analyse the analogy in Figure 10.16 to see how NAD and FAD work (NAD and FAD are their 'nicknames'). The competitors are representing NAD and FAD molecules and the potato bags are representing energy electrons, which are transported from one section of a mitochondrion to another during the process of aerobic respiration.

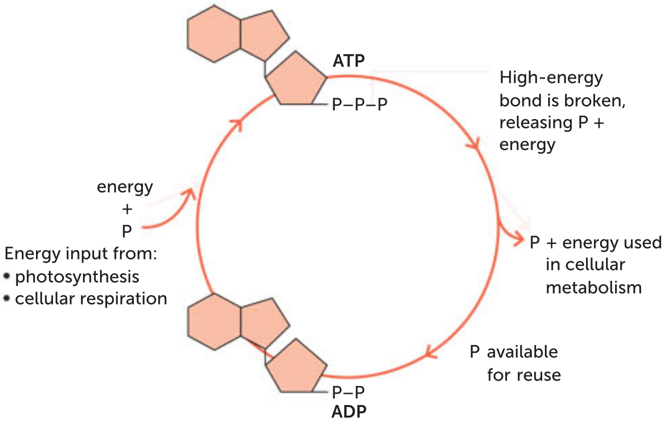


FIGURE 10.15 The ATP–ADP cycle is the cell's way of renewing its supply of immediate energy.

FIGURE 10.16 An analogy for transportation of energy by NADH and $FADH_2$

Question set 10.5

REMEMBERING

1 Explain the relationship between ADP and ATP.

APPLYING

2 Compare a battery to ATP. Describe how they are similar.

3 Explain the analogy being made in Figure 10.16.

4 The following is a simple equation representing the formation of ATP from ADP.

$$\text{ADP} + \text{P} + \text{energy} \rightleftarrows \text{ATP}$$

What does this equation tell you about ATP and energy? What can you infer about energy when a cell utilises the stored ATP?

10.6 PHOTOSYNTHESIS

Photosynthesis is a biochemical process, in producers, that uses light energy and the raw materials carbon dioxide and water to synthesise organic compounds. The light energy is transformed into chemical energy and the energy is stored specifically within the bonds in organic compounds. Many enzymes are involved in the multi-step process of photosynthesis to produce products that include glucose and oxygen. The overall word and chemical equations are shown in Table 10.2.

TABLE 10.2 A summary of photosynthesis

REACTANTS	REQUIREMENTS	PRODUCTS
Word equation		
Carbon dioxide + water	$\xrightarrow[\text{chlorophyll}]{\text{sunlight}}$	glucose + oxygen
Chemical equation		
$6CO_2 + 12H_2O$	$\xrightarrow[\text{chlorophyll}]{\text{sunlight}}$	$C_6H_{12}O_6 + 6O_2 + 6H_2O$
Simplified chemical equation		
$6CO_2 + 6H_2O$	$\xrightarrow[\text{chlorophyll}]{\text{sunlight}}$	$C_6H_{12}O_6 + 6O_2$

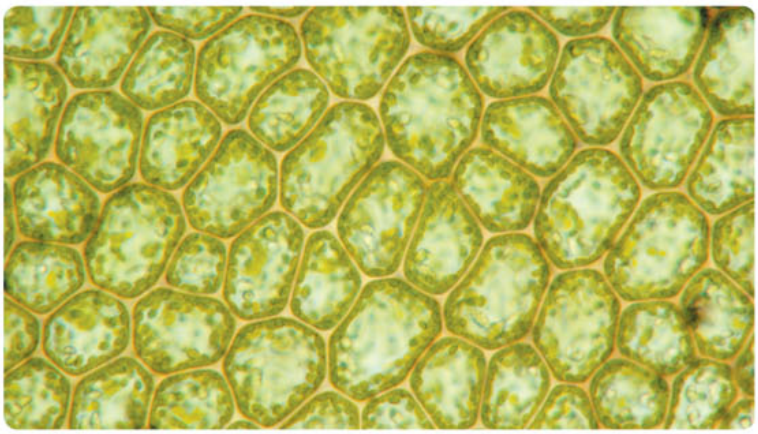
Photosynthesis actually occurs as a series of steps in a biochemical pathway, each catalysed by specific enzymes.

Chloroplasts

Chloroplast
Use the interactive animal and plant cells to view and learn more about the chloroplast. Do they exist in both animal and plant cells?

Photosynthesis requires light as an energy source, and this is captured by the pigment chlorophyll, found in the organelles called chloroplasts. Chloroplasts have an outer and an inner membrane. The **stroma** is enclosed by the inner membrane. This is a gel-like matrix rich in enzymes. Suspended in the stroma is a membrane system, the **thylakoid membranes**. These are flat, sac-like structures that are called **grana** (singular granum) when grouped together into stacks.

The photosynthetic reaction is divided into two distinct stages: the **light-dependent stage** and the **light-independent stage**. Each stage is confined to specific sites within the chloroplast.



Science Photo Library/John Durham

FIGURE 10.17 Photosynthesis takes place in the chloroplasts.

The light-dependent stage

When a chlorophyll molecule in the thylakoid membrane absorbs light energy, electrons within the molecule become energised. The energy is used to split water molecules (H_2O) into hydrogen ions (H) and oxygen gas (O_2), a by-product of photosynthesis. ATP molecules are formed at this stage. Electrons are donated to another energy-carrying molecule called NADP to form NADPH, which is used together with ATP in the light-independent reactions. The light-dependent stage is also called the light reactions.

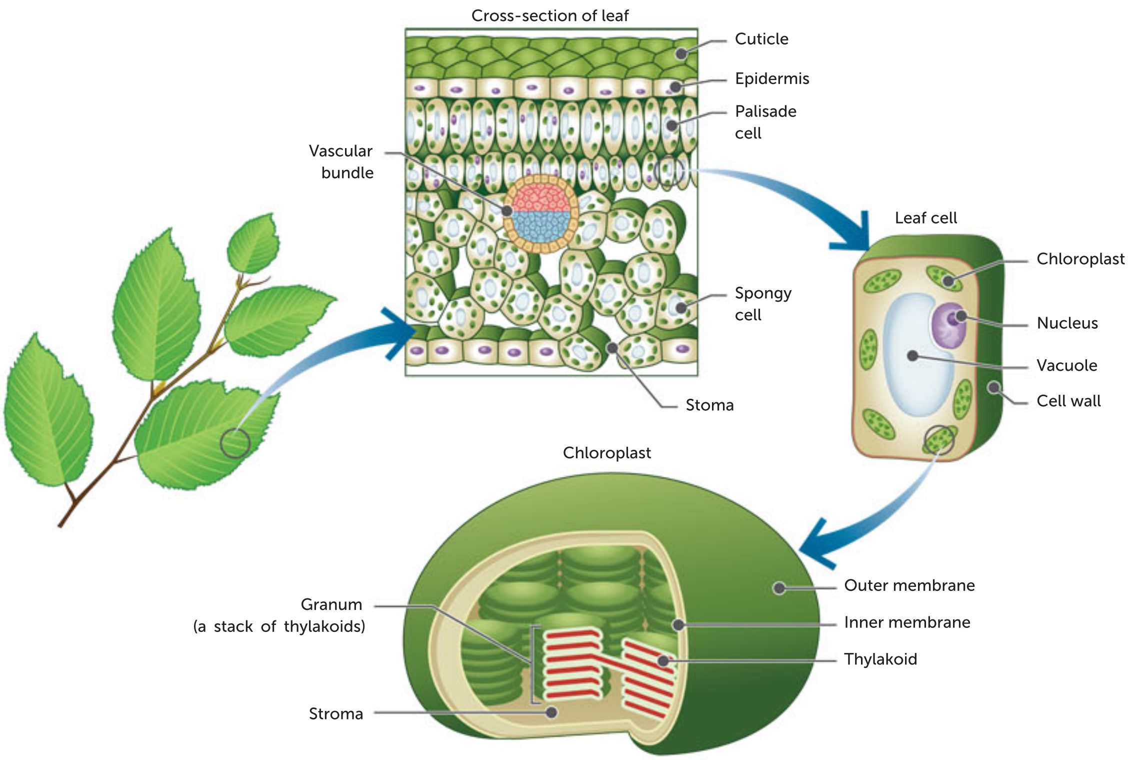


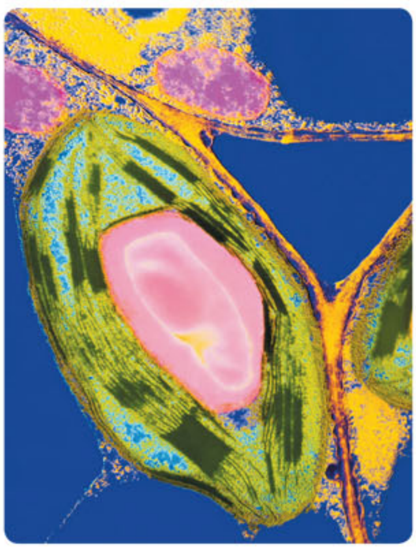
FIGURE 10.18 The structure of a chloroplast, and its location within a plant cell and leaf. Multiple stacks of thylakoids, known as grana, are surrounded by stroma.

Light energy is absorbed by different pigments within the thylakoid membranes. These pigments include chlorophylls (green), carotenoids (orange) and xanthophylls (yellow). Chlorophylls absorb the wavelengths of blue and red light, and they reflect the green wavelengths, which is why plant parts having an abundance of chlorophyll molecules appear green to us. All green algae and plants have types of chlorophyll as their major photosynthetic pigments.

The light-independent stage

The light-independent reactions occur in the stroma (fluid part) of the chloroplast. In these reactions, glucose molecules are produced from carbon dioxide and hydrogen ions. This reaction requires a supply of carbon dioxide gas (CO_2), hydrogen ions (H in NADPH) and chemical energy in the form of ATP. ATP molecules formed in the light-dependent stage provide the chemical energy for the conversion of carbon dioxide to glucose molecules (complex organic compounds). These reactions are anabolic and result in carbon being stored in glucose (carbon fixation).

Many chemical reactions are involved in both the light-dependent and light-independent stages of photosynthesis.



Science Photo Library/Dr Jeremy Burgess

FIGURE 10.19 False-colour transmission electron micrograph of a green chloroplast from a leaf of the plant *Plectranthus scutellarioides*. The green, thread-like strands are thylakoid membranes. They pack together tightly to form grana. The large pink region is a starch grain, where the products of photosynthesis are temporarily stored after they have been produced in the light-independent reactions that take place in the stroma (magnification 5000×).

During daylight hours, chloroplasts convert the newly formed glucose molecule to sucrose or starch. Of all plant carbohydrates, sucrose is the most easily transported, while starch is the most common storage form. Starch is stored briefly in the stroma during the day, and at night, cells convert starch to sucrose for export to other cells in leaves, stems and roots that lack chloroplasts.

Key concept

The biochemical process of photosynthesis uses light energy to synthesise organic compounds and can be represented as a balanced chemical equation. Light-dependent and light-independent reactions occur at different sites in the chloroplasts.

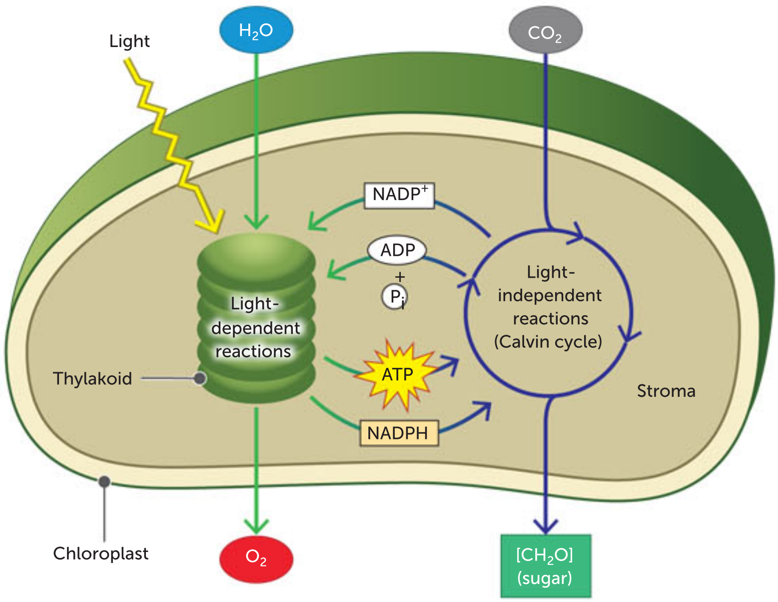


FIGURE 10.20 Photosynthesis is a series of reactions occurring in two stages: the light-dependent and the light-independent stages (Calvin cycle).

TABLE 10.3 A comparison of the light-dependent reactions and light-independent reactions of photosynthesis

FEATURE	LIGHT-DEPENDENT REACTIONS	LIGHT-INDEPENDENT REACTIONS
Site in chloroplast	Thylakoids/grana (stacks)	Stroma (fluid)
Energy conversion	Light energy to produce ATP from ADP and NADPH from NADP	ATP and NADPH (hydrogen/electrons) carry energy to light-independent reactions. ATP returns to ADP + P and NADPH returns to NADP
Reactants	Water (H_2O)	Carbon dioxide (CO_2) and hydrogen (H_2)
Products	Oxygen (O_2) and hydrogen (H_2)	Glucose ($C_6H_{12}O_6$/complex organic compounds/ carbohydrates)
Other name	Light reactions	Calvin cycle

Factors that affect the rate of photosynthesis

The rate of photosynthesis is affected by abiotic factors such as light intensity, carbon dioxide availability and temperature. The term '**limiting factor**' is used to describe a factor that restricts the rate of a reaction, regardless of the level of other factors; these factors are all limiting factors for photosynthesis.

Light intensity

Plants use chlorophyll to absorb sunlight and convert it into chemical energy. The light energy from the Sun is what fuels the reactions that transform carbon dioxide and water into glucose and oxygen. Without light energy, photosynthesis cannot proceed.

As the availability of sunlight increases and more light energy hits more of the chlorophyll molecules, the rate of photosynthesis increases. At a certain light level, the rate tends to stop increasing due to a different limiting factor, or because all of the chlorophyll is saturated with light. At this maximum point the photosynthetic rate will plateau.

Carbon dioxide concentration

Carbon dioxide availability can limit the rate of photosynthesis. Carbon dioxide and water are the reactants that are converted into glucose. Regardless of the availability of the other reactant, water, if there is limited availability of carbon dioxide then the rate of the reaction slows.

As the availability of carbon dioxide increases, the rate of photosynthesis increases until the process reaches saturation, at which point the plant has reached its maximum rate of photosynthesis. With excess carbon dioxide, the rate plateaus because the reaction cannot produce glucose molecules at a faster rate.

Temperature

Enzymes catalyse the reactions that take place during photosynthesis. Enzymes are proteins and their activity is affected by temperature, which makes temperature another major limiting factor in photosynthesis.

The optimal temperature is the temperature that causes enzyme activity to be at a maximum, which in turn leads to a maximum rate of photosynthesis. This can be understood by considering the collision theory. Higher temperatures lead to greater kinetic energy and more collisions between substrate particles and enzyme particles. At very low temperatures, particles move much less, and fewer collisions occur, so that the rate of photosynthesis decreases. When temperature extends beyond optimal, the enzyme becomes unstable as hydrogen bonds are disrupted, decreasing enzyme activity rate. Eventually, when the temperature has reached a certain point, the enzyme denatures by changing shape at the active site. This results in a complete loss of activity. A loss of enzyme activity will result in a sharp decline in the rate of photosynthesis.

As well as affecting enzyme activity, high temperatures affect the availability of water, and this can directly affect the opening of stomata. In hot, dry conditions, stomata close to conserve water, reducing the rate of photosynthesis.

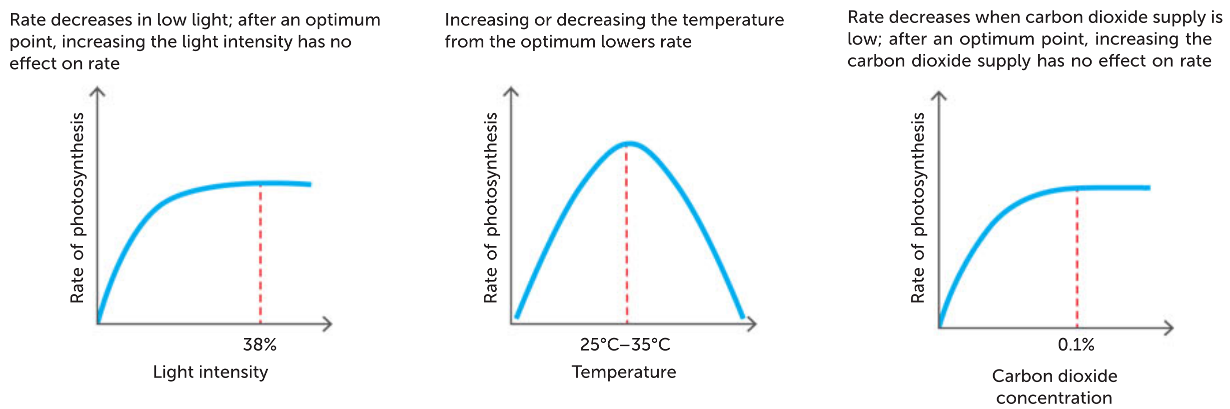


FIGURE 10.21 Factors that affect the rate of photosynthesis

Key concept

The rate of photosynthesis is affected by the availability of light and carbon dioxide, and temperature.

SCIENTIFIC LITERACY

Innovative research: plant energy biology

The Australian Research Council Centre of Excellence in Plant Energy Biology (PEB) is focused on better understanding the way in which plants capture, convert and use energy in response to environmental change, with a view towards improved plant energy efficiency. The centre's collaboration between the University of Western Australia, the University of Adelaide, Australian National University and La Trobe University utilises complementary skills and research, in conjunction with global research, to address the challenge of feeding our global population. A PEB priority is to be a leading Australian centre for advanced training and education for plant and computational biologists.

The world faces three interconnected threats to food security: limited agricultural resources (land, water and key nutrients); a rising human population and per capita food consumption; and a yield gap resulting from reduced productivity of crops due to mismatches between crop genetics and unpredictable environments.

Plants use solar energy to convert the simple, energy-poor substrates of water and carbon dioxide into complex, energy-rich, organic materials (photosynthesis). The carbohydrate products of photosynthesis are, in turn, used to energise and materialise the production, operation and maintenance of the rest of the organism. Photosynthesis is a major determinant of the productivity of a plant.

PEB aims to increase the efficiency of the photosynthetic processes of energy capture, conversion and use by plants, by improving their ability to allocate resources and their tolerance to environmental challenges.

PEB proposes a novel approach to improve sustainable plant yield by optimising the overall efficiency of energy capture, conversion and use in plants, rather than optimising single nutrient inputs or product outputs. Scientists at PEB believe that targeting complex processes (including plant metabolism, transport and development) for efficiency gains will be more effective at enhancing overall plant photosynthesis and productivity. They study net primary productivity, which is how much carbon dioxide plants take in during photosynthesis minus how much carbon dioxide the plants release during respiration (metabolising sugars and starches for energy).

We have finite land, nutrients and water. Increasing the rate of photosynthesis and productivity is a remarkable challenge within these limitations. The effects of limiting factors on productivity are further enhanced by our changing climate and weather.

The enhancement of plant energy efficiency is being approached by PEB through three research programs which combine to translate molecular insights into whole plant performance. These three programs are:

Program 1: Energy metabolism and signalling
Program 2: Gatekeeper cells and specialisation
Program 3: Gene variants and epigenetics.

Source: Adapted from https://plantenergy.edu.au/

Questions

1 State the three interconnected threats to food security.
2 Explain why collaboration is a better method for finding solutions than solo research.
3 Describe how PEB aims to improve plant yield.
4 Discuss the relationship between the rate of photosynthesis and productivity.

Biofuel innovation
Find out about recent investigation into the use of respiration to increase biofuel production by reading this news from the Berkeley Lab.

Interested in the science of beer?
Scroll to the end of the page to watch a video on how yeast respiration is used to produce this beverage.

NASA Earth observatory
NASA developed an interactive global overview of primary productivity. You can view spatial and temporal scales of productivity here

Combining algal and plant photosynthesis

CASE STUDY

Plant scientists at the University of Cambridge in England have embarked on plans to improve crop yields by solving some of the limitations of photosynthesis.

Professor Howard Griffiths and Dr Julian Hibberd are two scientists at the university. Their CAPP (Combining Algal and Plant Photosynthesis) Project aims to address the growing demand for food and fuel by improving the process of photosynthesis.

In most plants, growth rate is limited by the rate at which carbon dioxide from the atmosphere is taken up and converted to sugars in the process of photosynthesis. The enzyme responsible for the first step in this process, Rubisco, does not work at its potential maximum efficiency at the current levels of carbon dioxide present in the atmosphere. If levels were much higher, photosynthesis would be faster and plants would grow faster. There is a mechanism present in tiny green algae that results in high concentrations of carbon dioxide inside their photosynthesising cells (called a carbon concentrating mechanism, or CCM), enabling Rubisco to work at maximum efficiency.

Therefore, the ultimate aim is to introduce elements of algal photosynthetic systems into the model land plant *Arabidopsis thaliana*, to increase its photosynthetic efficiency. If successful, this may help pave the way for the production of 'super-efficient' crop plants in the future.

Professor Griffiths says, 'Plants really matter, and for the next generation, plant and microbial productivity will become the focus of key global issues: the basis for feeding an additional 2–3 billion mouths, to drive forward an economy currently trading on past sunlight, and maintain biodiversity in the face of climate change'.

The scientists are confident that now is a pivotal time for current progress in understanding photosynthesis to be harnessed with genetic techniques and traditional breeding resources to improve crop yields for the future. Nevertheless, the project is not a trivial undertaking, as Dr Hibberd explains: 'We're looking ahead to at least 15–20 years from now, to transform crop production in the decades when the potential yield of current crops has been exhaustively maximised'.

Source: http://www.cam.ac.uk/research/news/turbocharging-a-new-green-revolution

Questions

1 Find out more about the plant *Arabidopsis thaliana*. Outline why it is widely used for studying plant science.

2 Consider a field trial to test the effectiveness of a modified crop plant.
 a Describe the risks.
 b Propose safeguards that would be required.

3 How willing would you be to eat a crop plant that has been modified by scientists? Give reasons for your decision.

4 How important is the development of super-efficient crops to you? Do you think it is as important to someone from a developing country? Explain your response.

Question set 10.6

REMEMBERING

1 Name the products or outputs of the light-dependent reactions that are used as inputs in the light-independent reactions of photosynthesis.

2 Name the product of photosynthesis that contributes to the growth of plants.

3 Write an overall word equation and a balanced chemical equation for photosynthesis.

UNDERSTANDING

4 Do all living plant cells carry out photosynthesis? Explain your answer.

5 Distinguish between the light-dependent and the light-independent stages of photosynthesis in terms of location, requirements and products. Draw a table to organise your answer.

APPLYING

6 Discuss the concept of a limiting factor and the rate of photosynthesis.
7 Relate the structure of the chloroplast to its function.
8 Create a poster summarising what you have learned about photosynthesis.

10.7 CELLULAR RESPIRATION

Cellular respiration is a biochemical process that occurs in different locations in the cytosol and mitochondria, and metabolises organic compounds (glucose), aerobically or anaerobically, to release usable energy in the form of ATP. It occurs in a series of steps in a biochemical pathway, each catalysed by specific enzymes. Both producers and consumers perform respiration in their cells by releasing the energy stored in the bonds in glucose molecules to produce energy in the form of ATP. Cellular respiration is also referred to as respiration.

Aerobic respiration can be summarised in three main steps; glycolysis, the citric acid cycle (Krebs cycle) and the electron transport chain (also referred to as oxidative phosphorylation). In aerobic respiration, glucose combines with oxygen to produce energy in the form of ATP. Aerobic respiration produces most of its ATP in organelles called mitochondria. In addition, respiration can also proceed in the absence of oxygen and the site for this type of respiration is the cytoplasm.

All organisms, with the exception of the Archaea, use glucose as the primary source of energy to drive cellular metabolism. The chemical bonds in glucose are broken, resulting in more stable products and the release of free energy in the form of ATP. The reactions of aerobic cellular respiration are summarised in Table 10.4.

TABLE 10.4 A summary of aerobic cellular respiration

REACTANTS		PRODUCTS
Word equation		
Glucose + oxygen	$\longrightarrow$	carbon dioxide + water + energy (ATP)
Chemical equation		
$C_6H_{12}O_6 + 6O_2$	$\longrightarrow$	$6CO_2 + 6H_2O$ + energy (ATP)

The word 'aerobic' is used to indicate that oxygen is present. The equations in Table 10.4 simply show the initial reactants and the final products. There are approximately 20 reactions that occur in this biochemical pathway, each catalysed by specific enzymes. Most animals, plants, protists, fungi and bacteria are aerobes: they all require oxygen for cellular respiration.

However, oxygen is not always present and many micro-organisms use other molecules instead. These organisms are called anaerobes and live in environments without oxygen. For all organisms, the breakdown of glucose to supply the cell with available energy, regardless of whether oxygen is present or not, starts with a biochemical pathway called glycolysis.

Glycolysis

Glycolysis takes place in the cytosol of cells. The biochemical pathway of glycolysis is made up of 10 reactions, with each step controlled by a specific enzyme. The initial reactant is glucose and the final product for each molecule of glucose is two molecules of a compound called **pyruvate** ($C_3H_6O_3$).

The glycolysis pathway also produces a net of two ATP molecules per molecule of glucose that may be used by the cell as a source of energy. These ATP molecules, which can be used by the cell immediately, may be sufficient for the needs of certain micro-organisms, but this amount of portable energy is not sufficient for multicellular organisms. What occurs after glycolysis in both prokaryotic and eukaryotic cells? This depends on whether oxygen is present. It is only in the presence of oxygen that pyruvate is actively transported through to the inner membrane and into the matrix of the mitochondrion.

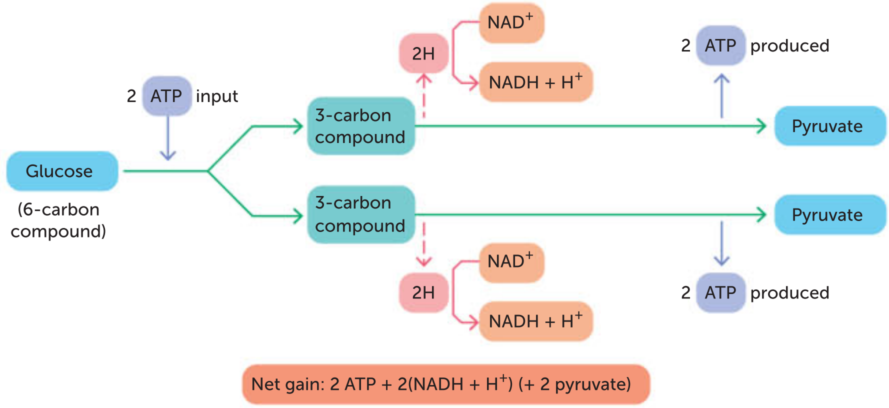


FIGURE 10.22 Overview of glycolysis

Mitochondria

Mitochondria (singular mitochondrion) are small, regularly shaped structures found scattered throughout the cell's cytosol. They are often described as the 'energy powerhouse' of the cell because large numbers of ATP (energy) molecules are produced in them. Mitochondria are the site of aerobic respiration. Mitochondria have an outer and an inner membrane, and an intermembrane space. The inner membrane folds many times to create structures called cristae (singular crista), which have a high surface area to maximise energy production via the electron transport chain (oxidative phosphorylation). Embedded in the cristae are enzymes known as adenosine triphosphate (ATP) synthase, respiratory electron transfer chain proteins and transport proteins. Many metabolic enzymes are also found in the matrix of the mitochondria (the viscous space within the inner membrane that is the site of the citric acid cycle) along with DNA.

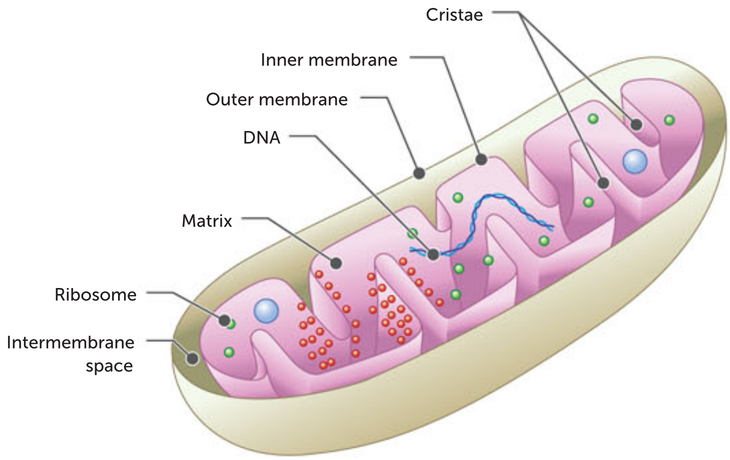


FIGURE 10.23 The structure of a mitochondrion

Different types of cells have different numbers of mitochondria. Some simple cells contain only one or two mitochondria. However, complex animal cells that need a lot of energy, like muscle cells, can have thousands of mitochondria.

Mitochondrion
Use the interactive animal and plant cells to view and learn more about the mitochondria. Do they exist in both animal and plant cells?

The mitochondria
Try to describe what is happening as you watch this animation.

Aerobic respiration: cellular respiration with oxygen

Aerobic respiration is a series of reactions (that can be summarised by an overall equation, Figure 10.24) that takes place in the presence of oxygen and by which organisms obtain energy from organic molecules, via the production of ATP (a usable form of energy).

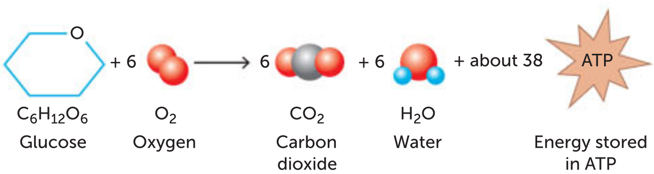


FIGURE 10.24 Aerobic respiration: the production of ATP energy in the presence of oxygen

In eukaryotic cells that are supplied with oxygen, the two molecules of pyruvate formed in glycolysis enter the mitochondrion (Figure 10.25).

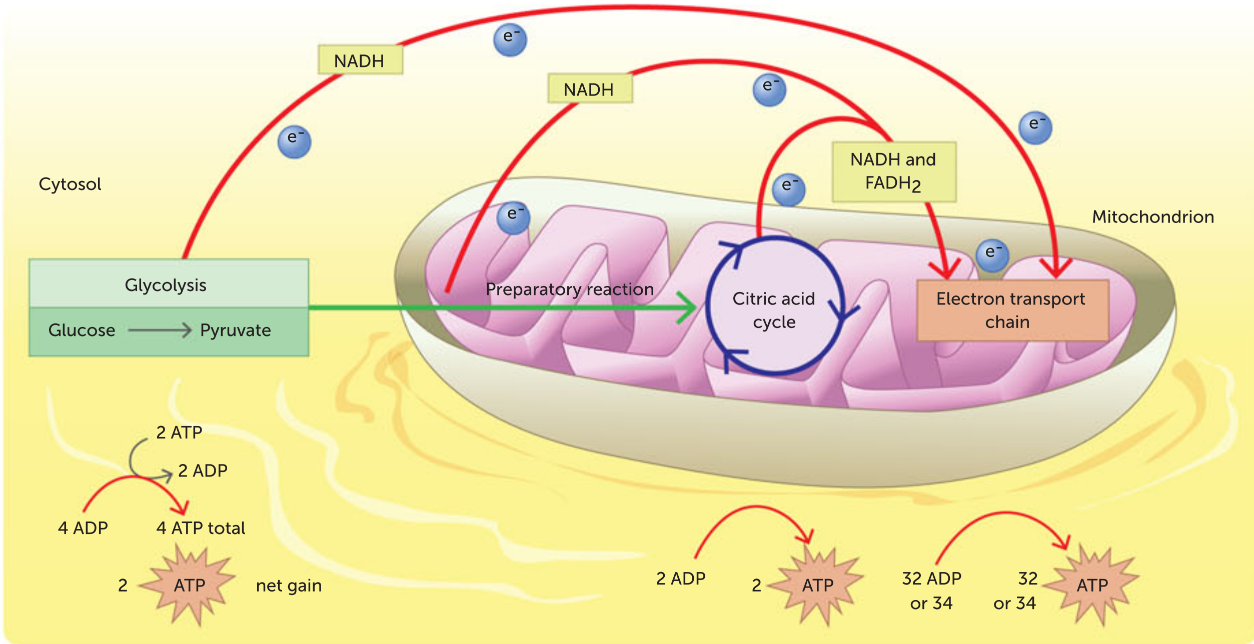


FIGURE 10.25 Aerobic respiration starts in the cytosol and continues in the mitochondria

Inside the mitochondrion, the citric acid cycle and the electron transport chain take place (Table 10.5). These steps are facilitated by various compounds within the mitochondrion, and as a result, carbon dioxide molecules and water are produced. From all the reactions associated with aerobic cellular respiration, it is possible to produce a net 36 ATP molecules in one cycle. Combined with glycolysis, aerobic respiration can produce up to 38 ATP.

TABLE 10.5 The steps of aerobic respiration

STEP	DESCRIPTION
1 Glycolysis (the splitting of glucose)	One molecule of glucose (6-carbon compound) is broken down into two 3-C molecules. Energy is invested initially to the value of 2 ATP. The process gives a net gain of 2 ATP. During the process, 2 NAD are given 2 H atoms (and 2 electrons) to form 2 NADH.
2 Citric acid cycle (production of energy-carrying molecules NADH, $FADH_2$, ATP)	In the presence of oxygen, pyruvate molecules enter the mitochondria then, after a series of reactions, enter the citric acid cycle in the matrix. The carbon molecule enters a cycle of biochemical reactions. For each pyruvate molecule, the citric acid cycle produces 3 NADH and 1 $FADH_2$ and releases 2 CO_2. For each glucose molecule, the total yield from the citric acid cycle is 2 ATP, 6 NADH and 2 $FADH_2$ The energy carried in the NADH and $FADH_2$ molecules will lead to the further production of ATP via the electron transfer chain in aerobic respiration.
3 Electron transport chain (electrons and oxygen arrive at cristae to help ADP convert to ATP)	Electrons are transported by the energy-carrying molecules NADH and $FADH_2$ from the citric acid cycle. The energy produces a chemical gradient across the inner mitochondrial membrane. Oxidative phosphorylation occurs as ATP is generated from ADP + P. Oxygen and hydrogen ions combine to form water. Approximately 28 ATP are released (depending on whether NADH or $FADH_2$ was shuttled into the mitochondria from the cytosol).
Total ATP produced	30–38 ATP

The citric acid cycle
For further extension about the citric acid cycle watch this video then try the quiz.

Electron transport system and ATP synthesis
For further extension about the electron transport system watch this video then try the quiz.

TABLE 10.6 A comparison of the three main steps in aerobic respiration

FEATURE	GLYCOLYSIS	CITRIC ACID CYCLE	ELECTRON TRANSPORT CHAIN
Site	Cytosol	Matrix of mitochondria	Cristae of mitochondria
Net ATP produced	2	2	32–34
Reactants	Glucose	Pyruvate	Oxygen (assisted by energy molecules)
Products	Pyruvate	Carbon dioxide	Water

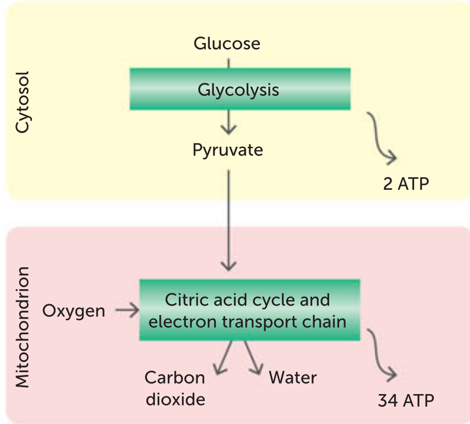


FIGURE 10.26 A simple overview of the stages of aerobic respiration

Anaerobic respiration: cellular respiration without oxygen

Anaerobic respiration is a type of cellular respiration where respiration takes place in the cytosol in the absence of oxygen. Many bacteria and protists live in places where oxygen is absent or not always available. Such organisms have evolved biochemical pathways that allow glycolysis to continue in the cytosol by utilising molecules other than oxygen. They produce ATP using anaerobic pathways. Prokaryotes have evolved many anaerobic pathways, but eukaryotes commonly use two forms, which are referred to as **alcohol fermentation** and **lactic acid fermentation**. No matter which type of anaerobic respiration occurs, they all begin with glycolysis.

Cellular Respiration and the Mighty Mitochondria
View the Cellular Respiration and the Mighty Mitochondria channel and find many other helpful videos on the Amoeba Sisters' channel.

Shutterstock.com/colorsbw

FIGURE 10.27 Alcohol fermentation is used to produce bread and wine. In bread, the alcohol is baked out.

Alcohol fermentation

Plants and many micro-organisms, including yeast and some bacteria, carry out anaerobic cellular respiration. The products of alcohol fermentation are carbon dioxide and ethanol, an alcohol. The overall summary for alcoholic fermentation is given as follows.

Key concept

A simplified word equation for alcohol fermentation is:

Glucose → ethanol + carbon dioxide + 2 ATP

Humans make use of these metabolic waste products in the production of wine, beer and bread (Figure 10.27). Plants, however, cannot make use of ethanol. It cannot be reconverted into carbohydrate, nor can it be broken down in the presence of oxygen. Furthermore, alcohol is toxic to cells and cannot be allowed to accumulate. Many plants (or parts of plants), such as germinating seeds and roots living in water-logged soil, can respire anaerobically for a short time when there is little oxygen. However, before the concentration of ethanol reaches a certain level they must revert to aerobic respiration, otherwise they will be poisoned by the ethanol. This is also true for yeast.

Lactic acid fermentation

Lactic acid is the end product of anaerobic respiration in animals. When possible, your body will generate most of its energy using aerobic methods. However, in some circumstances, such as in working muscles during strenuous exercise, your body requires energy to be produced faster than the oxygen can be delivered to cells. In these cases, the working muscles generate energy anaerobically, leading to a build-up of lactic acid. Once the strenuous exercise slows down, oxygen is available once again and lactic acid is converted back to pyruvate, allowing continued aerobic metabolism and energy for the body's recovery from the strenuous event.

Aerobic respiration produces a lot of energy. In anaerobic respiration, glucose is not broken down as completely as it is in aerobic respiration and so less energy is released. A lot of energy still remains 'locked up' in the ethanol or lactic acid molecules.

Key concept

Lactic acid fermentation (in animals):

Glucose → lactic acid + 2 ATP

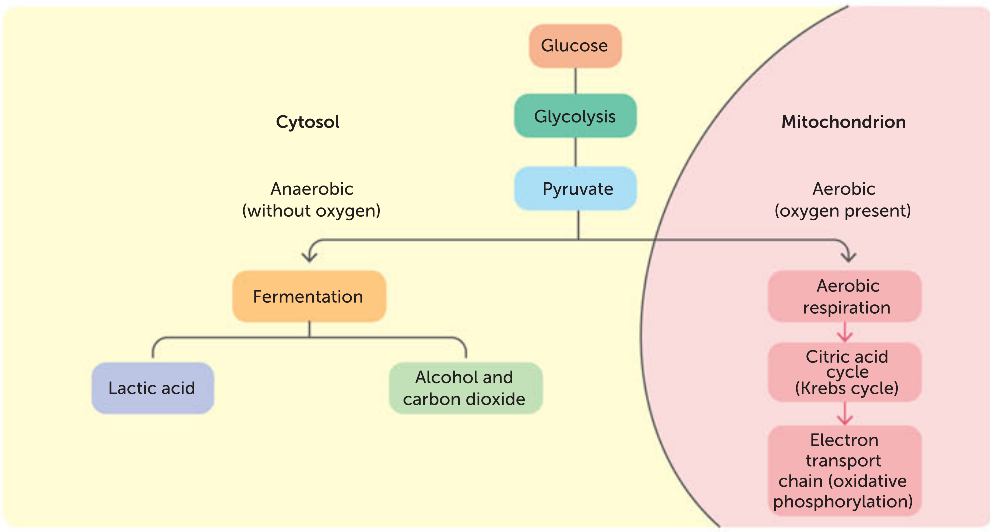


FIGURE 10.28 A summary of aerobic and anaerobic pathways

TABLE 10.7 A comparison of aerobic and anaerobic respiration

FEATURE	ANAEROBIC	AEROBIC
Site	Cytoplasm	Mitochondrion
Requires oxygen?	No	Yes
Waste products	Animals: lactic acid Plants: carbon dioxide and alcohol	Carbon dioxide and water
Amount of ATP produced	2 per glucose molecule	30–38 per glucose molecule
Reactions involved	Glycolysis Fermentation	Glycolysis Transition reaction Citric acid cycle (Krebs cycle) Electron transport chain (oxidative phosphorylation)
Advantages	Faster production of ATP	More ATP produced

Key concept

The biochemical process of cellular respiration occurs in the cytosol and mitochondria, and metabolises organic compounds, aerobically or anaerobically, to release usable energy in the form of ATP. It can be represented as a balanced chemical equation.

The products of anaerobic respiration vary in different organisms (plants, yeast, bacteria and animals).

Factors that affect the rate of respiration

As temperature increases, respiration rate increases, until (as temperature gets too high) it begins to drop again. Above a certain temperature the enzymes involved denature.

As the level of glucose available to the cell increases, respiration rate increases, until a maximum level is reached.

Similarly, as oxygen levels increase, respiration rate increases, until a maximum level is reached.

Rats on treadmills

CASE STUDY

Some people are born with less ability to take up oxygen and transfer energy than others. Scientists exploring this phenomenon bred rats over 11 generations to be good or poor runners. The best runners could last up to 42 minutes on a treadmill before becoming exhausted, whereas the less-fit rats averaged just 14 minutes. This research suggests that the ability to use oxygen efficiently is genetically determined as well as being elevated by training.

Furthermore, the rats with high aerobic capacity were less likely to have risk factors linked to cardiovascular disease and stroke, such as high blood pressure and high cholesterol levels. The main player here seems to be the mitochondria. Researchers found that low-aerobic-capacity rats had comparatively reduced levels of enzymes and proteins used by the mitochondria.

Key concept

The rate of respiration is affected by temperature and the availability of oxygen and glucose.

Photosynthesis and aerobic cellular respiration are interdependent

The outputs of photosynthesis are the inputs of aerobic cellular respiration. Similarly, the outputs of aerobic cellular respiration are the inputs of photosynthesis. In autotrophs, the two processes can occur in the same individual cells when both chloroplasts and mitochondria are present. But many cells in green plants, such as root cells, do not have chloroplasts. These cells, and those of heterotrophs, depend on the products of photosynthesis to carry out cellular respiration. When the uptake of carbon dioxide for photosynthesis is equal to the volume of carbon dioxide produced by respiration, this is known as the 'compensation point'.

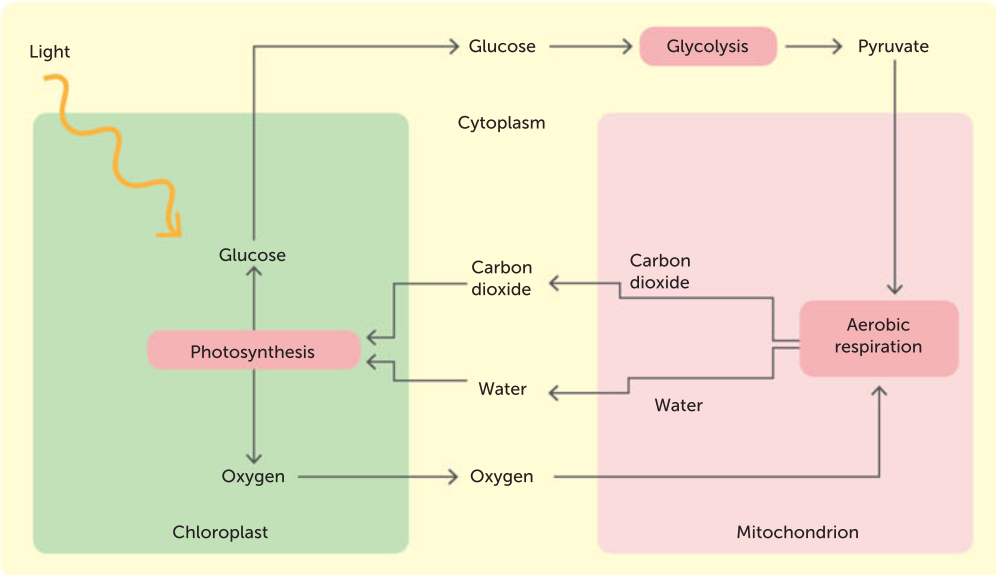


FIGURE 10.29 Photosynthesis uses the products of cellular respiration, and cellular respiration uses the products of photosynthesis.

TABLE 10.8 A comparison of aerobic respiration and photosynthesis

FEATURE	PHOTOSYNTHESIS	AEROBIC RESPIRATION
Site	Chloroplasts	Mitochondria
When?	In the presence of light	All the time
Input	Carbon dioxide and water	Glucose and oxygen
Output	Glucose and oxygen	Carbon dioxide and water
Energy sources	Light	Chemical bonds
Energy result	Energy stored	Energy released as ATP

Question set 10.7

REMEMBERING

1 Write a balanced equation for aerobic cellular respiration.

2 Identify the initial substrate of glycolysis and the final product.

3 Describe where glycolysis takes place in all cells.

4 List two differences between aerobic respiration and fermentation.

UNDERSTANDING

5 Compare the products of anaerobic respiration with those of aerobic respiration, in animals and plants.

6 Name the source of the by-product carbon dioxide in aerobic cellular respiration.

APPLYING

7 Describe the conditions under which aerobic cells carry out fermentation.

EVALUATING

8 Discuss why alcohol fermentation, rather than lactic acid fermentation, is used in cake and bread making.

9 Draw a Venn diagram to show similarities and differences in aerobic and anaerobic respiration.

CHAPTER 10 INVESTIGATIONS

10.1

INVESTIGATION

The effect of light on photosynthesis

Living plant cells carry out cellular respiration all the time. When light is present, green plant cells also undergo photosynthesis.

When studying water plants, the rate of photosynthesis and cellular respiration can be measured by the amount of carbon dioxide used or produced. This can be observed indirectly by recording the pH of the surrounding water. When carbon dioxide dissolves in water, it forms carbonic acid (H_2CO_3) according to the following equation:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

If the amount of carbon dioxide increases, more carbonic acid forms and the acidity increases (pH decreases). If the amount of carbon dioxide decreases, carbonic acid levels also decrease, reducing the amount of acid so that the pH increases and the surrounding watery solution becomes more basic.

Aim

To test the effect of light on the rate of photosynthesis

Materials

- two healthy leaf shoots of *Elodea* (or an alternative freshwater oxygenator available from the local aquarium or biological supplier)
- five test tubes (four of them with stoppers)
- aluminium foil
- phenol red indicator in a dropper bottle
- 0.1 mol/L ammonia solution in a dropper bottle
- 0.1 mol/L hydrochloric acid in a dropper bottle
- beaker
- grow-lux lamp or bright light

WHAT ARE THE RISKS IN DOING THIS EXPERIMENT?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Hydrochloric acid and ammonia can be corrosive.	Avoid contact with skin and eyes. If spilt or splashed, rinse affected area immediately with plenty of water and report any accidents to your teacher. Eye wash facilities and equipment should be readily available.
Phenol red indicator can irritate skin and eyes.	Take care to avoid contact with skin and eyes.
Elodea is a noxious weed.	Dispose of *Elodea* safely, away from waterways.

Procedure

1. Half-fill a test tube with tap water and add two to three drops of phenol red indicator. Note the colour.
2. Add five drops of 0.1 mol/L ammonia solution. Note any colour change.
3. Add five drops of 0.1 mol/L hydrochloric acid. Note any colour change, and then add a further five drops of hydrochloric acid. Record your results. (Note that this part of the experiment is simply to produce some reference indicator colours.)
4. Collect enough aged tap water in a beaker (preferably the water the *Elodea* was in) to fill four test tubes in a beaker. Add five to six drops of phenol red to the water (in the beaker) to give it a good colour.
5. Place an *Elodea* shoot into each of two test tubes and fill with the water–phenol red mixture. Label the tubes A and B. Fill the other two test tubes with more of the same water and label these C and D.
6. Stopper the four tubes and record their colours.

7 Wrap tube A and tube C with aluminium foil.
8 Place all tubes under a grow-lux lamp or in bright light (but not direct).
9 Observe all four tubes the next day. Record any colour changes.
10 Remove the foil from the tubes and leave them in the light for another day. Observe and record their colours.

Results

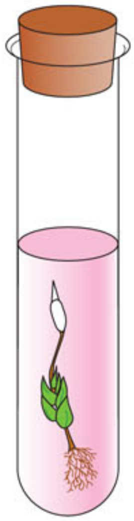
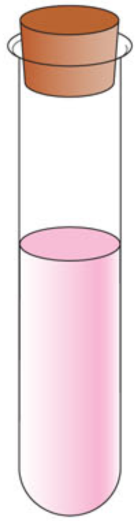
1 Copy Table 10.9 and record in it the indicator colours for:
   a tap water and phenol red
   b tap water, phenol red and 0.1 mol/L ammonia
   c tap water, phenol red, 0.1 mol/L ammonia and 0.1 mol/L hydrochloric acid.

TABLE 10.9 Reference indicator colours

TAP WATER AND PHENOL RED	TAP WATER, PHENOL RED AND 0.1 mol/L AMMONIA	TAP WATER, PHENOL RED, 0.1 mol/L AMMONIA AND 0.1 mol/L HYDROCHLORIC ACID

2 Copy Table 10.10 and record the colour of tubes A to D.

TABLE 10.10 The effect of light on photosynthesis

	TUBE A	TUBE B	TUBE C	TUBE D
	Plant with foil wrap	Plant without foil wrap	Foil wrap without plant	No plant and no foil wrap
				
INITIAL OBSERVATIONS				
Colour pH				
DAY 1 OBSERVATIONS				
Colour pH				
DAY 2 OBSERVATIONS				
Colour pH				

Pool your data with other groups in the class to establish repetition of samples.

3 Explain the results seen in tube A after one day.
4 Explain the results seen in tube B after one day.
5 Describe the colour of the indicator in tubes A and C the day after the foil was removed. Explain why the indicator was this colour for each tube.

Discussion

1 Explain why aluminium foil was wrapped around the test tubes instead of putting them in a dark place.
2 Name the tubes that were the control. List the variables being tested in this experiment.
3 Write balanced equations for:
   a photosynthesis
   b cellular respiration.
4 a Describe the conditions under which plants carry out photosynthesis.
   b Describe the conditions under which plants carry out cellular respiration.
5 Explain why it was necessary to stopper the test tubes.
6 Explain why tubes C and D were used.
7 Predict what gas, other than carbon dioxide, could be used as a measure of the rate of photosynthesis and respiration. Explain why the concentration of carbon dioxide is easier to measure in this experiment.
8 Discuss the advantages of using water plants for this experiment.
9 Identify some possible sources of error in your experiment.

Conclusion

1 Propose conclusions about the rate of photosynthesis compared to the rate of respiration if:
   a there is a net production of carbon dioxide
   b there is a net use of carbon dioxide
   c the amount of carbon dioxide remains the same.
2 Discuss what effect light has on the rate of photosynthesis compared to the rate of cellular respiration.

Taking it further

Devise an experiment to investigate the effect of different light intensities on the rate of photosynthesis.

SOUTHERN Biological — Developed exclusively by Southern Biological

The effect of light wavelength on photosynthesis

10.2 INVESTIGATION

Aim

To investigate the effect of different wavelengths of light on the rate of photosynthesis

Materials

- algal balls (60)
- four 7-mL dram vials
- light source
- hydrogen carbonate indicator (approx. 40 mL)
- six plastic pipettes
- set of pH standards
- coloured cellophane: red, purple and green
- strainer
- spoon
- disposable gloves

WHAT ARE THE RISKS IN THIS DOING INVESTIGATION?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Some algae pose an environmental hazard.	Know and follow all regulatory guidelines for the disposal of laboratory wastes.
Disposable gloves may pose allergy risk.	Use a type of glove that does not have an allergy risk and is suitable for the chemicals being used.

Procedure

1. Separate the algal balls from the surrounding liquid using the strainer.
2. Using the spoon, place an equal number of balls into each of the dram vials.
3. Using a plastic pipette, fill all the vials with hydrogen carbonate indicator, then cap them, ensuring the caps are secured.
4. Put one vial aside to act as your control.
5. Wrap a piece of coloured cellophane around each remaining vial.
6. Place each vial approximately 10 cm away from your chosen light source. Make sure they are in a place that will not expose them to too much heat.
7. After 40 minutes, note the colour of the hydrogen carbonate indicator in each vial by comparing it to the set of standards. (You can use a colour chart if standards are not available.)
8. Copy and complete Table 10.11 by recording the results of your experiment. Use the colour standards number as your reference.

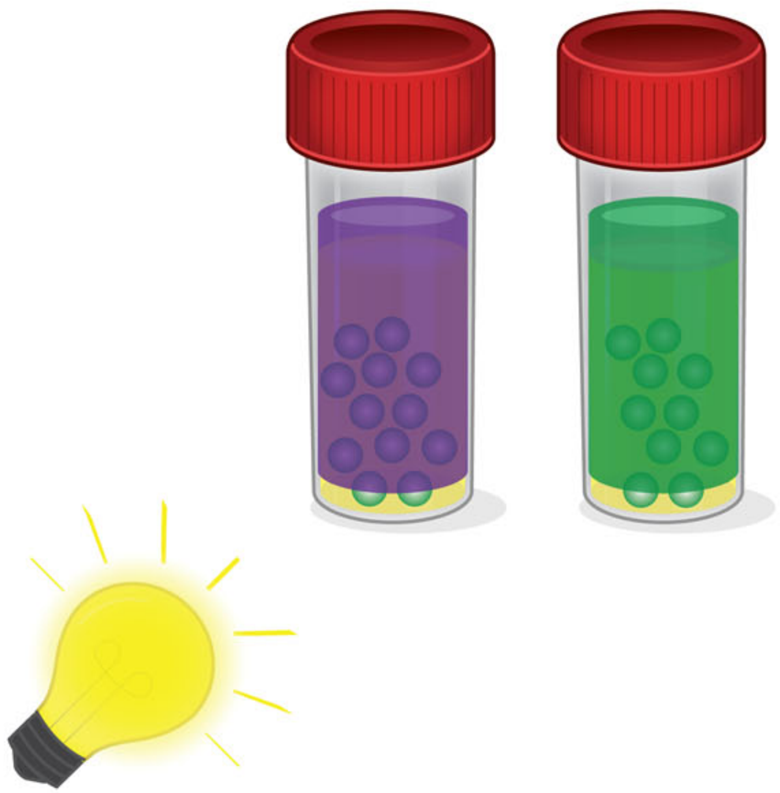


FIGURE 10.30 The set-up for the experiment

Results

TABLE 10.11 Results of colour change experiment

CELLOPHANE COLOUR	COLOUR OF SOLUTION BEFORE EXPOSURE	COLOUR OF SOLUTION AFTER EXPOSURE	COLOUR CHANGE (COMPARE 'AFTER' WITH 'BEFORE')
None (control)			
Red			
Purple			
Green			

Discussion

1. State your hypothesis for this experiment. Does wavelength affect the rate of photosynthesis?
2. Construct a bar graph to show the changes in carbon dioxide for different wavelengths of light.
3. Why do we include a control in the experiment? What does this control represent in terms of light wavelength?
4. Describe the process that is happening in the vials with regards to photosynthesis and respiration.

Taking it further

Other factors that affect photosynthesis include such things as light availability. Design an experiment to test how distance away from light affects the rate of photosynthesis.

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10.3 INVESTIGATION

The effect of temperature on trypsin activity

Casein is a protein commonly found in mammalian milk. Casein is digested by trypsin, an enzyme which splits proteins into peptides, making them ready for other enzymes to further cut them down to amino acids, which can be absorbed and used by the body. Trypsin works in the small intestine, after acid and pepsin in the stomach have started protein digestion. Casein is relatively hydrophobic, meaning it is not very soluble in water; however, when trypsin is added to a dilute solution of milk powder, the casein in the milk powder is digested and the solution goes clear.

Aim

To determine the optimal temperature for trypsin activity

Materials:

- 1% trypsin solution
- 3% solution of skim milk powder
- pH 7 buffer solution
- water bath
- six test tubes
- bungs or cork for test tubes
- test-tube rack
- stopwatch
- marker pen
- plastic pipettes
- thermometer
- lab coats
- safety glasses
- disposable gloves

WHAT ARE THE RISKS IN DOING THIS INVESTIGATION?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Trypsin can cause allergic reactions in sensitive people.	Be aware of anyone with allergies and ensure they are not exposed to trypsin.
Trypsin can be irritating to the skin and eyes on contact.	Wear appropriate personal protective equipment at all times, including eye protection and gloves. Wash skin immediately if contact does occur.
Disposable gloves may pose an allergy risk.	Use a type of glove that does not have an allergy risk and is suitable for the chemicals being used.
Water baths set at high temperatures can cause scalding.	Take care when working with water baths with temperatures set higher than 50°C. Do not touch the glass beaker.

Procedure

1. Set the water bath to 20°C.
2. Collect and mark three test tubes with an 'X' on the glass halfway down the tube.
3. Using a pipette, add 10 mL of the milk powder solution to each of the three test tubes.
4. Collect another three test tubes and add to each 3 mL of pH 7 buffer solution and then 3 mL of trypsin solution.
5. Place all six test tubes in the 20°C water bath for 10 minutes. Use a test-tube rack to ensure the six tubes are standing up.

6 Pour the trypsin and buffer solution from one test tube into one of the test tubes containing the milk powder solution.
7 To mix thoroughly, place a cork in the test tube and invert it approximately five times.
8 Place the test tube onto a test tube rack with the X positioned at the back, so that you must look through the solution in order for the X to be visible. Immediately begin a timer.
9 Record the time it takes for the milk solution to become clear. This may be achieved by measuring the time it takes for the X to be visible through the solution.

FIGURE 10.31 Test tube marked 'X'

10 Repeat this process (steps 6–9) for the remaining four test tubes and record the time for each of the three experiments.
11 Calculate the average reaction time. Copy Table 10.12 and record the result in it.
12 Your teacher will now assign you one of four temperatures to test: 30°C, 40°C, 50°C or 60°C. As a class, you will test all four temperatures, pool your data and compare your results. Set the water bath to your assigned temperature.
13 Once your water bath has reached the desired temperature, repeat the procedure (steps 2–10) to test how the reaction time is affected by the different temperature.
14 Calculate the average time for your assigned temperature and record your data in Table 10.12.
15 Record in Table 10.12 the average results obtained by the class for the other temperatures. If other temperatures were tested more than once (like the 20°C control test), find the average time.

Results

Draw a graph of your processed data. Be sure to clearly label both axes.

TABLE 10.12 Results

TEMPERATURE (°C)	MEAN TIME TO BECOME CLEAR (s)
20	
30	
40	
50	
60	

Discussion

1 What is your hypothesis?
2 What is your independent variable?
3 What is the range of your independent variable?
4 What is your dependent variable?
5 What variables did you control and how did you control them?
6 What are the advantages of taking an average result for three samples instead of recording a single result?
7 What type of distribution does the data show?
8 What is the optimal temperature for trypsin activity?
9 Compare the terms 'protein', 'peptide' and 'amino acid'. Using these terms, describe the process that takes place in the test tubes.

Conclusion

Summarise your findings using the data provided. Relate your results to your hypothesis.

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10.4 INVESTIGATION

Aerobic and anaerobic respiration

Cellular respiration is a combination of metabolic reactions that takes place within organisms to convert energy from nutrients into ATP, and that produces waste products. Cellular respiration begins with a series of chemical reactions known as glycolysis, which produces some ATP. Many cells gain energy through either aerobic cellular respiration or fermentation. Which of these processes occurs is dependent on the abilities of the organism and on the presence or absence of oxygen. In aerobic cellular respiration, cells gain energy from glucose in the presence of oxygen. This process is made possible through the Krebs cycle. In contrast, fermentation does not require the presence of oxygen. Two common types of fermentation are lactic acid fermentation and alcohol fermentation. Yeast cells are able to perform cellular respiration in both aerobic and anaerobic environments to produce ATP.

Aim

To observe in yeast two methods of obtaining energy for ATP production: aerobic cellular respiration and fermentation

Materials

- two syringe stands
- two metal washers
- two syringes (10–20 mL)
- two plastic pipettes
- 80–100 yeast balls
- 5 mL distilled water
- 5 mL glucose solution
- 5 mL Janus Green B oxygen indicator solution
- two glucose test strips
- two glass beakers (for 37°C water baths)
- spoon

- timer or stopwatch
- marker
- paper towels

WHAT ARE THE RISKS IN DOING THIS EXPERIMENT?	WHAT ARE THE RISKS IN THIS INVESTIGATION?
Janus Green B may cause eye irritation.	Wear lab coats, safety glasses and gloves; wash hands thoroughly at the end of the investigation.
Yeast may cause an allergic reaction.	Wash hands after use. Do not eat in class. Be aware of any allergies.
Disposable gloves may pose an allergy risk.	Use a type of glove that does not have an allergy risk and is suitable for the chemicals being used.

Procedure

Determining the initial glucose concentration

1 Using a plastic pipette, add 2 drops of Janus Green B oxygen indicator to the glucose solution. Swirl the cup gently to mix.
2 Collect a glucose test strip and dip the yellow square tab at the tip into the glucose solution for a couple of seconds.
3 To remove excess liquid from the test strip, pat it dry against a paper towel. Leave it to rest for 60 seconds.
4 To determine the initial concentration of glucose in milligrams per decilitres, compare the colour of the test strip with the colour chart on the packaging.
5 Record this initial glucose concentration in a table like Table 10.13.
6 Repeat steps 1–4 with distilled water (in place of glucose solution) to determine the glucose concentration of the control. Record the results in Table 10.13.

Assembling the respirometers

1 Collect your syringe and remove the white plunger from the clear chamber. Using a marker, label your respirometer C for control.
2 Place a washer over the base of the syringe stand to enable the respirometer to remain submerged in a water bath during data collection (Figure 10.32a)
3 Carefully place the clear syringe chamber on the syringe stand and use the plastic spoon to fill the syringe chamber to the 1.0-mL mark with yeast balls (Figure 10.32b). Be careful not to transfer excess water into the chamber as you add the yeast balls. If necessary, a strainer may be used.
4 Carefully reinsert the white plunger back into the opening of the syringe chamber (Figure 10.32c). Only insert the plunger enough to connect the two pieces (approximately 2 mm). Remove the respirometer (the clear syringe chamber and white plunger) from the base of the syringe stand and invert it.
5 Dislodge the yeast balls from the tip of the syringe by lightly tapping the clear chamber.
6 Gradually compress the plunger on the inverted respirometer to the 1.0-mL mark (Figure 10.32d). Ensure you do not allow the yeast balls to be expelled through the syringe.

FIGURE 10.32 Setting up the syringe

7 Place the tip of the syringe in the blue solution and slowly draw up (aspirate) 3 mL of the sugar and oxygen indicator solution until the solution reaches the 4.0-mL mark on the syringe. The total volume of the yeast balls combined with the oxygen indicator solution is now 4 mL.
8 Place the respirometer back onto the syringe stand with the washer. Do not depress the white plunger.
9 Repeat the process for the control respirometer, drawing liquid from the glucose and Janus Green B indicator solution.

Data collection from the respirometer system

1 Collect two glass beakers filled with 200 mL of warm water. The water should be approximately 37°C (body temperature).
2 Label one beaker 'Yeast balls + glucose' and the other 'Yeast balls + water' (this is a control).
3 Carefully submerge each respirometer into the appropriately labelled beaker.
4 Record the starting volume for each respirometer as 4 mL.
5 Using the graduated volume markings on the syringe chamber, record the volume of each syringe and the colour of the indicator solution every minute for 30 minutes. Copy Tables 10.13 and 10.14 and record this information in them, along with any other observations you make.
6 To calculate the change in gas volume at each 1-minute interval, calculate the difference between the initial reading (4 mL) and the final reading on the syringe.
7 When the plunger reaches the 10-mL mark, stop collecting data and remove the respirometers from their water baths.
8 To disassemble the respirometers, cover with a paper towel and carefully remove the white plunger from the clear chamber containing yeast balls.
9 To determine the final concentration of glucose within each respirometer, dip the end of a glucose test strip into the solution in each syringe and compare the colour of the test strips with the colour chart on the packaging.
10 Record the final glucose concentration levels in Tables 10.13 and 10.14.
11 Share your individual experiment results with the class. Generate a class data set and calculate the class mean volume for each time interval in the glucose respirometer. Record the results in a table like Table 10.13.

Results

After processing your results in Tables 10.13 and 10.14, graph your results.

TABLE 10.13 Glucose respirometer results

Water bath temperature (°C):
Initial colour of the solution:
Final colour of the solution:
Initial glucose concentration (mg/dL):
Final glucose concentration (mg/dL):

TIME (min)	READING ON PIPETTE (mL)	INITIAL READING (mL)	CARBON DIOXIDE VOLUME (YOUR GROUP) (mL)	COLOUR OF INDICATOR SOLUTION	OBSERVATIONS	CARBON DIOXIDE VOLUME (CLASS MEAN) (mL)
0						
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						
26						
27						
28						
29						
30						

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TABLE 10.14 Non-glucose respirometer results

Water bath temperature (°C):
Initial colour of the solution:
Final colour of the solution:
Initial glucose concentration (mg/dL):
Final glucose concentration (mg/dL):

TIME (min)	READING ON PIPETTE (mL)	INITIAL READING (mL)	CARBON DIOXIDE VOLUME (YOUR GROUP) (mL)	COLOUR OF INDICATOR SOLUTION	OBSERVATIONS	CARBON DIOXIDE VOLUME (CLASS MEAN) (mL)
0						
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						
26						
27						
28						
29						
30						

Discussion

1. Were the results consistent among the class? If not, what are potential reasons for the variations? Were there any experimental errors or uncontrolled variables?
2. Explain why the average value of results from several experiments is more reliable than a single set of test results.
3. How does this experimental design address the suggestion that the carbon dioxide released in this experiment does not require the presence of carbohydrate?
4. Explain why the indicator solution in the respirator changed colour.
5. Provide two pieces of evidence from the experiment that illustrate that glucose was fermented by yeast balls during cellular respiration.
6. Yeast cells serve as a model organism for demonstrating the cellular processes occurring in other eukaryotic cells, such as those of humans. The cells of our body normally do not carry out fermentation, yet we give off carbon dioxide when we exhale. Explain why.

Taking it further

Following the same procedure as in this experiment, is it possible that carbon dioxide can be released from sugar without yeast? Design an additional controlled experiment that would allow you to test this idea.

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WS Chapter 10 Activity sheet

CHAPTER 10 SUMMARY

- Internal cellular membranes allow many chemical reactions to occur at the same time. Membrane-bound cellular structures can store products and concentrate reactants. Increasing the surface area of membrane-bound cellular structures allows for more enzymes to be available for chemical reactions.
- Metabolic pathways are ordered, enzyme-regulated sequences of reactions.
- Enzymes have specific functions which can be affected by factors including:
  - temperature
  - pH
  - presence of inhibitors
  - concentrations of reactants and products.
- The main metabolic pathways that transfer energy through living systems are photosynthesis and respiration.
- Anabolic reactions build large molecules from smaller molecules; they require an input of energy.
- Catabolic reactions break down large molecules to smaller ones; energy is released.
- Enzymes enhance reaction rates by lowering the amount of activation energy required to start a reaction.
- Chemical reactions in cells occur in a series of regulated steps called biochemical pathways.
- The molecular structure of proteins, including enzymes, determines how they perform their functions. The active site of an enzyme has a highly specific shape for a particular substrate to which it attaches.
- There are two models of enzyme action: the lock-and-key model and the induced-fit model.
- Enzymes work very rapidly. They are not destroyed or altered by reactions – they can be reused. Enzymes can work in either direction of a metabolic reaction.
- Enzymes work best when the cellular environment stays within a limited range of temperature and pH.
- When temperatures are higher than the enzyme's range, the enzyme is denatured and cannot work again. When temperatures are lower than the enzyme's range, the rate of reaction is slowed down but the enzyme is not destroyed.
- Enzymes can be inhibited by a large amount of product, or by competitive inhibitors binding to the active site.
- Some enzymes need other molecules, such as cofactors and coenzymes, to activate them.
- ATP is the main energy carrier in a cell. When one of the phosphates of ATP is removed, ADP is produced. Energy is released in this process.
- Photosynthesis is a series of reactions where cells utilise light energy to break down water and carbon dioxide molecules and build up glucose, oxygen and water molecules.
- The light-dependent stage of photosynthesis occurs when light is absorbed by chlorophyll in thylakoid membranes of chloroplasts. In this stage, water molecules are split into hydrogen ions and oxygen gas.
- The light-independent stage of photosynthesis occurs in the stroma of a chloroplast; hydrogen ions and carbon dioxide are combined to produce glucose.
- Aerobic cellular respiration is a series of steps where cells break down glucose and oxygen molecules and build up carbon dioxide and water molecules.
- Glycolysis is the first stage of cellular respiration and it occurs in the cytoplasm; glucose is broken down to pyruvate with a net yield of 2 ATP molecules for each glucose molecule.
- If oxygen is available, pyruvate produced from glycolysis enters mitochondria, where aerobic cellular respiration is completed; there is an approximate net yield of 36 ATP molecules for each glucose molecule.
- If oxygen is not available, pyruvate produced from glycolysis undergoes a series of steps in anaerobic cellular respiration to either produce ethanol and carbon dioxide

(alcohol fermentation) or lactic acid (lactic acid fermentation) in the cytoplasm; there is a net yield of 2 ATP molecules.
- The outputs of photosynthesis are the inputs of aerobic cellular respiration. The outputs of aerobic cellular respiration are the inputs of photosynthesis.
- Various factors affect the rates of photosynthesis and respiration, including temperature and availability of substrates.

CHAPTER 10 GLOSSARY

Activation energy the minimum amount of initial energy required to start a chemical reaction

Active site the place on the surface of an enzyme molecule where substrate molecules attach

ADP (adenosine diphosphate) a low-energy compound composed of adenine and ribose with two phosphate groups attached; it is converted to ATP for energy storage when it gains a phosphate group

Aerobic respiration a type of cellular respiration that takes place in the cytosol and mitochondria in the presence of oxygen

Alcohol fermentation a form of anaerobic respiration (occurring when no oxygen is present); glucose is converted to ethanol, a type of alcohol

Anabolic reactions the reactions in living things that involve the synthesis of complex molecules from simpler ones and usually require energy to form new bonds

Anaerobic respiration a type of cellular respiration which takes place in the cytosol in the absence of oxygen

ATP (adenosine triphosphate) a high-energy compound composed of adenine and ribose with three phosphate groups attached; it stores a usable form of energy; it releases energy for cellular reactions when its last phosphate group is removed and it is converted to ADP

Biochemical processes chemical processes that occur in living cells and result in products needed by cells; most are from chains and cycles of biochemical reactions, with each step controlled by a separate, specific enzyme

Catabolic reactions the reactions in living things that involve the breakdown of complex molecules into simpler ones and usually release energy from breaking bonds

Catalyst a substance that speeds up chemical reactions without being used up in the reaction

Cellular metabolism all of the chemical processes occurring in a living cell

Cellular respiration a biochemical process that occurs in the cytosol and mitochondria, and metabolises organic compounds (glucose), aerobically or anaerobically, to release usable energy in the form of ATP; products of anaerobic respiration vary between organisms (plants, yeast, bacteria, animals); the overall process of aerobic respiration can be represented as a balanced chemical equation

Coenzyme a small, non-protein organic substance that must be present in addition to an enzyme to catalyse a certain reaction

Cofactor a small, inorganic substance that must be present in addition to an enzyme to catalyse a certain reaction

Denatured (of proteins) structurally changed by factors such as pH and temperature; if the protein is an enzyme, the change destroys the shape of the active site and results in a loss of function

Endergonic reaction an energy-requiring chemical reaction

Enzyme a specific biological catalyst that increases the rate of a chemical reaction without being altered itself by lowering the amount of energy required for the reaction to proceed

Enzyme–substrate complex a substance formed when an enzyme molecule and a substrate molecule join

Exergonic reaction a reaction that releases energy

Glycolysis an energy-yielding process occurring in the cell cytosol in which glucose is partially broken down to pyruvate in enzyme reactions that do not require oxygen; this first stage of cellular respiration produces two ATP molecules

Grana a stack of thylakoid membranes in a chloroplast that contain chlorophyll

Induced-fit model a model suggesting that the shape of an enzyme's active site undergoes specific changes, induced by the substrate, to achieve a high degree of specificity with the substrate

Inhibitor a substance that competes with a substrate for an enzyme's active site

Lactic acid fermentation a form of anaerobic respiration (occurring when no oxygen is present) that occurs in animal cells and some anaerobic bacteria; glucose is converted to lactic acid

Light-dependent stage the first stage of photosynthesis; it requires light energy, which is absorbed by chlorophyll; water molecules split to produce oxygen and hydrogen ions, and ATP

Light-independent stage the second stage of photosynthesis; through a series of reactions, carbon dioxide, hydrogen ions and ATP produce a carbohydrate

Limiting factor a factor that restricts the rate of a reaction, regardless of the level of other factors

Lock-and-key model a model suggesting that the shape of a substrate molecule is an exact fit to the shape of an enzyme's active site

Metabolism the sum of all the biochemical reactions in an organism; can be divided into two types, catabolic reactions and anabolic reactions

Model a representation that describes, simplifies, clarifies or provides an explanation of the workings, structure or relationships within an object, system or idea

Phosphorylation the process when a bond forms between an available phosphate group and ADP, producing ATP

Photosynthesis a biochemical process that uses light energy to synthesise organic compounds; light-dependent and light-independent reactions occur at different sites in the chloroplast and make up separate parts of the overall process that can be represented as a balanced chemical equation

Product the substance at the end of a reaction

Psychrophile an organism that lives in extremely cold conditions

Pyruvate a three-carbon compound that is the end product of glycolysis

Respiration see *cellular respiration*

Stroma the jelly-like, semi-fluid interior of a chloroplast

Substrate a reactant on which an enzyme acts

Thermophile an organism that lives in high-temperature environments

Thylakoid membrane the interconnected, folded membranes within chloroplasts

CHAPTER 10 REVIEW QUESTIONS

Remembering

1 Draw a lock-and-key model and an induced-fit model of a generalised catabolic reaction to show the work of an enzyme.

2 Recall three factors that alter the speed of enzyme-controlled reactions.

Understanding

3 Identify each of the following as either an anabolic or catabolic process, and justify your choice in each case.

a photosynthesis

b cellular respiration

Applying

4 The pH of human blood and body fluids (excluding gastric juices) is approximately 6.8–7.0. Explain why maintaining this level of pH is important.

5 Figure 10.33 shows the relationship between net carbon dioxide production and uptake by a green plant.
   a Determine at what time the rate of photosynthesis would be equal to the rate of respiration.
   b Decide if the plant was put in light or dark conditions for the first 10 minutes of the experiment. Explain why you think so.
   c Predict what happened at 10 minutes to cause the change.
   d Suggest a reason why the carbon dioxide uptake levelled off at 30 minutes. Predict some limiting factors.
   e Predict what would happen to cellular metabolism if the temperature surrounding the plant increased beyond the plant's optimal conditions.
   f Explain why the carbon dioxide concentration in the air surrounding the plant can be used as a measure of the rate of photosynthesis.

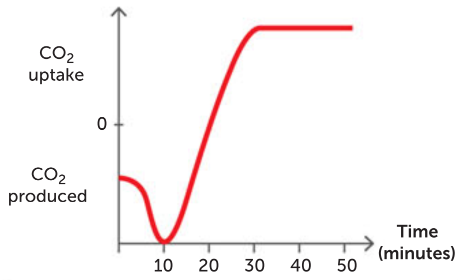

FIGURE 10.33 Carbon dioxide inputs and outputs for a plant over time

6 ATP is like currency in an economy. Use the ATP–ADP cycle to explain how it can be likened to spending and earning money.

7 The compensation point is when the rate of photosynthesis exactly equals the rate of cellular respiration. Predict how plant growth is likely to be affected at the compensation point.

Analysing

8 If plant cells make their own food, explain why they need mitochondria.

9 A jar of preserved fruit looks frothy and smells of alcohol. Explain what has happened. Suggest what could be done to prevent this happening.

10 A human enzyme called protease works best at 37°C.
   a Predict what would happen to the enzyme's activity at very low temperatures.
   b Propose how this may differ from the activity of the enzyme at very high temperatures.
   c Describe what has happened to the active site in both cases.

Evaluating

11 Enzymes are responsible for both sperm and male sex hormone production in the testicles of human males. Some of these enzymes have an optimal temperature of 33°C, which is about 4°C lower than body temperature. Discuss whether an increase in temperature would affect sperm production.

12 Many cut fruits will brown quickly when exposed to air. This is caused by the naturally occurring enzyme polyphenol oxidase. If the freshly cut fruit is rubbed with lemon juice, the brown discolouration almost disappears. Explain why this happens.

13 You are given two test tubes containing two types of yeast cells that are the same in every way except that one can carry out only aerobic respiration and the other can carry out only anaerobic respiration. They are labelled A and B, respectively. Predict which tube would have rapid growth and which would have comparatively slow growth. Justify your choice.

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Creating

14 Create a table of differences to compare the biochemical processes of photosynthesis and respiration.

Reflecting

15 Reflect on the rationale for research, development of technologies and computer analysis of chemical processes in plant cells.

PRACTICE EXAM QUESTIONS

1 Mitochondria are the sites of:
- **A** photosynthesis.
- **B** chemosynthesis.
- **C** respiration.
- **D** transpiration.

[Q25 2011 Stage 2 SCSA]

2 Some species of photosynthetic algae live in the outer layers of the bodies of jellyfish. The algae produce glucose that is absorbed by the jellyfish. What is the most likely outcome if a jellyfish is kept in the dark?
- **A** The jellyfish will require more carbon dioxide.
- **B** The growth rate of the jellyfish will slow down.
- **C** Neither the algae nor the jellyfish will be affected.
- **D** The algae will die but this will not affect the jellyfish.

[Q29 2011 Stage 2 SCSA]

3 Which of the following processes removes carbon dioxide from the atmosphere?
- **A** photosynthesis
- **B** anaerobic respiration
- **C** aerobic respiration
- **D** decomposition

[Q2 2010 Stage 2 SCSA]

4 Leaf cells performing photosynthesis will most likely:
- **A** lack mitochondria but have chloroplasts.
- **B** lack chloroplasts but have mitochondria.
- **C** have both chloroplasts and mitochondria.
- **D** have neither chloroplasts nor mitochondria.

[Q12 2010 Stage 2 SCSA]

5 A cell's enzymes consist of:
- **A** proteins.
- **B** carbohydrates.
- **C** lipids.
- **D** nucleic acids.

[Q21 2010 Stage 2 SCSA]

6 Which of the following statements about enzymes is true?
- **A** The concentration of an enzyme increases during a reaction.
- **B** The concentration of an enzyme remains constant during a reaction.
- **C** Enzymes speed up a reaction until the enzyme is completely used.
- **D** Enzymes slow down reactions that produce toxic wastes.

[Q21 2010 Sample WACE exam Stage 3 SCSA]

7 Photosynthesis occurs in some plant cells.
- **a** Name two (2) inputs of photosynthesis. (2 marks)
- **b** Name two (2) outputs of photosynthesis. (2 marks)

[Q31a 2011 Stage 2 SCSA]

8
- **a** Does respiration occur in plant cells? Explain your answer. (2 marks)
- **b** Name two (2) outputs of respiration. (2 marks)

[Q31b 2011 Stage 2 SCSA]

9 Two major activities occurring in many of the leaf cells of green plants are shown in Figure 10.34. (6 marks)

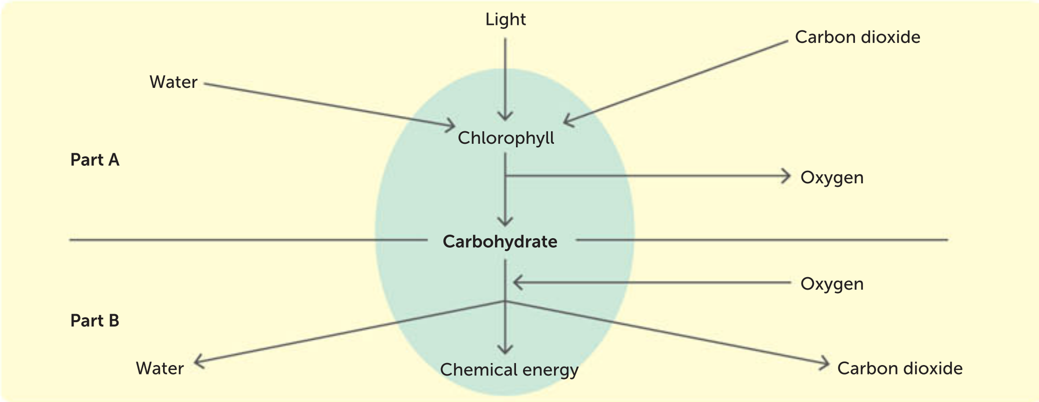

FIGURE 10.34 Two major processes

a Name the process represented in Part A of the diagram and write a balanced chemical equation for it. (2 marks)
b Name the process represented in Part B of the diagram and write a balanced chemical equation for it. (2 marks)
c In what organelle of the cell does Part A in the diagram mainly occur? (1 mark)
d In what organelle of the cell does Part B in the diagram mainly occur? (1 mark)

[Q22a,b 2010 Sample WACE exam Stage 3 SCSA]

10 Describe the process during which the energy in glucose is converted to a usable form of energy during the three main steps of cellular respiration. (10 marks)

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11
CELLS IN MULTICELLULAR ORGANISMS

CHAPTER 11 CONTENT

STARTER QUESTIONS

1 Can certain cells within a multicellular organism stay alive independently of other cells from the same organism?
2 If all the cells in one organism contain the same genetic material, the same genome, why do some cells have different structures and functions compared with other cells?
3 What important role do stem cells play in complex multicellular organisms?

SCIENCE UNDERSTANDING

» multicellular organisms have a hierarchical structural organisation of cells, tissues, organs and systems

School Curriculum and Standards Authority (2017).
Biology ATAR course: Year 11 syllabus: Science inquiry skills.

James Vodicka

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11.1 A HIERARCHY IN STRUCTURE: FROM ATOMS TO ORGANISMS

Cells are the smallest structural and functional unit of all living things (organisms). Cells are made of matter. All matter is composed of **atoms** (the smallest units of matter), which can be organised into complex biological molecules. **Molecules** are the smallest part of a chemical compound. These molecules can be built together to form the **organelles**. Organelles are specialised structures or compartments within cells that have specific functions. An organelle's structure directly relates to its function.

There are patterns in the basic structural organisation within cells. These patterns are used to classify cells as either **prokaryotes** (whose cells have no membrane-bound organelles, which means they do not possess a nucleus) or **eukaryotes** (whose cells have membrane-bound organelles).

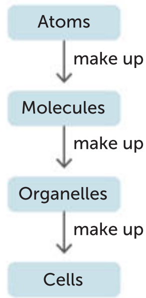


FIGURE 11.1 A hierarchy of structures: from atoms to cells

While there are structural differences between cells, they all share a similar overall pattern. All cells possess a **cell membrane** (also known as a plasma membrane), which encloses a semi-fluid substance called the **cytosol**. The cytoplasm includes the cytosol and the organelles suspended in the cytosol. All cells also contain genetic material and ribosomes.

Although all living things are made of cells, organisms can vary in their shape, size, structural complexity and organisation. Organisms that are made up of a single cell are referred to as **unicellular** and those made up of many cells are **multicellular**. The early forms of life on our planet were most likely unicellular. Multicellular organisms evolved comparatively recently in our evolutionary history.

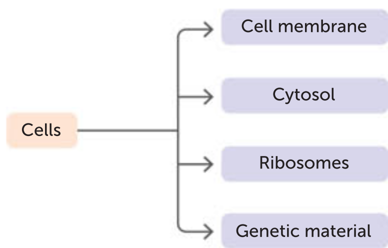


FIGURE 11.2 All cells contain genetic material, a cell membrane, cytosol and ribosomes.

Unicellular organisms are simpler than multicellular organisms

Simple unicellular prokaryotes, such as species in Domains Archaea and Bacteria, are thought to be the earliest organisms to inhabit Earth. They probably lived in our oceans between 3.5 and 4 billion years ago, in very different environmental conditions to those we currently live in. Prokaryotes are still the most widespread organisms on Earth. They are still evolving and adapting; however, their small size and simplicity comes with limitations. A key issue is that only a limited number of metabolic activities can be performed within the cell at one time. In contrast, eukaryotic cells can perform many more processes due to their more complex structure. Some unicellular organisms, such as protozoans, are eukaryotic. These are complete, functioning organisms.

A single cell has a high surface-area-to-volume ratio. This means that the size of the cell membrane (its surface area) is sufficient to service the total volume of the cytoplasm. All the needs of the organism (e.g. nutrients, energy and water) and functions (e.g. intake of nutrients and energy, processing of nutrients to release energy and expulsion of waste products) take place inside the boundary of the cell membrane. The microscopic size of the cell allows these processes to occur efficiently, relying mostly on diffusion. Oxygen, nutrients and carbon dioxide can diffuse directly across the cell membrane in amounts sufficient to meet the needs of the entire cell.

Key concept

Unicellular organisms are made up of a single cell and multicellular organisms are made up of many cells.

9780170452847

Paramecium: an example of a unicellular eukaryote

Within the Kingdom Protista, there are many forms of cells that meet their survival needs in many different ways. A paramecium is an example of a relatively simple-structured, unicellular eukaryotic organism. Paramecia are usually found in ponds, slow-moving streams or any enclosed area containing water. They are able to obtain all their requirements for survival directly from their surroundings.

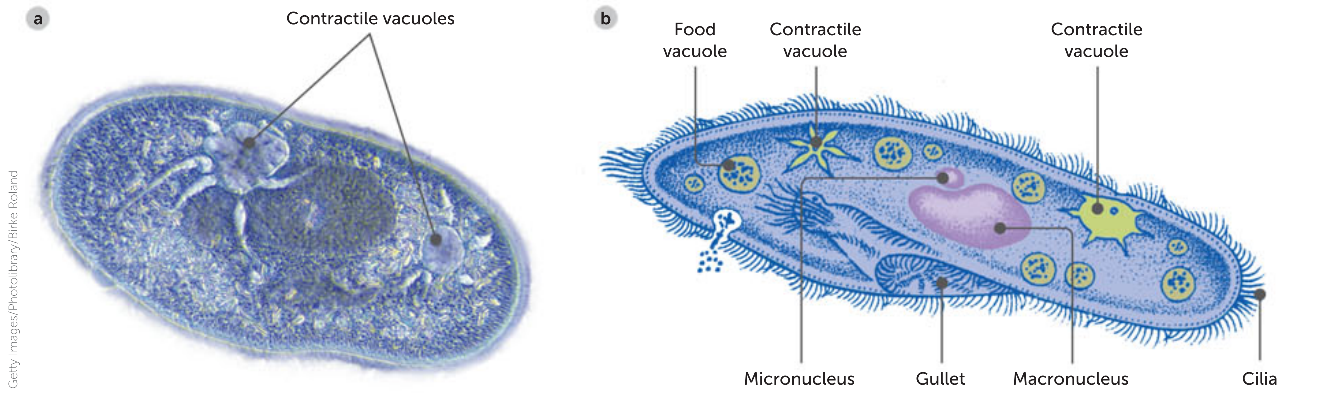


FIGURE 11.3 a A paramecium; **b** sketch of a paramecium, showing cell structures

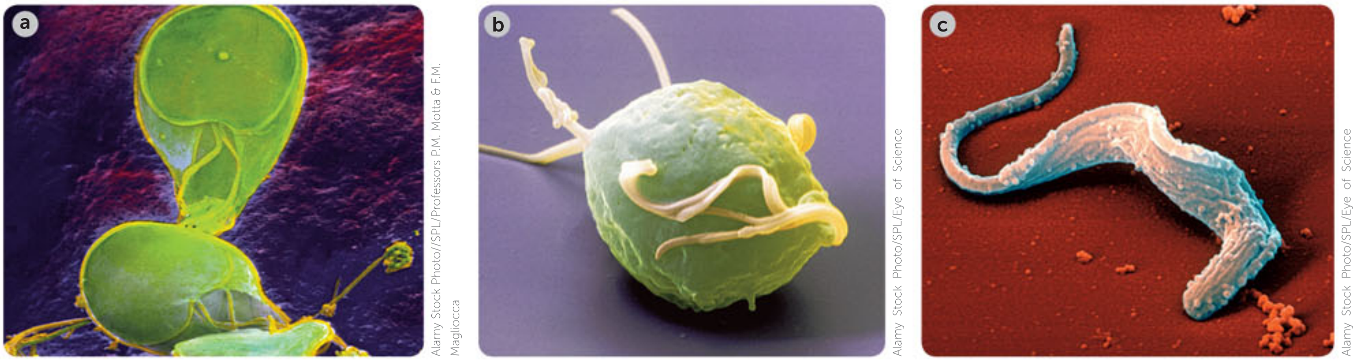


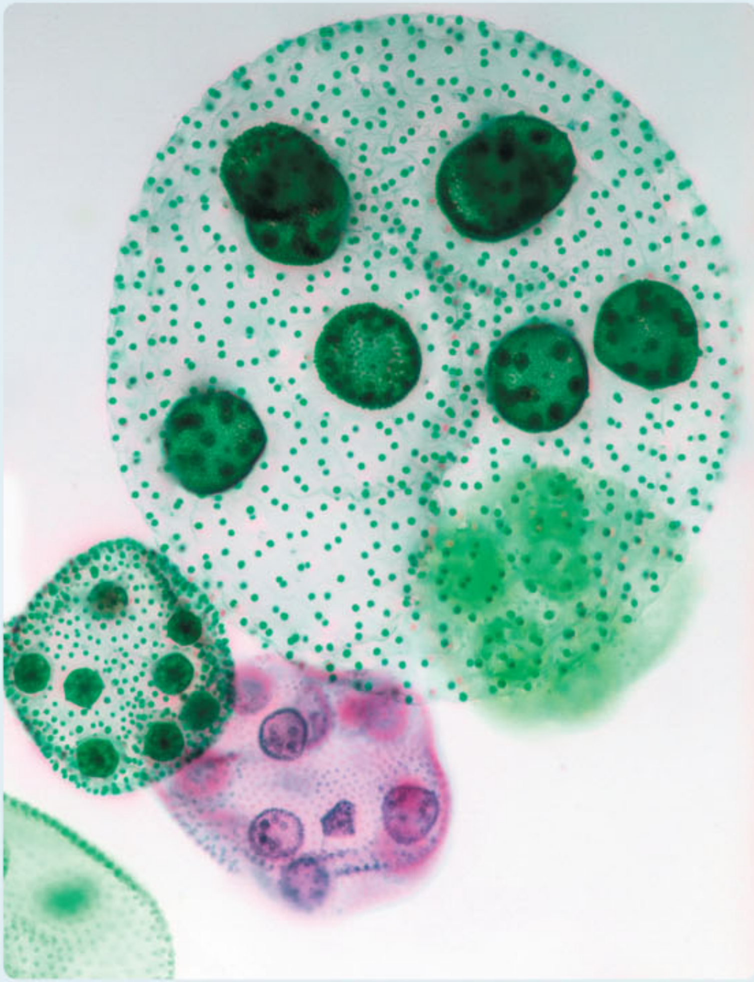
FIGURE 11.4 The diversity in structure of unicellular eukaryotes: **a** *Giardia lamblia*; **b** *Trichomonas vaginalis*; **c** *Trypanosoma brucei*

The unicellular paramecium is shaped like a football and covered in cilia. The movements of the cilia are synchronised, enabling the organism to move through the water. One feature that sets paramecium apart from some other protists is that it gathers its organic nutrient requirements, such as bacteria, algae and yeasts, from its surroundings. By using its cilia, it sweeps food, along with some water, into its oral groove and then into the mouth of the cell. The food travels through the cell mouth into the gullet, which is a temporary holding area for the food. When there is enough food in the gullet, the food breaks away and forms a food vacuole. Throughout this process, the vacuole is making its way to the back end of the cell. Expulsion of wastes from the food vacuole occurs through an anal pore. The paramecium collects the excess water that enters the cell with the food in a contractile vacuole and expels it from the vacuole back into the environment.

11.1 APPLICATION

Little 'animals' in water

The first person to see protozoans and bacteria was Antonie van Leeuwenhoek, a Dutch businessman and self-taught microscopist. Leeuwenhoek was born in Delft, Holland, in 1632 and received little schooling, but became a successful fabric merchant. Like other drapers, he used magnifying glasses to closely inspect cloth. Partly inspired by Robert Hooke's work, Leeuwenhoek began to grind his own lenses and build basic types of microscope. Driven by curiosity, he observed protozoans and bacteria in fresh water, lice, bees, samples taken from the human mouth and even his own excrement. When he observed the explosion of gunpowder through a microscope, he was nearly blinded! Leeuwenhoek wrote careful descriptions of his observations and, over the course of 50 years from 1673, sent 190 letters to the Royal Society in London, who translated and published them. From his reports, modern scientists have been able to identify many of the micro-organisms he saw.



Alamy Stock Photo/Jennifer Formica

FIGURE 11.5 *Volvox* live in a variety of freshwater habitats and can grow spherical colonies of up to 50 000 cells. They were first described by Antonie van Leeuwenhoek in 1700.

Questions

1 How did Antonie van Leeuwenhoek's discoveries impact society?
2 Why were his discoveries so important?

Multicellular organisms are more complex

Not all of the cells within a multicellular organism are the same. While the cell of a unicellular organism undertakes all living functions (e.g. respiration, digestion, reproduction and excretion), this is not the case in multicellular organisms. In multicellular organisms, there are different types of cells, each type with a specialised structure and function. These cells are so specialised they cannot exist independently of other cells.

The evolution from unicellular organisms to multicellular organisms required three organising principles. These were the ability of cells to divide, specialise and communicate with other cells.

Question set 11.1

REMEMBERING

1 Rearrange the following structures in ascending order of structural complexity: cell, atom, organelle, molecule.

2 State the major difference between a prokaryotic cell and a eukaryotic cell.

3 Identify an advantage and a disadvantage of being:

  a unicellular

  b multicellular.

4 List three organising principles that were required for the evolution from unicellular organisms to multicellular organisms.

UNDERSTANDING

5 Describe the structure of a paramecium and explain how certain structures enable it to gain its nutrients.

11.2 CELL SPECIALISATION AND DIFFERENTIATION

The amazing diversity of cell shape and structure usually relates to each cell type's specific function. This **specialisation** can increase the efficiency with which an organism functions and can be essential for its survival. The process a cell goes through to become specialised is called **cellular differentiation**. **Differentiation** is the process of an unspecialised cell becoming specialised in structure and function, and it occurs mostly during embryonic development in multicellular organisms. At this stage, the specialist cells become organised in tissues and organs so that collectively they can perform specific functions.

Almost all the cells in a particular multicellular organism have the same genome (total genetic material). How then do cells end up with different structures? The answer is that different genes are expressed (switched on to produce proteins) in different cells. The activities of a cell depend on the genes being expressed and the proteins it produces as a result.

All **specialised cells** originate from **stem cells**. Stem cells differ from other cells in the body in three important ways. The first difference is that they are unspecialised (have not yet specialised into a particular type of cell). The second difference is that they have the potential to divide and replicate for long periods of time. The third difference is that these relatively unspecialised cells can differentiate to form different specialised cells. In mammals, stem cells can differentiate into a diverse range of specialised cells such as lung, pancreas, blood, skin and **neuron** cells. Figure 11.6 shows how diverse the cells of multicellular organism can be.

Same total genes, but different sets are expressed

With the exception of sex cells (such as sperm and ova), eukaryotic cells are produced by a type of cell division called **mitosis**. Mitosis produces cells that are genetically identical to each other and to the original cell. This means that all of the non-sex cells within a multicellular organism should be genetically identical to each other. But if various specialised cells all contain the same genetic instructions, why don't they look the same? How are they able to perform different functions?

While the genetic information is the same in all cells of a multicellular organism, not all of this information is used in every cell. Only a small portion is actively 'switched on' in each cell. The specific genetic instructions (located in genes in chromosomes) that will be 'switched on' and expressed to make specific proteins depends on the function of the specific cell.

It is the immediate environment of the differentiating cell and its location in the developing organism that determines which genes will be activated ('switched on'). Factors in its environment cause each cell to differentiate and become specialised. Specialised cells each have a specific shape and function. In humans, this differential gene expression can result in more than 200 different cell types.

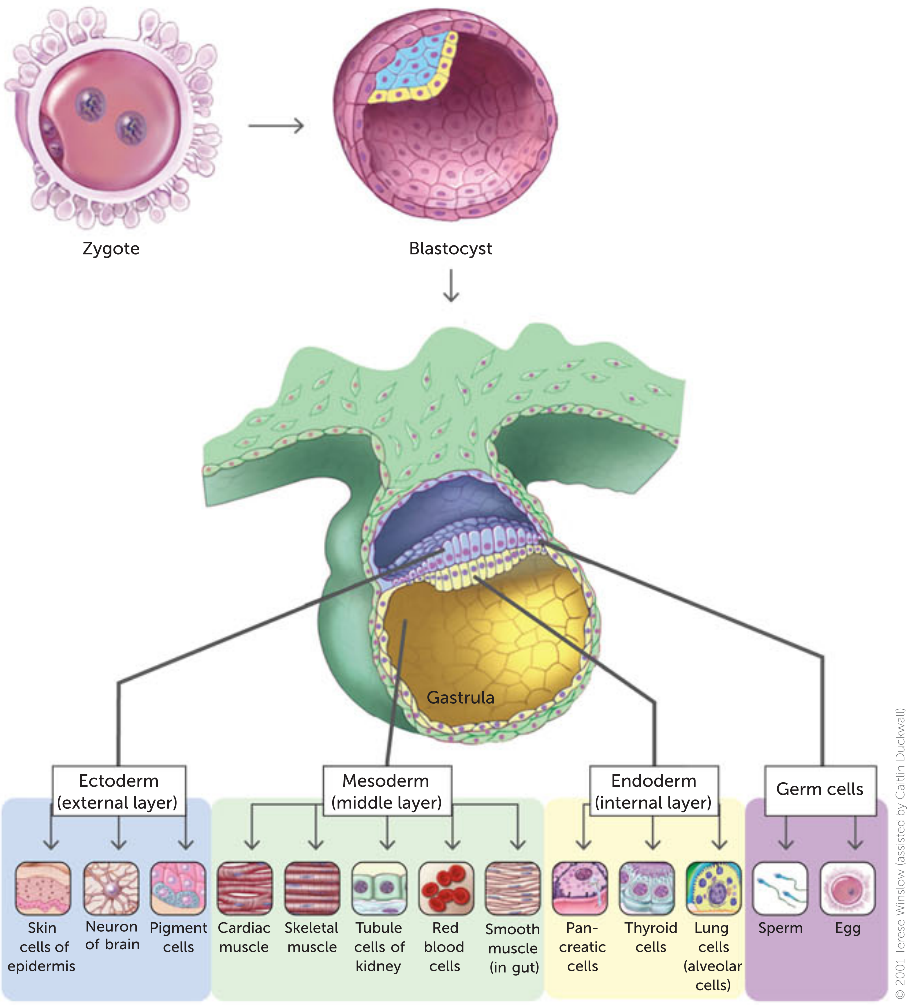


FIGURE 11.6 Differentiation is a process in which cells become more specialised as they mature.

Key concept

Cellular differentiation occurs when a stem cell gives rise to specialised cells that have different structures and functions, as a result of the activation of particular sets of genes. It mostly occurs during embryonic development in multicellular organisms.

Specialised cells come at a cost

While specialised cells increase efficiency and reduce duplication of effort, there is a cost. Within a multicellular organism, specialisation brings about the need for communication and coordination between cells. Specialised cells are totally dependent on the activities of other cells to perform tasks that they cannot. Nerve cells, for example, effectively transport nerve impulses, but they rely on red blood cells to deliver oxygen, heart muscles to pump the oxygenated blood to them and other cells to provide nutrients and remove their wastes. If a nerve cell is isolated from the organism of which it is part, unlike a unicellular organism, it is not able to function on its own and it dies.

Question set 11.2

REMEMBERING

1 State whether each of the following statements is true or false. Justify each of your decisions.
   - a The process of specialisation is called cellular differentiation.
   - b Different types of specialised cells contain different DNA.
   - c All specialised cells originate from stem cells.

2 Outline three ways in which stem cells are different from other cells in the body.

UNDERSTANDING

3 All cells within a multicellular organism contain the same genetic information, but the structure and function of specialised cells differs. Explain how this is possible.

4 Discuss the advantages and disadvantages of a cell becoming specialised.

5 Explain the importance of communication and connections between the cells of a multicellular organism.

11.3 ANOTHER HIERARCHY IN STRUCTURE: CELLS, TISSUES, ORGANS, SYSTEMS

Moving muscle cells
View beating myocytes in this video clip.

Groups of specialised cells working together to perform a similar function make up **tissues**. Likewise, a collection of different types of tissues working together to perform a particular function is called an **organ**. Your heart is an organ. It consists of cardiac muscle tissue, which uses **nervous tissue** to direct its contractions. Chambers of the heart are lined with epithelial tissue that prevents leaking and also connective tissue to add strength and elasticity.

In a similar pattern, a collection of organs that work together to perform a particular function is called a **system**. Each organ system contributes to the survival of all living cells in the body. You might think this is stretching things. For example, how could muscles and bones help each small, individual cell stay alive? Yet it is the interactions between the skeletal system and the muscular system that allow us to move towards sources of nutrients and water. Parts of these organ systems

Cells
↓ make up
Tissues
↓ make up
Organs
↓ make up
Systems
↓ make up
Multicellular organisms

FIGURE 11.7 A hierarchy of structure: from cells to multicellular organisms

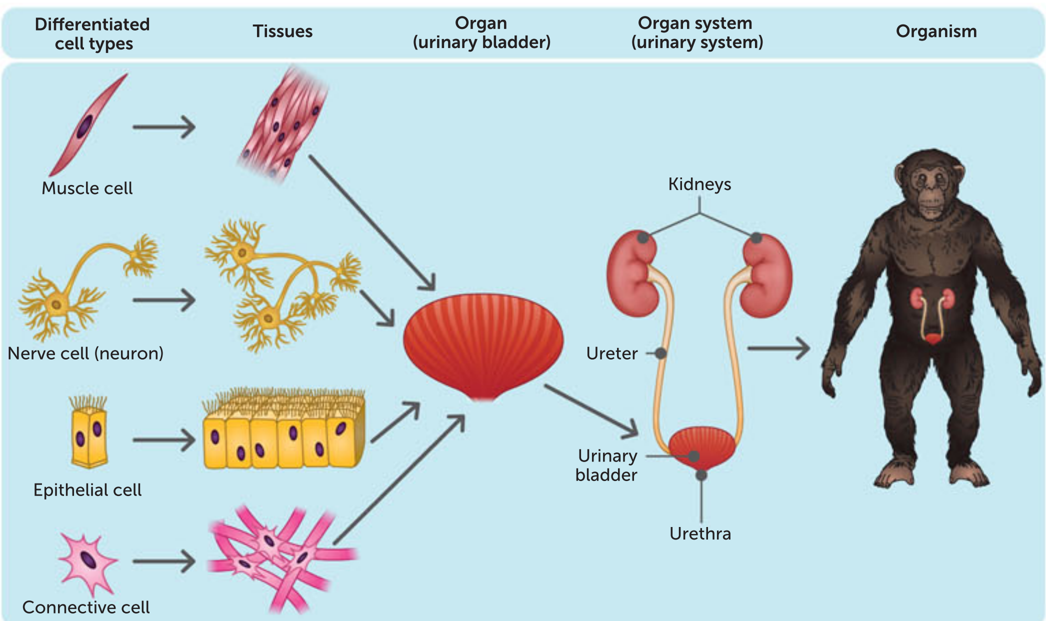


FIGURE 11.8 The organisation of cells, tissues, organs and organ systems in a mammal

help keep blood circulating to cells, such as when contractions of leg muscles help move blood in veins back towards the heart. The circulatory system rapidly transports oxygen and other substances dissolved in blood to cells, and moves metabolic products and wastes away from them. The respiratory system swiftly delivers oxygen from the air to the circulatory system and takes up carbon dioxide wastes from it. Skeletal muscles assist the respiratory system, and so it goes throughout the entire body.

While the skeleton helps support and give shape to your body, it is merely one of the many systems that work together to keep you alive. Each of these systems is made up of different organs, which are made up of different types of tissue, which are made up of collections of specialised cells. While sharing some features with the other cells in the body, the cells in the skeleton also possess different features, which suit them to their specific function. These cells have become so specialised that they cannot live independently of other types of cells in your body.

In multicellular organisms, cells of similar shape are organised into tissues that together perform the same function. Different tissues are organised into an organ that carries out a particular function. Groups of organs working together to achieve a particular function make up a system.

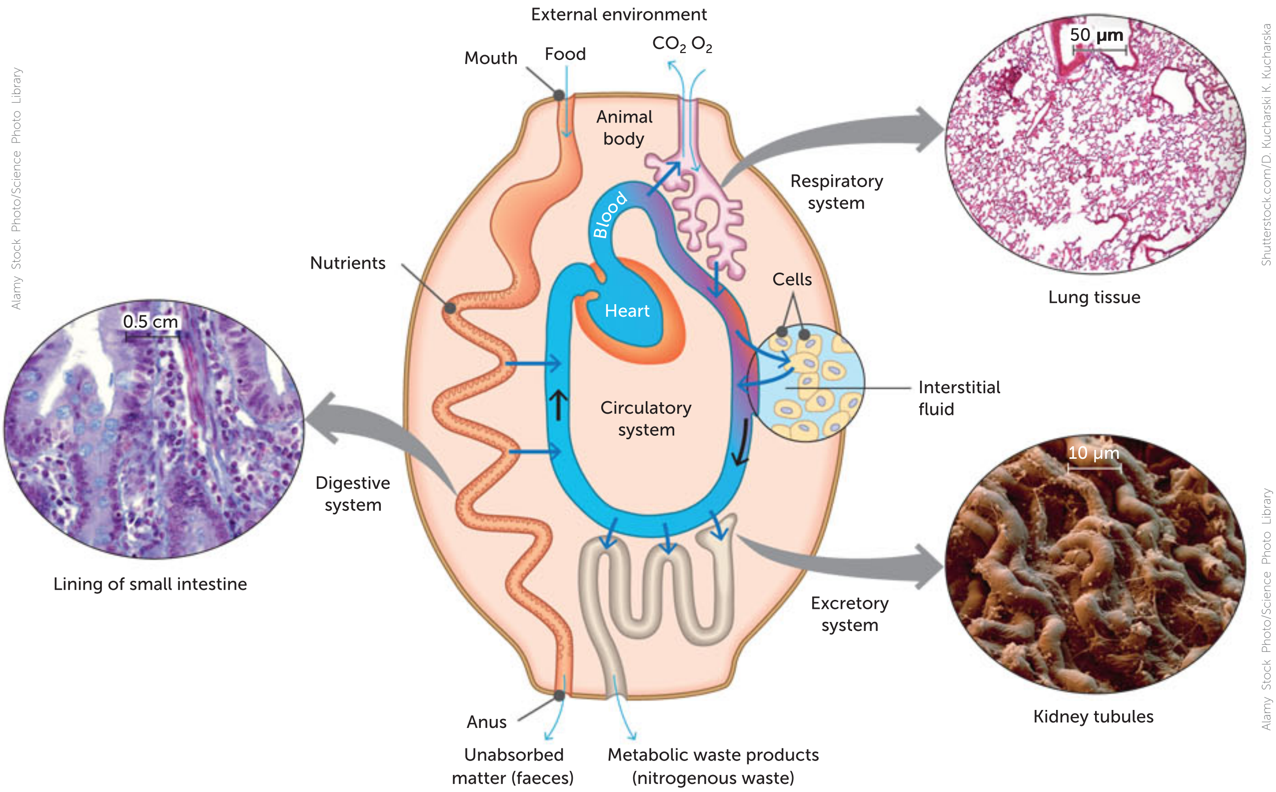


FIGURE 11.9 Cells of multicellular organisms work together to meet each other's needs.

Animal cell specialisation and organisation

The blue whale (*Balaenoptera musculus*) is the largest mammal on the planet. Reaching an average weight of 100 000 kg and length of approximately 25 m, it feeds almost entirely on a tiny, shrimp-like crustacean called krill. The krill provides all its nutritional needs. The whale is able to move through the oceans at an average speed of 20 km h^{-1} but can reach speeds close to 50 km h^{-1} when necessary. Being able to move at this speed, they were not hunted much by whalers before 1868. It was at that time that a Norwegian whaler, Svend Foyn, developed an exploding-harpoon gun and revolutionised the whaling industry.

FIGURE 11.10 The blue whale has cells similar in shape and function to humans, despite being considerably larger.

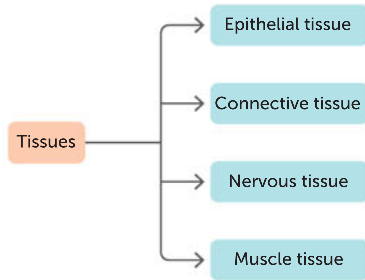


FIGURE 11.11 Complex animals consist of four basic tissue types.

B. musculus is able to dive and remain submerged for up to 20 minutes at a time, surfacing and forcibly blowing air through its blowhole 8–15 times. Blue whales reach sexual maturity at 6–10 years, and are able to produce calves once every 2–3 years, with a 12-month gestation period. The young are weaned at 7–8 months when they have reached 16 m in length and weigh 21 000 kg. If you could zoom in on the blue whale and look at it at the microscopic level, you would see that it is made up of trillions of cells working cooperatively together.

Blue whale cells, like human body cells of similar shape and function, are organised into tissues. Amazingly, the bodies of all complex animals consist of only four basic types of tissues. These are epithelial, connective, muscle and nervous tissues.

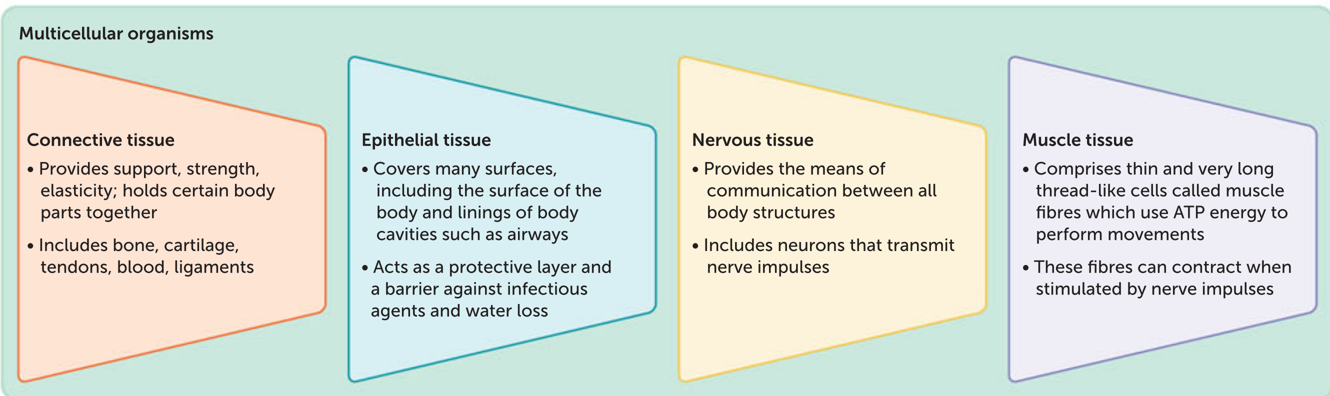


FIGURE 11.12 A summary of the four basic tissue types in complex multicellular animals

Connective tissue

Connective tissue provides support and holds various parts of the body together. It plays a key role in binding and supporting other tissues, and protects against damage, infection and heat loss.

Cells in connective tissue are sparsely scattered through a non-living material called the semi-fluid extracellular matrix. There are different types of connective tissue and they can vary in their density of cells and ways in which cells are specialised. The main types of connective tissue in vertebrates are loose connective tissue, fibrous connective tissue, **adipose** (fat) tissue, **cartilage**, **bone** and **blood**. Differences in the structure of each of these types of connective tissue are related to their specialised functions. For example, human red blood cells are small (around 10 μm), enabling them to easily move through capillaries. Also, these cells lose their nucleus as they mature, which gives them more space to carry oxygen.

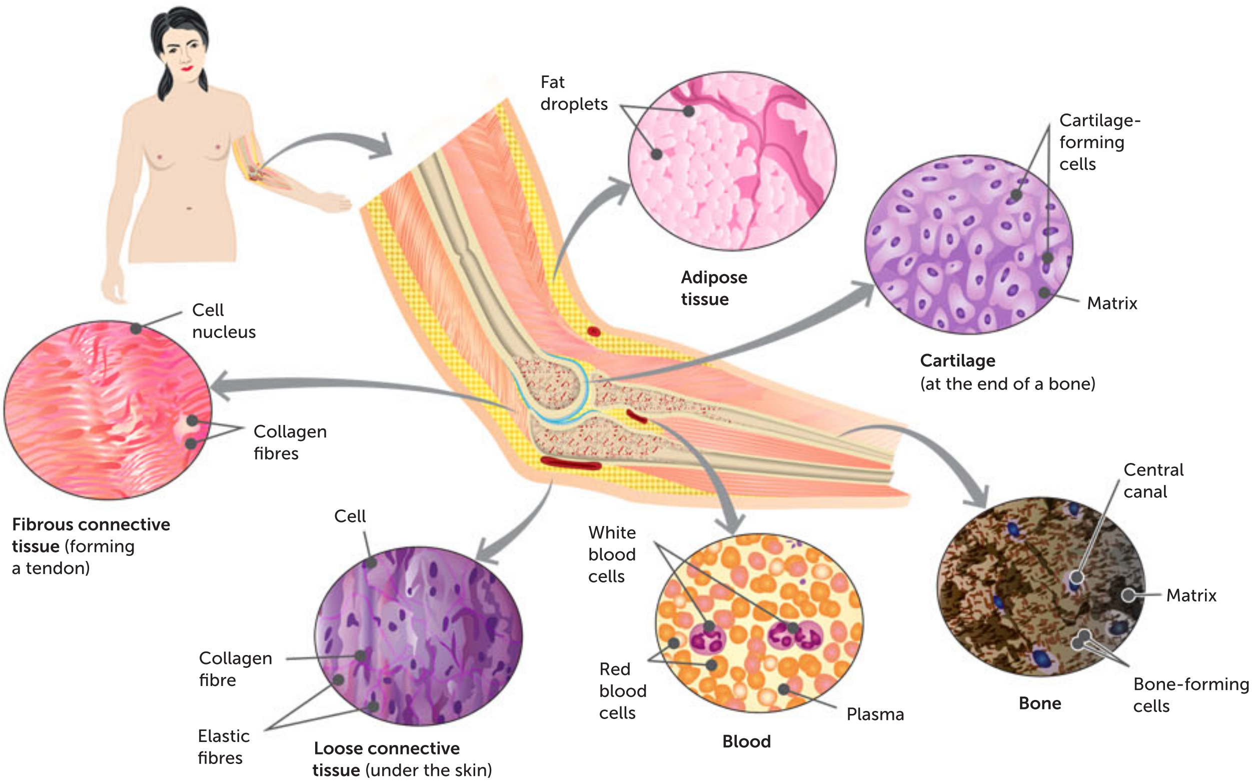


FIGURE 11.13 Pinch and pull some of the skin on the back of your hand. The collagen in the connective tissue is involved in stopping your skin from tearing away from your bone. The elastic fibres function to restore your skin back to its original place and shape. This figure shows examples of different types of connective tissue.

Epithelial tissue

Epithelial tissue is a covering that protects organs, lines body cavities and covers the surface of the body. Epithelial cells line internal and external surfaces such as blood vessels, digestive organs, kidney tubules, skin and airways. Epithelial cells are usually organised into tightly packed single or layered sheets. This cell organisation increases their effectiveness as barriers that protect against mechanical injury, invasive micro-organisms and loss of fluid.

As well as providing a barrier and protecting organs, some epithelial tissue may be specialised to function in absorption, secretion or excretion. For example, the epithelial tissue that lines the respiratory tract secretes mucus that lubricates the surface and keeps it moist. The cilia of these cells help the mucus to move along the surface, trapping particles and sweeping them back up the trachea. This helps to keep lungs clean and healthy. Table 11.1 summarises some different types of epithelial cells and their functions.

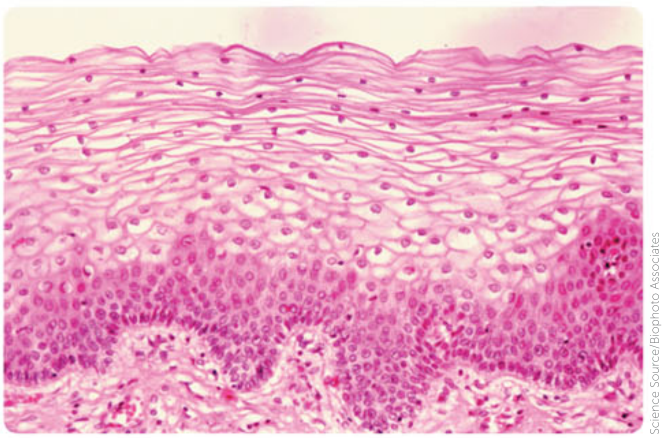
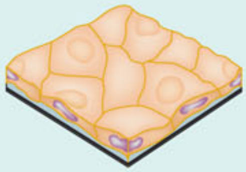
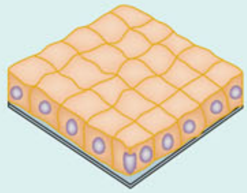
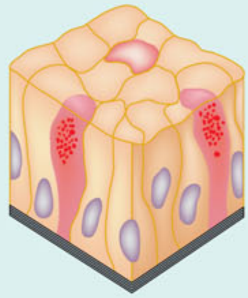
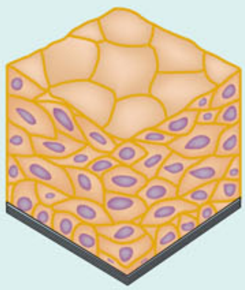
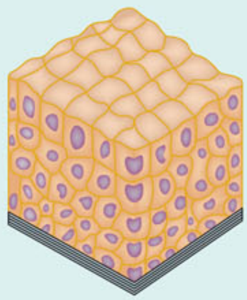
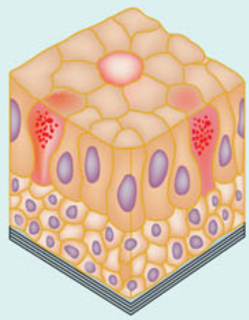


FIGURE 11.14 The human tongue contains stratified squamous epithelial cells.

TABLE 11.1 Epithelial tissue plays a key role in lining or covering surfaces and body cavities. The number of cell layers and shape of the cells on their surface are two criteria used to classify epithelial cells.

	TYPES OF EPITHELIAL CELLS		
	SIMPLE SQUAMOUS	**SIMPLE CUBOIDAL**	**SIMPLE COLUMNAR**
Structure			
Location	Lining of blood vessels and alveoli of lungs	Kidney tubule lining	Most digestive organ linings
Function	Lines blood vessels and air sacs of lungs Permits exchange of nutrients, wastes and gases	Lines kidney tubules and glands Secretes and reabsorbs water and small molecules	Lines most digestive organs Absorbs nutrients, produces mucus Goblet cell
	STRATIFIED SQUAMOUS	**STRATIFIED CUBOIDAL**	**STRATIFIED COLUMNAR**
Structure			
Location	Outer layer of skin, vagina, mouth	Sweat gland duct lining	Mammary gland, epididymis and larynx lining
Function	Protects against abrasion, drying out, infection	Lines ducts of sweat glands Secretes water and ions	Lines epididymis, mammary glands, larynx Secretes mucus Basement membrane

Nervous tissue

Nervous tissue provides the means of communication between all body structures. The cells in nervous tissue are highly specialised; for example, the elongated shape and the extensions of motor neurons are well suited to their function of passing messages through the nervous system to other parts of the body.

Neurons are cells that have extensions called dendrites, a cell body and an axon. The shape of the dendrites increases the surface area for message detection. After detection, the electrical message (impulse) is then carried along the axon to the axon terminal where it is converted into a chemical message (neurotransmitter), which is released into the synapse. The message may either interact with another neuron or with an effector (e.g. muscle or gland) to bring about a response.

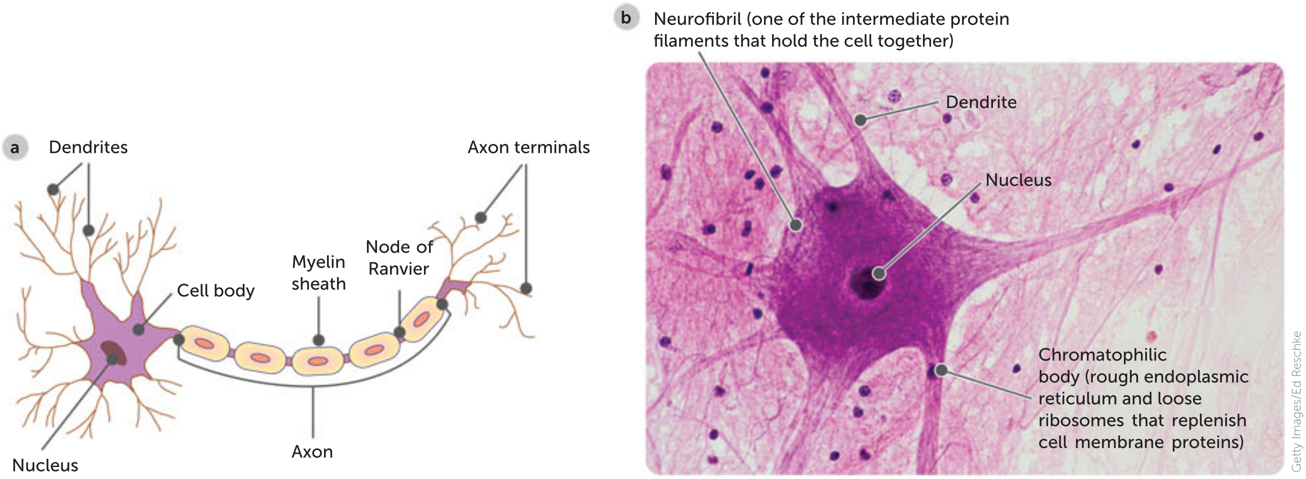


FIGURE 11.15 a A diagram of a motor neuron; **b** a micrograph of a motor neuron

Muscle tissue

Muscle tissue is made up of thin and very long thread-like cells called muscle fibres. These fibres are capable of contracting when stimulated by nerve impulses. The contraction is a type of tension force which leads to the generation of other types of forces, such as a push or a pull. Contraction of these fibres accounts for much of the energy requirements in an active animal. The three main types of muscle tissue are: skeletal muscle, cardiac (heart) muscle and smooth muscle.

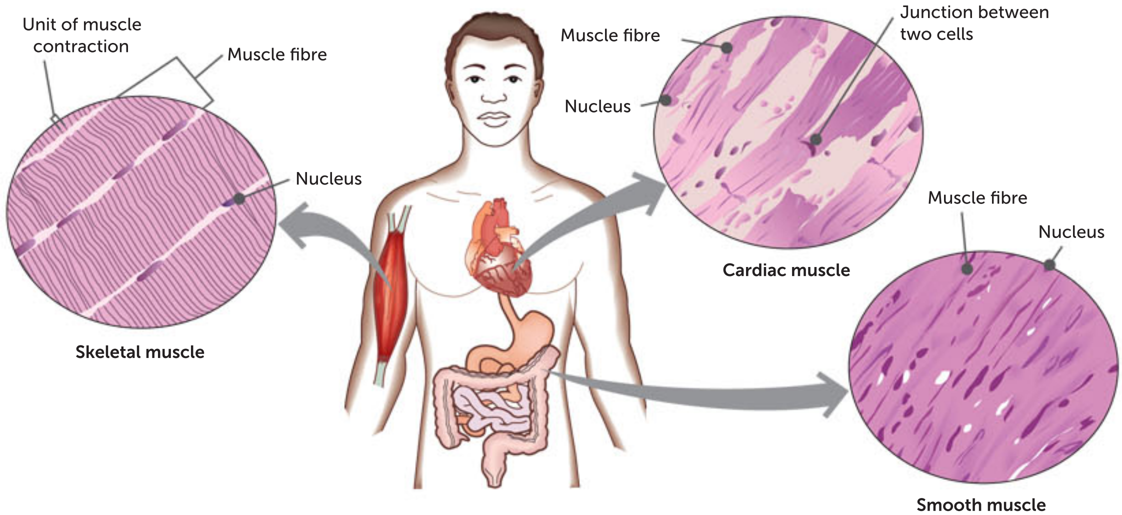


FIGURE 11.16 The contraction and relaxation of voluntary muscles (such as skeletal muscle in biceps) requires conscious thought. On the other hand, involuntary muscles (such as cardiac muscle in your heart and smooth muscle in your stomach) contract and relax without conscious thought.

Key concept

The bodies of all complex animals consist of only four basic types of tissues: epithelial, connective, muscle and nervous tissues.

SCIENTIFIC LITERACY

Harry Perkins Institute: cell research

The Harry Perkins Institute of Medical Research (the Perkins) is the leading WA medical research institute focused on the major diseases affecting the adult community: cancer, cardiovascular disease, diabetes and rare genetic diseases. With a foundation of over 20 years of scientific discovery and a collaborative team of over 450, the Perkins is well placed to deliver pioneering medical breakthroughs and translate these discoveries into more effective treatments and cures for the global community.

One of the latest facilities at the Perkins is a single-cell sequencing centre. The centre is used to analyse the genome and find out other useful information about healthy and unhealthy cells. It will be transformative for cancer research in WA, delivering new insights into tumour biology, cancer progression, methods for earlier detection and innovative new ways to kill cancer cells.

The project is a large-scale collaborative syndicate uniting cancer researchers across Perth, with 18 institutions including numerous medical research institutes, four universities, major hospitals and the WA Department of Health involved. The facility will generate a molecular atlas of hundreds of cancer samples donated by patients – a resource which will help researchers uncover which genes are switched on and off in every cell within a tumour.

Rather than treating cancers with a broad-brush approach, the centre will allow researchers to use cutting-edge technology to study tumours at a single-cell level. Tumours are heterogenous populations of cells; this means they are made up of thousands of different cell types, each with a variety of mutations that cause the cell to resist immune intervention and spread out of control. Single-cell transcriptome sequencing is used to understand the characteristics and cell type components of the population so that precise treatment can be designed. Extensive sequencing is needed for generating meaningful data at single-cell level.

Source: Harry Perkins Institute of Medical Research

Harry Perkins Institute of Medical Research/Tobey Black

Harry Perkins Institute of Medical Research/Tobey Black

FIGURE 11.17 Students and scientists using biotechnological techniques at the Harry Perkins Institute

Part of the research at the Perkins targets breast cancer. When specialised cells such as cells in breast tissue experience uncontrolled growth, a tumour can grow. This can be caused by changes in DNA that inactivate tumour suppressor genes which leads to uncontrolled cell growth. Breast cancer is studied in mice instead of humans when new treatments are tested (Figure 11.18).

The Lotterywest BioDiscovery Centre
This centre provides the chance for students to work with scientists, using research-grade equipment and the latest technology in a research laboratory setting. The research projects used relate to real-world scientific discovery. The experiences give students a taste of a number of STEM career pathways.

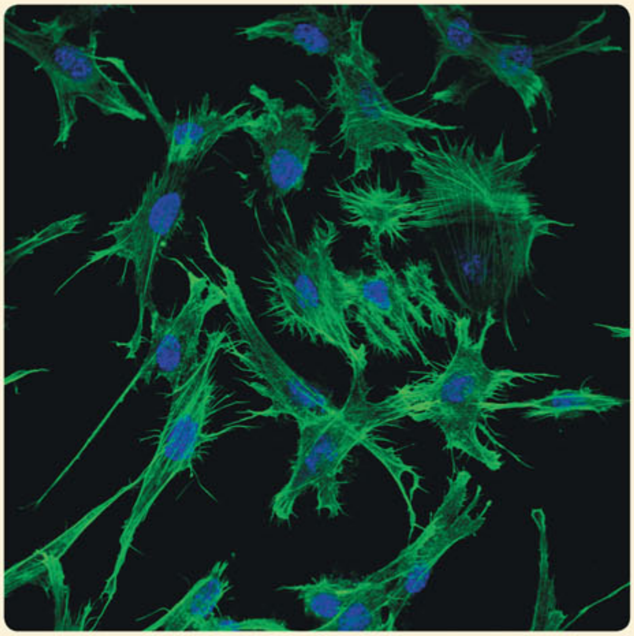


FIGURE 11.18 Breast cancer cells interacting with therapeutic nanoparticles (extremely small particles). The nanoparticles have interacted with peptides inside mouse breast cancer cells: green shows actin filaments and blue is nuclei.

Questions

1 Suggest why mice were used instead of humans for breast cancer research.

2 The facility will 'generate a molecular atlas of hundreds of cancer samples donated by patients'. How will this help scientists determine the cause of a particular cancer?

3 Suggest how the development of new technologies could result in replacing or reducing the numbers of animals required for medical testing.

4 If we have the ability to manipulate and regulate the differentiation of cells, should we? Consider this question for the two contexts below and in each case, justify your response.
   a in humans
   b in other species.

Plant cell specialisation and organisation

While plants do not have all of the same systems that animals do, they do have specialised cells that make up tissues with specific functions to assist in their survival. As in animals, the individual cells are organised into tissues (such as photosynthetic tissue), which form the organs (such as the leaf) of the plant body. Each of these tissues is specialised to perform important functions that support the life of the plant. These include obtaining energy, producing organic compounds, distributing materials, removing wastes and exchanging gases. Figure 11.19 illustrates and describes the main parts of a growing plant.

The structure of a **vascular** plant ensures that each organ – the leaves, stem, roots, flowers and seeds – receives what it needs. The organs are grouped into two systems.

1 The shoot system is comprised of all parts of the plant found above ground. This includes the plant stem, as well as the leaves and reproductive organs that grow from the tips of actively growing stems. The shoot system is responsible for supporting the plant physically and for the transportation of resources, as well as the absorption of oxygen and carbon dioxide, reproduction and carrying out photosynthesis in leaves.

2 The root system is generally below ground and is responsible for absorbing water and nutrients from the soil. The roots and root hairs are part of the root system.

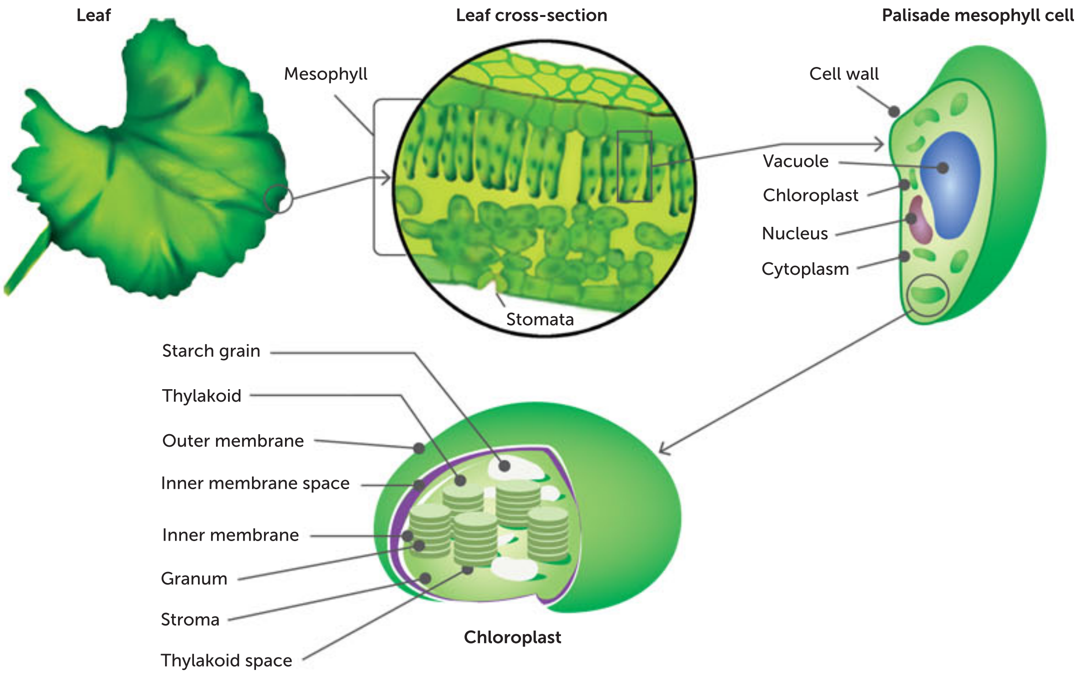


FIGURE 11.19 Plants have a wide variety of cell types that are organised into tissues, organs and systems. A leaf, for example, is an organ that contains specialised cells organised in particular patterns within it.

In a vascular plant, there are four main types of plant tissues: meristematic, dermal, ground and vascular. These tissues perform specialised functions such as storage, transportation, photosynthesis and growth.

Meristems are the only places in a plant where cells divide (by mitosis); they are found at the tips of roots and shoots, and in a ring around the inside of stems and branches. This enables growth in length as well as width. Some meristematic cells differentiate after division.

Dermal tissue is composed of the outermost cell layers of a plant. The **epidermis** is the outermost part of the dermal layer. As for animals, the dermal layer protects the plant from cuts, invasion by micro-organisms and water loss. On leaves and stems, these cells usually produce a waxy **cuticle**. This wax is vital to the prevention of water loss from leaves and other delicate tissues. Epidermal cells also produce fine hairs on the surfaces of many leaves and stems. In many plants, these discourage plant eaters. Some contain harmful irritants that are released into the skin when touched. Epidermal root tissue produces large numbers of extremely fine extensions called **root hairs**. These hairs aid in the absorption of water and minerals. In woody plants, a bark layer forms when layers of specialised cells that soon die replace the epidermis.

Ground tissue is composed of all the internal cells of a plant other than vascular tissue. It includes a variety of different cell types that are specialised for storage, support and photosynthesis. Examples of ground tissue include the fleshy portions of apples, pears, potatoes and carrots.

Vascular tissue is involved in the transport of substances in the plant. Chapter 13 provides more detail on the vascular tissues found in plants: the phloem and the xylem.

Key concept

Vascular plants contain four main types of tissues: meristematic, dermal, ground and vascular tissues. These tissues perform specialised functions such as storage, transportation, photosynthesis and growth.

The whole (multicellular organism) is greater than the sum of its parts

In complex structures, the whole is often greater than the sum of its parts. Each of the different specialist cells in a complex multicellular organism has a specialised function, which can give rise to the whole organism having new abilities, as a result of specialised components interacting. These new abilities can be seen in multicellular organisms when individual cells cooperate to form tissues; tissues work together in organs; organs work together to form a particular function in systems; and these combined systems cooperate to maintain life. The interaction and cooperation between cells, tissues, organs and systems provides multicellular organisms with abilities that are beyond the limitations of a single cell, tissue, organ or system. The interacting, interdependent parts of an organism function collectively to result in the 'whole' being more than the sum of an organism's parts.

Question set 11.3

REMEMBERING

1 Copy and complete Table 11.2 to summarise key features of the four main tissue types found in complex animals.

TABLE 11.2 A summary of tissue types in animals

TISSUE TYPE	MAIN FUNCTION	TWO AREAS IN BODY WHERE FOUND	ONE EXAMPLE OF SPECIALIST CELL TYPE
Connective			Blood
E ________			
N ________			
M ________			

2 Name the four major tissue types in plants, and briefly describe their functions.

UNDERSTANDING

3 Starting with cells, list the hierarchy of organisation within a complex multicellular organism by copying and completing the flow diagram below or creating one of your own.

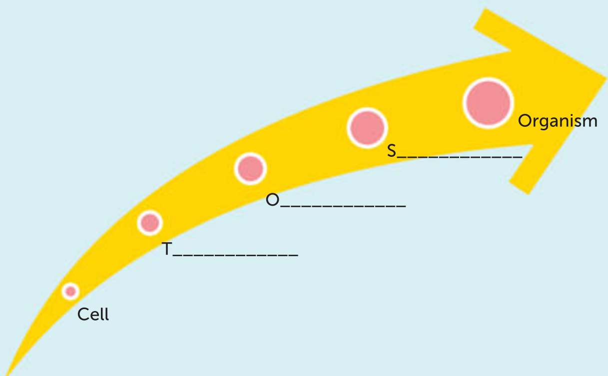


FIGURE 11.20 A hierarchy of organisation

4 Describe how structure relates to function in specialist muscle cells.

5 Create a concept map that summarises the relationship between the different types of tissues, organs and systems in a typical vascular plant.

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CASE STUDY Specialist cells could combat devil facial tumour disease

Currently, many of our native Tasmanian devils are susceptible to a contagious condition called devil facial tumour disease (DFTD). The transmission of the disease from devil to devil occurs via biting during play and mating. Like humans, Tasmanian devils have an immune system with specialist cells in their blood that perform an immune response when they encounter substances called antigens on the surface of foreign bodies such as infectious disease agents, including viruses and bacteria. Some specialist white blood cells, called cytotoxic lymphocytes, normally function to destroy infectious agents.

In this case, instead of being a virus, bacteria or fungi, the infectious agents are contagious tumour cells (cancer cells). DFTD cancer cells evade the specialist immune system cells by failing to express a certain molecule on their cell surface. Cancer cells grow without being detected or destroyed. The animal fails to develop an immune response. Since this was discovered, scientists have trialled various solutions, such as manipulating DFTD cells to produce a modified type that can induce a strong immune response. Vaccines have been tested and further testing of vaccine candidates (potential vaccines) and research is being undertaken by scientists working at institutions such as the Australian Research Council, as well as by collaborators overseas. If the correct vaccine can be produced, the specialist white blood cells can finally function to destroy the tumour cells.

Dr David Pemberton is the manager of the Save the Tasmanian Devil Program. He has published more than 50 scientific papers and three books on Tasmania devils, including co-authoring *Saving the Tasmanian devil: recovery through science-based management*. The book documents the research and efforts of many collaborators, who worked with captive devil populations; applied pathology, immunology and genetic research findings; and adaptive management.

Questions

1. Name a specialist cell found in blood.
2. What does DFTD stand for?
3. Name the infectious agent that causes the disease DFTD.
4. Describe how the tumour can grow without causing specialist white blood cells to generate an immune response.

Courtesy Dr Carolyn Hogg

FIGURE 11.21 Dr Carolyn Hogg, one of the co-authors of *Saving the Tasmanian devil: recovery through science-based management,* with a wild Tasmanian devil

CHAPTER 11 ACTIVITY AND INVESTIGATION

11.1 ACTIVITY

Whose rights?

Tissue engineering was first conceived in the 1980s when possibilities of synthetic scaffolds for cell implantation were being explored. In 1997, one of the first public introductions of this new technology was via 'Auriculosaurus' (a mouse with a human ear). Even though in this instance there was no actual mixing of genes between species, this image has cast a shadow on future tissue engineering of this type.

AAP/AP Photo/Xinhua

FIGURE 11.22 Auriculosaurus, an outcome of tissue engineering in mice

What to do

Read through the following questions and consider your responses for each.

If we are able to grow not just human cells and tissues but also organs, at what point does the object being grown have rights? When does it become human? What are the criteria that define 'human'? Is there a difference between organs growing separately and organs grown in systems? Do some organs, such as brains, have more 'rights' than others? Does the nervous system have more 'rights' than other systems?

What about a human organ grown in the body of another species? If a human brain was grown within a monkey or a dog, would this be regulated in the same way that an ear, eye, heart or lungs would be? Who decides these issues? Who regulates the situation, why and how?

What did you discover?

1 Share and discuss your opinions with your partner.
2 Consider each question again and construct a list of ethical and legal guidelines for scientists to use in the future.
3 Share and justify your guidelines with others in the class.

11.1 INVESTIGATION

Exploring tissues

A multicellular organism is made up of many cells that are dependent on each other to perform essential functions as a collective group. The cells have 'divided up the jobs' required to survive and each cell has become specialised to perform a specific task. Large, multicellular organisms are made of four basic tissue types: epithelial tissue, connective tissue, muscle tissue and nervous tissue.

Aim

To use a light microscope to observe and record the features of different types of specialised cells

Materials

- light microscope
- plastic ruler marked in mm or minigrid (optional)
- concave slides
- coverslips
- lens cleaning tissue

- paper towelling
- large beaker of water for used microscope slides and coverslips
- pipettes
- prepared slides of epithelial, connective, muscle and nervous tissues, such as:
  - animal cells – ciliated epithelial cells (e.g. trachea), glandular epithelial cells (e.g. inner lining of small intestine), human red and white blood cells, human nerve cells
  - plant cell – root hair cells
- annotated diagram or poster of a bacterial cell

Procedure

Note: Before you begin, make sure you familiarise yourself with how to use a microscope correctly, determine the field of view, determine the size of specimens and prepare a wet mount.

1. Observe each of the specimens provided. For each of your observations, draw a diagram ensuring you include the following details.
   - Give your diagram a title.
   - If there is more than one cell, select two or three representative cells.
   - Draw cells that are approximately one-third to one-half of an A4 page.
   - State the magnification used.
   - Include an estimate of the size of the cells observed (including units).
   - Draw in grey lead pencil, with no colour or shading.
   - Annotate your diagrams and include any relevant information (such as the presence of cell structures, size, shape, movement).

Results

1. Categorise the specimens observed into increasing levels of evolutionary complexity: unicellular prokaryote, unicellular eukaryote, colonies of cells or multicellular organisms.
2. Copy and complete Table 11.3 to summarise the estimated size measurements and key features recorded for each cell specimen. Also include information about the bacterial cell from the provided diagram.

TABLE 11.3 A summary of cells observed

SPECIMEN OR TYPE OF TISSUE	ESTIMATED SIZE (mm) AND MAGNIFICATION	SUMMARY OF FEATURES OF THE CELL

Analysis of results

1. a Identify any patterns in your observations of the cell structures present.
   b Suggest reasons for these observed patterns.
2. Bacterial specimens are difficult to view under the microscope. Suggest what difficulties there might be in observing these types of cells in the classroom.
3. From your observations, compare the complexity of the cells of unicellular organisms with that of cells from the multicellular organisms.
4. State one unique feature of a typical cell of each of these types: muscle, connective, epithelial and nervous tissue.

CHAPTER 11 SUMMARY

- All matter is composed of atoms that can be organised into complex biological molecules.
- Molecules can be organised into structures called organelles, which are found in cells.
- Unicellular organisms are made up of a single cell that can perform all of the necessary functions to keep it alive. Their small size allows for easy diffusion of such substances as oxygen, carbon dioxide and nutrients.
- Multicellular organisms are made up of many cells, which are specialised so that they have specific functions. Cells within a multicellular organism coordinate their functions.
- All specialised cells originate from stem cells. Stem cells differ from other cells in the body by being unspecialised, capable of self-renewal and able to differentiate to form different specialised cells.
- Specialisation can increase the efficiency with which an organism functions and can be essential for its survival. Specialised cells are dependent on the activities of other cells to perform tasks that they cannot.
- Cellular differentiation is a process by which cells become specialised so that they perform specific functions.
- Cellular specialisation within a multicellular organism brings about the need for communication and coordination between cells.
- Groups of specialised cells working together to perform a similar function make up tissues.
- A collection of different types of tissues working together to perform a particular function is called an organ.
- An organ system is a collection of different types of organs that work together to perform a function.
- There are four main types of tissues in animals: epithelial, connective, nervous and muscle tissues.
- Plants have two major organ systems: the shoot system and the root system.
- Plants have four main tissue types: meristematic, dermal, ground and vascular tissues.

WS Chapter 11 Activity sheet

CHAPTER 11 GLOSSARY

Adipose describes a type of connective tissue (e.g. cells containing fat droplets)

Atom the smallest fundamental particle of matter; composed of protons, neutrons and electrons

Blood a type of connective tissue (e.g. red blood cells)

Bone a type of connective tissue that provides support (e.g. skeleton)

Cartilage a type of connective tissue that holds parts of the body together (e.g. at the end of a bone)

Cell the basic structural unit of all life forms on Earth

Cell membrane the selectively permeable boundary of all living cells that maintains the contents of the cell and regulates movement of substances in and out of the cell

Cellular differentiation the process by which an unspecialised cell develops into a specialised cell

Connective tissue a basic tissue type in complex animals which provides support, strength and elasticity; it holds certain body parts together and includes bone, cartilage, tendons, blood and ligaments

Cuticle the non-cellular protective layer on the surface of a plant

Cytosol the fluid part of the cytoplasm, containing highly organised fluid material with dissolved substances; excludes the organelles

Differentiation the process by which cells become specialised in structure and function; occurs mostly during embryonic development in multicellular organisms

Epidermis the surface layer of plant or animal cells, generally responsible for separating and protecting the organism from its environment

Epithelial tissue a basic tissue type in complex animals which covers many surfaces, including the surface of the body and linings of body cavities such as airways, and acts as a protective layer and a barrier against infectious agents and water loss

Eukaryote a complex type of cell with a nucleus and membrane-bound organelles; a member of Domain Eukarya

Meristem a localised area of plant tissue in which cells actively divide to form new tissues; includes the growing tips of roots and stems

Mitosis a type of nuclear division that maintains the same number of chromosomes in daughter cells; it is the basis of bodily growth and asexual reproduction in many eukaryotic species

Molecule the smallest particle of a chemical compound

Multicellular describes an organism consisting of more than one cell

Muscle tissue a basic tissue type in animals; made of thin and very long thread-like cells called muscle fibres which use ATP energy to perform movements; the fibres are capable of contracting when stimulated by nerve impulses

Nervous tissue a basic tissue type in complex animals which provides the means of communication between all body structures and includes neurons that transmit nerve impulses

Neuron a nerve cell

Organ a collection of different types of tissues working together to perform a particular function

Organelle a specialised structure or compartment within a cell that has a specific function

Plasma membrane see *cell membrane*

Prokaryote a simple type of cell that lacks a nucleus and membrane-bound organelles; a member of Domains Archaea or Bacteria

Root hair a tube-like outgrowth of a root epidermal cell that increases the surface area of the root; responsible for absorbing water and nutrients

Specialisation (of cells) the possession of specific features that relate to a specific role or function

Specialised cell a cell that has specific features that enable it to perform its specific function

Stem cell an unspecialised, immature cell capable of giving rise to different kinds of specialised, differentiated cells

System a collection of organs that work together to perform a particular function

Tissue a group of specialised cells working together to perform a specific function

Unicellular describes an organism made up of a single cell

Vascular describes vessels that conduct fluid

Vascular tissue (in plants) the plant tissue devoted to the bulk transport of water, nutrients, sugars and other substances, comprising the xylem and phloem

CHAPTER 11 REVIEW QUESTIONS

Remembering

1 Copy and complete Table 11.4, inserting the most appropriate missing word from the list given.

leaf	connective tissue	systems	neurons	stomach	plants
tissues	excretory system	atoms	cells	oxygen	specific
within	digestive system	mitochondria	root cells		

TABLE 11.4 The levels of organisation in living things

LEVEL OF ORGANISATION	DESCRIPTION	EXAMPLES
Organisms	The sum of all of the organs ____________ working together	Animals, ____________, fungi
Organ systems	Different types of organs working together to perform ____________ functions	Reproductive system, circulatory system, ____________, respiratory system, ____________
Organs	Different types of ____________ working together to perform a specific function	Brain, heart, lung, ____________, ____________
Tissues	Different types of ____________ working together to perform a specific function	Skin tissue, epidermal tissue, muscle tissue, ____________
Cells	Building blocks of life	Blood cells, ____________, skin cells, bone cells, ____________, root hair cells
Organelles	Structures ____________ the cell with a specific function	Nucleus, ribosomes, chloroplasts, ____________
Molecules	Combinations of ____________	Proteins, carbohydrates, nucleic acids, lipids
Atoms	Combine to make up molecules	Carbon, hydrogen, ____________

2 Name:
   a four main types of tissues in humans
   b three examples of human body systems
   c two types of specialised cells
   d one example of connective tissue.

Understanding

3 Explain why cells in a multicellular organism cannot survive independently of other cells.

4 Distinguish between specialisation and differentiation.

5 If all cells of a multicellular organism contain the same genetic material, explain why they don’t all look the same.

Applying

6 Construct a Venn diagram to compare the features of unicellular organisms and multicellular organisms.

7 A student noticed bugs eating the tips of shoots in a plant in her garden.
   a Name the type of tissue found in the tips of the plant.
   b List other places this tissue would be found.
   c Suggest the effect of the loss of the tips on the plant.

Analysing

8 Provide arguments that having specialised cells in multicellular organisms is:
   a advantageous to the survival of the organism
   b disadvantageous to the survival of the organism.

9 Discuss what is meant by ‘The organism is a living unit greater than the sum of its parts’.

Creating

10 In 2007, scientists announced the development of a technology that induced fully mature specialised cells (e.g. human skin cells) to mimic the characteristics of embryonic stem cells. Stem cells are cells that can differentiate into other types of cells. These altered stem cells could provide a source of cells for replacement and regeneration after damage due to disease or injury, or even to reduce the effects of normal ageing. While these cells have great potential, there is still a lot that is unknown about these cells and their usefulness. Visit the website to make an argument for and against the uses of stem cells as medical therapies.

About stem cells
Find out much more about stem cell technology, the reasons it is controversial and the guidelines used in scientific research.

PRACTICE EXAM QUESTIONS

1 Which of the following organisms possess differentiated cells?
  A prokaryotes
  B unicellular eukaryotes
  C multicellular prokaryotes
  D multicellular eukaryotes

2 Which of the following is a correct feature of a specialised cell?
  A It can make new copies of itself.
  B It can differentiate into another type of cell.
  C It can express all of its genes depending on the needs of an organism.
  D Its function does not rely on its structure.

3 Multicellular organisms have a hierarchical structural organisation of parts. Which of the following shows the correct order of organisation?
  A cells, tissues, organs, systems
  B atoms, tissues, molecules, systems
  C atoms, molecules, cells, organelles
  D cells, atoms, organelles, organs

4 Dermal tissues in plants are likened to epithelial tissues in animals. In terms of structure and function, state why. (4 marks)

5 Explain, using examples, the difference in structure and function between muscle, nervous and epithelial tissue in complex animals. (10 marks)

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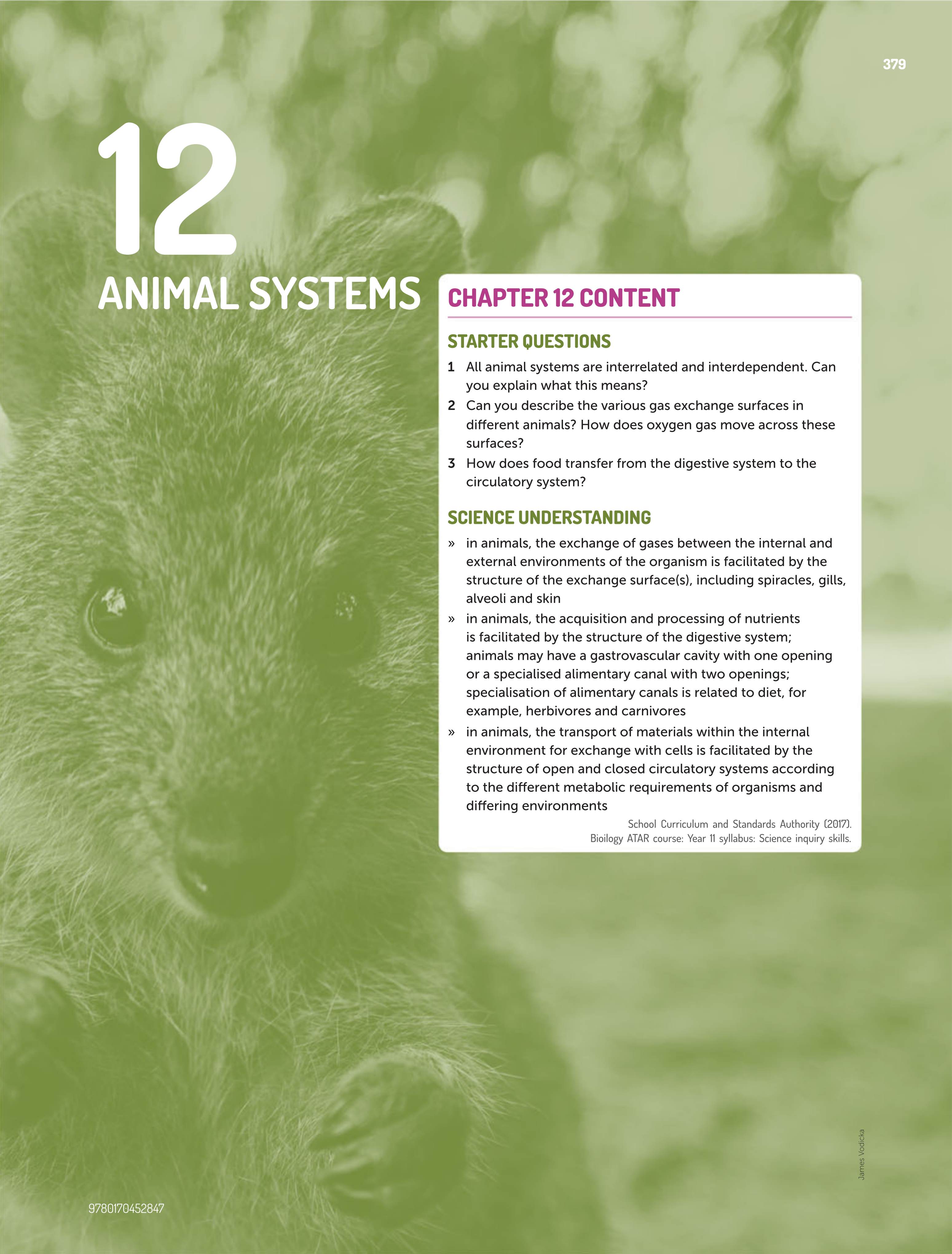


12 ANIMAL SYSTEMS

CHAPTER 12 CONTENT

STARTER QUESTIONS

1 All animal systems are interrelated and interdependent. Can you explain what this means?
2 Can you describe the various gas exchange surfaces in different animals? How does oxygen gas move across these surfaces?
3 How does food transfer from the digestive system to the circulatory system?

SCIENCE UNDERSTANDING

» in animals, the exchange of gases between the internal and external environments of the organism is facilitated by the structure of the exchange surface(s), including spiracles, gills, alveoli and skin
» in animals, the acquisition and processing of nutrients is facilitated by the structure of the digestive system; animals may have a gastrovascular cavity with one opening or a specialised alimentary canal with two openings; specialisation of alimentary canals is related to diet, for example, herbivores and carnivores
» in animals, the transport of materials within the internal environment for exchange with cells is facilitated by the structure of open and closed circulatory systems according to the different metabolic requirements of organisms and differing environments

School Curriculum and Standards Authority (2017).
Bioilogy ATAR course: Year 11 syllabus: Science inquiry skills.

James Vodicka

12.1 OPEN AND CLOSED CIRCULATORY SYSTEMS

Most multicellular animals rely on specialised systems to gain required substances from their environment, transport them to cells, and transport and dispose of unwanted wastes. Substances that animals require include oxygen and nutrients.

We will learn about each of the animal systems separately, but as we do, think about how they are interconnected and interdependent. For example, the circulatory system (also known as the cardiovascular system) and the respiratory system work together to give cells a constant supply of oxygen for cellular respiration, and constant removal of carbon dioxide. The circulatory system transports the two gases from a 'pick-up' area to a 'drop-off' area, according to the needs of the organism. Oxygen enters and carbon dioxide exits across gas exchange surfaces in the respiratory system. The respiratory system supplies the oxygen and removes the carbon dioxide; the circulatory system delivers the oxygen to the cells and takes away the carbon dioxide so that it can be removed from the body. Both gas exchange and circulatory systems are required, in addition to several other systems, for organisms to survive.

A transport system must include the ability to reach every cell in the body, distributing the necessary requirements in a usable form and not disrupting the functioning of other systems in the body. The main function of the **circulatory system** is the transport of materials within the **internal environment** for exchange with all cells. Nutrients and gases are exchanged for wastes. The circulatory system consists of three general components that together provide these essential features:

1 a fluid in which materials are transported, such as blood
2 a system of interconnected blood vessels or spaces throughout the body in which the fluid moves
3 a muscular pump, usually a heart, that pushes the fluid through the blood vessels or spaces.

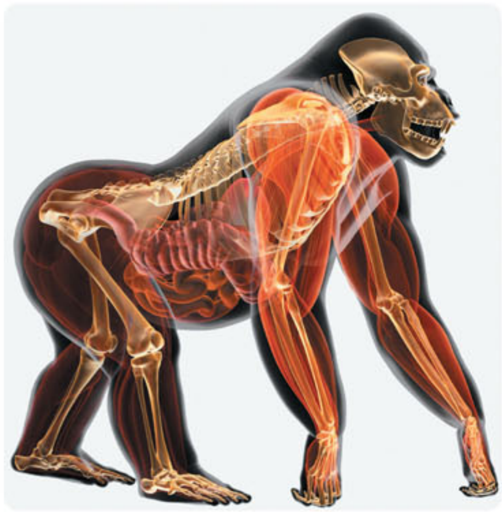


FIGURE 12.1 Animal systems work together.

Circulatory systems are open or closed

Circulatory systems can be either open or closed. In an **open circulatory system**, the fluid circulates freely in the body cavity in which it bathes the cells. Substances can then enter cells by diffusion. Diffusion is the passive movement of substances from an area of high concentration to an area of low concentration across a semipermeable membrane. The fluid in open circulatory systems is called **haemolymph** because blood is mixed with interstitial fluid. Contraction of one or more muscular hearts pumps haemolymph through the open areas into spaces surrounding organs. Within these organs, haemolymph and body cells exchange substances such as gases. Relaxation of the muscular heart draws the haemolymph back from the organs through pores. **Valves** in the pores close to prevent the backflow of the circulating fluid and ensure one-way (forward) flow. After haemolymph surrounds the organs, it returns to the heart. The heart is tubular or sac-like in many organisms with an open circulatory system. All arthropods (e.g. grasshoppers) contain an open circulatory system.

Simple organisms such as planarians (or flatworms, members of the Phylum Platyhelminthes) do not require a distinct circulatory system because a simple structure such as a gastrovascular cavity can transport substances efficiently. The **gastrovascular cavity** is a central cavity with a single opening that functions to transport and digest substances. The combination of a gastrovascular cavity and flat body, along with the process of diffusion, is enough to provide the substances needed. Diffusion of substances only has to occur over a short distance because of the increased surface area.

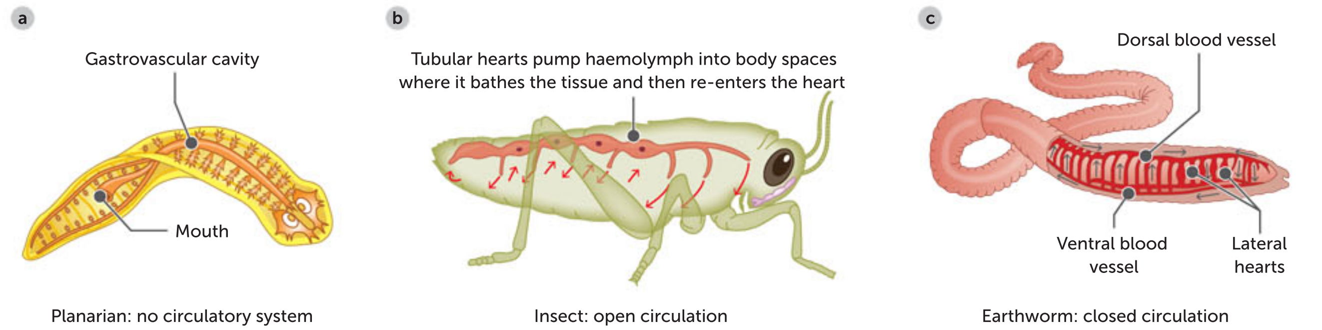


FIGURE 12.2 A comparison of having **a** no, **b** open and **c** closed circulatory systems

In a **closed circulatory system**, the fluid flows through enclosed vessels called arteries, veins and capillaries. The fluid is called blood and it is distinct from the **interstitial fluid** found outside of blood vessels (in small spaces between cells). One or more hearts pump blood into large vessels that branch into smaller vessels that wind through tissues. The network of smaller vessels exchanges gases and nutrients with interstitial fluid and body cells. Annelids (such as earthworms), Cnidaria (such as squids) and all vertebrates have closed circulatory systems.

The two types of circulatory systems have their structural differences and advantages. These are summarised in Table 12.1.

TABLE 12.1 A comparison of open and closed circulatory systems

	FEATURE	OPEN	CLOSED
STRUCTURAL DIFFERENCES	Fluid	Haemolymph	Blood
	Blood vessels	Simple vessels release fluid into open body cavity	Arteries, veins, capillaries
	Contact with cells	Direct: fluid directly bathes cells; gases and nutrients exchanged directly between haemolymph and cells	Indirect: fluid travels inside vessels alongside cells until substances are transported to cells through capillary wall, interstitial fluid and cell membranes
	Pathway of blood	From heart(s) through a blood vessel to an open body cavity, then returns to heart via openings (ostia)	From heart(s) to lungs and/or body and back to heart through closed vessels
ADVANTAGES	Pressure	Outside of arteries, there is no sustained pressure; less energy is required	Arteries are thick-walled to enable high blood pressure for faster delivery of blood and the substances it carries (but more energy is required); pressure becomes lower over length of capillaries; thinner-walled veins return blood to the heart under lower pressure compared to arteries
	Body size	Advantageous for animals with small body (high surface area) due to having lower energy needs	Advantageous for larger animals who are active and need a fast rate of oxygen supply
	Efficiency of blood flow, rate of metabolic activity and size of animal	Slow flow and limited supply inhibits rate of metabolic activity and limits size of animal	Fast flow and steady supply facilitates higher rate of metabolic activity and larger size of animal
	EXAMPLES	Arthropods, such as insects and spiders, and some molluscs, such as oysters	Human, earthworm, turtle, frog

Key concept

In an open circulatory system, the fluid (called haemolymph) circulates via the body cavity and bathes the cells; substances enter cells by diffusion.

In a closed circulatory system, the fluid (blood) flows through enclosed vessels (arteries, veins and capillaries) and is distinct from the interstitial fluid found between cells.

Single and double circulatory systems

Closed systems efficiently transport oxygen and nutrients into, and wastes out of, body cells. Blood flow to different parts of the body can be controlled by the contraction and relaxation of smooth muscle cells in the walls of blood vessels. Blood flows in one direction from the heart, to the body and back to the heart. Substances diffuse across capillaries and into cells. There are two types of closed circulatory systems in vertebrates: single circulatory systems and double circulatory systems.

Single circulatory systems contain one circuit. This type of system is found in bony fish and sharks. The heart pumps the blood to the **gills** to be re-oxygenated, after which the blood flows to the rest of the body and back to the heart. The blood loses pressure at the gills and flows around the rest of the body and back to the heart under low pressure. A fish has a two-chambered heart with one **atrium** (a chamber of the heart that receives blood from the body) and one **ventricle** (a chamber that receives blood from the atrium and pumps it out to the body), and oxygenated blood proceeds directly from the gills to the tissues.

Double circulatory systems contain two circuits: a pulmonary circuit, which transports blood to the lungs and back to the heart, and a systemic circuit, which transports the oxygenated blood around the body and back to the heart. These circuits are found in all vertebrates other than fish; that is, in birds, reptiles, amphibians and mammals. In birds and mammals, the chambers of the heart that deliver blood to each system are fully separated and there is no mixing of oxygenated and deoxygenated blood. In contrast, in amphibians and most reptiles, the heart is not completely divided, allowing for some mixing of oxygenated and deoxygenated blood. Oxygenated blood is blood that has just returned from picking up oxygen from the lungs. Deoxygenated blood is blood that has just returned from dropping off oxygen to body cells.

Key concept

Single circulatory systems (found in bony fish and sharks) contain one circuit. The heart pumps blood to the gills to be re-oxygenated, then blood flows to the rest of the body and back to the heart.

Double circulatory systems (found in birds, reptiles, amphibians and mammals) contain two circuits. The pulmonary circuit transports blood to the lungs and back to the heart, and the systemic circuit transports oxygenated blood around the body and back to the heart.

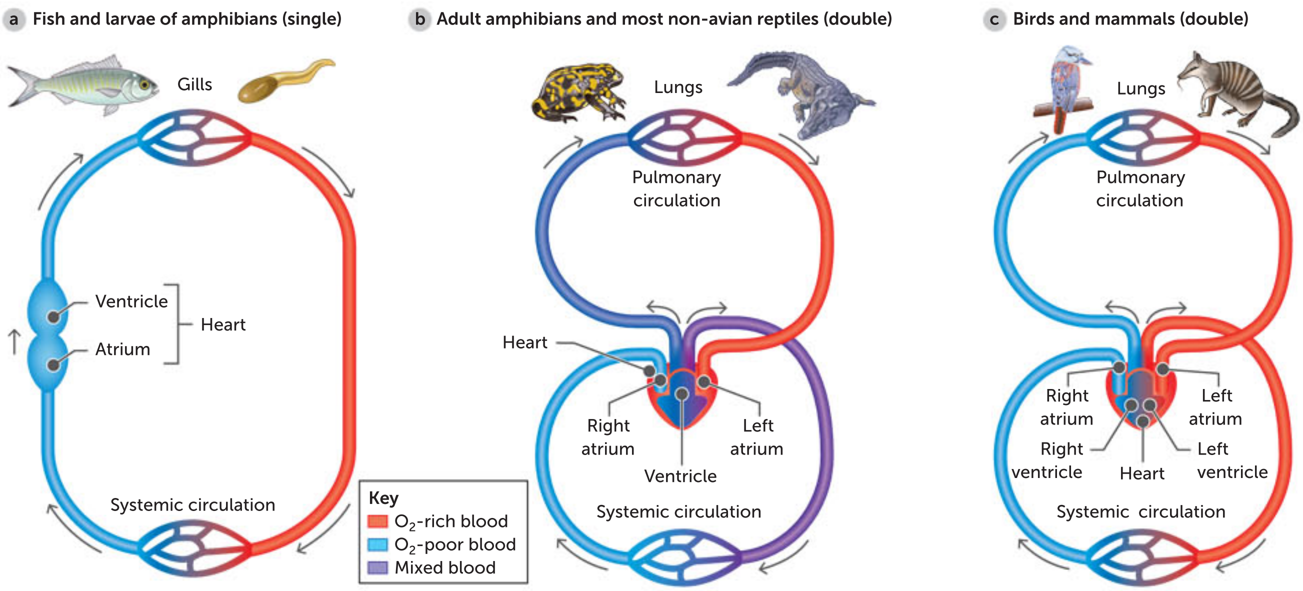


FIGURE 12.3 A comparison of the closed circulatory systems of major vertebrates

In mammals and birds, the oxygenated blood comes back from the lungs to the heart to be pumped out again at a much higher pressure. Amphibians have two atria, like mammals, but only one ventricle. It might seem that deoxygenated and oxygenated blood would become mixed in the single ventricle, but the separation of the two bloodstreams is surprisingly complete and there is far less mixing of the blood than you would expect. The blood sent to the lungs is largely deoxygenated, while the blood delivered to the head and brain is mostly highly oxygenated.

Question set 12.1

REMEMBERING

1 State the three major components of a circulatory system.

2 Compare a closed single circulatory system with a closed double circulatory system.

UNDERSTANDING

3 Prepare a diagram that compares open and closed circulatory systems.

APPLYING

4 Devise a table that:
 a clearly identifies the common features of the circulatory systems of fish, amphibians and mammals.
 b compares the differences found in the circulatory systems of fish, amphibians and mammals.

12.2 THE MAMMALIAN CIRCULATORY SYSTEM

The heart, blood and blood vessels make up the circulatory (cardiovascular) system in humans and most mammals. The closed, double circulatory system is the transport system of the human body and has four principal functions:

1 transportation of water, oxygen and carbon dioxide
2 distribution of nutrients and removal of wastes
3 maintenance of body temperature
4 circulation of hormones.

Cardiovascular system quiz
Take the quiz to see how much you already know about the cardiovascular system (circulatory system).

Circulatory fluid: the blood

The average 70 kg adult human is nourished and protected by about 5 L of blood. Approximately 55% of the blood is liquid, called **plasma**; the remaining 45% is composed of blood cells, including **erythrocytes**, **leukocytes** and **platelets**. The blood cells are considered to be a tissue because they are cells that work together for a common cause. Table 12.2 summarises the components of blood.

TABLE 12.2 The structure and function of the major components of the blood tissue

BLOOD COMPONENT	STRUCTURE AND FUNCTION
Plasma  Alamy Stock Photo/Science Photo Library	• Pale-yellow fluid component of the blood with which the solid blood components, along with body heat, dissolved gases, nutrients, wastes and hormones, are transported around the body

BLOOD COMPONENT	STRUCTURE AND FUNCTION
Erythrocytes (red blood cells)  iStock.com/Alllex	• Contain haemoglobin, a molecule that enables the cell to bind oxygen molecules • Do not have a nucleus in their mature stage, allowing the cell to carry more haemoglobin
Leukocytes (white blood cells)  Alamy Stock Photo/ Kittipong Jirasukhanont	• Function mainly to protect the body against invading micro-organisms and toxins • Some types destroy micro-organisms by engulfing them and then using enzymes to digest the micro-organism and the leukocyte itself; others are specialised in producing antibodies that are an important part of the body's immune system
Platelets  Alamy Stock Photo/Mediscan	• Function primarily to initiate blood clotting; when the platelet membrane breaks, the platelet releases a substance that reacts with proteins in the plasma to create a mesh of fibres, preventing further blood loss

Red blood cells and oxygen transport

Red blood cells are produced in the bone marrow. Just before they are released from the bone marrow and move into the circulatory system, their nucleus breaks down. This makes them pliable and elastic so that they can twist and flex as they move through blood vessels that are sometimes narrower than their unbent size. The lack of nuclei also allows more space to carry oxygen.

The main function of red blood cells is to carry oxygen and, to a lesser extent, carbon dioxide. Normally only about 0.3 mL of oxygen can dissolve in 100 mL of blood. However, red blood cells have an iron-containing pigment called haem and a special protein called globin, which gives them their red colour. **Haemoglobin** enables blood to carry about 20 mL of oxygen per 100 mL of blood. This is about the same as the proportion of oxygen in air.

Blood and carbon dioxide transport

Cellular respiration in each cell produces carbon dioxide as a waste product. Its removal ensures the cell pH level is maintained for optimal function. Just as the bloodstream can deliver oxygen to every cell in the body, it can also remove carbon dioxide from every cell in the body.

Carbon dioxide is quite soluble and reacts with water to form **carbonic acid**. This is normally a slow reaction. In red blood cells, however, the enzyme carbonic anhydrase speeds up the reaction. The carbonic acid produced diffuses into the plasma. Approximately 70% of the carbon dioxide produced by cells is carried as carbonic acid in the plasma back to the lungs. The rest is either carried in the plasma as carbon dioxide (7%) or attaches to haemoglobin in red blood cells (23%).

As the blood passes through the lungs, the concentration gradient for carbon dioxide between the lungs and the blood causes the previous reactions to reverse. The carbonic acid reverts back to carbon dioxide and water. The carbon dioxide leaves the internal environment of the blood, passing into the **external environment** of the lungs where it and the water are exhaled.

12.1 APPLICATION

The colour of blood

Nearly all vertebrates use haemoglobin in blood cells to transport oxygen around the body. The blood is bright red when oxygenated and a deep burgundy colour when deoxygenated. There is a group of fish, however, that have colourless blood. Antarctic ice fish lack haemoglobin and thus their blood is transparent. One explanation for this relates to their environment: the ocean water they live in varies from 2°C to −2°C. In water with lower temperatures, blood moves more slowly. If haemoglobin and red blood cells are not present in blood, the blood is less viscous. It is advantageous for fish to make their blood a little thinner and easier to circulate. The sea water does not freeze even when it is below 0°C because the solutes in the water reduce its freezing point. The blood contains a type of anti-freeze made of glycoproteins, and these cause the blood to be transparent. Insects also have colourless 'blood' (actually haemolymph), and some marine worms have green blood.

Questions

1 What is the advantage to the Antarctic ice fish of lacking haemoglobin?
2 Use your knowledge of the circulatory system to explain why insects have colourless haemolymph and some marine worms have green blood.

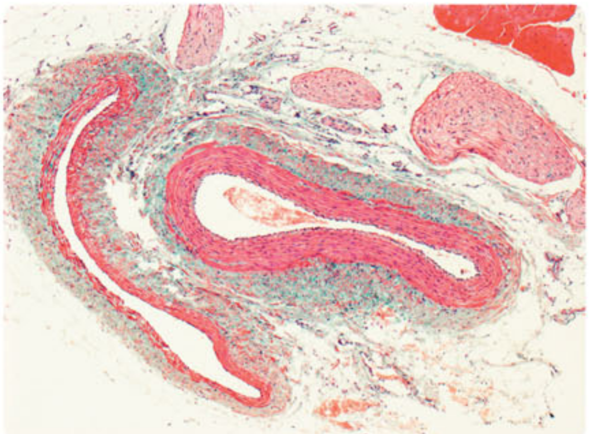
The blood vessels

The driving force behind the blood flow around the mammalian body is the heart, so all vessels must be connected to this organ. There are three main types of blood vessels. **Arteries** take blood away from the heart, **veins** carry blood towards the heart and **capillaries** are found between these two blood vessels. **Arterioles** are smaller arteries and **venules** are smaller veins; both act as continuous bridges between the larger vessels and capillaries. Therefore, the major organs of the circulatory system are the heart, arteries, arterioles, veins, venules and capillaries.

Figure 12.4 shows a cross-section of the walls of an artery and a vein. You can see that the walls of the artery are thicker than those of the vein. This is because arteries have a lot more muscle and elastic fibres than veins. The muscle and fibre tissues of the arteries lead to the production of blood pressure as the heart beats, and forces the blood through the narrow central cavity. Arteries swell as each wave of blood is ejected from the heart. They then recoil elastically to propel the blood further on.

Veins have valves in them to help keep the blood flowing towards the heart. This knowledge can be applied, for example, by people who have to stand still for a long time in hot weather (such as soldiers on parade). They sometimes feel faint, because too much blood is staying in the veins in their legs. Because the blood is not returning to the heart quickly enough, the brain is deprived of enough oxygenated blood. By continually contracting and relaxing the muscles in their legs (e.g. by wiggling their toes), they can move the blood up to their hearts and avoid fainting.

Unlike arteries or veins, capillaries have very thin walls and are very narrow. In fact, their walls are only one cell thick. This makes it possible for diffusion of all the nutrients that a cell needs, such as glucose and oxygen, to occur. Wastes, such as carbon dioxide and urea, are also able to pass through their walls, but in the other direction – from the cells to the blood. The diameter of capillaries is



Alamy Stock Photo/Science Photo Library

FIGURE 12.4 A cross-section of an artery and a vein about the same as or smaller than a red blood cell, which further increases the diffusion rate of gases. Capillaries are so numerous and so small that every cell in the body is only a few millimetres away from a capillary.

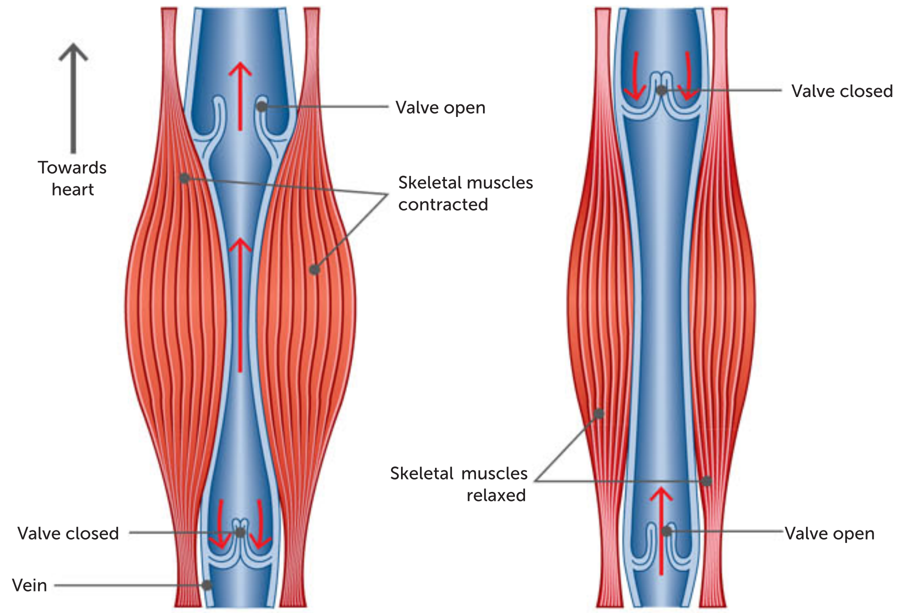


FIGURE 12.5 The contraction of skeletal muscles, in conjunction with the presence of valves in the veins, helps blood return to the heart.

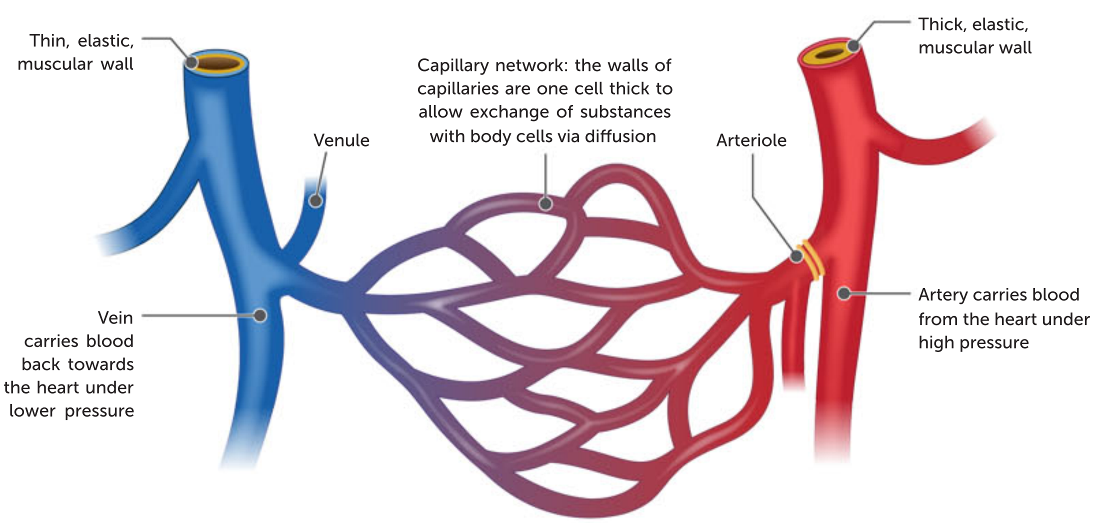


FIGURE 12.6 A comparison of arteries, arterioles (small arteries), veins, venules (small veins) and capillaries

The circulatory pump: the heart

Blood is pumped around the body by the heart. The heart is made of muscle and, in humans, it can contract continuously about 70 times a minute, day and night, for as long as we are alive. Cardiac tissue is found only in the heart. It is the coordinated contractions of cardiac muscle that provide the pumping action of the heart.

The heart has four chambers (Figure 12.7). Two are thin-walled atria (singular atrium) and the other two are the more muscular ventricles.

Deoxygenated blood enters the right atrium, via the **vena cava**, from the general body system of blood vessels, the **systemic circulation**, and passes into the right ventricle. When the right ventricle contracts, blood is forced into the pulmonary artery, which leads to the lungs. This is called **pulmonary circulation**. Here, oxygen diffuses into the blood and carbon dioxide passes out from the blood into the air in the lungs. The now oxygen-rich or oxygenated blood passes back into the heart through the left atrium and then into the left ventricle. When this ventricle contracts, the blood is forced into the **aorta**, the largest artery. Through its many branches, the aorta takes blood to all parts of the body. The **septum** is the dividing wall that separates the right and left chambers of the heart, keeping the deoxygenated blood on the right side of the heart from mixing with the oxygenated blood on the left side.

The blood is kept flowing in one direction in the heart by the presence of four valves: one between each atrium and ventricle (the two **atrioventricular valves**) and one between each ventricle and the artery it leads to (the **pulmonary valve** and the **aortic valve**). The two ventricles contract at the same time and the two atria contract at the same time, but the ventricles and atria contract at different times from each other. This leads to the two atrioventricular valves snapping shut at the same time as the ventricles contract. The pulmonary and aortic valves close when the ventricle finishes contracting, so that blood under pressure from the enlarged, elastic arteries does not flow back into the heart.

When you use a stethoscope to listen to the heart, it is the sound of the valves closing and the sudden stop of blood flow that you hear as 'heart beats'. The trained listener can determine if particular valves are not shutting completely and if the timing of valve closure is abnormal.

Follow the pathways of blood through the heart
Use these websites to follow the pathway of blood through the heart

Sheep heart dissection
Investigate the steps involved in dissecting a sheep's heart.

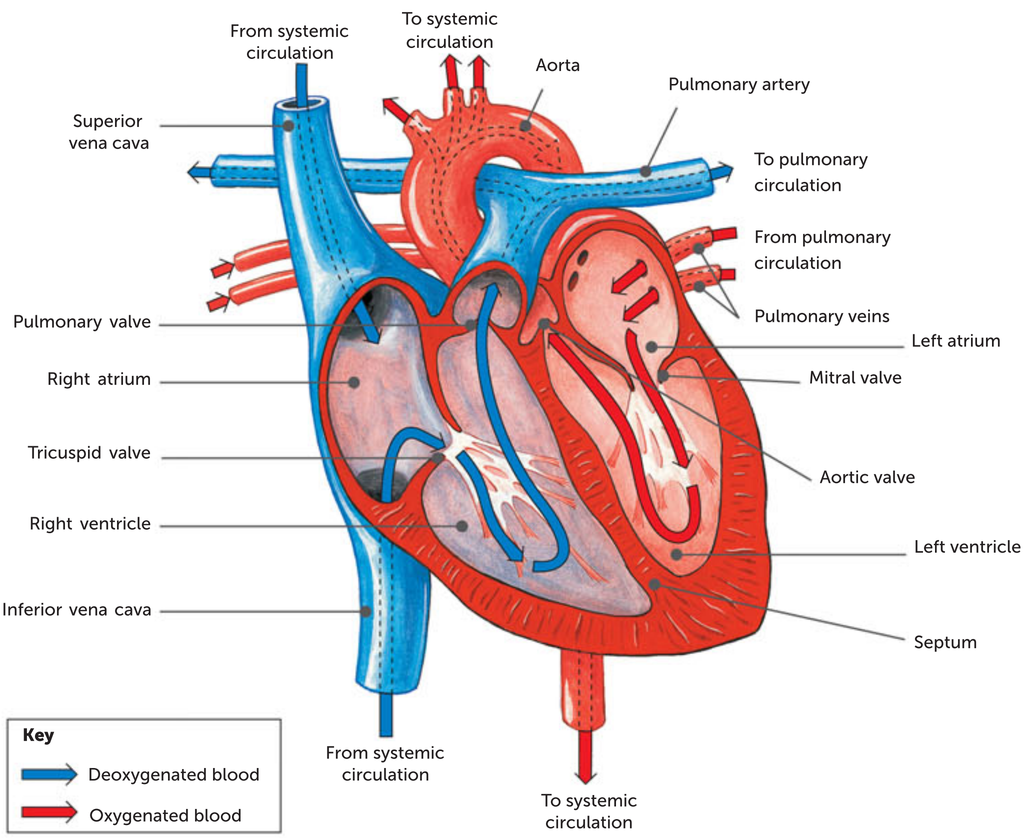


FIGURE 12.7 Blood flow through the human heart

Human circulatory system
Read and watch the videos available here on the human circulatory system (pulmonary and systemic circulation). Then later return to this site to learn about the other three systems

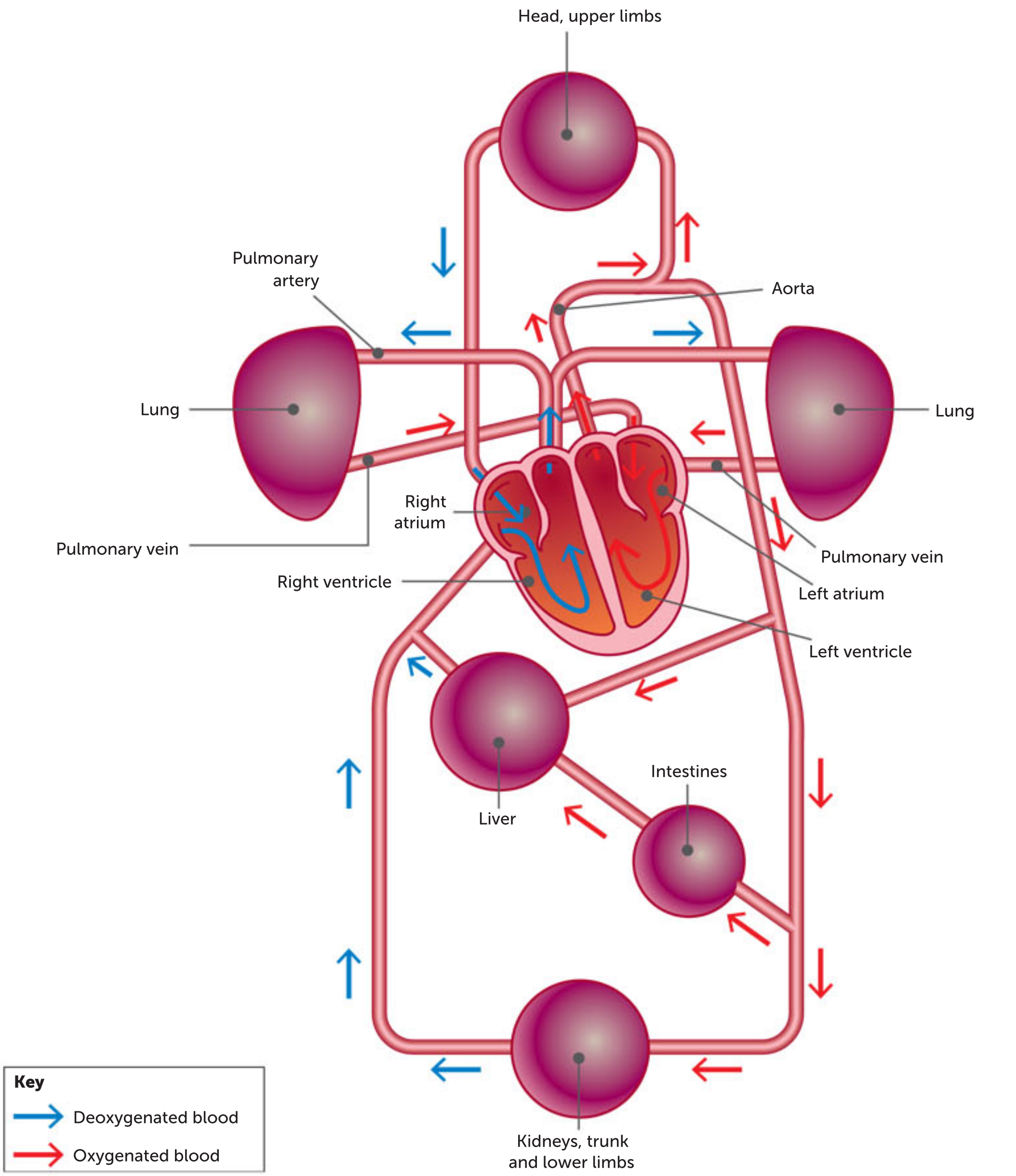


FIGURE 12.8 Blood circulation in mammals

The lymphatic system

Gases and small molecules entering the internal environment are not the only substances to pass through capillary walls. Blood pressure forces some fluid and some small protein molecules out of the capillaries at the arterial end. Most of the water from this fluid passes back into the capillaries at the venous end, where the blood pressure is lower, by osmosis.

However, some water and proteins would be left in the spaces between the cells if it were not for the **lymph vessels**. Lymphatic capillaries are small, blind-ending tubes that allow the fluid and protein to enter through tiny flaps between the cells in their walls that act as one-way valves. The fluid flows in the lymph vessels towards the heart to re-join the blood circulation. It is pushed along in much the same way as blood in the veins is moved, by contracting muscles. Valves in the lymph vessel walls maintain a unidirectional flow to the heart.

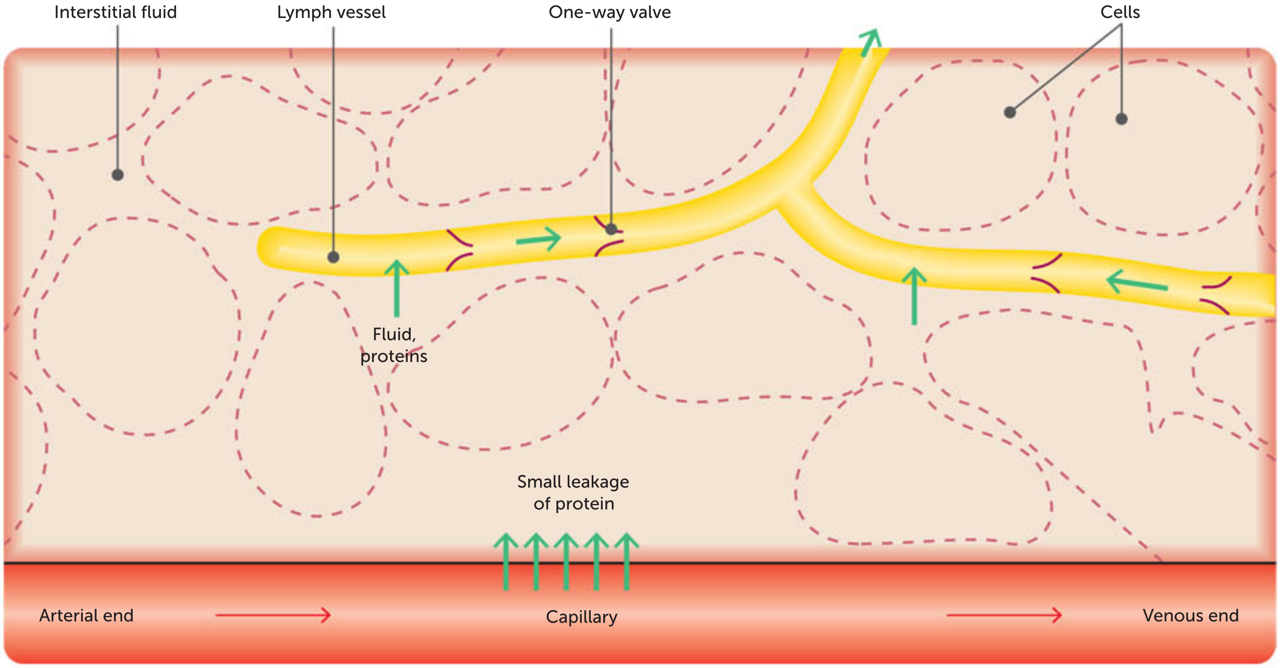


FIGURE 12.9 Fluid and proteins are removed by the lymph vessels, which, with one-way valves, transport the fluid from between cells towards the heart.

Question set 12.2

REMEMBERING

1 Name the components and main functions of the circulatory system.

2 Describe features of the heart that allow it to receive blood from other parts of the body.

3 Explain the events that occur in the heart to ensure that oxygenated blood is pumped around the body.

4 List the functions performed by white blood cells.

5 Outline the features of platelets and describe their functions.

UNDERSTANDING

6 Explain the benefits of having haemoglobin in red blood cells.

7 Outline the main differences between the three types of blood vessels.

8 Describe the differences between systemic and pulmonary circulation, and outline the significance of each system.

9 Distinguish between the lymphatic system and the circulatory system.

10 Explain what is meant by the internal and external environment of a single cell in a multicellular organism. Name the barrier between the two environments.

APPLYING

11 If you were shown a blood vessel attached to the heart, explain how you would know if it was an artery or a vein.

12 Draw a simplified diagram of the heart and show, using arrows, the direction of blood flow.

12.3 RESPIRATORY SYSTEMS

All animals exchange gases with their surroundings. However, unlike water and food, gases cannot be stored easily within living tissues, and so most animals must exchange gases with the atmosphere on a continual basis.

Gas exchange in animals is the diffusion of oxygen from the external to the internal environment and the diffusion of carbon dioxide from the internal to the external environment. It occurs across gas exchange surfaces such as alveoli, skin, spiracles and gills. The type of gas exchange organ used depends on the size, shape and complexity of the animal, as well as the environmental conditions it lives in, such as a terrestrial or an aquatic environment (Table 12.3). Gas exchange must provide a steady supply of oxygen to cells (for aerobic respiration) and continuous removal of carbon dioxide.

TABLE 12.3 Mechanisms of gas exchange in animals

SIZE, SHAPE, ENVIRONMENT OF ANIMAL	GAS EXCHANGE SURFACE	GAS EXCHANGE MECHANISM	EXAMPLES
Microscopic	Plasma membrane	Direct diffusion of dissolved gases	Parasitic jellyfish
Simple, small or flat	Body surface	Direct diffusion of dissolved gases	Platyhelminths (flatworms)
Aquatic and semi-aquatic	Gills or skin	Dissolved oxygen diffuses across gills or skin into capillaries and carbon dioxide diffuses out	Bony fish (gills include thin filaments with high surface area) Amphibians (moist skin and simple lungs)
Moderately small terrestrial insects	Spiracles	Diffusion of dissolved gases via tracheal system	Grasshoppers, cockroaches
Small to medium terrestrial animals	Fine tubes in air sacs	Diffusion of dissolved gases within air sacs and lungs	Birds
Large terrestrial animals	Alveoli in lungs	Respiratory system: inhalation coupled with diffusion of dissolved gases in lungs	Mammals Reptiles

The mechanism of gas exchange between the external environment and the internal environment is similar for all living organisms. In microscopic organisms, gas exchange occurs by diffusion across the cell membrane. Larger terrestrial animals have a gas exchange system inside the body to prevent dehydration of the gas exchange surfaces.

The surface across which the gas exchange occurs needs to:

- be moist, so the gases can dissolve in the water and diffuse from one side of the membrane to the other
- be thin and permeable, so the gas molecules can move across it easily and quickly
- have a large surface area in relation to the volume of the organism, so as to adequately provide the gaseous requirements

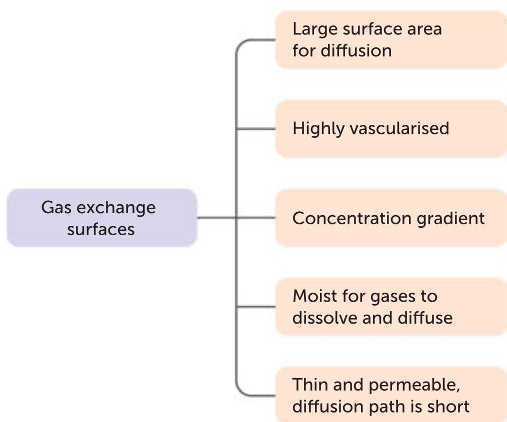


FIGURE 12.10 The features of gas exchange surfaces (factors that affect the rate of gas exchange)

- have a greater concentration of required gas on one side of the membrane than the other, so that a concentration gradient is maintained
- be highly vascularised; this means it has a dense network of very narrow capillaries, either just beneath the surface (in the case of skin) or wrapped around each structure (in alveoli). The narrow capillaries slow the movement of blood to provide sufficient time for exchange to occur.

In animals, the exchange of gases between the internal and external environments of the organism is facilitated by the structures of the exchange surface(s), which include spiracles, gills, **alveoli** (tiny air sacs; singular alveolus) and skin. Large animals cannot maintain gas exchange by diffusion across their outer surface. The process of diffusion is not efficient enough for their body's needs. They have a variety of respiratory surfaces (spiracles, gills, alveoli and skin) that all increase the surface area for exchange.

- **Spiracles:** the **tracheal system** in insects relies on spiracles, which are openings at the body surface that lead to tracheae, tubes made of chitin that allow oxygen to pass in by diffusion. The tracheae branch into smaller tubes known as tracheoles, which carry air directly to cells for gas exchange. Body movements, such as pumping the abdomen, speed up the rate of diffusion of gases from the tracheal system into body cells. Insects have water at the ends of their tracheoles for oxygen to dissolve in, to enable diffusion.
- **Gills:** the gills in aquatic animals must have water passing through them. When water passes over gills (via the mouth), the dissolved oxygen in the water rapidly diffuses across the gills into the bloodstream. Long, thin filaments increase the area of the surface, which is highly vascularised (has many capillaries) and uses the countercurrent system. Fish constantly open their mouths and swim to allow water to pass over their gills.
- **Alveoli:** the lungs of mammals take in oxygen by inhalation, and the air is warmed and moistened. Oxygen and carbon dioxide are exchanged with the blood at the surface of the alveoli. There are 20–30 spherical alveoli per sac, and each sac looks like a bunch of grapes. Air flows into the alveolar sacs, then circulates into alveoli where gas exchange occurs with the capillaries that are wrapped around the alveoli.
- **Skin:** the skin of amphibians is a respiratory surface, where gases dissolve and diffuse across cell membranes. A dense network of capillaries lies just below the skin, facilitating gas exchange between the external environment and the circulatory system.

Respiratory surfaces are covered with thin, moist epithelial cells that allow oxygen and carbon dioxide to pass. The gases can only move through cell membranes when they are dissolved in water, thus respiratory surfaces must be moist.

Gas exchange
Explore three different gas exchange mechanisms: mammal, birds and insects

Tracheal gas exchange system in insects
Watch the videos to further understand the respiratory system in insects. They include an insect dissection.

TABLE 12.4 A summary of the four gas exchange surfaces in animals

	SPIRACLES	GILLS	ALVEOLI	SKIN
Examples	Grasshoppers and cockroaches (and many other insects)	Bony fish, sharks and rays (aquatic animals)	Mammals	Amphibians (which also have simple lungs) and earthworms
Main structures	Openings called spiracles found along the thorax and abdomen	Thin filaments that are highly branched and folded; capillaries	Trachea, bronchi, bronchioles, lungs, alveoli, capillaries	Thin, moist skin and capillaries
Mechanism	Tracheal system	Diffusion of dissolved gases in gills	Inhalation coupled with diffusion of dissolved gases in lungs	Diffusion of dissolved gases via skin
Medium oxygen is found in and its concentration	Air; 21%	Water; concentration is much lower than air: as water temperature increases, oxygen solubility decreases	Air; 21%	Air; 21%
Efficiency	Low	Very high efficiency	High	Moderate

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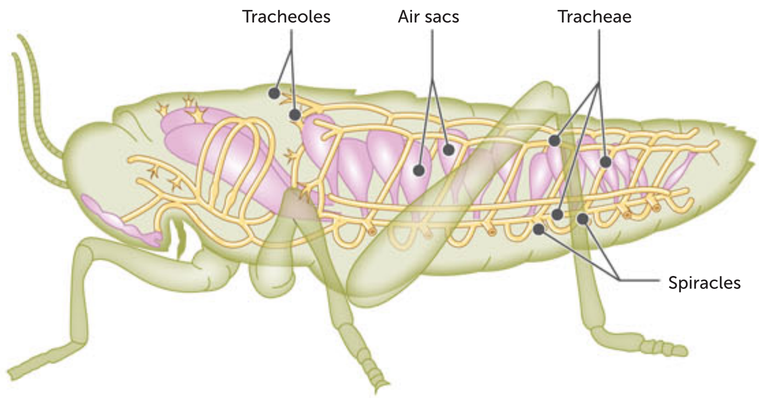

FIGURE 12.11 Gas exchange in insects occurs via spiracles.

> **Key concept**
>
> All cells in all organisms, whether unicellular or multicellular, must exchange gases with their environment.

Gas exchange in amphibians

Skin is a highly permeable respiratory organ that allows for moderately efficient gas exchange. Amphibians such as frogs exchange gases between their internal circulatory system and their external environment through their skin. They have capillaries that lie just underneath the skin.

As young tadpoles, amphibians also have gills as their respiratory organ. As adults, they use a combination of simple lungs and skin. Amphibian lungs are not as effective as mammalian lungs because their **diaphragm** (muscle) is not as developed. In a mammalian system, the diaphragm muscle contracts to create a pressure gradient that forces breath into the lungs. Amphibians such as frogs must instead actively push air into their lungs.

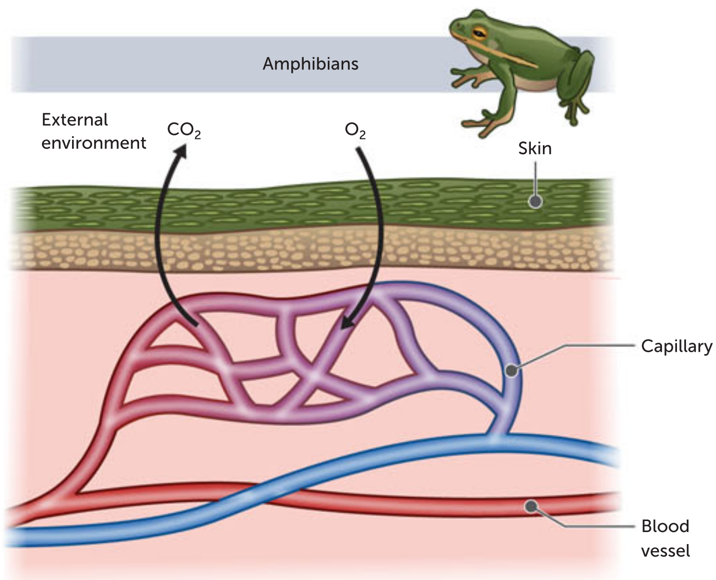

FIGURE 12.12 One method of gas exchange in amphibians is through the skin.

Gas exchange in mammals

Most mammals are terrestrial and obtain all their oxygen requirements from the air. They are **endothermic** (use heat energy generated by their own metabolic activity, including respiration, to maintain their internal body temperature) and are mobile. Aerobic cellular respiration taking place in their cells generates heat as a by-product. To maintain a constant body temperature, their demand for oxygen is high. The heat generated ensures that the conditions are ideal for the normal functioning of all the cell's metabolic processes. These processes rely on the functioning of enzymes, which have an optimal temperature range. The mammalian lung has evolved to meet all demands for gas exchange.

Air passes into the body through the nose and mouth. It travels past the throat and **larynx** (voice box) into the **trachea**, which is strengthened with rings of cartilage to stop it collapsing. The trachea branches into two **bronchi** (singular bronchus), which lead to the lungs. On entering the lung tissue, each bronchus continually divides into smaller tubes called **bronchioles**. Eventually, each bronchiole ends in a cluster of tiny air sacs called alveoli (singular alveolus).

The alveoli endothelial tissues not only provide a moist surface for gas exchange, but also increase the surface area of the lung tissue enormously. There are about 700 million alveoli in the human lung and together they provide a surface area that is approximately the size of a tennis court.

A network of capillaries surrounds each alveolus. The thin wall of the alveolus provides the boundary of the external environment, while the thin wall of the capillary provides the boundary for the internal environment (the blood). Exchange between the two environments occurs by diffusion. The capillaries are so narrow that, as the red blood cells are pushed through them, they are partially squashed into a conical shape. This not only increases the amount of surface area in contact with the capillary wall, but ensures there is little fluid between the blood cell and the alveolar wall, so the distance the oxygen and carbon dioxide molecules have to travel is very short, approximately 1–3 μm. The narrow capillaries also slow the rate of the movement of blood, maximising the transfer of gases across the capillary walls.

Each alveolus is covered, internally, with a thin layer of fluid in which the oxygen dissolves before it diffuses into the cells.

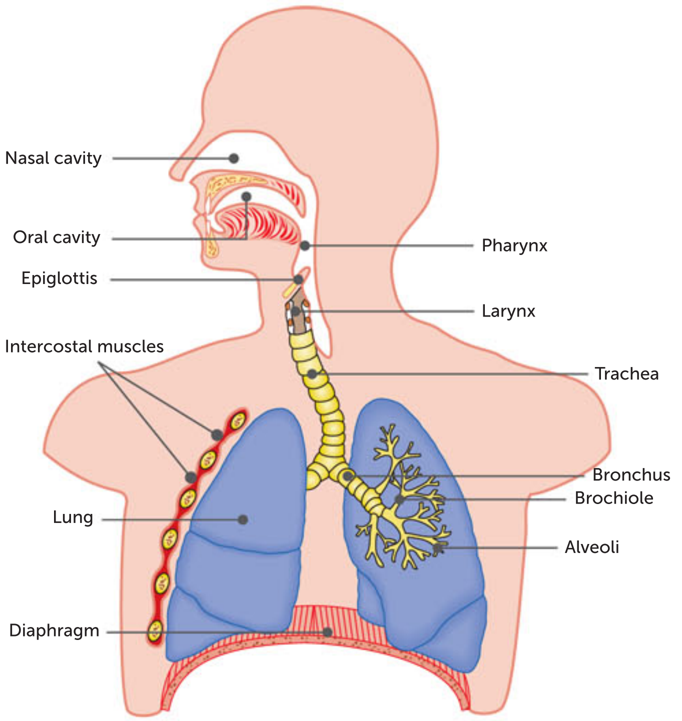

FIGURE 12.13 The gas exchange system in humans

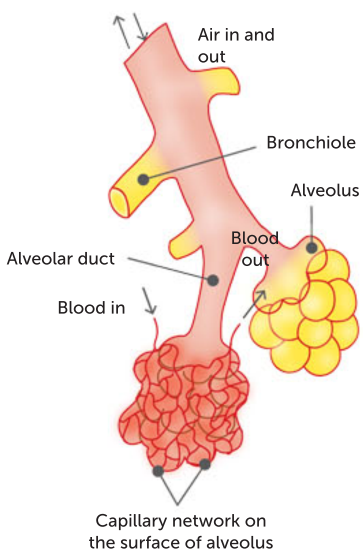

FIGURE 12.14 Each alveolar sac is surrounded by a network of capillaries.

Ventilation and breathing rate

For the body to extract oxygen from its surroundings, air must enter the gas exchange area (the alveoli) and diffuse into cells. Air is moved in and out of the lungs by movements of the ribs and the diaphragm. The diaphragm is a muscle that, along with action by the intercostal muscles in between ribs, can contract to expand the volume of the thoracic cavity. This results in a decrease in pressure inside the lungs, causing air to rush in. During exhalation, the diaphragm and some intercostal muscles relax, causing the volume of the thoracic cavity to decrease, leading to an increase in air pressure inside the lungs. This results in air rushing out of the lungs.

TABLE 12.5 A summary of the processes of inhalation and exhalation

INHALATION	EXHALATION
Diaphragm and some intercostal muscles contract	Diaphragm and some intercostal muscles relax
Rib cage (and chest cavity) expands	Rib cage (and chest cavity) contracts
Volume of thoracic cavity increases, causing lung air pressure to decrease	Volume of thoracic cavity decreases, causing lung air pressure to increase
Air rushes in along the pressure gradient	Air rushes out along the pressure gradient

The rate of breathing is controlled mainly in response to the level of carbon dioxide in the blood. Most of the carbon dioxide produced by cells in respiration is converted into carbonic acid in the plasma. This leads to the production of bicarbonate ions, and these pass into the blood plasma, where they are transported to the lungs for removal. This leads to a new equilibrium and a fall in breathing depth and rate.

Reptiles also use alveoli in the lungs as their gas exchange surface. The muscles of the chest wall or throat can be used to drive inhalation. Birds are similar to reptiles in that they use lungs, but they differ in that their lungs are small, are missing alveoli (they have air capillaries instead) and have nine air sacs. Air is forced through a circuit in one direction as blood flows in the other direction. This results in a more efficient rate of gas exchange. Birds need a high rate of supply of oxygen to provide their high metabolic needs during flight.

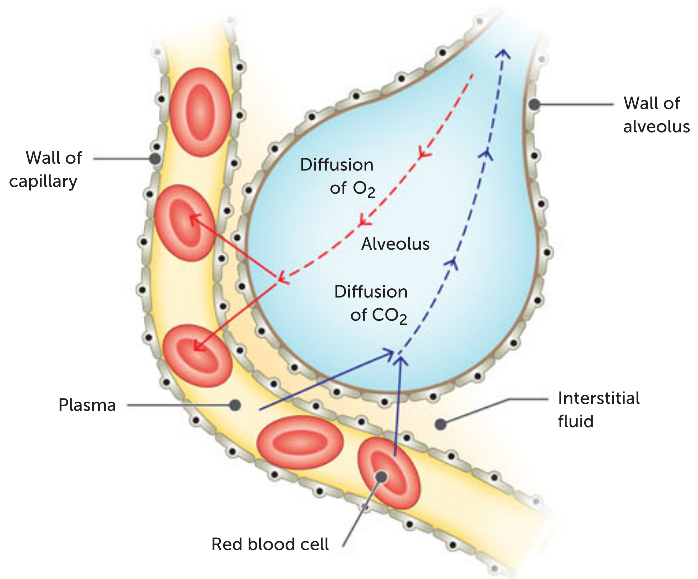

FIGURE 12.15 The diffusion distance for oxygen and carbon dioxide moving between the alveoli, red blood cells and plasma is very short.

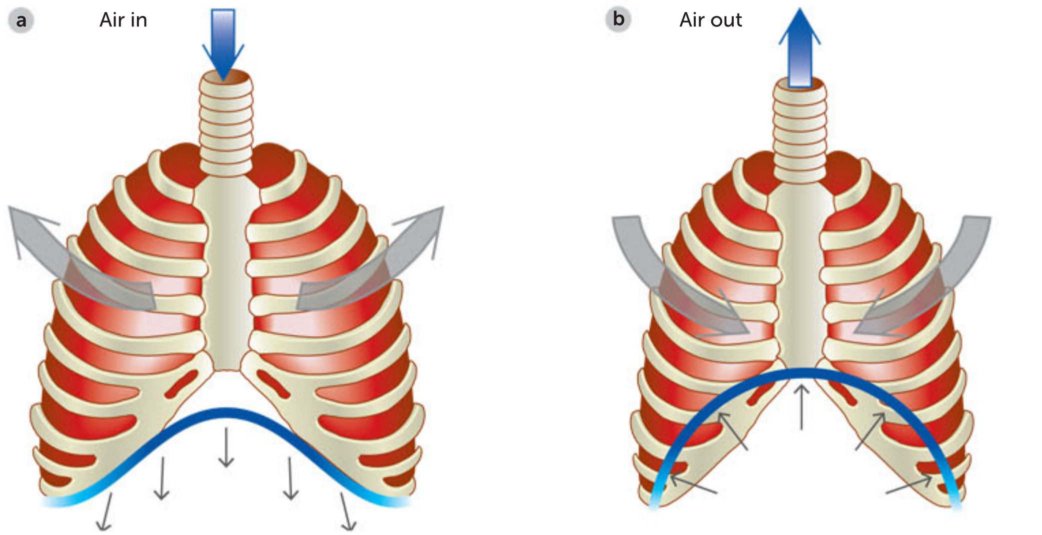

FIGURE 12.16 Changes in the size of the thoracic cavity during breathing. The blue line under the rib cage indicates the diaphragm position when you **a** inhale and **b** exhale.

Dissection of a blue mackerel
Interested in a fish dissection? This procedure was created for secondary students. Scroll down to view the main organs including the gill filaments, the gas exchange surface in a fish.

Gas exchange in fish

Aquatic animals also need an oxygen supply, but they have the added complication of having to extract oxygen dissolved in the water. Fish are able to exchange carbon dioxide and oxygen with their surroundings using gills. Gills have the features required of all gas exchange surfaces (Figure 12.10, page 390). However, gills do not look like the gas exchange surfaces of air-breathing land animals. The main structure of the gill relies on the buoyancy of the water in which it is immersed to expand its surface area, thus exposing more of the animal's blood supply to the oxygen-drenched water. Gills rely on water flowing over them to ensure maximum oxygen uptake.

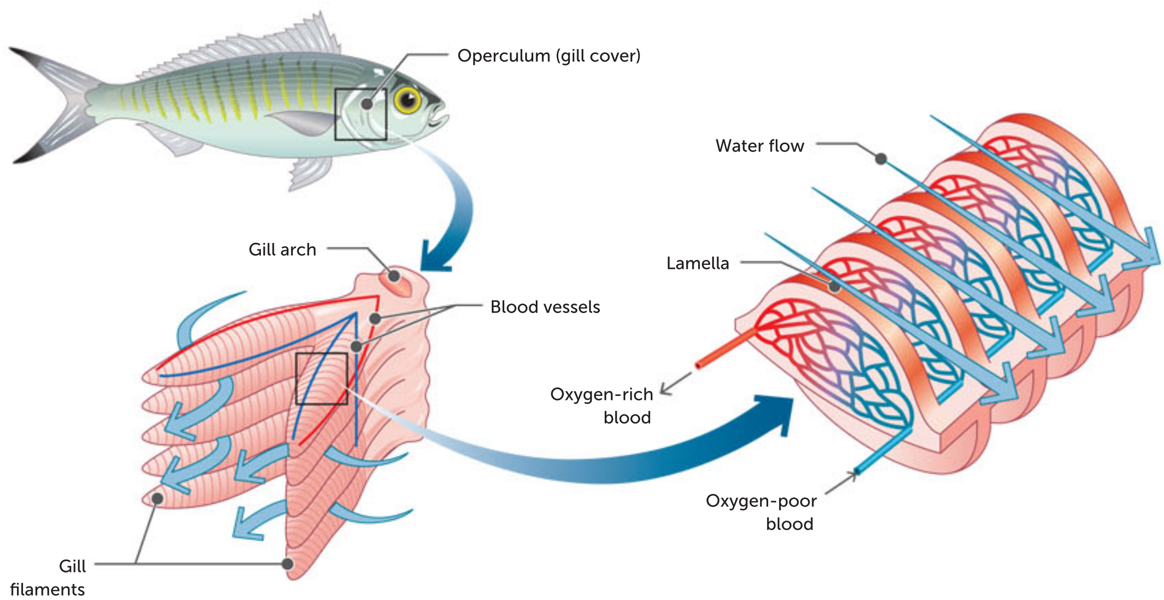

FIGURE 12.17 The gas exchange structures in the gills of a fish. Water flows through gill filaments in the opposite direction from blood flowing inside the blood vessels (countercurrent flow).

There is a variety of ways the gills function in different fish. Most bony fish maintain a flow of water through the gills by what could roughly be described as the equivalent of drinking water but, instead of swallowing the water, they force it out through the gills. Some fish that are very active, such as sharks and tuna, cannot get enough oxygen this way. They swim with their mouths open, letting the water pass into their mouths and then flow directly through the gills.

Bony fish have a covering over the gills, the **operculum**, that not only protects the gills but also helps in moving the water into and out of the **opercular cavity**.

Each gill is composed of two layers of leaf-like **filaments**, which project from the gill arch. The upper and lower surfaces of the filaments have numerous gill plates, which greatly increase the surface area of the gill. The gill arch contains an artery that brings deoxygenated blood to the gill, and each gill plate is well supplied by capillaries that branch from this artery. Because the water flowing over the gill has a higher concentration of oxygen and a lower concentration of carbon dioxide, there are concentration gradients for each gas, so that oxygen diffuses into the blood capillary and carbon dioxide diffuses out. The oxygenated blood is carried away from the gill and the excess carbon dioxide is washed away from the gill by the incoming water.

If fish are taken out of the water, their gills collapse because air does not provide the support that water does. Although air contains more oxygen than water, the fish will die out of the water as the surface area available to exchange gases decreases dramatically and the gills are no longer kept moist.

Countercurrent gas exchange animations
Watch these videos to help you understand and explain countercurrent gas exchange.

Countercurrent flow

Gills are very efficient at removing oxygen from water. They need to be, because there is only around 5% of the amount of oxygen present in water as there is in the same volume of air. Water flows over gills in one direction, while blood flows in the opposite direction through gill capillaries. This countercurrent flow maximises oxygen transfer because it maintains a concentration gradient along the whole structure (Figure 12.18).

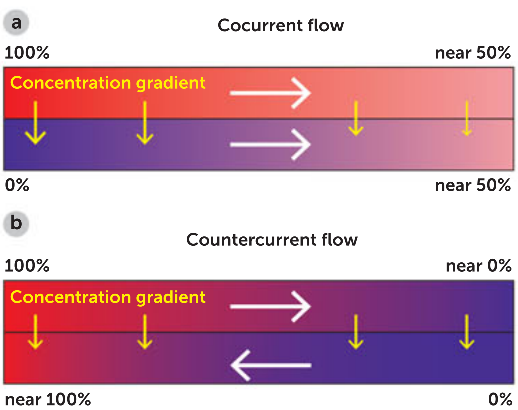

FIGURE 12.18 Comparing cocurrent flow with countercurrent flow: **a** in cocurrent flow, the concentration gradient between the two areas is reduced the longer they flow together; **b** in countercurrent flow, the concentration gradient is maintained.

FIGURE 12.19 In bony fish, gills are located under a bony lid called the operculum (gill cover). Neighbouring filaments touch, so that the water flowing over them is directed past gas exchange surfaces before being expelled.

Question set 12.3

REMEMBERING

1 List the characteristics of an efficient gas exchange surface.
2 Describe the structures of these gas exchange surfaces.
  a gills
  b spiracles
  c lungs

UNDERSTANDING

3 Explain why living things need to continuously exchange gases with their external environment.
4 Explain what happens to the ribs and diaphragm during inhalation and exhalation.
5 Is the air inside the bronchioles part of the internal or external environment? Explain your answer.
6 Explain how fish achieve the highest efficiency of gas exchange.

ANALYSING

7 Compare countercurrent flow with cocurrent flow.

12.4 DIGESTIVE SYSTEMS

All organisms require access to nutrients that must eventually reach cells. The digestive system in simple animals may involve a gastrovascular cavity with one opening; the simplest example, the sponge, has no digestive system at all. In more complex animals, the digestive system involves a specialised canal with two openings. **Alimentary canals** have specialised structures that relate to the animal's specialised diet; for example, a **herbivore** (having a diet of plant or plant products) requires a different set of features compared to a **carnivore** (having a diet of other animal flesh). In all animals, the common function of digestion is the same: to acquire nutrients in the form of large, complex macromolecules and break them down into molecules that are simple and small enough to be absorbed into the bloodstream (move across the cell membrane and into the internal environment).

Key concept

Animals may have a gastrovascular cavity with one opening or a specialised alimentary canal with two openings; specialisation of alimentary canals is related to diet, as shown by the differences between herbivores and carnivores.

Digestion takes two forms:

1 **Mechanical digestion** (physical digestion) is when large pieces of food are broken down into smaller pieces of food through chewing or muscular movement in the stomach. The aim of this is to increase the surface area of the food so it can be acted on more effectively by enzymes in chemical digestion.
2 **Chemical digestion** is when enzymes break down complex substances into their simplest forms, such as carbohydrates to glucose, proteins to amino acids, and lipids to glycerol units and fatty acid chains.

Key concept

Digestion is the process by which animals break down nutrients acquired in the form of large, complex macromolecules into molecules that are small enough to be absorbed into the bloodstream (by moving them across the cell membrane and into the internal environment).

Digestion takes place in the **digestive system** (also called the gastrointestinal tract). The digestive system has four main roles and these involve the functioning of specialised structures.

1. **Ingestion**: the acquisition (taking in) of nutrients
2. **Digestion**: the breakdown of complex organic molecules into smaller components by mechanical and chemical means
3. **Absorption**: the taking up of digested molecules into the internal environment of the cells of the digestive tract
4. **Egestion**: the removal (elimination) of undigested waste food materials from the body

The gastrovascular cavity

Simple animals such as those that belong to Cnidaria (e.g. jellyfish or corals) or Platyhelminths (flatworms, e.g. planarians) contain a gastrovascular cavity as their primary organ of digestion. The cavity has only one opening, through which food enters and wastes pass out. Digestion involves chemical digestion with enzymes that help break down large molecules into simpler molecules and is completed within the vacuoles of cells.

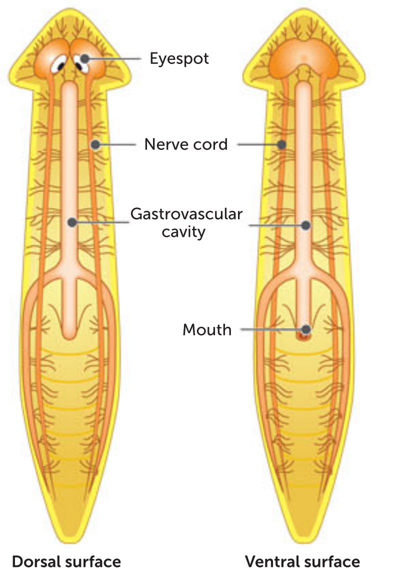

FIGURE 12.20 A planarian's digestive system (gastrovascular cavity)

The alimentary canal in humans

An alimentary canal is a more specialised digestive system which comprises the passage from mouth to anus, and includes all the organs that food passes through. It has two openings, one for the entry of food and the other for the elimination of waste. The digestive system also includes organs that are connected to the alimentary canal and which may supply further chemicals for digestion. Thus, in humans and most mammals, the digestive system is one long tube made up of many different types of tissues, and is open at both ends.

Digestion in humans involves the breakdown of large 'packages' of energy and nutrients. The largest packages are in the form of the food taken in, such as bread, meat, butter, fruit and vegetables. The nutrients within these packages, however, are mainly in the complex forms of substances such as carbohydrates (starch and cellulose), proteins and lipids (oils and fats). These complex forms are too large to pass across the cell membrane and into the cells where they are required.

Humans consume a varied diet and their digestive system deals with this variety in a specific way. The structures involved are similar in all mammals, with some individual adaptations for specialist feeders. We will explore those adaptations later in this chapter.

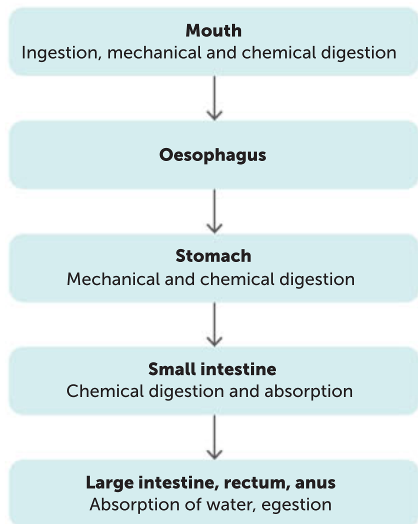

FIGURE 12.21 The passage of food in the digestive system (alimentary canal)

Ingestion

Most animals ingest food through the mouth. Once food has entered the mouth, mechanical and chemical digestion commence. The molar teeth at the rear of the mouth help to grind the food into smaller pieces. The **tongue**, a strong muscle, helps to move the food around the mouth, thereby increasing food contact with the teeth. As this is happening, the enzyme **amylase** is secreted from salivary glands situated near the base of the tongue. This enzyme is present in saliva and is specifically suited to the chemical breakdown of complex carbohydrates, such as starch, into simpler carbohydrates, such as maltose. The action of the teeth increases the surface area of the food to allow greater action by the enzyme.

TABLE 12.6 The macromolecules and their simpler, molecular forms after digestion

COMPLEX MACROMOLEULE	SIMPLE MOLECULE
Protein	Amino acids
Lipids	Glycerol and fatty acids
Carbohydrates	Monosaccharides (e.g. glucose)
Nucleic acids	Nucleotides

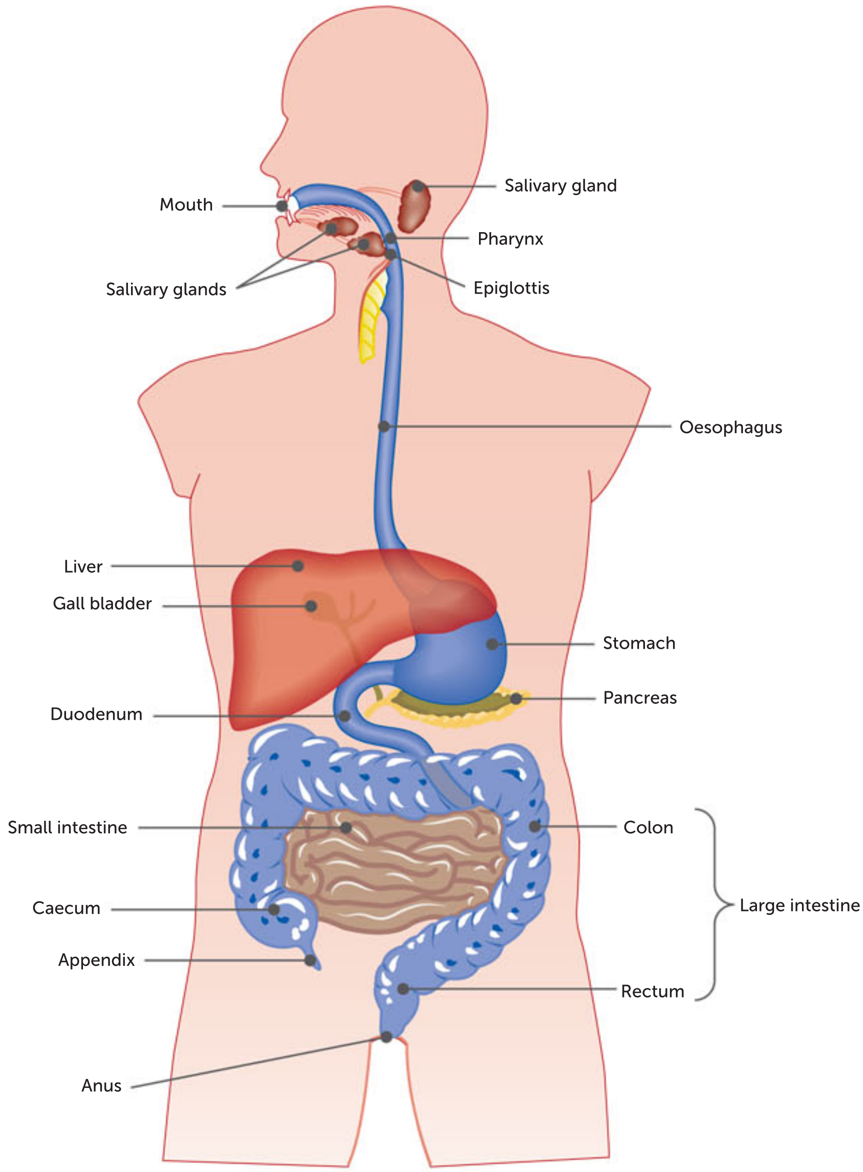

FIGURE 12.22 The human digestive system

The digestive system
Explore the digestive system at the visible body website.

Crash course biology
Find out some interesting facts about different types of digestion.

FIGURE 12.23 Various animals and their methods of ingestion

Digestion and secretion

Once the food is ready for swallowing, it moves to the back of the mouth, and the tongue helps push it into the **oesophagus**. The oesophageal opening is extremely close to the opening of the trachea (windpipe). A small flap of tissue, the **epiglottis**, closes off the trachea, preventing food from entering the respiratory tract. The food moves down the oesophagus with the aid of unidirectional muscular contractions known as **peristalsis**. Some chemical digestion of starch will continue here until the food reaches the stomach.

In the stomach

The **stomach** is a muscular part of the gut with the potential to stretch significantly. In animals with specialised diets, this is a very useful ability. The vegetarian koala and wombat eat vast amounts of low-energy food and require a space where the digestion of this material can take place. Circular muscles called **sphincters** regulate the movement of food into and out of the stomach. Sphincters act like the drawstrings on a bag: when the sphincter muscles contract, the opening closes.

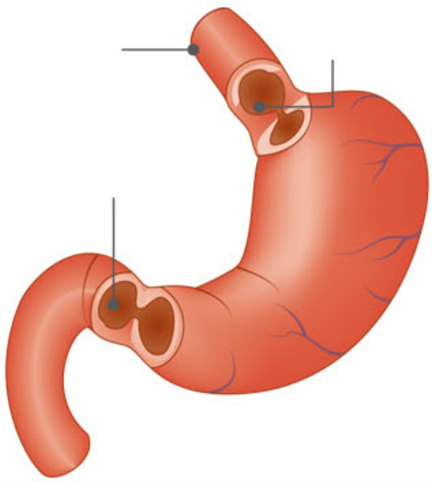

FIGURE 12.24 The structure of the human stomach

Mechanical digestion occurs in the stomach as the muscles of the stomach wall relax and contract (churning). The food is still in very large pieces and the aim is to allow the enzymes easy access to most of the surface of the food. The main focus of digestion in the stomach is the chemical digestion of proteins.

The presence of food in the stomach stimulates the **secretion** of **gastric juice** from cells lining the stomach wall. This substance contains mucus, water, hydrochloric acid and a protein-digesting enzyme called pepsin. The presence of hydrochloric acid makes the pH of the stomach around 2.0–3.0, the perfect environment for the action of this enzyme. The enzyme breaks down the long-chain polypeptides of proteins into smaller-chain polypeptides.

Food will remain in the stomach for up to 6 hours until it resembles a 'soupy' substance known as **chyme**. However, further digestion along the length of the gastrointestinal tube is required before the polypeptides are broken down into amino acids, which are small enough to be absorbed into the cells of the body.

In the small intestine

From the stomach, digested food then moves into the small intestine by the action of peristalsis. Another sphincter (small, muscular opening) at the base of the stomach controls the amount of food leaving the stomach and entering the small intestine. This prevents too much food entering the small intestine too quickly. In adult humans, the small intestine is approximately 7 m long, and has a surface area of 4500 m^2. The first part of the small intestine, the duodenum, is the site of high levels of chemical digestion.

Secretions from the pancreas enter the duodenum at the top of the small intestine. These secretions, known as **pancreatic juice**, contain a mixture of the enzymes amylase, trypsin and lipase. The chyme entering the duodenum is combined with these enzymes.

Bile, a substance produced by the liver, passes down the bile duct and into the duodenum. If there is no food to digest in the small intestine, the bile is stored in the **gall bladder**. Bile is involved in the mechanical breakdown of fats. Bile is not an enzyme but instead has a detergent-like action on the fats. It acts mechanically to emulsify fats down into smaller pieces, thereby increasing the surface area for the action of the enzymes called lipases. Lipases are enzymes that are produced by the pancreas and act on the fat droplets. They chemically break down fat into fatty acids and glycerol.

The pancreas also produces the enzyme trypsin. This enzyme acts on the long-chain polypeptides and breaks them down to shorter-chain peptides. A second group of pancreatic enzymes, erepsins, completes the digestion of the short-chain peptides by breaking them down into individual amino acids.

From the duodenum, food enters the rest of the small intestine where digestion of all food nutrients continues. Digestion of proteins continues and eventually the smaller amino acids are available for absorption into the blood and from there to the body cells. Carbohydrates continue to be broken down into simple sugars such as glucose, which can also be absorbed.

Key concept

Mechanical digestion increases the surface area across which digestive enzymes may act.

Chemical digestion describes the action of the digestive enzymes on the nutrients, chemically breaking them down until they are of a molecular form and size that can be absorbed by cells in the body.

TABLE 12.7 A summary of chemical digestion (enzymes are in *italic*)

LOCATION	CARBOHYDRATE	PROTEIN	LIPIDS (FATS)
Mouth	Complex carbohydrates (polysaccharides) ↓ *Amylase* (in saliva) ↓ Smaller carbohydrate (maltose)		
Stomach		Proteins ↓ *Pepsin* ↓ Small polypeptides	
Small Intestine	Polysaccharides ↓ *Pancreatic amylase* ↓ Maltose ↓ *Disaccharidases* ↓ Monosaccharides (simple carbohydrates/glucose)	Small polypeptides ↓ *Trypsin* (and others) ↓ Amino acids	Fat globules ↓ Bile salts* ↓ Fat droplets ↓ *Pancreatic lipase* ↓ Glycerol, fatty acids, glycerides

*Note: Bile is not an enzyme but is produced by the liver and stored in the gall bladder, and delivered to the duodenum for digestion; it acts as a detergent to increase the surface area available to the action of lipase.

Absorption

The digestive tract discussed so far is still considered to be part of the external environment. While in the small intestine, the products of digestion are small enough to be removed from the digestive tract (the external environment) and transported across a cell membrane into the internal environment of the bloodstream. Absorption of some substances can occur along the length of the gut. For example, substances such as alcohol and some drugs can be absorbed through the stomach wall into the bloodstream. Because of this, the effects of such substances are felt very quickly. However, most nutrients are absorbed along the length of the small intestine.

In the small intestine, nutrients such as glucose, amino acids, fatty acids and glycerol move from the gut into the blood by means of diffusion and active transport. The structure of the small intestine is perfect for the uptake of nutrients. The lining is moist and thin, with a rich supply of blood vessels. Special structures, known as **villi**, project from the surface of the small intestine tissue, increasing the surface area of the gut lining and thus facilitating efficient absorption. Each villus is supplied with a network of capillaries. Glucose and amino acids are absorbed into the capillary network; fatty acids and glycerol are absorbed and enter the lymphatic system. Along with the digested nutrients, water absorption also occurs in the small and large intestines.

Egestion

The **large intestine** is the final length of the gut. This section consists of two main parts: the colon and the rectum. The main functions of the large intestine are to compact undigested food material, such as dietary fibre, and to absorb water and some salts back into the body. Bacteria present in the colon act on the undigested matter, producing vitamins A and K. These vitamins are absorbed through the lining of the large intestine. Peristalsis continues through the large intestine, pushing the waste material into the rectum (a storehouse for the waste material). This waste material, **faeces**, is eliminated from the body through the anus.

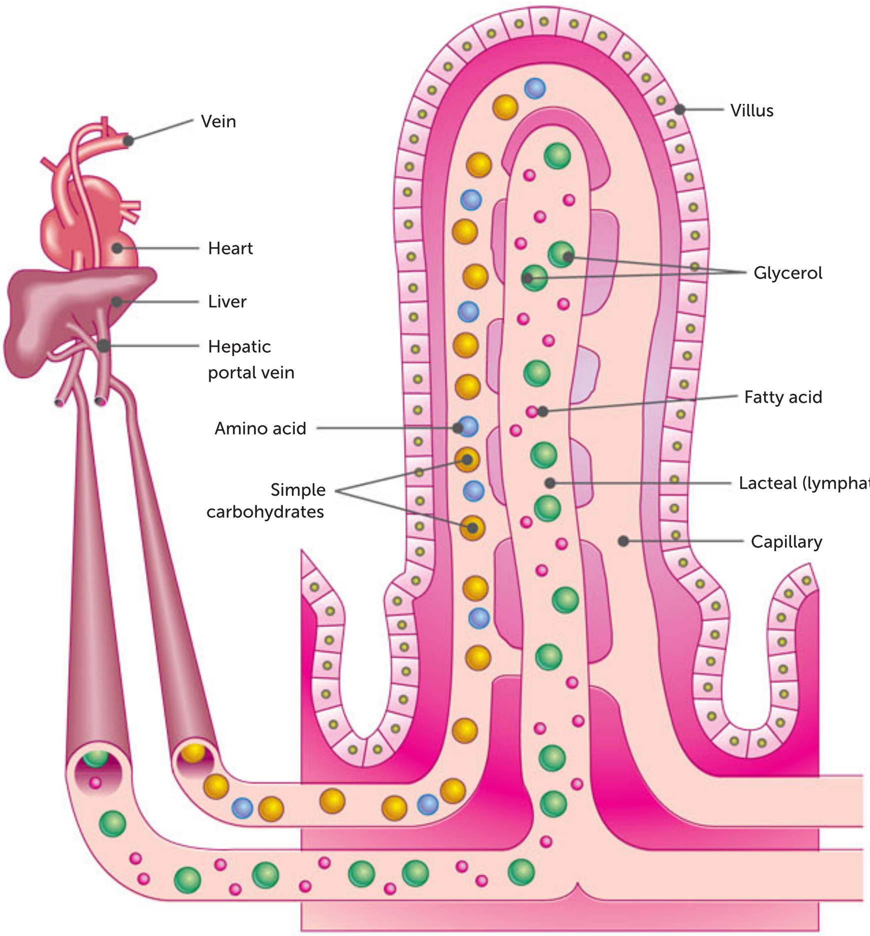

FIGURE 12.25 A cross-section of a villus. Amino acids and simple carbohydrates are absorbed into the villi lining the small intestine.

Specialisation of alimentary canals

The type of diet an animal eats determines the features that the animal has that it uses to obtain its food. Vertebrates have **dentition** (teeth) that suits their diet. For example, a seal is a carnivore that feeds predominantly on fish, and it has sharp, gripping teeth to grab hold of the slippery surface of the fish. Many carnivores have pointed incisors and canines, and jagged premolars and molars. The functions of these specialised teeth are to kill prey, and to cut and rip pieces of flesh during their meal. Further examples of carnivores are dingoes and sharks.

Herbivores usually have molars with broad, ridged surfaces. The function of these specialised teeth is for grinding tough plant material. The incisors and canines may be used to bite off vegetation.

Omnivores have dentition that suits eating both plants and animals: blade-like incisors for biting, pointed canines for tearing, and premolars and molars for grinding and crushing.

Not many animals have the same **omnivorous** diet that most humans have. Differing diets call for different digestive systems.

Herbivores

The alimentary canal of a herbivore refers to the organ system that digests plant materials in the herbivore's body. The diet of herbivores contains a lot of plant cell walls containing cellulose, which is difficult to digest, so the alimentary canals of herbivores are much longer than those of carnivores.

Koalas exclusively eat the leaves of a few species of eucalypt trees. Eucalypt leaves are very tough and difficult to digest due to the large amount of cellulose they contain. Cellulose is one of the more complex carbohydrates and thus requires a specialised digestive treatment for all possible nutrients to be extracted from it. And in the same way as we have seen with the digestion of proteins and starch, a specific enzyme is required to break down cellulose; this is known as cellulase. This enzyme is secreted by a variety of micro-organisms in the gut of the koala, and is not produced by the digestive system of any other mammals. As well as being rare, cellulase requires a large surface area on which to work and it takes time to act. Mechanical digestion increases the surface area that is exposed to the action of enzymes such as cellulase, which carry out the necessary chemical digestion.

Ruminant or cud-chewing herbivores such as the cow have an enlarged stomach at the end of the oesophagus. This is divided into four chambers, of which the **abomasum** is the true stomach. Grass and other plant material is ground up by the molars and then passed down the oesophagus into the first chamber, the **reticulum**. Here it forms into balls of cud that are regurgitated and chewed again when the cow is not actually feeding. When the cud is swallowed for the second time, it passes into the **rumen**, the largest chamber. Here it mixes with great numbers of cellulose-digesting bacteria, along with large amounts of saliva added from the salivary glands. The rumen is similar to a fermenting chamber and, in anaerobic conditions, the cellulose is chemically digested, releasing carbon dioxide and methane gas as by-products. The contents of the rumen empty into the duodenum, via the omasum, where the soluble products of digestion are absorbed.

Non-ruminant herbivorous mammals also possess fermentation chambers where

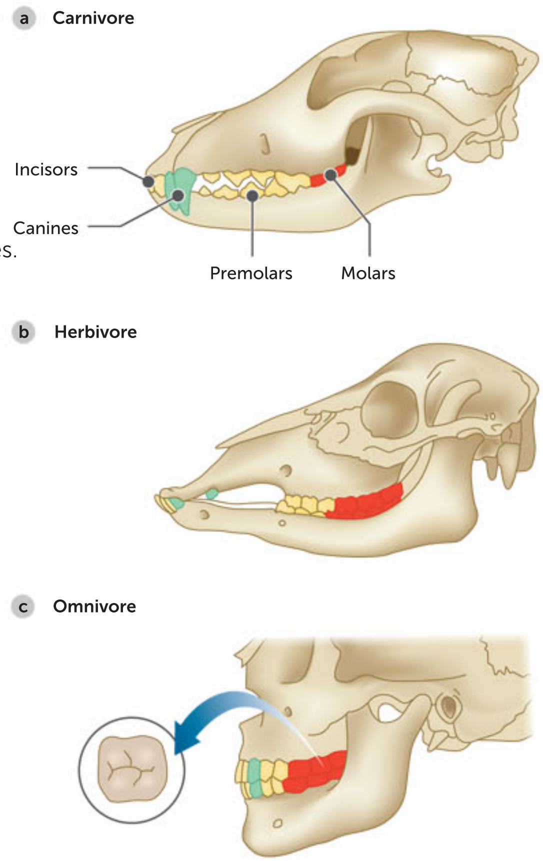

FIGURE 12.26 A comparison of the dentition of animals with different diets

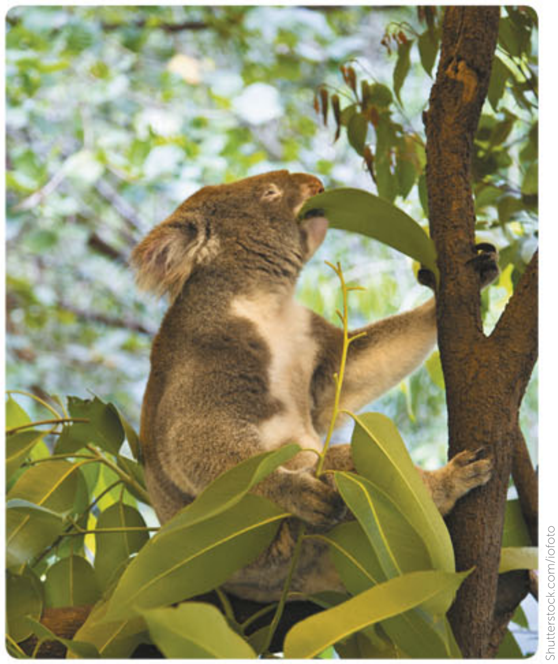

FIGURE 12.27 Koalas chew their food until it is a fine paste in order to provide a large surface area for the action of the enzyme cellulase.

bacteria digest cellulose. In horses and rabbits they are the caecum and appendix, organs that connect where the small intestine joins the large intestine. However, there are some disadvantages to having a fermentation chamber near the end of the gut. Food isn't regurgitated and the products of digestion cannot be returned to the small intestine for absorption. To make up for this, rabbits and hares re-ingest their own faeces. If rabbits are deprived of eating their soft faeces, they show signs of nutritional deficiency.

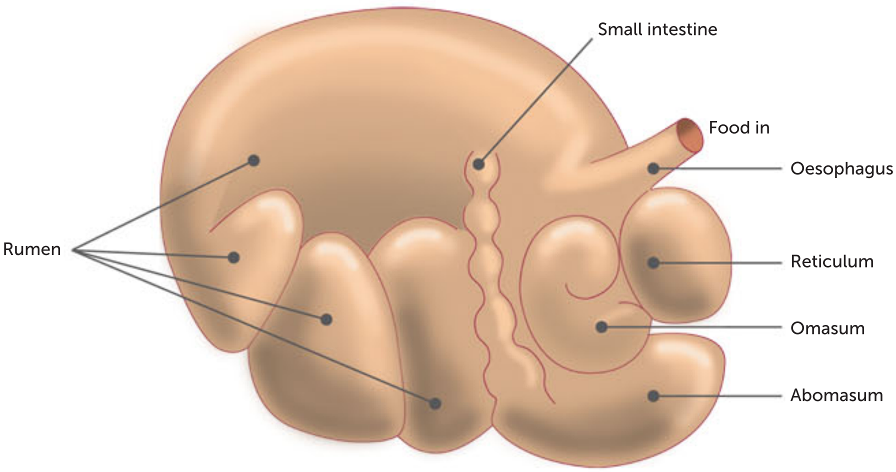

FIGURE 12.28 A cow's stomach

Carnivores

The alimentary canal of a carnivore refers to the organ system that digests animal tissues in a carnivore's body. Since animal tissues, which contain protein, are relatively easy to digest, the alimentary canals of carnivores are shorter and simpler compared with the alimentary canals of herbivores. Carnivores have strong, sharp teeth. They do not have digestive enzymes in their saliva.

Key concept

The alimentary canal is the passage along which the food passes from mouth to anus during digestion. The main difference between the alimentary canal of herbivores and carnivores is that herbivores have a longer alimentary canal than carnivores. Herbivores take a longer time to digest and absorb nutrients while carnivores readily absorb nutrients. The different types of digestive systems are specialised to meet particular dietary needs.

Omnivores

Omnivores, such as humans, chickens, bandicoots and bilbies, eat both plant and animal matter for food. They lack the specialised structures to be completely herbivorous or completely carnivorous. Like other digestive systems, the alimentary canals of omnivores break down large packages of energy and nutrients from plant and animal sources into simpler forms that can cross the cell membranes into cells and to be transported to where they are required. Omnivores usually have simple stomachs. Their intestine is generally longer than that of carnivores, but the size ratio of the small intestine compared to the large intestine can vary greatly.

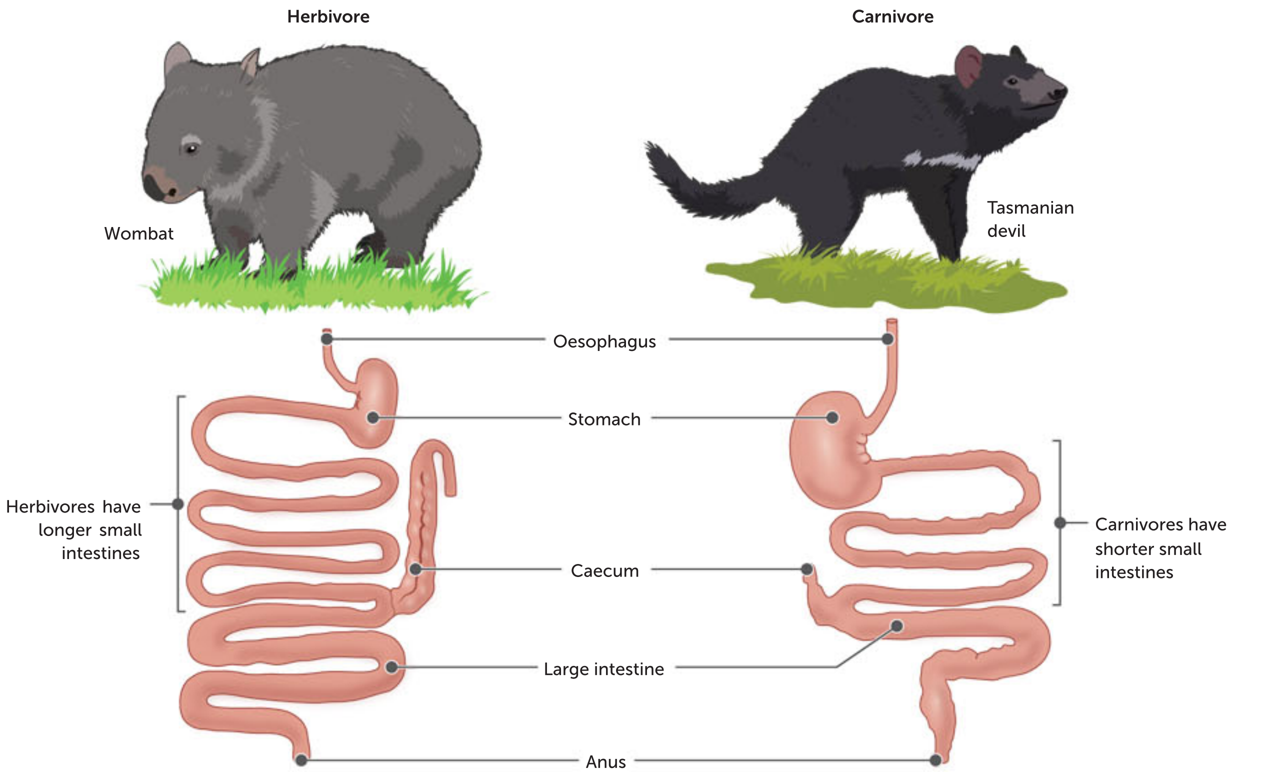

FIGURE 12.29 Examples of the alimentary canals of a herbivore and carnivore

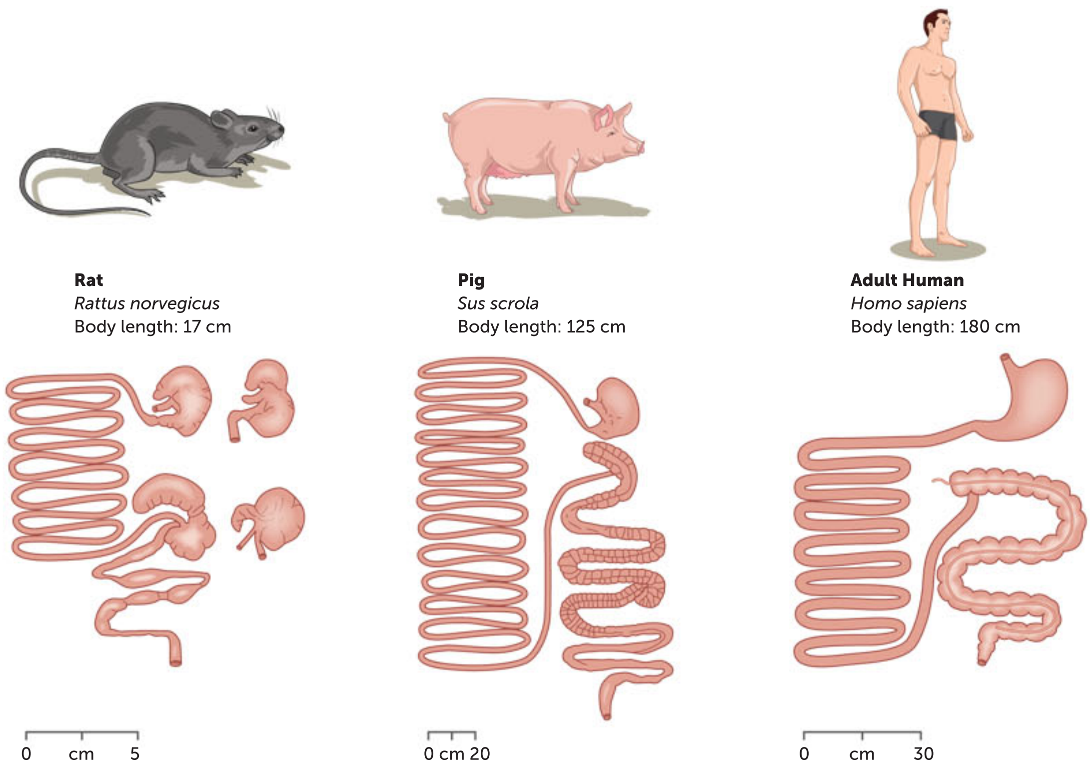

FIGURE 12.30 Examples of the alimentary canals of some omnivores

Animals with no digestive system

Microscopic animals and simple animals such as sponges have a high surface-area-to-volume ratio. They do not possess a digestive system. This means that the size of the cell membrane (its surface area) is sufficient to service the total volume of the cytoplasm. All the needs of the organism (e.g. nutrients, energy and water) and functions (e.g. intake of nutrients and energy, processing of nutrients to release energy and expulsion of waste products) take place inside the boundary of the cell membrane. The microscopic size of the cell allows these processes to occur efficiently, relying mostly on diffusion. Oxygen, nutrients and carbon dioxide can diffuse directly across the cell membrane in amounts sufficient to meet the needs of the entire cell.

Question set 12.4

REMEMBERING

1 Describe the main functions of the digestive system. Name the end products.
2 List, in order, the structures that food must pass through in a typical vertebrate digestive system.
3 State the function of the following enzymes: amylase, pepsin, trypsin and lipase.

UNDERSTANDING

4 Compare the alimentary canals of herbivores and carnivores.
5 Compare the dentition of carnivores and herbivores.
6 Suggest a reason why cows chew their cud.

ANALYSING

7 Design a summary table for digestion, listing each organ involved and its function.
8 Compare the structure of the cow's stomach to that of the human stomach. Account for the differences.
9 Compare the human digestive system to that of a planarian.

12.5 EXCRETORY SYSTEMS (EXTENSION TOPIC)

Like most machines, the human body is not 100% efficient at converting raw materials into useful substances or extracting energy from them. As you have learned, cellular respiration produces carbon dioxide, which is dissolved in the blood and leaves the body via the respiratory organs.

Another source of waste is produced during the breakdown of protein. Mammals, including humans, must include protein in their diet as a source of amino acids. However, amino acids cannot be stored in the body. The main waste produced by the breakdown of proteins is ammonia, which is toxic. In terrestrial mammals, it is converted into **urea**, which is excreted in **urine**. Fish excrete their waste nitrogen in ammonia and birds excrete it in uric acid.

In humans, cells in the liver convert the ammonia to less toxic urea. Urea is dissolved in the blood and carried to the organs that excrete it from the body, the kidneys. In most animals, the urea is diluted by water. In many terrestrial animals, including humans, kidneys need to maintain the delicate balance between the amount of water in the blood and the concentration of solutes dissolved in it. The main processes that occur in this system are **filtration** of blood, **reabsorption** of water and solutes, and collection of urine.

Key concept

The excretory system helps animals maintain the important balance between the amount of water in the blood and the concentration of solutes dissolved in it.

Human kidneys

The main organs of the human excretory system are the **kidneys**. The kidneys are two bean-shaped organs, each about as big as a fist, located in the back of the upper abdomen at either side of the spinal column (Figure 12.31). A branch of the aorta, the **renal artery**, brings blood containing nitrogenous waste and water, blood proteins, red blood cells and minerals dissolved in the blood plasma to the kidneys. Because the kidneys are the filters that remove wastes from the blood, they may hold as much as 25% of the body's blood at any given time.

The renal artery branches into smaller and smaller vessels until millions of capillaries are formed. Each capillary enters a nephron where filtration of the blood occurs.

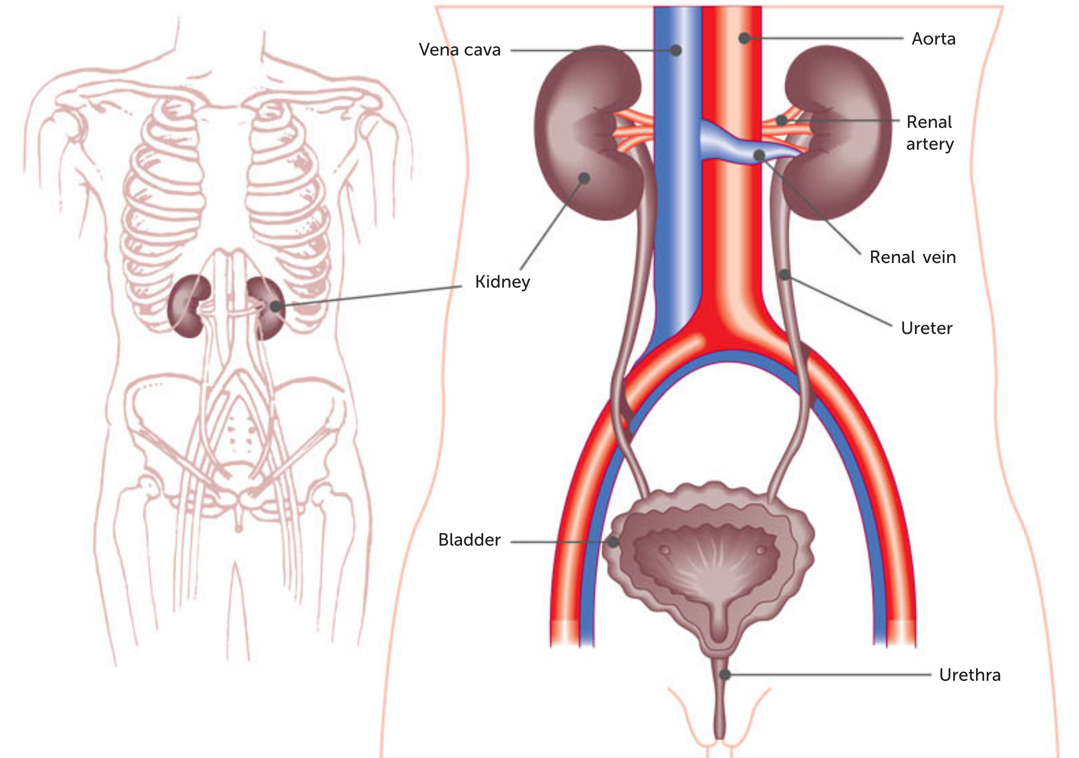

FIGURE 12.31 The human excretory system

Nephron structure and function

Each kidney consists of approximately one million slender tubules called **nephrons**, extending from the cortex of the kidney down into the medulla (Figure 12.32). It is at the nephrons that water and solutes are filtered from the blood and amounts to be reclaimed are adjusted. Each nephron consists of a ball of capillaries called a **glomerulus**. The glomerulus is situated inside the **Bowman's capsule**, which looks like a hollow rubber ball that has been pressed in on one side. As the capillaries that form the glomerulus are tightly bound into the smaller Bowman's capsule and pumped by the renal artery, blood in the glomerulus is under very high pressure. This pressure forces out some of the water and all solutes from the blood, except protein, through tiny pores and into the Bowman's capsule. This **filtrate** has just moved into the external environment, because it has passed through the cell membrane that separates it from the internal environment.

The filtrate moves to the **proximal tubule**, then to a hairpin-shaped **loop of henle**, and finally to the **distal tubule**. A collecting duct, the nephron's last region, is part of a duct system leading to the kidney's central cavity, the **renal pelvis**, then into a ureter.

Blood does not give up all of its water and solutes. The unfiltered part flows into capillaries threading around the nephron's tubular parts. In these capillaries, the blood reclaims water and solutes from the tubules. Then it flows into veins and back to the general circulation.

Key concept

The nephron is the basic functional unit of the kidney.

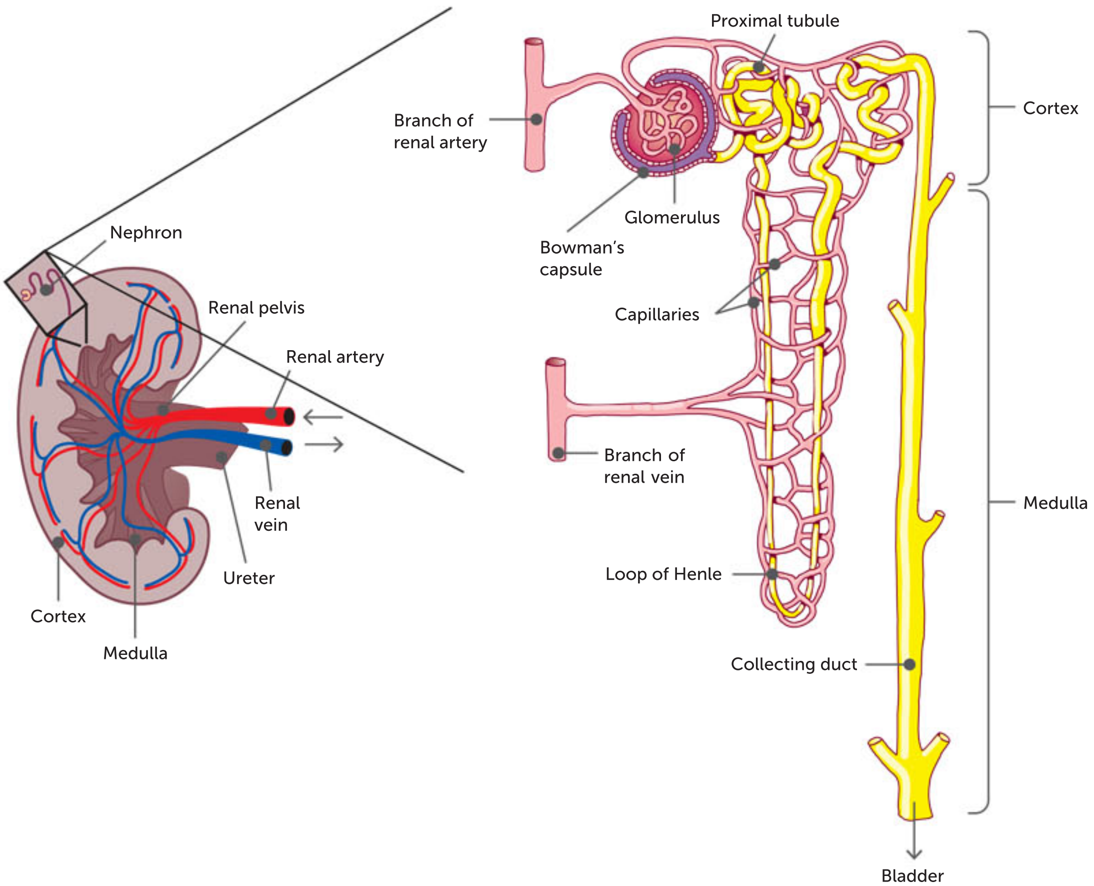

FIGURE 12.32 The structure of the kidney and the functional unit, the nephron

TABLE 12.8 A summary of the roles of each part of the nephron

NAME AND STRUCTURE	FUNCTION
Glomerulus: a cluster of capillaries that carry blood from the renal artery	**Filtration:** fluid passes from the bloodstream to the Bowman's capsule. Water and small solutes (urea, glucose, amino acids and salt) are filtered out of the glomerulus and into the Bowman's capsule, and are called the filtrate
Bowman's capsule: a hollow, cup-shaped end of the nephron with double walls one cell thick	**Filtration:** the filtrate that diffuses into the hollow space of the Bowman's capsule is passed on to the tubule
Proximal tubule: a hollow, winding, large-diameter tube (Hint: the proximal tubule is in close 'proximity' to the Bowman's capsule)	**Reabsorption:** some solutes are actively pumped back into the capillaries (e.g. salts). Most of the urea stays inside the tubule
Loop of Henle (descending): the straight part of the loop through which the filtrate moves away from the proximal tubule	**Reabsorption:** the concentration of water inside the tubule is greater than that of the surrounding blood vessels; water moves out of the tubule and into the blood by osmosis. Urea stays inside the tubule

NAME AND STRUCTURE	FUNCTION
Loop of Henle (ascending): the straight part of the loop through which the filtrate moves to the distal tubule	**Reabsorption:** sodium is actively pumped out of the tubule and into the blood. The walls of the ascending loop of Henle are impermeable to water, so it remains inside
Distal tubule: a hollow, winding, large-diameter tube (Hint: the distal tubule is 'distant' to the Bowman's capsule.)	**Reabsorption and secretion:** here there is a final adjustment of water and dissolved materials. If the body is dehydrated, the permeability of the distal tubule is increased so water returns to the capillaries by osmosis. If the body is not dehydrated, permeability decreases, so water remains within the tubule and dilutes the urine that leaves the body
Collecting ducts: a system of urine-collecting ducts that regulate urine volume and concentration	**Urine collection:** The filtrate is processed into urine and carried to the renal pelvis; eventually the urine will pass into the bladder **Reabsorption:** as urine is processed, water moves by osmosis from the duct into the surrounding blood; the volume of water returned to the blood stream depends on how dehydrated the organism is. When an organism is dehydrated, anti-diuretic hormone increases the permeability of the duct, allowing more reabsorption of water

How our kidneys work
Watch the video and draw up a table that summarises the excretory process in mammals.

Excretory process

Kidneys filter water and solutes from blood. Most of this is reabsorbed back into blood, but the excess leaves the kidneys as urine. The body adjusts for excess water intake by increasing urine output. Conversely, it adjusts for increased exercise or decreased water intake by reducing urine output. The kidneys not only prevent the build-up of wastes but also help maintain water balance by controlling the volume, composition and pressure of body fluids.

Key concept

The main functions of the excretory system include filtration of blood, reabsorption of water and solutes, and secretion of urine.

CASE STUDY

Kidney donation

For many years, licenced drivers have been encouraged to complete documentation that allows their organs to be donated in the unfortunate circumstance of a fatal accident. Where appropriate, the organs are transplanted into recipients who would otherwise die from an impaired or non-functioning organ. Research over the years has indicated, in the area of kidney transplantation specifically, that organ donation from live donors offers prolonged normal organ functioning. It has been found that an organ from a perfectly matched sibling donor can function successfully for up to 35 years. From a less perfectly matched donor, the life span of the organ is 20 years. However, deceased donor transplants see the kidney maintaining function for a maximum of 10 years. Research indicates that the most long-lasting and successful transplants are from living relatives. Occasionally, however, the match between the related donors and recipients are not perfect, and an altruistic unpaired kidney exchange can occur.

In this situation, incompatible donors are matched and six simultaneous surgeries are undertaken. Most donors are able to return

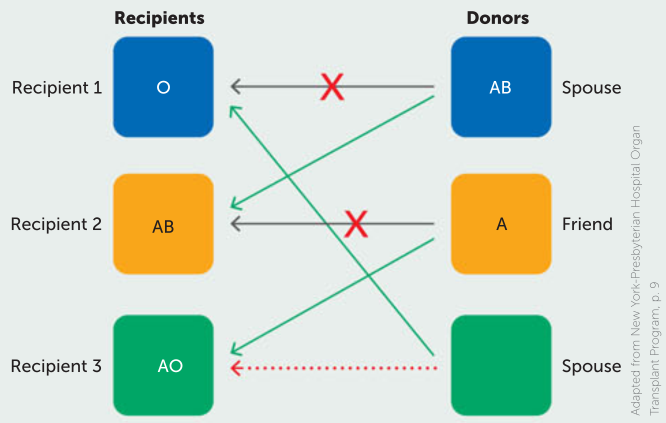

FIGURE 12.33 An example of an altruistic unpaired kidney exchange. Recipient 1 and his spouse were incompatible on blood type. Recipient 2 and her friend were incompatible on tissue type. Recipient 3 and her spouse were compatible. The three pairs participated in an unpaired exchange so that all three recipients could receive kidneys.

to work within a month of surgery, whereas recipients are mostly back within 3 months of the transplant.

However, in a case where a kidney is required urgently, medical specialists are able to provide other alternatives. Such was the case for 35-year-old Amity Bishop whose kidneys had failed. Family members volunteered; however, none were compatible. A transplant from an incompatible donor would lead to rejection of the organ by Ms Bishop's immune system.

A new procedure, overseen by the Director of Renal Medicine at the Alfred Hospital, Rowan Walker, involved reducing the antibodies in Ms Bishop's blood through a series of plasma exchanges. This meant passing the patient's plasma through a machine that removed the antibodies. The lack of antibodies would allow Ms Bishop to receive her mother's donated kidney and prevent its rejection.

Following the transplant, antibody levels rose again, but, for reasons that are not fully understood, the recipient's body accepted the new kidney.

Source: Hagan, K. (2013) 'Kidney transplant a long-shot life saver', *The Age*, 23 July.

Questions

1 Identify the type of kidney transplant that maintains function for the longest time.
2 Describe the common complications that arise when kidneys are used from incompatible donors.
3 Explain how incompatible kidney transplant rejection has been overcome at the Alfred Hospital.

Other vertebrate kidneys

All vertebrates have kidneys, but they are not all the same as mammalian kidneys. The kidneys of freshwater fish are larger than those of marine fish because they have to put out a larger volume of urine. Some marine fish lack glomeruli because their urine is formed only by secretion of ions, not by filtration.

The loop of Henle occurs only in mammals and some bird kidneys, enabling these animals to produce highly concentrated urine. In fish, the nephrons lie in a straight line. The Australian spinifex hopping mouse has relatively long loops of Henle, producing very concentrated urine and thus reabsorbing enough water that the animal hardly needs to drink.

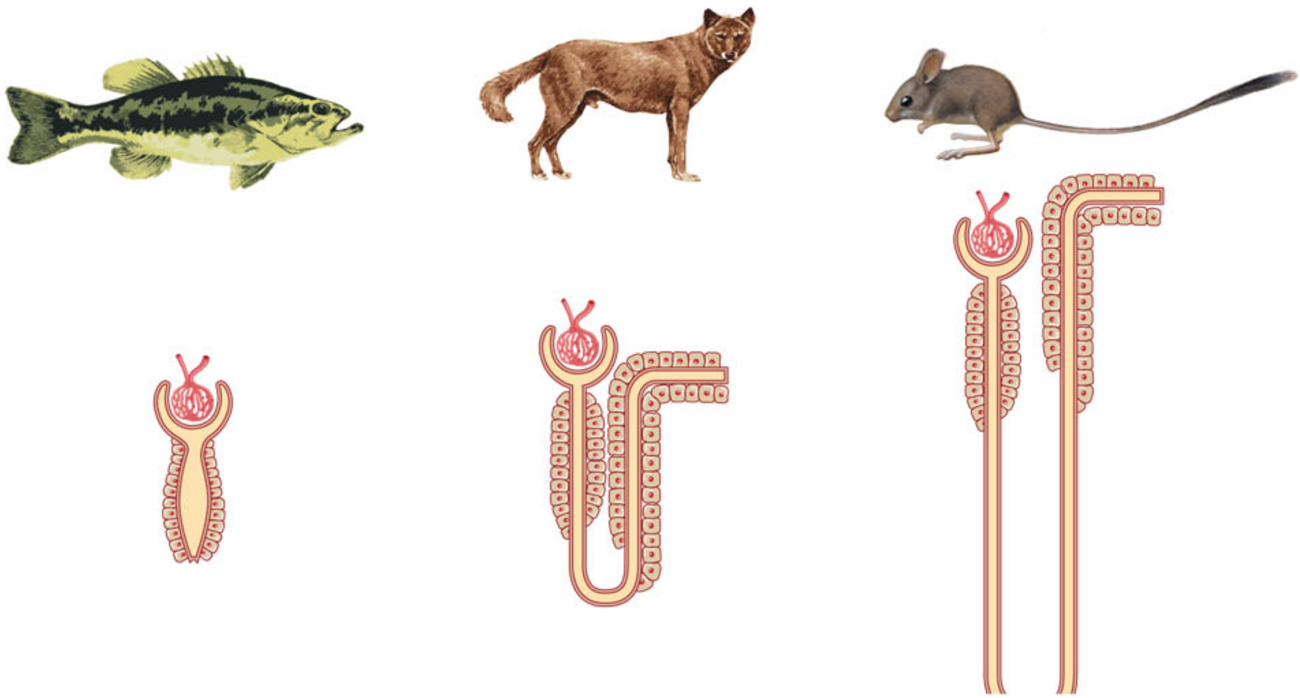

FIGURE 12.34 A comparison of the structural differences in nephrons between vertebrates

Body systems are interdependent

Can you name a system that can maintain its optimal function without the help of another system? None of the systems can complete or sustain its function and keep an organism alive without the help of at least one other system.

An example of two systems that are interdependent is the digestive and circulatory systems. For the circulatory system to function adequately, the heart muscles require glucose for cellular respiration to enable the cells to produce a usable form of energy. If the heart muscles obtain enough energy, they can pump blood around the body, delivering essential gases and nutrients to all cells. However, the circulatory system relies on the digestive system to break complex carbohydrates down to small, simple molecules that can be absorbed into the bloodstream fast enough to provide a consistent supply of energy. And for the walls of the alimentary canal in the digestive system to continuously contract and relax muscles in peristalsis, the cells need both oxygen and glucose. The digestive system needs the circulatory system to supply all muscle cells involved in peristalsis with glucose and oxygen for cellular respiration.

SCIENTIFIC LITERACY

Organ trafficking

International organ trafficking is a growing trade. The increase is down to two factors. First, a reduction in the number of legitimate organs available for transplant – due, in part, to better road safety legislation, which has cut the number of healthy young adults dying prematurely in road traffic accidents. And second, an increase in the number of people waiting for transplants, which have become more routine in recent years. As a result, organised criminals can now make a fortune from unethical clinics who will buy a heart, kidney or pancreas for wealthy patients.

It is now possible to order an organ on the Internet. It's also possible, if you are poor, desperate and willing to part with, say, a kidney, to broker a deal with traffickers. Recent research by the World Health Organization (WHO) found that traffickers illegally obtain 7000 kidneys each year around the world.

Organ trafficking operates in various ways. Victims can be kidnapped and forced to give up an organ; some, out of financial desperation, agree to sell an organ; or they are duped into believing they need an operation and the organ is removed without their knowledge. Some victims are murdered to order if a large sum has been paid in advance.

This illegal trade has risen to such a level that an estimated 10 000 black-market operations involving purchased human organs now take place annually – more than one every hour – according to WHO. It estimates that organ trafficking accounts for 5 to 10 per cent of all kidney transplants worldwide.

Bindel, J. (2013) 'Organ trafficking: a deadly trade.' *The Telegraph*, 1 July.

Questions

1. Suggest reasons why organ trafficking has grown in recent years.
2. Discuss the human rights and ethical concerns of organ trafficking.
3. Consider the situation of a person giving informed consent to donate their kidney in return for a payment. Create arguments for and against this action.

Question set 12.5

REMEMBERING

1. List, in order, the pathway that nitrogenous waste takes, starting from blood and ending with the collecting duct.
2. Name the structure where the final amount of water is reabsorbed.
3. Define the term 'filtrate'.

UNDERSTANDING

4. Draw a labelled diagram showing the structure of a nephron. On your diagram, indicate where filtration, reabsorption and secretion occur.
5. Explain what happens during filtration in the kidney.

ANALYSING

6. Describe how the circulatory and respiratory systems are interdependent.

CHAPTER 12 INVESTIGATIONS

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INVESTIGATION 12.1

The action of pepsin

Pepsin is a digestive enzyme that is found in many organisms. It occurs in many different forms, but in every case, its function is to aid digestion by breaking proteins down via hydrolysis into their component amino acids. In this investigation, you will observe the action of pepsin on albumin, a globular protein.

Aim

To determine the optimal conditions for pepsin activity

Materials

- seven test tubes
- test-tube rack
- Bunsen burner
- test-tube holder
- 0.1 mol/L hydrochloric acid solution
- 20 mL albumin suspension
- pepsin solution
- 250-mL beaker
- plastic pipettes
- marker pen
- water bath
- distilled water
- disposable gloves

WHAT ARE THE RISKS IN DOING THIS INVESTIGATION?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Bunsen burner flame can cause severe burns.	Ensure safe use and avoid heating flammable liquids.
Albumin may cause allergic reactions.	Students who have allergies to egg whites should avoid contact.
Disposable gloves may pose an allergy risk.	Use a type of glove that does not have an allergy risk and is suitable for the chemicals being used.
Water baths set at high temperatures can cause scalding.	Take care when working with water baths with water temperatures higher than 50°C. Do not touch the glass beaker.

Procedure

1 State your hypothesis.
2 Collect seven test tubes. Label them as shown in Figure 12.35.

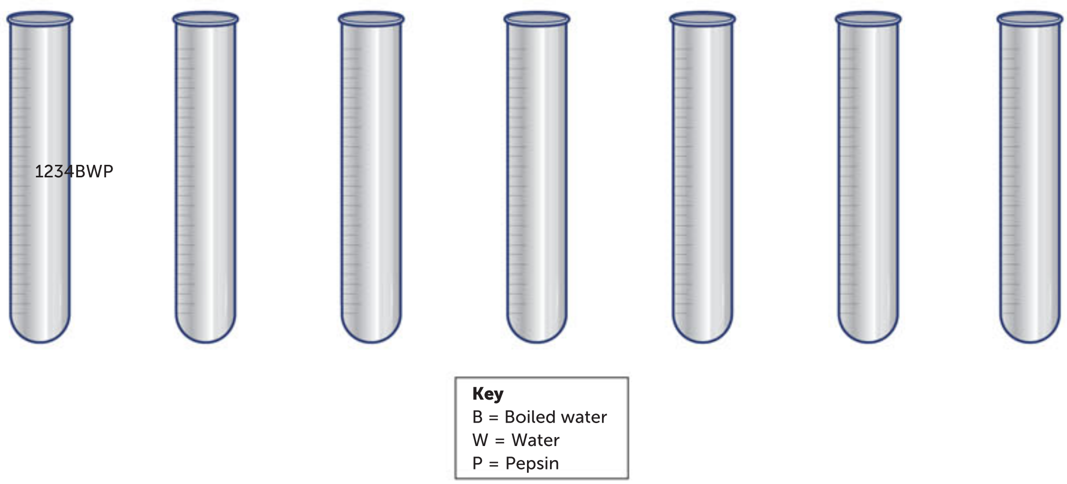

FIGURE 12.35 Labelling of test tubes

3 Add 5 mL of the albumin suspension into each of the four numbered test tubes.
4 Add 5 mL of distilled water to the tube labelled 'W'.
5 Add 2 mL of pepsin to the tube labelled 'B'. Holding it with the test-tube holder, bring this tube to boiling point over a Bunsen burner flame. The glass will become hot during this stage, so be careful to avoid burns.

FIGURE 12.36 Correct procedure for heating a test tube

6 Add 3 drops of distilled water to test tube 1.
7 Add 2 mL of pepsin solution to the tube labelled P.
8 Add 3 drops of dilute hydrochloric acid to the test tubes numbered 2, 3 and 4.
9 Prepare a water bath and maintain the temperature at 40°C.
10 Place your test tubes in the water bath for 5 minutes to warm them. It is only necessary to place the boiled test tube (labelled B) in the water bath if it has cooled down.
11 Add 1 mL of the warmed water from test tube W to test tube 2.
12 Add 1 mL of the boiled pepsin from test tube B to test tube 4.
13 Add 1 mL of warmed pepsin solution from test tube P to test tubes 1 and 3.
14 Place test tubes 1–4 back into the water bath and set your timer for 6 minutes. After 6 minutes, remove all test tubes from the water bath and place them in a test-tube rack.
15 Observe the contents of the test tubes and compare their appearance. Copy Table 12.9 and use it to record your results.

Results

TABLE 12.9 Pepsin digestion results

TEST	HYPOTHESIS	APPEARANCE
1	Albumin, pepsin, water	
2	Albumin, water, hydrochloric acid	
3	Albumin, pepsin, hydrochloric acid	
4	Albumin, boiled pepsin, hydrochloric acid	

Discussion

1 Do the results support or refute your hypothesis?
2 Why was the water added to test tubes 1 and 2 in those particular quantities?

3 Why is the albumin suspension cloudy? What does the change from cloudiness to a clear liquid suggest has happened?
4 What do the results in test tube 4 suggest?
5 What do the results in test tube 2 suggest?
6 What can you infer from a comparison of the results of test tubes 1 and 3?
7 Antacids are bases that reduce the amount of acid in the stomach. This can reduce the discomfort sometimes associated with having a highly acidic environment in the stomach. What might happen if someone consumed more than the recommended number of antacids in a short period?
8 Can you think of another function of stomach acid besides digestion?

Taking it further

Test the effectiveness of different antacid medications on gastric enzyme function.

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12.2 INVESTIGATION

Modelling kidney function

The kidneys work with the circulatory system to produce urine, removing cellular wastes, excess salts and toxins from the blood. Urine is formed by a process of filtration, reabsorption and secretion in the nephrons and associated collecting ducts. Using dialysis tubing and simulated blood, we can model how the glomerulus selectively filters substances based on their size and characteristics. Some substances are too large to pass through the membrane, whereas smaller substances can pass through and be detected in the liquid surrounding the dialysis tubing. While the filtration that occurs within the kidney is far more controlled than in this model, this investigation provides a great illustration of how filtration occurs in the production of urine.

Aim

To investigate how the circulatory system and kidneys work together to produce urine by creating a model of the kidney

Materials

- two pipettes
- two microscope slides
- two coverslips
- 250-mL glass beaker
- three salt test strips
- 10 mL simulated kidney blood
- 20 cm section of dialysis tubing
- 25-mL graduated cylinder
- bulldog clip or similar
- clock or timer
- disposable gloves

WHAT ARE THE RISKS IN DOING THIS INVESTIGATION?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Simulated kidney blood may stain skin and clothing.	Avoid any direct contact with skin and clothing, and wear appropriate personal protective equipment, including gloves and lab coat.
Glass could break and cause injury.	Inspect and discard any chipped or cracked glassware, no matter how small the damage. Sweep up any broken glass with a brush and dustpan.

Procedure

1 Pour 100 mL of water into your beaker.
2 Place the tip of your salt test strip into the water for 3 seconds and gently swirl. Pat the test strip dry on a paper towel to remove excess liquid, and set a timer for 3 minutes. After 3 minutes, inspect the test strip, determine the results and record them in a data table such as Table 12.10.
3 Tie one end of the dialysis tubing into a knot. Ensure it is pulled tight but do not allow the tubing to tear.
4 Measure 10 mL of simulated blood using a graduated cylinder and carefully pipette it into the dialysis tubing. Once filled, twist the tubing to close the end and seal it using a bulldog clip.
5 To ensure there is no simulated blood on the surface of the prepared dialysis tubing, rinse it with tap water.
6 Place the dialysis tubing into a small beaker containing water, and add additional water until the filled portion of the dialysis tubing is fully submerged. Allow the model to rest for 30 minutes.

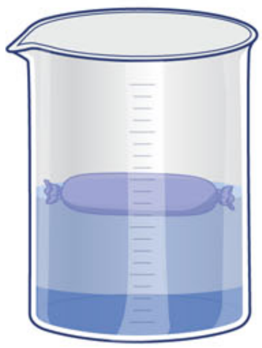

FIGURE 12.37 The dialysis tubing in the beaker

7 Using a pipette, add one drop of simulated blood onto a microscope slide. Place a coverslip on top and observe the 'blood' under the microscope. Draw a sketch of what you observe.
8 After 30 minutes, test the salt content of the filtrate using a new test strip. Place the strip in the filtrate for 3 seconds and swirl gently. Remove excess water and wait 3 minutes to determine the results. Copy Table 12.10 and use it to record the salt content and any colour changes.
9 Using a pipette, add one drop of filtrate onto a new microscope slide and place a coverslip on top. Observe the slide under the microscope and sketch what you see.

Results

TABLE 12.10 Data table

TEST	HYPOTHESIS	OBSERVATION
Initial water colour	N/A	
Filtrate colour (after 30 min)		
Initial colour dialysis tube contents	N/A	
Colour dialysis tube contents (after 30 min)		
Salt in plain water		
Salt in filtrate (after 30 min)		

Discussion

1 Which portion of the nephron were you modelling in this procedure? Explain.
2 Why was it necessary to test the water for salt before you added the dialysis tubing?

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3 Imagine you left the tubing model in the beaker for 2 days; how would the salt content in the filtrate change?
4 Compare the water filter and kidneys. Examine in what way the water filter you created functioned like a kidney and in what ways it did not.
5 What did the dialysis tubing retain? What was able to pass through the membrane?
6 Explain the difference between the solution within the dialysis tubing and the surrounding water that caused substances to travel through the membrane.

Taking it further

1 Kidney disease can be described as a systemic disease despite directly affecting the kidneys. In what ways can the whole body be affected if the kidneys do not function adequately?
2 Explain how the following systems interact with the urinary system:
- circulatory
- nervous
- digestive
- respiratory.

3 When blood is present in urine, it can be an indication of any of several disorders, such as high blood pressure. How could high blood pressure be responsible for these results?
4 Explain the interaction that occurs between the circulatory system and kidneys to produce urine.

12.3 INVESTIGATION

Dissection of a kidney

The excretory organ of mammals is the kidney. Its main function is to filter blood. It also has a role in maintaining specific concentrations of ions and water within the body. These concentrations may vary according to external environmental conditions.


Shutterstock.com/Ozgur Coskun

FIGURE 12.38 Dissecting a sheep's kidney

Aim

To become familiar with the structure of the mammalian kidney

Materials

- sheep or pig kidney
- scalpel
- cutting board

WHAT ARE THE RISKS OF DOING THIS INVESTIGATION?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Scalpels are sharp and can easily cut skin.	Handle the scalpel carefully and report any injuries to your teacher immediately.

Procedure

1 Observe the outside appearance of a kidney.
   a Draw the external shape of the kidney, including any tubes that may be attached to it.
   b Using Figure 12.32 (page 409), label any structures you observe.
2 Cut through the middle of the kidney lengthwise to show the cortex, medulla and pelvis.
   a Make a second drawing of the dissected kidney and label the structures that you see.

Results

Include your two drawings of the kidney. Ensure each drawing is clearly labelled, including the vessels leading into and out of the structure.

Analysis and discussion

1 a Name the vessels through which blood enters the kidney.
   b Name the vessels through which blood leaves the kidney.
   c Identify and describe what substance surrounds the kidney that makes the identification of the vessels difficult.
2 Describe how the pelvis of the kidney differs from the rest of the organ. Name the structure that leads away from the pelvis. Where does it lead to?
3 In which structures of the kidney would you expect to find the glomerulus, the loop of Henle and the collecting ducts? Explain your answer using reference material.
4 Give reasons why the presence of blood in the urine could indicate a damaged kidney. Explain which structure would most likely be damaged in this instance.

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WS Chapter 12 Activity sheet

CHAPTER 12 SUMMARY

- The circulatory system has four main functions: transporting water, oxygen and carbon dioxide; distributing nutrients and removing wastes; maintaining body temperature; and circulating hormones.
- The general circulatory system consists of fluid, blood vessels and spaces in which fluid moves, and a pump to push the fluid.
- Small, simple animals have open circulatory systems. Larger and more complex animals have closed circulatory systems.
- Blood is a connective tissue that consists of plasma, red and white blood cells, and platelets.
- Red blood cells (erythrocytes) transport oxygen from the lungs to all body tissues. They are packed with haemoglobin. They also transport some carbon dioxide from body tissues to the lungs.
- White blood cells (leukocytes) protect against foreign substances that enter the body.
- Platelets are fragments of cells that work to reduce blood loss by forming clots in the case of injury.
- The major organs of the mammalian circulatory system are the heart, arteries, veins and capillaries. Arteries have thick, muscular walls; vein walls are thinner but veins have a bigger central cavity and contain valves. Capillaries are very thin-walled and narrow.
- The muscular mammalian heart has four chambers: two atria and two ventricles. Structures including valves in the heart ensure blood flows in one direction around the body.
- Gas exchange surfaces need to be moist, thin and permeable, have a large surface area and be in a situation where there is a concentration gradient.
- Gas exchange surfaces are varied: they include lungs (alveoli), spiracles, skin and gills.
- In mammals, air passes into the mouth and nose and travels through to the alveoli in the lungs.
- Gas exchange in humans takes place between the alveoli and the capillaries that surround them.
- Fish exchange gases between the external and internal environment via their gills.
- Digestion is the process where large, complex molecules are broken down into simple substances. Mechanical digestion is the physical breakdown of substances, and chemical digestion is when agents including enzymes change the chemical structure of substances to produce smaller molecules.
- The role of the digestive system includes ingestion, digestion, absorption and egestion.
- Starch digestion starts in the mouth, and protein digestion starts in the stomach. Digestion is completed and most nutrients are absorbed in the small intestine. The pancreas secretes the main digestive enzymes. Bile from the liver helps in fat digestion.
- The excretory system removes nitrogenous wastes from the body. Kidneys are the organs where filtration of blood and regulation of blood water content occurs.
- Kidneys have many nephrons. The start of a nephron is cup-shaped (Bowman's capsule). It continues as three tubular regions (the proximal tubule, loop of Henle and distal tubule, which empties into a collecting duct).
- Blood pressure forces water and small solutes from capillaries into the Bowman's capsule. Most of the filtrate gets reabsorbed from the tubules and is returned to the blood.
- The organ systems in animals are interdependent.

CHAPTER 12 GLOSSARY

Abomasum the true stomach of ruminant or cud-chewing mammals, which have a four-chambered stomach

Absorption the main role of the digestive system; the taking up of digested molecules

Alimentary canal the specialised pathway food takes in complex animals; it includes the passage from mouth to anus, with all the organs food passes through

Alveoli (singular alveolus) the tiny air sacs located on the end of the bronchioles

Amylase an enzyme that digests starch; present in saliva and secreted from salivary glands near the base of the tongue

Aorta the largest artery; it carries blood that is leaving the heart to flow to all parts of the body (i.e. the systemic circulation)

Aortic valve the valve between the left ventricle and aorta

Arteriole a small artery

Artery a blood vessel that takes blood away from the heart

Atrium (plural atria) a thin-walled chamber of the heart into which blood from the body arrives

Atrioventricular valve the valve between the atrium and ventricle

Bile a substance produced by the liver that moves into the duodenum; it has a detergent-like action that helps in mechanical digestion of fats

Bowman's capsule the structure in which the glomerulus is found, at the beginning of the nephron

Bronchi (singular bronchus) the branches of the trachea that lead to the lungs

Bronchiole a smaller tube of the bronchus

Capillary a very small blood vessel, found between arteries and veins

Carbonic acid the substance to which most of the carbon dioxide produced in respiration is converted in the plasma

Cardiovascular system see *circulatory system*

Carnivore an animal whose diet consists of animal flesh

Chemical digestion a process whereby complex substances are broken down into their simplest forms via enzyme action

Chyme the 'soupy' contents of the stomach (partially digested food)

Circulatory system the heart, blood and blood vessels that ensure nutrients and wastes are carried around the body as needed

Closed circulatory system a type of circulatory system in which blood is circulated inside vessels; more efficient than an open circulatory system

Dentition the type of teeth of an animal, which is specialised and reflects the animal's diet

Diaphragm the muscular organ that, along with the muscles between the ribs, moves air into and out of the lungs

Digestion the breaking down of complex organic molecules mechanically and chemically

Digestive system the series of organs where digestion takes place; also known as the gastrointestinal tract

Distal tubule the portion of the nephron between the loop of Henle and the collecting duct

Double circulatory system a circulatory system that has two circuits: the pulmonary circuit, which transports blood to the lungs and then back to the heart, and the systemic circuit, which pumps blood around the body and back to the heart

Egestion the removal of waste food materials from the body

Endothermic describes animals that are able to maintain relatively constant body temperature using heat by metabolism

Epiglottis a small flap of tissue that closes off the trachea, ensuring food travels down the oesophagus to the stomach, and not into the lungs

Erythrocyte a red blood cell that is non-nucleated when mature; contains haemoglobin pigment that transports oxygen from the lungs to the tissues

External environment (of a cell) the environment surrounding a cell, outside the cell membrane

Faeces the waste material eliminated from the body through the anus

Filament a component of gills; each contains numerous gill plates to greatly increase the surface area of the gill

Filtrate the fluid filtered from blood that passes through the nephron

Filtration a separation technique used by kidneys to remove metabolic wastes from the blood and form urine

Gall bladder the organ that stores bile if there is no food to digest in the small intestine

Gas exchange (in animals) the diffusion of oxygen from the external to the internal environment and carbon dioxide from the internal to the external environment

Gastric juice a substance produced when food is in the stomach; contains mucus, water, hydrochloric acid, and pepsin and protease enzymes

Gastrointestinal tract see *digestive system*

Gastrovascular cavity a central cavity with a single opening that functions to transport substances and in digestion; occurs in simple animals

Gill the respiratory organ of fish, and some amphibians, in which oxygen is extracted from water flowing over internal surfaces

Glomerulus a network of capillaries located in the Bowman's capsule of the kidney, where the first step in filtering the blood through the nephron occurs

Haemoglobin the respiratory pigment of most vertebrates and some invertebrates; contains iron

Haemolymph the fluid in open circulatory systems

Herbivore an animal whose diet consists of plant or plant products

Ingestion the taking in of nutrients

Internal environment (of a cell) all material contained within the cell membrane

Interstitial fluid the fluid between the cells of a multicellular organism

Kidney an organ that excretes the urea dissolved in the blood out of the body via the bladder

Large intestine the final length of the gut, consisting of the colon and the rectum; functions to compact undigested food material, and absorb water and some salts back into the body

Larynx the voice box

Leukocyte a type of white blood cell that forms in both lymph glands and bone marrow, and defends the human body against infectious diseases and foreign particles; the number circulating increases when injury or infection occurs

Loop of Henle the portion of a nephron that connects the proximal convoluted tubule to the distal convoluted tubule

Lymph vessel a thin-walled tube with valves that carries lymph around the body

Mechanical digestion the process whereby large pieces of food are broken down through chewing or muscular movement in the stomach

Nephron the structure of the kidney where filtration of the blood occurs

Oesophagus a vessel that transports food from mouth to stomach

Omnivorous describes a diet consisting of both animal and plant foods

Open circulatory system a circulatory system in which transport liquid washes freely over the internal organs; less efficient than a closed circulatory system

Opercular cavity the cavity in which the gills of bony fish are located

Operculum a protective covering over the gills in bony fish

Pancreatic juice the secretions released by the pancreas into the small intestine via the duodenum; contains amylase, trypsin and lipase

Peristalsis the unidirectional muscular contractions that enable food to move down the oesophagus

Plasma the pale-yellow liquid component of the blood that holds blood cells, proteins and nutrients in suspension

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Platelet a small cell fragment involved in the clotting property of the blood

Proximal tubule the section of the tubule in the nephron that leads from the Bowman's capsule to the loop of Henle

Pulmonary circulation the system of vessels that carries blood to and from the lungs

Pulmonary valve the valve between the right ventricle and the pulmonary artery

Reabsorption the movement of molecules, ions and water needed by the body, from the filtrate, through the nephron and capillary walls, back into the blood

Renal artery the branch of the aorta that brings blood (containing nitrogenous waste and water, blood proteins, red blood cells and minerals dissolved in the blood plasma) to the kidneys

Renal pelvis the section of the kidney where urine is collected and directed to the ureter

Reticulum the first chamber of the four-chambered stomach of ruminant or cud-chewing mammals

Rumen the largest chamber of the four-chambered stomach of ruminant or cud-chewing mammals

Secretion (general) the release of certain substances from cells to their external environment; also, the substances secreted; (in excretion) the transfer of substances into the collecting duct of the nephron, adding to a collection of substances that form urine

Septum the heart wall that keeps the deoxygenated blood on the right side of the heart from mixing with the oxygenated blood on the left side

Single circulatory system a circulatory system that has only one circuit, such as is found in fish; the heart pumps blood to the respiratory surface to be oxygenated and it then flows to the rest of the body under low pressure

Sphincter a small, muscular opening that surrounds tube-like organs and controls the passage of material from or to an organ by contracting and relaxing

Stomach a muscular part of the gut that holds food and releases protein-digesting enzymes and hydrochloric acid

Systemic circulation the system of blood vessels that circulate blood to most of the body

Tongue an organ that helps to move the food around the mouth and increases food contact with the teeth

Trachea an organ that carries gases to the lungs via the bronchi and bronchioles; it is strengthened with rings of cartilage to stop it collapsing

Tracheal system in insects, a system of tubes made of chitin that allows oxygen to pass in by diffusion; the mechanism for gas exchange in insects

Urea a water-soluble nitrogenous waste product excreted by terrestrial mammals, including humans; formed by the breakdown of amino acids in the liver

Urine the liquid excreted by animals that contains waste products filtered by the kidneys and stored in the bladder

Valve a flap that ensures blood moves in one direction only through the heart and veins

Vein a blood vessel that carries blood towards the heart

Vena cava the vein that delivers deoxygenated blood from most of the body to the right atrium

Ventricle a muscular chamber of the heart which pumps blood away from the heart

Venule a small vein

Villi the projections from the surface of the small intestine that increase its surface area and thus increase absorption

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CHAPTER 12 REVIEW QUESTIONS

Remembering

1 Name the organs that make up the following human body systems.
   a circulatory system
   b respiratory system
   c digestive system
   d excretory system
2 Name where in the body the following processes occur.
   a production of urine
   b absorption of amino acids
   c absorption of water from the products of digestion
   d absorption of oxygen into the blood stream
   e digestion of protein
   f digestion of complex carbohydrates
   g ingestion

Understanding

3 List the body systems that ensure all cells receive or achieve the following.
   a oxygen
   b amino acids
   c lipids
   d removal of waste products from the blood
4 Prepare a table that lists all the sections of the human alimentary canal and describe what occurs in each section.
5 Describe the differences in the structures involved in systemic and pulmonary circulation.
6 Valves are membranous structures found in some blood vessels and between various chambers of the heart. Explain how the material from which they are made helps them undertake their function.
7 Visit the weblink 'Structure and function of the heart' and complete the quiz.
8 Define the following terms and describe their role in the human kidney.
   a renal pelvis
   b nephron
   c loop of Henle
   d collecting duct

Structure and function of the heart
Take this short quiz to test your knowledge of the various heart structures.

Applying

9 Imagine you have eaten a very large meal of fish. Fish contains a lot of protein and a small amount of fat. Outline how the structure and function of your digestive system will assist the delivery of amino acids to your cells.
10 If you suffered a major cut to an artery causing severe blood loss, part of the treatment after stopping the bleeding would be to wrap you in a thermal blanket and place an intravenous drip into a vein. Explain why these two steps are necessary.

Analysing

11 Cows do not have canine teeth, but have many flat molars for grinding their food. Explain how this assists them in gaining their nutrition.
12 Draw an annotated diagram showing the mechanisms at work for inhalation and exhalation.

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Evaluating

13 The major function of the large intestine is to absorb water. If you were suffering from diarrhoea, you would absorb 10 mL of water over 4 hours. If you were suffering from constipation, you would absorb 100 mL over 4 hours. Predict the amount of water you would absorb if you were not suffering from either condition.

14 Explain why pepsin is only functional in the stomach.

Creating

15 Create a poster to show diagrammatically how two or more of the systems discussed in this chapter are interdependent.

PRACTICE EXAM QUESTIONS

1 The element nitrogen always occurs in which of the following organic compounds?

A proteins
B carbohydrates
C lipids (fats)
D starches

[Q3 2011 Stage 2 WACE exam 2011 SCSA]

2 Insects have an open circulatory system. In open circulatory systems:

A there are no blood vessels.
B the heart has three chambers.
C the heart has four chambers.
D the internal organs are bathed in blood.

[Q14 2011 Stage 2 WACE exam 2011 SCSA]

3 Small, flat, simple organisms do not require a specialised internal circulatory system. The main reason is because they:

A are so small and simple.
B have a large surface-area-to-volume ratio.
C have a small surface-area-to-volume ratio.
D require very small amounts of gases and nutrients.

4 The human alimentary canal consists of many parts. Which of the following correctly lists some of these parts in the order that food travels through them?

A small intestine, large intestine, anus, rectum
B stomach, pancreas, duodenum, small intestine
C stomach, small intestine, large intestine, rectum
D trachea, stomach, small intestine, large intestine

5 Draw and label the four chambers of the human heart. Indicate which chamber receives oxygenated blood. (5 marks)

6 The lung is the respiratory organ of mammals. However, respiration occurs in the cells. Using mammals as an example, explain how:

a oxygen is transported from the external environment to the body cells (5 marks)
b carbon dioxide is transported from the body cells to the external environment. (5 marks)

[Q38 2010 Stage 2 WACE exam 2011 SCSA]

7 There is a common mechanism of gas exchange between the external and internal environment for all living organisms. Name this process and describe it. (3 marks)

8 Gas exchange surfaces have common features. Account for four of them. (4 marks)

9 a Give an example of an animal that has an open circulatory system and one that has a closed circulatory system.
b Describe the difference between these two systems. (6 marks)

10 Spiracles and gills are two types of gas exchange surface. Name an example of an animal that has each type of surface, and compare and contrast two main structures and functions. (10 marks)

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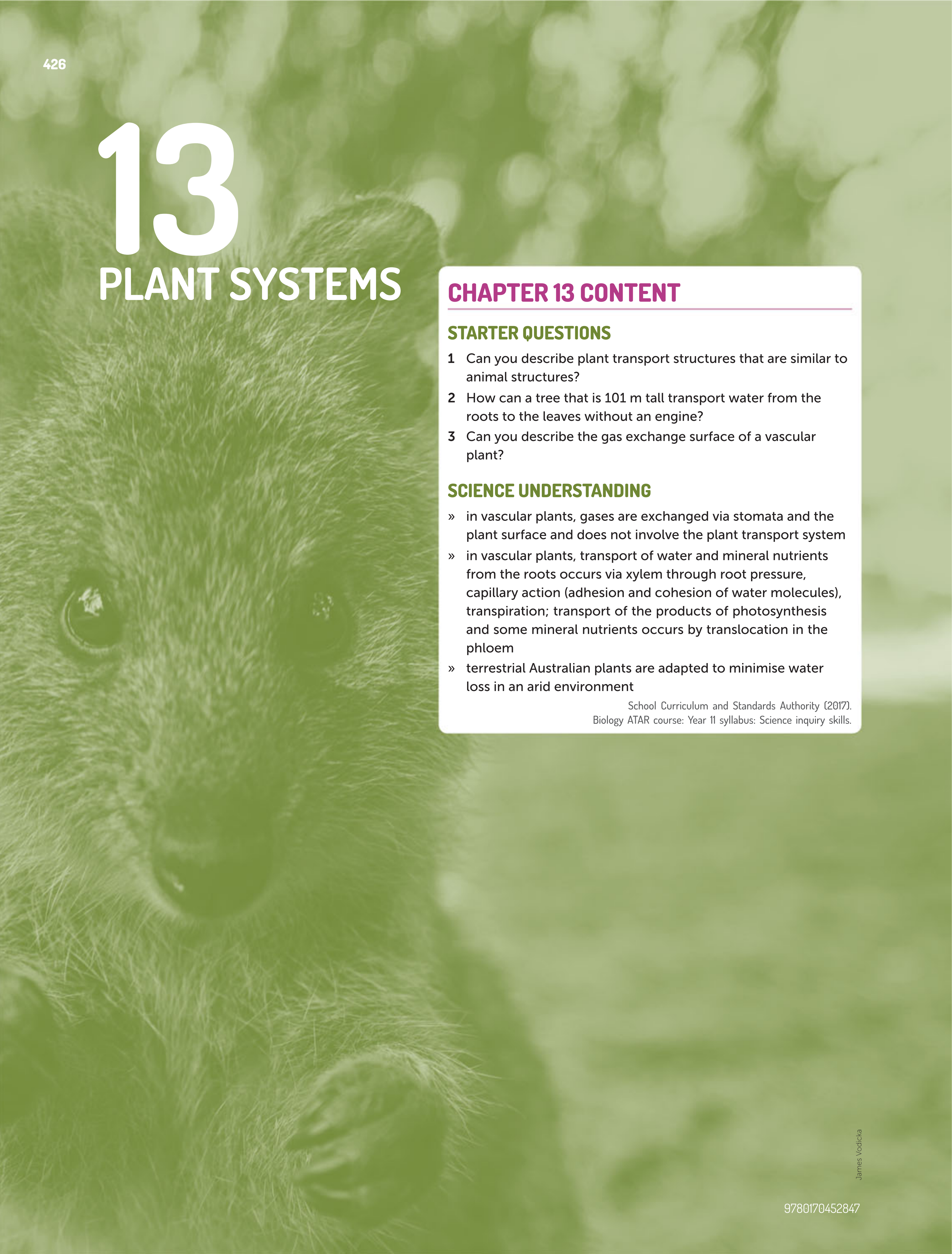

James Vodicka

13 PLANT SYSTEMS

CHAPTER 13 CONTENT

STARTER QUESTIONS

1 Can you describe plant transport structures that are similar to animal structures?

2 How can a tree that is 101 m tall transport water from the roots to the leaves without an engine?

3 Can you describe the gas exchange surface of a vascular plant?

SCIENCE UNDERSTANDING

» in vascular plants, gases are exchanged via stomata and the plant surface and does not involve the plant transport system

» in vascular plants, transport of water and mineral nutrients from the roots occurs via xylem through root pressure, capillary action (adhesion and cohesion of water molecules), transpiration; transport of the products of photosynthesis and some mineral nutrients occurs by translocation in the phloem

» terrestrial Australian plants are adapted to minimise water loss in an arid environment

School Curriculum and Standards Authority (2017).
Biology ATAR course: Year 11 syllabus: Science inquiry skills.

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13.1 VASCULAR PLANT STRUCTURE AND FUNCTION

The tallest flowering tree species in the world is *Eucalyptus regnans*. Known as mountain ash in Victoria and swamp gum in Tasmania, there is one specimen a few kilometres from Hobart that is 101 m tall. Aptly named 'Centurion', this particular swamp gum is estimated to be approximately 400 years old. At some stage in its life the crown appears to have snapped off and regrown. Because redwoods are classified as conifers, Centurion currently represents the tallest flowering plant, the tallest hardwood tree and the tallest eucalypt in the world. One of the greatest physiological challenges for tall trees is how to draw water and **nutrients** from the roots to the canopy. A tree like Centurion must draw many litres of water more than 100 m high, and against the force of gravity.

Plants have specialised cells that make up **tissues** with specific functions to assist in their survival. Like in animal systems, individual specialist plant cells are organised into tissues (such as photosynthetic tissue), which form the organs (such as the leaf) of the plant body. Each of these tissues is specialised to perform important functions that support the life of the organism. These include obtaining energy, producing organic compounds, distributing materials, removing wastes and exchanging gases.

Simple, **non-vascular** plants do not have roots but do contain simple leaves. They live in moist environments and are relatively small plants. The focus of this chapter is on the more complex and larger vascular plants. Recall from Unit 1 that **vascular plants** contain vascular tissue; tissue that

Forestry Tasmania, photo by David Mannes

FIGURE 13.1 'Centurion' in Tasmania is an example of *E. regnans*, the tallest flowering plant species in the world.

transports water and nutrients around the plant body. **Vascular tissue**, which connect the roots and stem in a plant, include the **xylem** (which transports water) and the **phloem** (which transports sugar, the product of photosynthesis).

The structure of a vascular plant ensures that each organ – the leaves, stem, roots, flowers and seeds – receives what it needs. The organs are organised into systems. In plants there are two systems: the shoot system and the root system.

1 The shoot system is comprised of all the parts of the plant found above ground: leaves, stem, flowers and seeds. It is responsible for the transportation of resources, the absorption of oxygen and carbon dioxide, reproduction and carrying out photosynthesis in leaves.
2 The root system is below ground and is responsible for absorbing water and nutrients from the soil. Water moves into the root system via **osmosis** (the movement of water across a selectively permeable membrane from a region of low solute concentration to one of high solute concentration). Nutrients in the form of ions enter via diffusion or **active transport**.

FIGURE 13.2 Liverworts are non-vascular plants with thin, simple leaves and no roots.

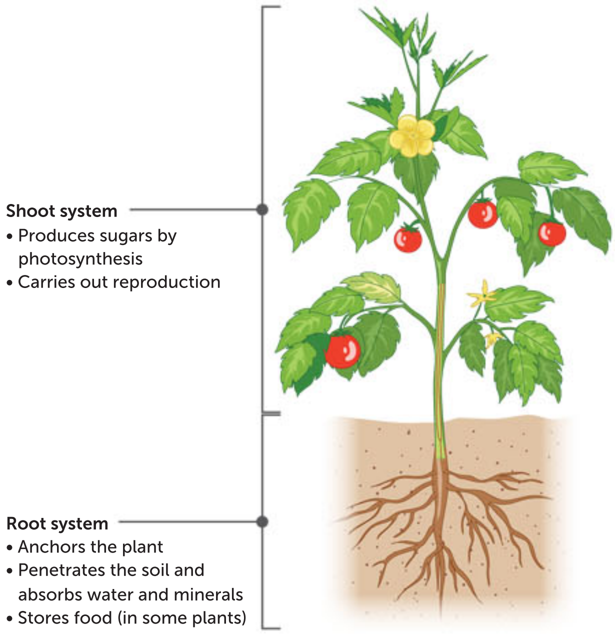


FIGURE 13.3 Vascular plants have structures that are more complex than those in simple plants. Their structures are organised into systems.

Key concept

Non-vascular plants are small, live in moist environments, and have simple leaves but no roots. Vascular plants contain vascular tissues (xylem and phloem) that transport water and nutrients around the plant body. They have two systems: the shoot system and the root system.

Vascular tissue

In a vascular plant, there are specialised cells and tissues called vascular tissues that distribute organic compounds (mostly products of photosynthesis), water, minerals and gases around the plant. Vascular tissue is composed of two different types of tissues: xylem and phloem.

Xylem is responsible for the transport of water, along with minerals and other nutrients needed for growth and other processes, from the roots to the leaves in one direction (unidirectional); this occurs after water is absorbed from the soil through the root system via osmosis into **root hair** cells. Xylem consists of tubular, elongated cells that allow water to pass freely. As xylem cells mature, they die, leaving behind hollow cells supported by the remaining cell walls. These are ideally suited to the transport of water. The dead xylem tissue forms the woody part of many plant stems. Wood is composed entirely of xylem tissue and provides the main support for most large plants such as trees.

Phloem transports sugars, in the form of sucrose, and other photosynthesis products from one part of a plant (usually where they are made, the leaves, or where they are stored, the roots) to where they are needed and therefore transportation can be in either direction. Phloem consists of conductive tissue composed of thin-walled cells. Unlike mature xylem cells, which are dead, phloem cells are living. There are two types of phloem cells: sieve tube cells and companion cells. **Sieve tube cells** are long, thin phloem cells that have large pores through the cell walls at either end. These cells have no nuclei, mitochondria or vacuoles. The sieve tube cells are arranged end-to-end into sieve tubes.

The sieve tube cells share cytoplasm. As a result, each sieve tube forms a channel through which sugars and other plant products can flow. **Companion cells** are phloem cells that are found alongside the sieve tubes. Companion cells have a cell nucleus and other cell organelles that are lacking in the sieve tube cells. They control the activities of the sieve tube cells. In trees, the phloem is the innermost part of the bark.

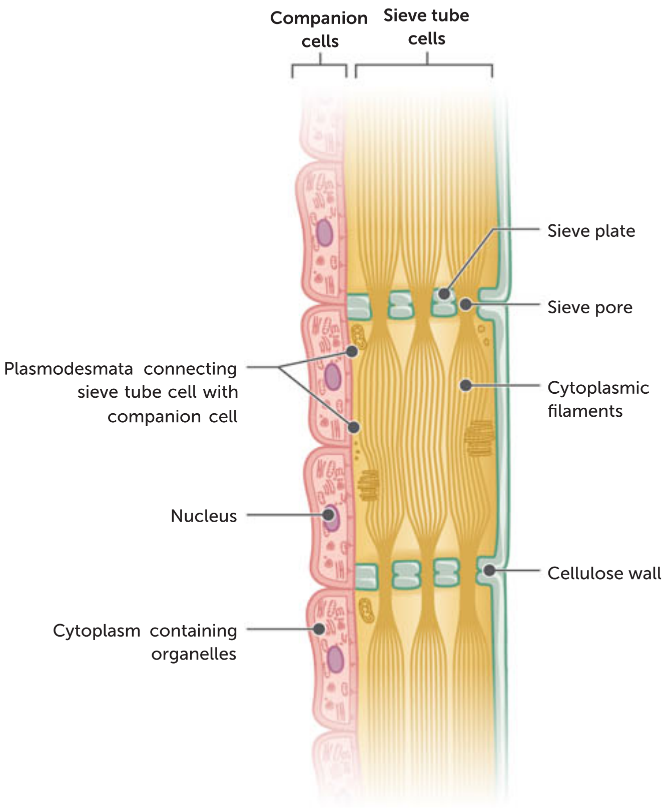


FIGURE 13.4 The two types of phloem cells: sieve tube cells, with the sieve plates connecting the cells, and companion cells

The functioning plant

As with any living organism, the eucalypt has specific processes to ensure the inputs it uses are maximised; and then outputs are either utilised or removed. In plants, some of these processes occur within the individual cells.

Two processes that take place in plant cells are photosynthesis and cellular respiration. For photosynthesis to occur, the necessary inputs need to reach the leaves, which are the photosynthetic organs of the plant. Apart from taking in water and carbon dioxide, the leaves also need maximum exposure to sunlight. Gases such as carbon dioxide and oxygen are exchanged via stomata and the plant surface. The organic substances produced in photosynthesis then need to be distributed, via the phloem, throughout the plant root and shoot systems to where they are either used or stored.

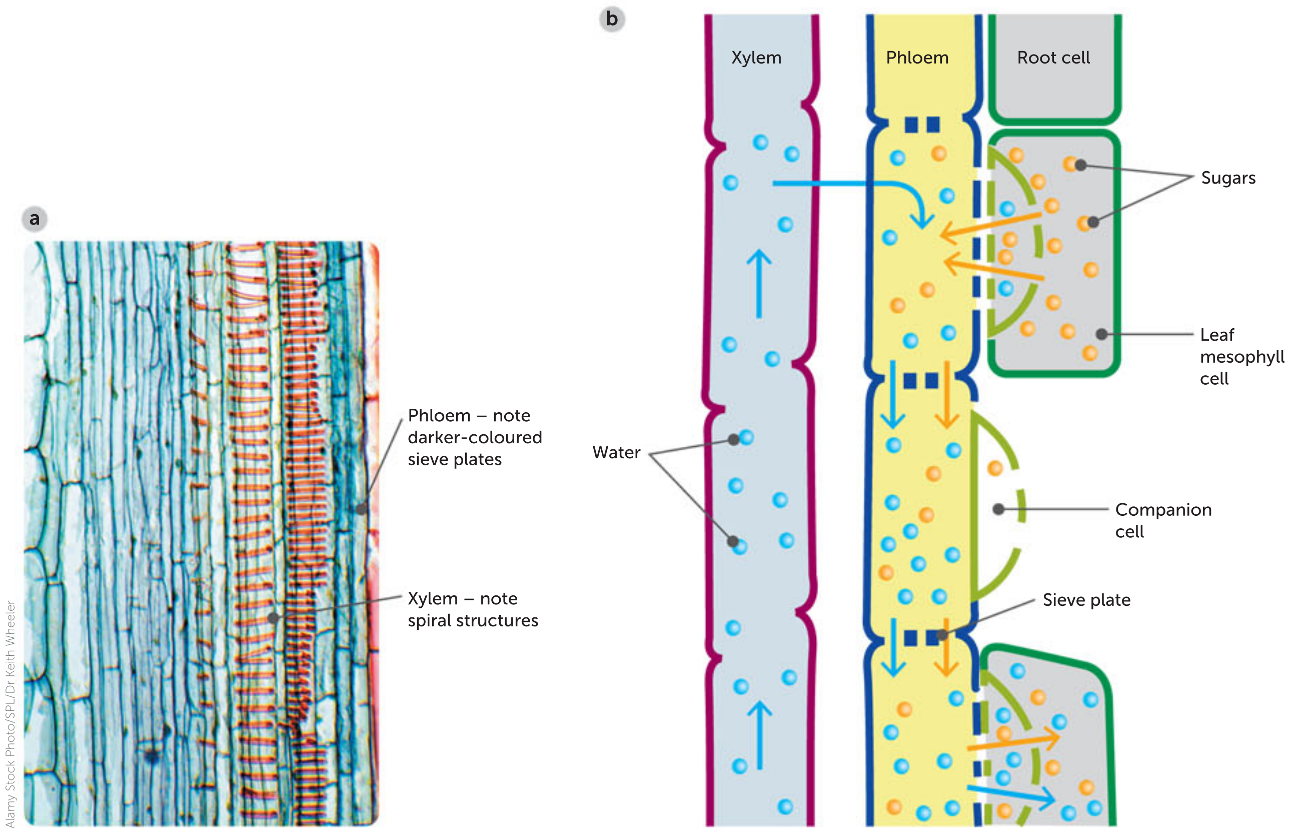


FIGURE 13.5 a A micrograph of a longitudinal section of a stem, showing both xylem and phloem; **b** a schematic diagram of vascular tissue, showing the movement of water (blue arrows) and sugars (red arrows). Sugar is moved into the sieve tube cells against a concentration gradient. This causes water to move from the xylem by osmosis into the sieve tube cells.

Transport of water and sugar in plants
This animation shows plant transport, demonstrating how water travels through the plant and how sugars are distributed around the plant.

Xylem and phloem
Watch parts 1–3 to build a better understanding of vascular plant transport.

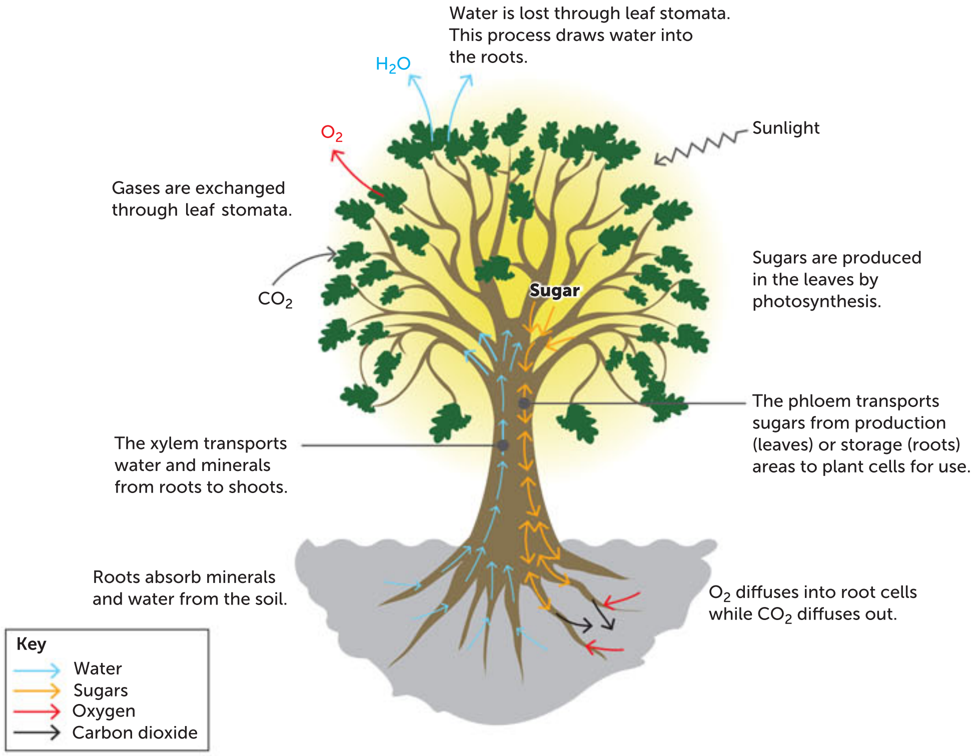


FIGURE 13.6 A summary of transport in a vascular plant

Question set 13.1

REMEMBERING

1 State the main function of the following vascular tissues:

a xylem

b phloem.

UNDERSTANDING

2 List the essential requirements of a vascular plant, such as a eucalypt. Name the processes that need these requirements.

3 Compare the structure and function of the xylem and phloem cells.

4 Explain why a vascular plant requires a root system and a shoot system.

13.2 PLANT GAS EXCHANGE

In vascular plants, gases are exchanged via stomata and the plant surface. Gas exchange can occur independent of the plant transport system.

Plants obtain carbon dioxide gas, which they need for photosynthesis, through their leaves. The gases diffuse into the intercellular spaces of the leaf through pores called stomata. **Stomata** (singular stoma) are tiny openings in the surface (**epidermis**) of a plant leaf through which gases can enter or exit. They are normally found on the underside of the leaf. From the intercellular spaces, gases diffuse into the cells that require them. Each stoma consists of a central 'pore' or opening, surrounded by two guard cells.

Guard cells are pairs of cells that open and close a stoma to control the entry and exit of gases. A change in the amount of water inside a pair of guard cells causes them to change shape, which can open or close the stoma. When the guard cells swell with water, they are described as **turgid**. Due to the relatively rigid (inelastic) inner wall and non-rigid (elastic) outer wall, the turgid guard cells bend and draw away from each other, resulting in an open stoma, and allowing gas exchange. When the guard cells shrink from lack of water, they are described as **flaccid** and this closes the stoma, preventing gas exchange. Gases that are exchanged include carbon dioxide, water vapour and oxygen.

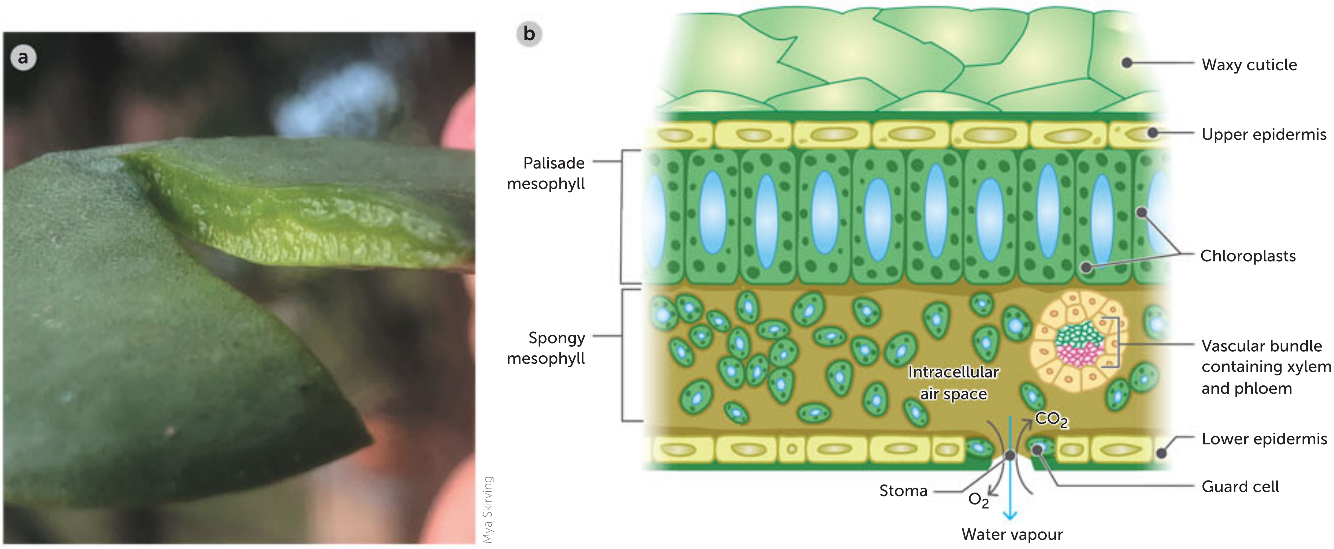
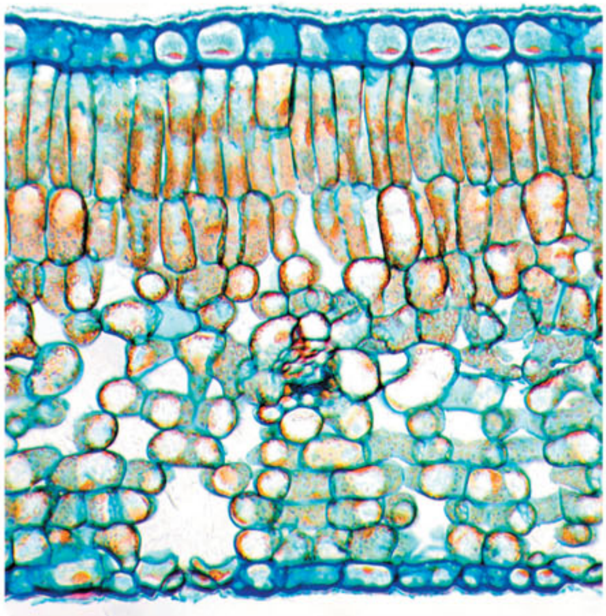


FIGURE 13.7 a Cross-section of *Echeveria* leaf; **b** cross-sectional diagram of a leaf showing where gas exchange takes place

Leaf structure
Watch this video to understand more about the structure of the leaf.

Usually, carbon dioxide enters, and water vapour and oxygen exit, via the stomata. Carbon dioxide is used in the process of photosynthesis in cells with chloroplasts, such as spongy **mesophyll cells** and **palisade cells**, found in the leaf of a plant. Oxygen is a product of photosynthesis. Any excess oxygen produced and not used for respiration exits via the stomata. Respiration occurs throughout the day and night, providing the plant with a usable form of energy called ATP. In contrast, photosynthesis only occurs during sunlight hours. Consequently, the rate of photosynthesis is much faster during the day compared to the rate of respiration. Water vapour exits through the stomata from the plant's water transport system if it is not used by the plant for metabolic processes such as photosynthesis or respiration.



Alamy Stock Photo/Science Photo Library

FIGURE 13.8 Light micrograph of a cross-section through a leaf (*Camellia sinensis*)

The plant has some control over the opening and closing of the stomata. To open the stomata, potassium ions are pumped into the guard cells by active transport. In this process, a potassium ion pump uses energy in the form of ATP to transport potassium into the guard cell. Recall that osmosis is the movement of water from an area of low solute concentration to an area of high solute concentration. As salts accumulate, a concentration gradient is created that draws water into the guard cell by osmosis. The guard cells swell as they fill with water, becoming turgid. A cell with high **turgor** experiences high pressure from a vacuole pushing against the cell wall. The guard cells become curved, which opens the stoma. Gas exchange is able to proceed through the stoma.

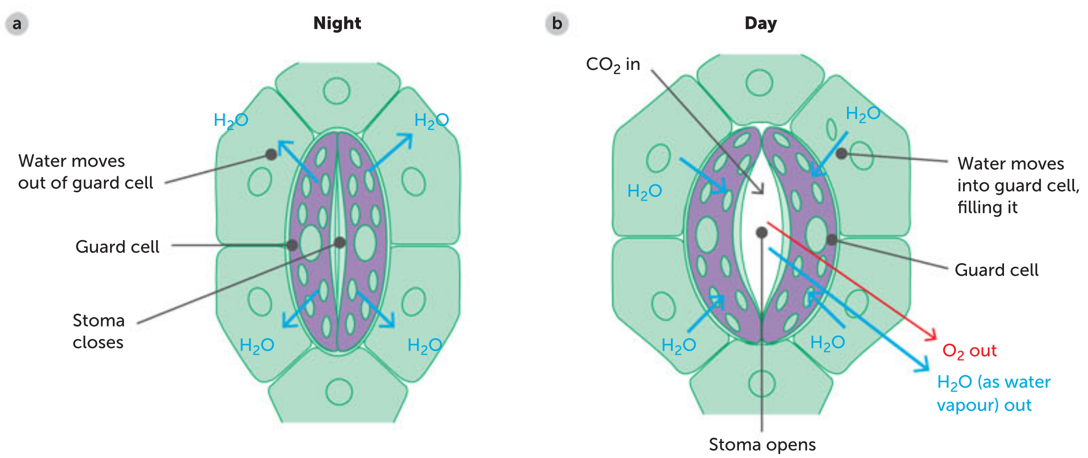


FIGURE 13.9 A schematic diagram of a stoma. The opening is surrounded by two guard cells, which can change shape to control the size of the opening. **a** When the stomata are closed, the leaf is sealed off from the outside. **b** When the stomata are open, gases, including carbon dioxide, are able to enter the leaf, while water vapour and oxygen gas escape. The movement of the guard cells occurs because of changes in turgor.

When a plant is affected by environmental conditions such as drought or heat, the reverse process occurs. Guard cells pump potassium ions out of the cell, and water is drawn out of the cells by osmosis and moves back into surrounding epidermal cells. The guard cells become flaccid and the gap between the two guard cells closes. Gas exchange ceases because the stoma is closed.

The timing of the opening and closing of stomata depends on a number of environmental factors. Under normal conditions, stomata open at daybreak and close at night, so light appears to be the main factor that initiates opening. Other conditions, however, can override the effects of light. For example, on a warm, sunny day, as the temperature increases, more and more water vapour is lost through the open stomata. If the water loss exceeds the uptake of water from the soil, the water content of the plant falls. Eventually, the guard cells will begin to lose their water and the stomata will close. Under conditions of decreased water availability, photosynthesis may be reduced and the concentration of carbon dioxide inside the leaf will rise. This also causes the stomata to close and no further carbon dioxide will diffuse into the plant. Conversely, a fall in the internal concentration of carbon dioxide can cause the stomata to open, allowing carbon dioxide to diffuse into the plant.

High levels of **humidity** can also affect the stomata. If the air is saturated with water vapour, the rate of water loss from the leaf cells is reduced, enabling the stomata to remain open. When the stomata are open, however, water is also lost through them as water vapour. If too much water is lost, the plant wilts. Plants need to balance their requirements for gases with their ability to withstand water loss.

Key concept

Vascular plants exchange gases with the atmosphere via open stomata on the underside of the plant surface.

Question set 13.2

REMEMBERING

1 Distinguish between the terms stoma, stomata and guard cells.
2 Name the three gases that are exchanged via stomata.
3 Recall the process by which gases move in and out of leaf cells. Compare this to how gases are transferred in root cells.

UNDERSTANDING

4 Identify the source and use of each of the three gases that move in and out of the leaf cell.
5 Draw and label diagrams of the following:
   a a stoma with a pair of guard cells that are turgid and then a stoma with a pair of guard cells that are flaccid
   b a cross-section of a leaf where gas exchange takes place.

13.3 PLANT TRANSPORT

Plants and animals have some similar basic functional demands. They all need to transport materials, such as water, sugars and mineral nutrients, from one part of the body to another. As we have seen, instead of having a circulatory system with blood vessels, plants transport water and materials inside xylem and phloem.

The transport of water and mineral nutrients from the roots occurs via the xylem as a result of root pressure, capillary action (adhesion and cohesion of water molecules) and **transpiration**. Transport of the products of photosynthesis and some mineral nutrients occurs by translocation in the phloem.

Plant structure and adaptations
Watch this introduction to vascular plants, their structures and adaptations.

Transport through the xylem: root pressure, capillary action and transpiration

All plants need to be able to get water to their leaves. Water is absorbed initially by the roots and moves against the pull of gravity through the stem to the leaves. When we look at how that occurs, we find the plant has a one-way water movement system in the xylem.

How does the water in the ground reach the uppermost leaves of the plant? Some of these leaves can be more than 100 m above the ground. Part of the answer lies hidden below ground, in the plant's root system.

Absorption in the root system and root pressure

The roots of a plant have several functions. They absorb water and minerals (in the form of ions) from the soil, support and anchor the plant and, in many plants, they are the main storage tissue. **Absorption** is the movement of water and dissolved substances into a cell, organ or organism.

The roots provide the surface through which water is taken up. Their surface area is greatly increased by the presence of thousands of root hairs, just behind the tip of the root. A plant's root hairs present an enormous surface area across which water is absorbed, due to their long, thin shape. The surface area of its root system can be up to 130 times greater than the surface area of its shoot system.

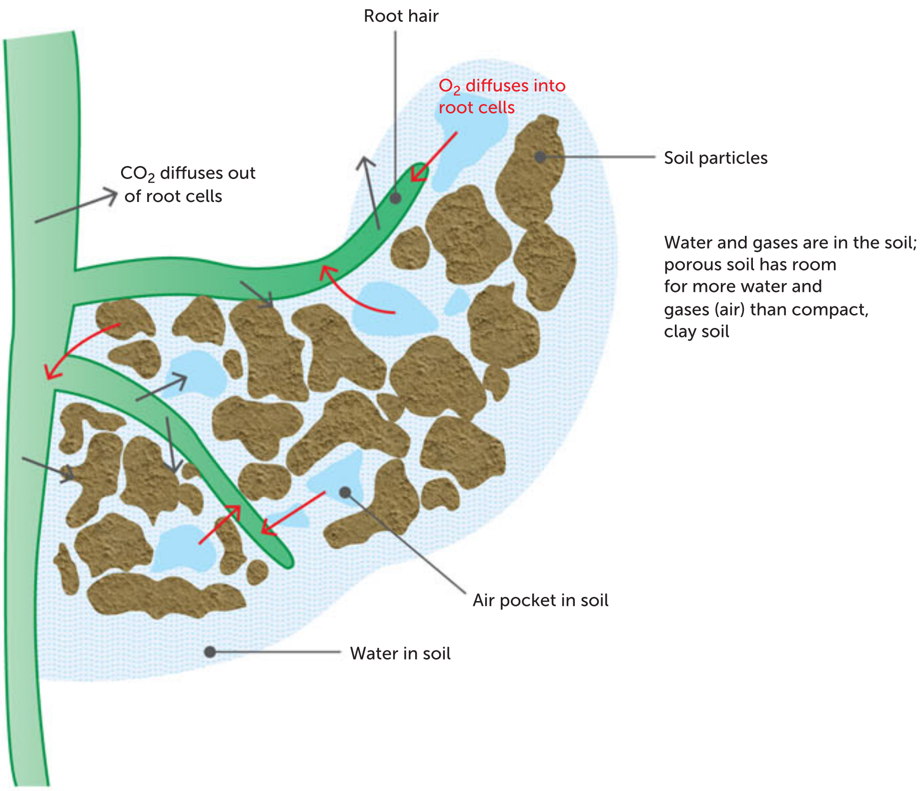


FIGURE 13.10 Gas exchange across root hairs in soil

Each root hair is a slender extension of one of the root epidermal cells that makes up the epidermis. These extensions increase the surface area for water absorption. The root hairs penetrate between the soil particles and are in close contact with the soil water.

Beneath the root's epidermis, large, thin-walled parenchyma cells make up the cortex that constitutes the main body of the root. In the centre, there is a core of vascular tissue that consists of several groups of xylem cells between which are distinct groups of phloem cells. The vascular tissues are arranged in such a way that, as the root grows into the soil, the vascular tissue also extends down the centre of the root, enabling the transportation of materials. As well as their roles in transporting materials, in many plants vascular tissues also strengthen the root system.

Water and dissolved minerals enter the root from the soil by the process of osmosis in the case of water molecules, and by diffusion and active transport in the case of dissolved ions.

Once inside the root hair, the water moves to the parenchyma cells and into the xylem vessel via pits in the cell walls. The force of the water entering the root and 'pushing' its way into the cells creates pressure. If the stem of a plant is severed, the cut end will exude copious amounts of water for some time. This suggests that there is a force pushing water up the stem from the roots. This force is known as **root pressure**. It forces water into the plant and works to ensure that the water and minerals reach the vascular tissue of the stem. Root pressure builds up within a plant due to the osmosis at the roots.

However, there are more processes involved in moving water from roots to leaves than just root pressure.

Key concept

Water and dissolved minerals enter the root from the soil by the process of osmosis in the case of water molecules, and diffusion and active transport in the case of dissolved ions.

Water transport in the shoots and vascular tissues

Water and dissolved minerals continue their journey to the leaves via the stem of the plant. In order to understand how this happens, we must first look at the internal structure of the stem; in particular, the vascular tissues.

The structure of the specialised tissues and their arrangement in the stem makes it possible for water and mineral ions to move upwards, sometimes to great heights. These tissues, along with phloem tissue, are grouped into a series of vascular bundles in the stem, each rather like an electric cable. **Vascular bundles** are sets of tubes of mainly xylem or phloem that run along most of the length of the plant.

We have looked at root pressure created when water enters the plant cells, but what aids the movement of water up the stem as root pressure is reduced? If you examine the surface of water in a glass, you can observe how water curves up against the sides of the glass. It is even easier to see this effect in a measuring cylinder. This can be explained by **adhesion**, the forces of attraction between water molecules and the molecules that make up the inside surface of the container. Xylem vessels are very narrow, so water is able to 'climb' some distance up these tubes due to adhesion forces. There are also forces of attraction between the water molecules themselves which help to pull the molecules up the narrow xylem vessel. This is called **cohesion**. Adding to the force of root pressure, the combined forces of adhesion and cohesion ensure the continuous column of water movement through the xylem tissue in the stem of the plant. The combination of cohesion and adhesion forces that allows water to flow in narrow spaces in opposition to gravitational forces is called **capillary action**. The continuous column of water through the plant is known as the **transpiration stream**. Capillary action is necessary for water to be transported up plant stems in a transpiration stream.

Capillary action video (Water: A Polar Molecule)
Watch this video to find out why water molecules demonstrate cohesion and adhesion forces.

Transpiration video
Follow this with a video to learn more about transpiration.

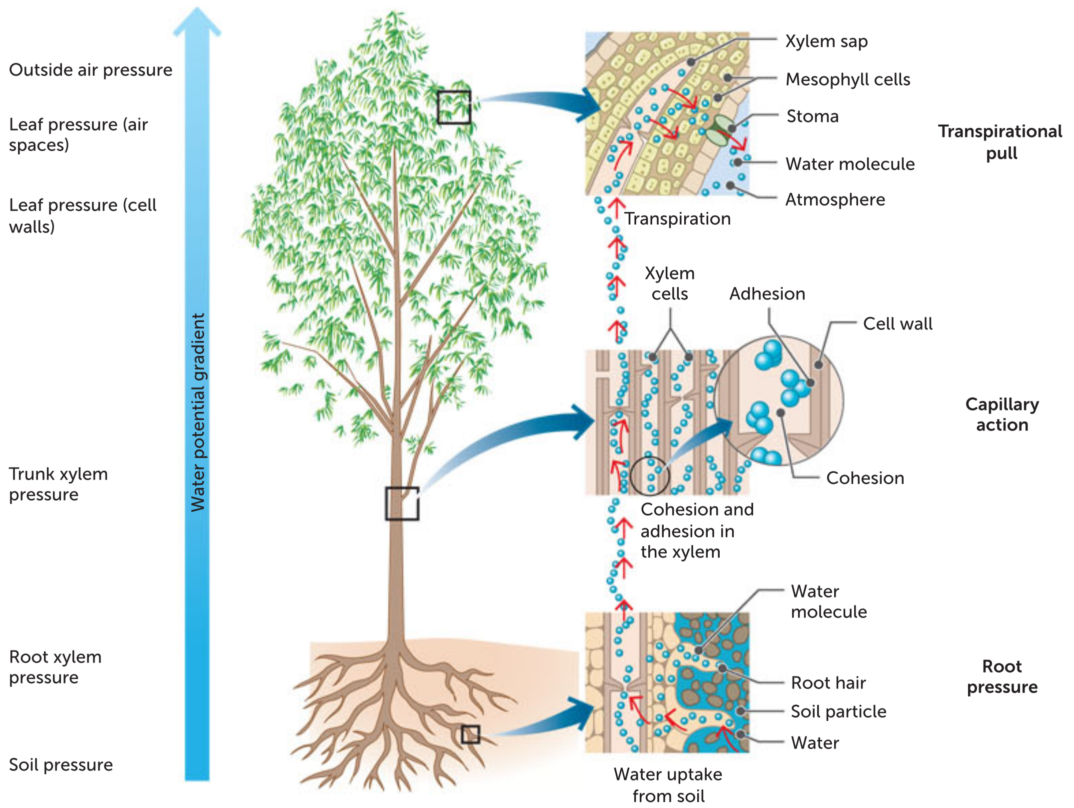


FIGURE 13.11 Water moves from the soil, into the root, up the stem, to the leaves and into the atmosphere, due to root pressure, capillary action and transpirational pull.

Transpiration

The constant upwards movement of the transpiration stream is also driven by the evaporation of water from the leaves, which is called transpiration. Transpiration is the loss of water vapour by evaporation from the surface of a plant, especially via stomata, which are on the underside of leaves. Continuous columns of water therefore exist from the 'top' of the plant, the leaves, down through the xylem to the roots. The force that maintains these columns is generated by energy from the Sun, which evaporates water from the leaf to the atmosphere; by the forces that act on the water in the stem; and by root pressure. This force by which water is pulled up large vertical distances through the xylem is called **transpirational pull**.

Water and minerals are moved passively through xylem due to a combination of root pressure and transpirational pull. Adhesion and cohesion assist with this journey.

When a plant loses more water through transpiration than it takes up through its roots, it wilts and is said to suffer from water stress. The loss of water from the leaves raises the tension of the water columns in the xylem, and the water concentration gradient from the soil to the xylem increases. As a result, the roots remove increasing amounts of water from the soil. Once the flow of the water to the roots slows down, stomata in the leaves close rapidly, thereby reducing water loss to a minimum.

Key concept

In vascular plants, transport of water and mineral nutrients from the roots occurs via xylem due to root pressure, capillary action (adhesion and cohesion of water molecules) and transpiration.

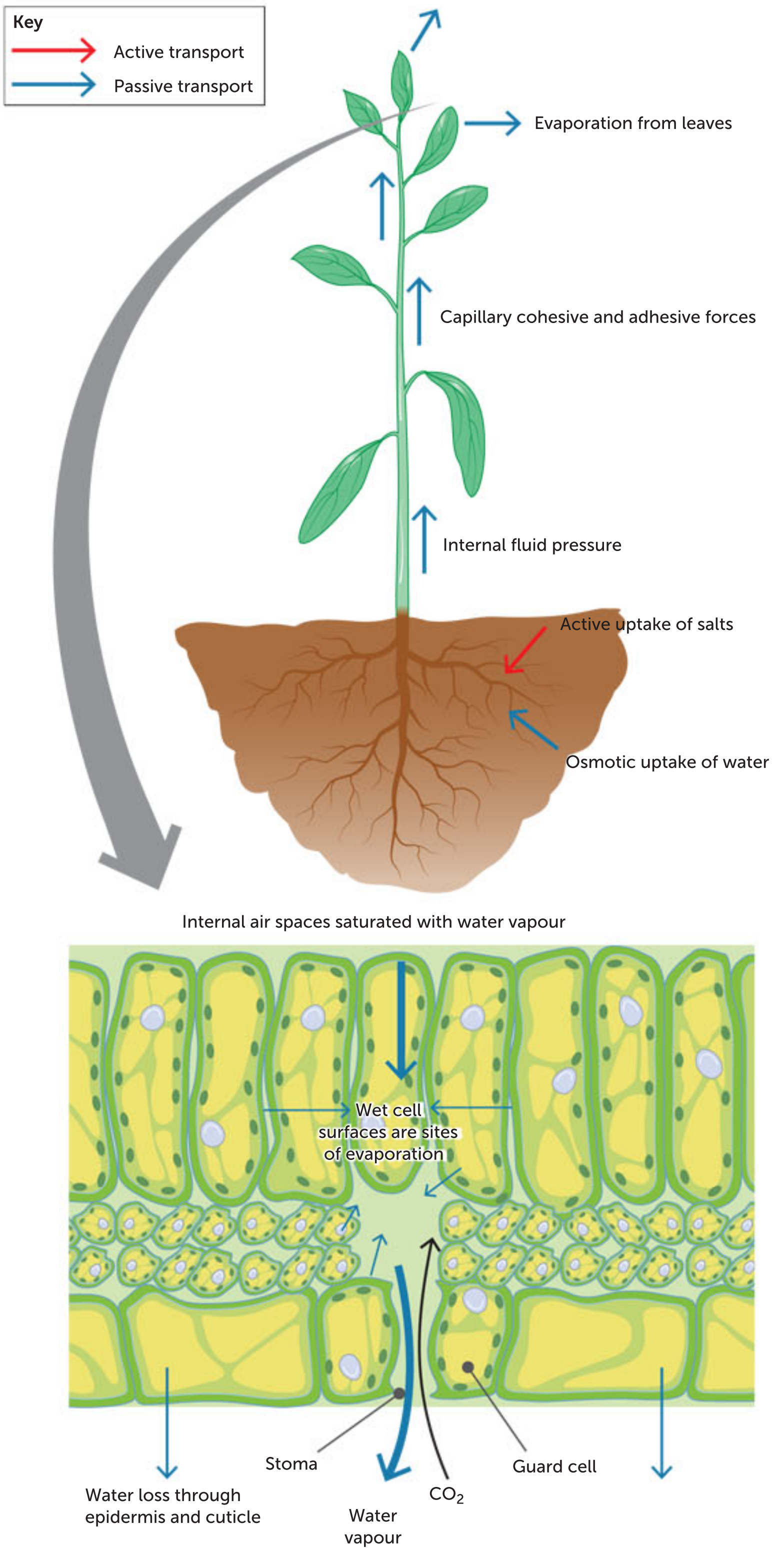


FIGURE 13.12 The process of transpiration in plants is solar powered.

Key concept

Transpiration is the loss of water vapour by evaporation from the surface of a plant, via stomata, which are generally found on the underside of leaves.

There are several factors that can affect the rate of transpiration (and therefore water loss). Some of these environmental factors and their effects are summarised in Table 13.1.

TABLE 13.1 Environmental factors and their effect on transpiration rate (and therefore water loss)

FACTOR	EFFECT
Light	Increase in light increases the rate of transpiration by warming the leaf and opening stomata
Humidity	Decrease in humidity (concentration of water vapour in the air) increases the rate of evaporation and diffusion of water vapour; this leads to an increase in the rate of transpiration because it creates a higher concentration gradient. Low humidity means dry air
Wind	Increase in wind increases the rate of evaporation; this leads to an increase in the rate of transpiration as humid air near the stomata is carried away, increasing the concentration gradient between the surface of the leaf and the area outside the leaf
Temperature	Increase in temperature increases the rate of transpiration due to an increase in evaporation, which increases the concentration gradient between water on the surface of the leaf and the area outside the leaf

Translocation: transport of photosynthesis products and some minerals

All the plant cells that are unable to photosynthesise need an energy source, especially those in the roots, stem and branches where active transport, cell division and growth are taking place. Glucose therefore needs transporting from the site of photosynthesis – which is mostly the leaves – to the stems and roots. Glucose is also known as organic (originating in a living thing) matter and food. Glucose can be stored in different forms, all of which can be used as an energy source for the plant.

The term 'nutrients' refers to substances such as minerals and vitamins. Plant nutrients generally refer to soluble minerals and salts, such as sodium, potassium and phosphorus. They do not provide energy to the cell. These are required for the complex chemistry that runs every cell, so they must also be transported around the plant.

At times when more sugars are produced than can be used by the plant, many plants form tubers, bulbs or corms. Excess products of photosynthesis are transported to these for storage as starch until they are needed. When the next growing season arrives, the stored starch is converted into soluble form and transported to the growing points of the new plant.

Translocation is the active movement of soluble sugars (made during photosynthesis) through the phloem of vascular plants from a source to a sink. It can occur in any direction, depending on the needs

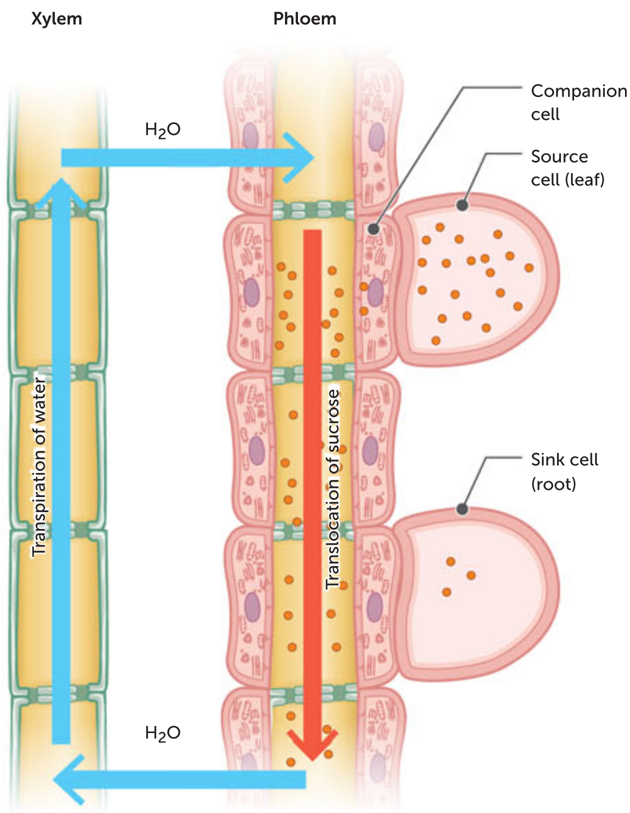


FIGURE 13.13 A comparison of transpiration and translocation

of the plant. Sugars, usually in the form of sucrose, are actively transported against a concentration gradient (from high to low concentration) into the sieve cells. This requires energy. The energy for this comes from the cellular respiration occurring in the mitochondria of the companion cells.

The movement of sugars is always from a source to a sink. A **source** is a plant organ that produces (by photosynthesis) or releases sugar. Leaves are the primary sugar source. A **sink** is a plant organ that uses or stores sugar; for example, growing roots, stems and fruits. A sink can be an area of active growth or sugar storage. The movement of sugars from a source to a sink is via the translocation process.

As the concentration of sugar in the phloem increases, water moves from the xylem by osmosis into the sieve cells. This increases the volume of liquid in the sieve cells, causing the sugary solution to move, usually down to the roots, but also to new growth or to fruits, which may be higher up the plant. The sugar moves from the sieve tube cells into the cells where it is needed for cellular respiration, with water following it, again by osmosis. Unused or stored nutrients can also be translocated out of leaves of deciduous plants before the leaves are dropped in autumn.

Phloem sap is mostly made up of a sugar solution; the sugar is sucrose in most species of plants. Phloem sap may contain up to 30% sucrose by weight, giving it a very syrupy consistency. It is also highly nutritious, which makes it very attractive to the range of sucking insects that feed on it.

As seasons change, plant sources and sinks may change. For example, during spring, materials that were stored through winter may be converted to sucrose and transported to a growing region.

Translocation video
Watch this video to learn more about translocation.

Key concept

In vascular plants, transport of the products of photosynthesis (soluble sugars) and some mineral nutrients occurs by translocation in the phloem, in any direction, from a source to a sink. Translocation uses energy.

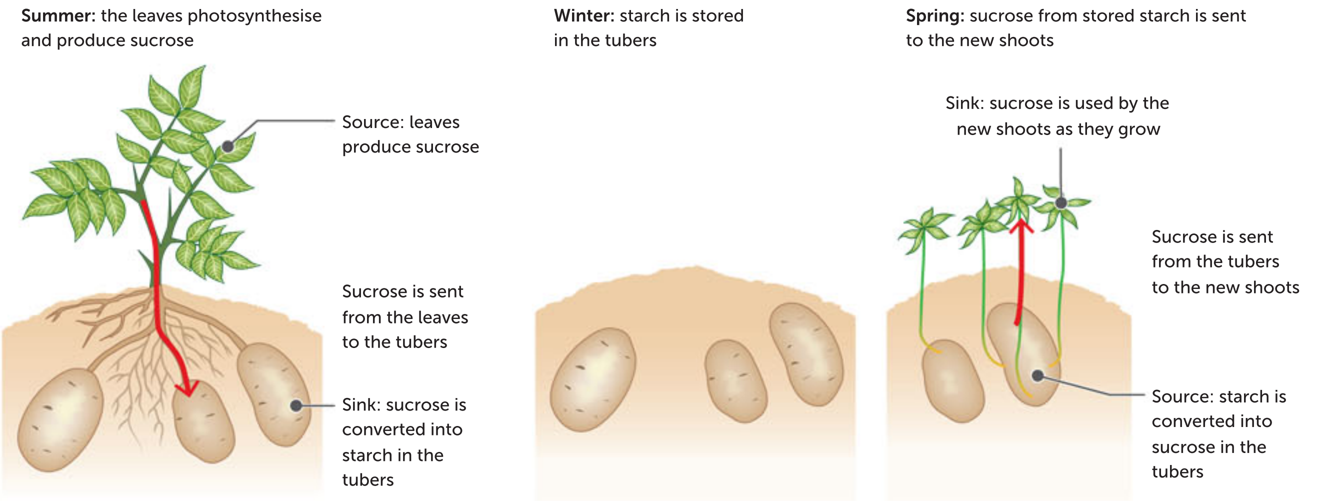


FIGURE 13.14 Plant sources and sinks can change as seasons change.

Special methods of obtaining minerals and nutrients

Some soils are low in or lack mineral ions, and plants living in them have special means of obtaining essential elements. For example, the roots of many plants that live in **humus-rich soils** that are deficient in mineral ions possess a mycorrhiza, an association between their roots and a fungus. The fungus has the effect of increasing the absorbing area of the root. In some cases, the fungus is located on the surface of the root; in other cases, it is internal. Either way, it can break down the humus into soluble nutrients, some of which are absorbed and used by the plant.

13.1 APPLICATION

Plant 'eats' animal!

Obtaining enough nitrogen-based compounds can be a problem for plants. A special adaptation to overcome this is seen in legumes, such as peas, beans and clover: they contain **nitrogen-fixing bacteria** in their roots. Some plants living in nitrogen-deficient soil resort to carnivorous methods and are able to digest animal matter to obtain their nitrogen requirements. The Australian pitcher plant (*Cephalotus follicularis*) is a native of the swampy, damp terrain of the south-west region of WA. This vascular plant cannot grow properly without certain mineral ions, and these happen to be scarce in the soggy soils where it lives. However, there are plenty of insects present. Nectar oozes from the edges of the specialised pitcher-shaped leaf and entices insects to land on the leaf. The insects land on downward-facing hairs and slip into the bottom of the pitcher, where there is a liquid containing enzymes that digest them. The products of digestion, which contain nitrogen, are absorbed into the leaf and transported through the phloem to wherever they are required in the plant.

Shutterstock.com/ZayacSK

FIGURE 13.15 The carnivorous Australian pitcher plant, *Cephalotus follicularis*

Questions

1 Describe how the Australian pitcher plant is adapted to its environment.
2 Why is nitrogen important to plants?

Waste removal

As well as removing unwanted gases via the stomata, deciduous plants can store other wastes in leaves, which then drop off in autumn. Some non-deciduous trees, such as mangroves, can also remove excess salt from their systems in this way. Plants that regularly lose their bark, such as many species of eucalypts including *Eucalyptus caesia*, can transfer unwanted material via the phloem to the bark before it is shed. Other wastes may be stored as insoluble crystals or dissolved in vacuoles. Woody plants can store some wastes in non-living tissue. The cell walls are used as a depository for toxic substances, some of which are modified to form **lignin**. Certain plants remove other wastes by exuding various resins, fats, waxes and complex organic chemicals, like the latex from rubber trees and milkweeds.

Alamy Stock Photo/Tim Graham

FIGURE 13.16 One way that trees lose wastes is by shedding leaves or bark where wastes have been stored, as seen with this Eucalyptus shedding its bark.

TABLE 13.2 A comparison of transpiration and translocation

FACTOR	TRANSPIRATION	TRANSLOCATION
Site	Xylem	Phloem
Material	• Water • Dissolved mineral nutrients	• Products of photosynthesis (organic molecules/sugar) • Some dissolved nutrients
Direction	One way: from roots to leaves	Two ways: from source to sink (usually leaves to areas of growth)
Energy requirements	Passive	Active
Mechanisms	• Root pressure • Capillary action • Transpiration	• Active transport of sugars into sieve tubes causing uptake of water by osmosis from surrounding cells • Dissolved sugars carried along phloem from source to sink • Removal of sugars at sink, where they can be used in respiration or converted to starch and stored
Rate affected by	• Temperature • Humidity • Wind	• Temperature • Sunlight
Cells	Dead: xylem cells	Living: sieve tube cells and companion cells

Question set 13.3

REMEMBERING

1. Describe the processes that move water into the root hairs.
2. List the features of the xylem that make it effective in transporting water around the plant.
3. Define and describe translocation.
4. Suggest where the energy for translocation comes from.
5. List the features of the phloem that make it ideal as a transport system for nutrients.
6. Describe the main function of the leaf.
7. List the substances that enter leaves and are used for photosynthesis.

UNDERSTANDING

8. Explain the forces that enable water in a xylem vessel to reach the top of a tree.
9. Explain where the energy for transpiration originates.
10. Explain why plants require mineral ions. Suggest what would happen if they didn't get sufficient amounts of these.
11. Create a poster to compare transpiration and translocation.

Algae architecture

CASE STUDY

The first algae-powered building in the world opened in Hamburg, Germany in 2013. A group of architecture and engineering firms collaborated to meet the challenge of designing more sustainable, low-energy-use buildings. Their solution, the Bio Intelligent Quotient (BIQ) House, took 3 years of research and development but resulted in a functioning 'green' building.

A 'bio-adaptive algae façade', made up of a double layer of 129 'SolarLeaf' vertical glass panels filled with 24 litres of algae and liquid, stretches along the front of two sides of the building. These shiny green living panels function in a number of ways. They form a layer of insulation against sound, heat and cold. As a functioning closed system, the algae behind the glass photosynthesise and convert solar energy into heat. The algae also take up carbon dioxide, produce oxygen and produce biomass. Each algal cell in this unicellular species can photosynthesise, so they can grow and produce biomass approximately 10 times faster than larger, multicellular plants. This biomass is harvested to produce biofuel to heat the building.

Within the first year of going live, the algae façade reached a conversion efficiency of

FIGURE 13.17 The algae-powered Bio Intelligent Quotient House in Hamburg, Germany

about 58% (converting captured sunlight into energy). This project marks the beginning of future designs for zero-energy and zero-carbon buildings. Six years after the opening of the first algae-powered building, Professor Sara Wilkinson, in collaboration with many partners, is at the testing stage of algae-powered buildings in Australia. She admits that it is an expensive approach currently, but it is not uncommon for renewable resources to have an expensive start. Once a technology is developed and refined, the cost improves. Two panels were mounted on the roof of the science faculty buildings at the University of Technology Sydney. Solar thermal energy production and algal biomass production are being measured. In the future, Professor Wilkinson is planning to test different species of algae to find out if some are more productive than others.

Questions

1. Identify the ways in which the engineers and architects have 'copied' their design from plant structures and function.
2. The glass panels are described as a closed system. Assess whether or not this is possible and explain your answer. Create a diagram to illustrate your explanation.
3. Predict other ways in which the concept of modelling designs based on plant structure and function could be applied.
4. Evaluate whether or not you think algae-based architecture is a beneficial application of scientific knowledge.

13.4 AUSTRALIAN TERRESTRIAL PLANT ADAPTATIONS

Australia is the driest inhabited continent in the world. As much as 70% of Australia is either **arid** or semi-arid land. The term 'arid' refers to a climate with little to no rain. It is difficult for plants to inhabit arid land. Many Australian plants have adaptations especially suited to their arid environment. An **adaptation** is any change in the characteristics of an organism that makes it better able to survive its environment. Plant adaptations are usually either physiological (a process or function) or structural (physical). The structural adaptations of Australian desert plants include altered root and shoot systems; thick, waxy cuticles; location of stomata; vascular tissues and lignin-reinforced tissues. Plants with such adaptations have come to dominate our arid landscapes, as they can survive even the harshest and driest land conditions.

Key concept

An adaptation is any change in the characteristics of an organism that makes it better able to survive its environment. Plant adaptations are usually either physiological (a process or function) or structural (physical).

To survive, plants need to open their stomata to let carbon dioxide enter for photosynthesis, but doing this leads to water loss from transpiration. Plants endemic to Australia have developed unique features to deal with this problem. In situations of severe water stress, such as in a drought, the guard cells may lose water during the day and the stomata will close. While this reduces the loss of water, it also cuts off the supply of carbon dioxide. This restricts the capacity of the leaf to carry out photosynthesis, thus restricting the overall growth of the plant during these environmental conditions.

However, a few plants have evolved mechanisms of storing carbon compounds for later use, allowing them greater control over when and under what conditions they open their stomata. These plants, such as pineapples and many cactuses and orchids, have evolved mechanisms whereby they can open their stomata during the evening, when it is cooler, and effectively store carbon dioxide for use in photosynthesis during the daytime. They are able to close their stomata during the hottest part of the day. All of these processes are examples of physiological adaptations.

iStock.com/sasimoto

FIGURE 13.18 Sturt's desert pea (*Swainsona formosa*) has relatively small leaves, a structural adaptation to its dry habitat.

The large surface area of leaves found in many plants, while allowing maximum photosynthesis, also contributes to high levels of evaporative water loss. This problem is overcome in some plants, such as South Australia's floral emblem, Sturt's desert pea (Figure 13.18), by two adaptations: the presence of an impermeable waxy cuticle on the leaf surface, and having relatively small leaves. Having small leaves means less evaporative surface per leaf. The waxy cuticle acts as a barrier to reduce water loss because the wax is not permeable to water.

The WA red and green kangaroo paw (*Anigozanthos manglesii*) has numerous adaptations to its environment. They include:

- roots that can bind sand, and have fine root hairs that may help to retain soil moisture around the root and possibly assist in extracting phosphorus from the soil
- a rhizome (rootstalk) that has a tough sheath forming a cylinder around numerous vascular strands to act as a barrier to reduce water loss
- tough, erect flowering stems that are brightly coloured to attract, and support the weight of, pollinating birds such as honeyeaters

iStockphoto.com/Samantha Haebich

FIGURE 13.19 The flower of the red and green kangaroo paw has several adaptations that help this plant survive in its environment.

- flowers that rapidly lose their colour and twist out of the way once pollinated so that bird pollinators can easily approach fresh, unpollinated flowers
- nectar that is produced in large amounts and is low in sugar, making it suitable for birds and mammals as pollinators.

Other adaptations of many desert plants include having very small stomata and fewer stomata than those of other plants. *Banksia* is a genus of native Australian plants with stomata that lie deep in the plants' tissues. This adaptation helps *Banksia* reduce water loss by keeping the hot, dry wind from blowing directly across the stomata.

Hakea laurina, a beautiful flower found in WA's southwest, belongs to a group of Australian natives that have many adaptations to reduce water loss. The leaf cuticle is 2–3 times thicker than the epidermal cells and it rises over the sunken stomata. Additionally, the inner layer of tissue has walls thickened with lignin that increase the water-storing capacity of the leaf, minimising water loss by evaporation. There are also inner fibres wrapped around the vascular tissue, restricting water loss from the xylem. Some hakea species, such as *H. gilbertii*, have reduced, needle-like leaves to reduce the surface area from which water can be lost. This adaptation of reduced, needle-like leaves can also be seen in Australia's spinifex grasses that live in Australia's vast sand dunes. Spinifex grasses can also roll their leaves when humidity is low to reduce water loss by having less surface area exposed to wind and direct sunlight.

FIGURE 13.20 WA has many plants with adaptations to reduce water loss. **a** Spinifex grasses and **b** *Hakea gilbertii* both have reduced, needle-like leaves. **c** The leaves of *H. laurina* have an especially thick cuticle and sunken stomata.

Key concept

Australian plants growing in arid environments have adaptations that minimise their water loss. For example, an impermeable, waxy cuticle on the leaf surface is a structural adaptation; opening their stomata during the evening is a physiological adaptation.

Question set 13.4

REMEMBERING

1 Define 'arid'.
2 Define 'adaptation' and state two types of adaptations demonstrated by desert plants.
3 State the difference between a structural adaptation and a physiological adaptation.

UNDERSTANDING

4 Describe one structural adaptation found in a terrestrial Australian plant.
5 Describe one physiological adaptation found in a terrestrial Australian plant.

SCIENTIFIC LITERACY

Improving plant growth under drought conditions

Regulation of stomatal closure directly affects plant gas exchange, the rate of photosynthesis and chloroplast function. An international, collaborative research team led by the Australian National University (ANU) has found a new way to help plants better survive drought by enhancing their natural ability to preserve water. During their investigations, they were able to help some plants survive 50% longer in drought conditions. They are hoping to apply the findings to major crops such as barley, rice and wheat.

Dr Wannarat Pornsiriwong, Dr Gonzalo Estavillo, Dr Kai Chan and Dr Barry Pogson from the ANU Research School of Biology led a research team to map a new molecular signalling pathway that controls the ability of plants to close the pores (stomata) on their leaves to conserve water during drought stress.

'If we can even alleviate drought stress a little it would have a significant impact on our farmers and the economy', Dr Pogson said.

He said the research found chloroplasts in cells surrounding the pores on leaves, called stomata, can sense drought stress and thereby activate a chemical signal that closes stomata to conserve water. 'This finding was completely unexpected and opens new avenues of inquiry into how chloroplasts can contribute to plant responses to the environment', Dr Pogson said.

Dr Chan continued the explanation by saying that boosting the chloroplast signal, by breeding, genetic or agronomic strategies, could be the key to help plants preserve water and boost drought tolerance.

The research was funded by the Australian Research Council (ARC) Centre of Excellence in Plant Energy Biology and was a collaboration between ANU, the University of Adelaide, Western Sydney University, CSIRO, Kasersart University (Thailand) and the University of California San Diego (United States). ARC have developed many teacher and student resources featuring this research, including virtual 360° videos.

Adapted from https://www.anu.edu.au/news/all-news/lending-plants-a-hand-to-survive-drought

Questions

1 Chloroplasts have a cell-signalling role in drought response. State the process that occurs in chloroplasts normally, when drought is not an issue.
2 Recall the role of guard cells in the opening and closing of stomata.
3 Describe the major finding from this team's investigations.
4 How might the research described here be used in the future?

Plant energy
Learn more about how plants respond in drought conditions.

Video
Watch a 360° video about this research project.

Research paper
This research has been published in a scientific journal.

9780170452847

CHAPTER 13 INVESTIGATIONS

INVESTIGATION 13.1

Plant transport systems

Water is an essential requirement for photosynthesis to occur. As most photosynthesis occurs in the leaves of plants, water and the substances dissolved within it must move through vascular plants via the xylem, from the roots to the leaves. Xylem consists of hollow cells of tracheids and vessels. Sugars, in the form of the disaccharide sucrose, and other nutrients move in the phloem. The phloem is made up of sieve tube cells and companion cells.

Aim

To examine how water is transported through a celery stalk and leaves

Materials

Each group will require:

- stick of celery that has been standing in red food dye or eosin for several hours; cut 2 cm from its base
- single-edged razor blade
- microscope, stereo microscope or hand lens
- microscope slides and coverslips
- mounted needles (optional)
- millimetre ruler, transverse and longitudinal stem sections of *Helianthus* (for Taking it further)

WHAT ARE THE RISKS IN DOING THIS EXPERIMENT?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Razor blades are sharp and can easily cut skin.	Handle razor blades carefully and report any injuries to your teacher immediately.
Food in the lab can be contaminated.	Do not eat the celery.

Procedure

1. Remove the celery from the coloured solution.
2. Examine the stalk and leaves for spread of the dye; holding them up to the light may help. Observe the areas where the dye is concentrated. Draw the distribution of dye in the leaf.
3. Cut thin transverse sections (1 mm) across the stem and branch (and leaf if possible). Arrange the sections onto a microscope slide.
4. Examine the sections under low power and make diagrams showing the distribution of the dye.
5. Cut another 1–2 mm piece of stem.
6. Use the razor blade to cut out a small piece of the area coloured by the dye and put this on a microscope slide.
7. Use a couple of razor blades or mounted needles to tease the piece of tissue apart.
8. Add a coverslip, using a drop of water if the tissue is becoming dry.
9. Use low power, then high power to find 'spirals' or 'coils'. Draw these structures.

Discussion

1. Describe how the dye is distributed in the plant. Has the whole stem turned a little pink or is the dye found in particular places? Explain your answer.
2. Discuss the assumption that the dye shows us where the xylem is.
3. Suggest what causes the dye to travel to the leaves.
4. The red dye is a solution. If a stem is placed in Indian ink, which is a mixture of small particles rather than a solution, the colour does not reach the leaves. Explain why this would be the case.

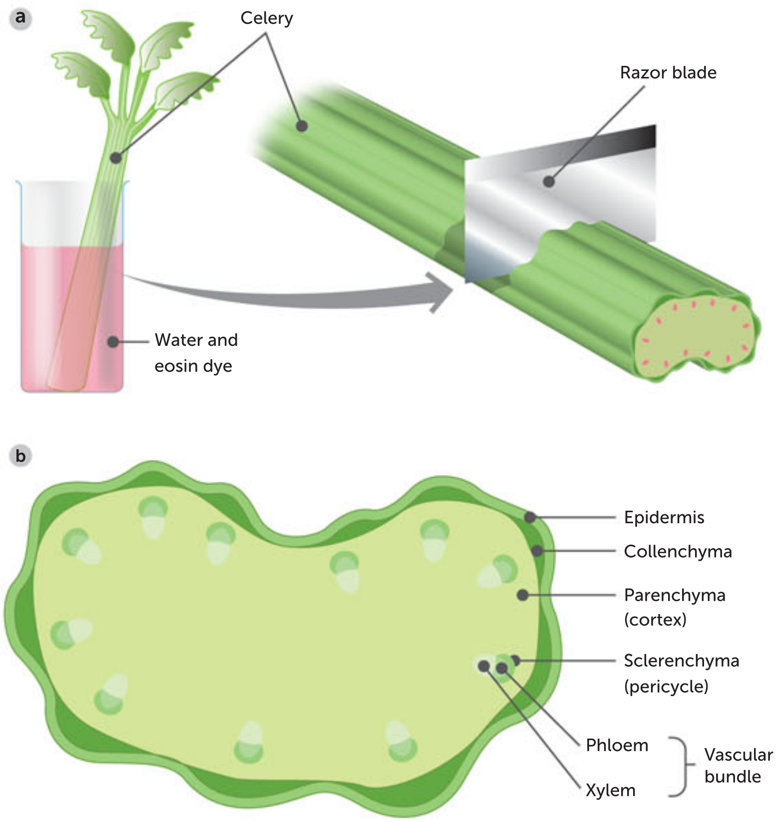


FIGURE 13.21 The movements of materials in xylem: **a** an experiment using celery to show the movement of materials in xylem; **b** a transverse section through celery stem, showing tissue distribution (light microscope view)

5 **a** Name the types of cells that the coils and spirals you should have seen are found around.
b Identify what the spirals are made of.
c The spirals have functions equivalent to those of the spirals of cartilage around the human trachea. Suggest their functions.

Taking it further

1 Examine prepared slides of transverse and longitudinal stem sections of *Helianthus* (sunflower) or another suitable plant. If the slide has been prepared with toluidine blue, lignin will be stained a greenish-blue colour; unlignified cell walls tend to stain a reddish-purple. Alternative stains may make the lignin a reddish colour.
a Draw some diagrams from the longitudinal and cross-sections, showing where the regions of xylem (lignified areas) and phloem are. You should also be able to draw other types of spirals and coils.
b In the phloem you may be able to find some sieve plates, sieve tubes (same diameter as the sieve plates) and companion cells (smaller). Draw and label all these.

13.2 INVESTIGATION

Leaf structure

Most plants obtain their requirements either through their roots or their leaves. The roots obtain water and mineral ions for distribution around the plant via the xylem. The leaves are the primary site of photosynthesis in the plant and have developed to become highly specialised in structure.

Leaves are made of an outermost layer of cells called the epidermis. Epidermal cells produce a waxy substance that forms a cuticle, which is impermeable to water and gas. Stomata are found in the epidermis, and allow gas exchange and transpiration to occur due to the function of specialised guard cells that open and close the stomata.

Inside the leaf are layers of cells packed with chloroplasts that utilise sunlight for the process of photosynthesis. The water needed for photosynthesis is brought to the leaves from the roots in the xylem, and the sugars produced are carried away in the phloem.

Aim

To observe the structure of a typical green leaf and relate the structure to the functions that it performs

Materials

- fresh, small, broad leaves of herbaceous plants such as broad beans, geraniums or impatiens
- single-edged razor blades or a knife
- monocular microscope
- two slides and coverslips
- carrot tissue, about 2 cm wide by 5 cm long
- white tile
- fine brush
- Petri dish of water
- ruler
- magnifying glass wall or hand lens
- *Eucalyptus* leaves, video microscope and digital camera (for Taking it further)

WHAT ARE THE RISKS IN DOING THIS EXPERIMENT?	HOW CAN YOU MANAGE THESE RISKS TO STAY SAFE?
Razor blades are sharp and can easily cut skin.	Handle razor blades carefully and report any injuries to your teacher immediately.

Procedure – Part A: Leaf structure

1 Using a hand lens or magnifying glass, examine the structure of the leaf closely while holding it up towards the light. In particular, focus your attention on the arrangements of veins throughout the leaf. Record your estimate of how far most parts of the leaf would be from the nearest vein (in mm).

Procedure – Part B: Preparation of a transverse section of a leaf

1 If the leaf is thin, fit it into a vertical slit made down the centre of the carrot tissue (Figure 13.23). This will provide a firm position while the sections are cut. Trim the leaf, making sure you use a knife or old razor blades for all trimming. Use a new blade only for cutting sections.

2 Cut very thin sections with the new razor as shown in Figure 13.24. Make sure that the carrot/leaf assembly is kept wet as well as the razor blade. This helps to minimise friction.

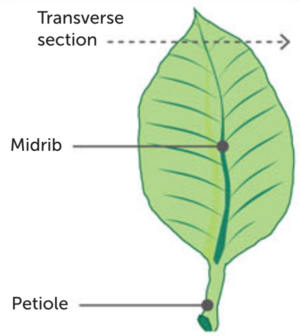


FIGURE 13.22 A transverse section of a leaf

3 Float the cut sections off the blade into a Petri dish of water.
4 Choose one or two of the thinnest sections (those that are colourless and almost transparent in parts). You will only be able to see all the cells referred to in this activity if your section is very thin (a few cells thin). Transfer these sections with a moist fine brush (not with forceps, which may damage them) onto a drop of water on a microscope slide. Make sure that the section is sitting with the cut edge facing up. Lower a coverslip onto the section.
5 Examine the transverse section with the microscope. You could irrigate your section with iodine solution, following your teacher's instructions, to reveal any starch present.

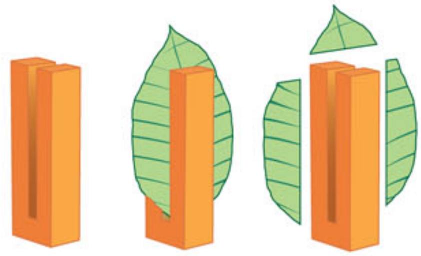


FIGURE 13.23 Using carrot as a support for cutting

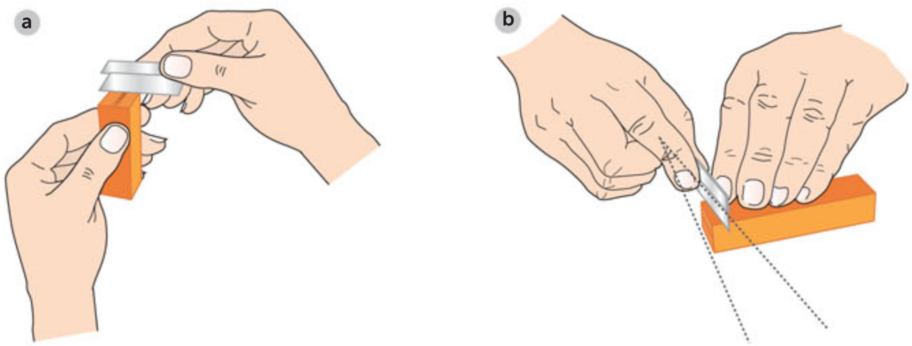


FIGURE 13.24 Two ways of cutting sections: a cutting towards you; b cutting across through the carrot and leaf at a slight angle to produce a very thin section at one end

Procedure – Part C: Examining the transverse section of a leaf

1 Examine the transverse section of the leaf under low power. If you have difficulty getting it to sit on its cut edge, gently press on the coverslip and slide it a little. This will cause the leaf section to roll and twist a little on the slide, thus turning part of it on its side. Check with your teacher that you are viewing your leaf correctly.
2 Identify the layers of cells labelled in Figure 13.25 in your specimen: the upper and lower epidermis, and the palisade and spongy mesophyll cells. Identify a stoma and the space behind it, called the substomatal cavity. Identify a vein (called a vascular bundle). Notice if there is a cuticle (a waxy layer) along the outer edge of the upper and lower epidermis.
3 Draw a labelled diagram showing the arrangements of the tissues in your section. Label all the cell layers that you can see.
4 Use the high power of the microscope to observe different cell shapes and contents, especially the large green chloroplasts. Draw diagrams of two or three cells of each tissue. Label the cell with all the parts that you can see (e.g. cell wall, chloroplasts).

Results and discussion

1 Describe what you observed about the furthest distance any part of the leaf is from a vein. Suggest reasons why this may be so important for the survival of the cells within the leaf.
2 Compare the surface area of a leaf to its volume. Suggest what advantages this provides to leaf function. Suggest what disadvantages this provides to leaf function and how these are overcome.
3 Name cells within the leaf that seem to be mainly involved in photosynthesis. Describe where they

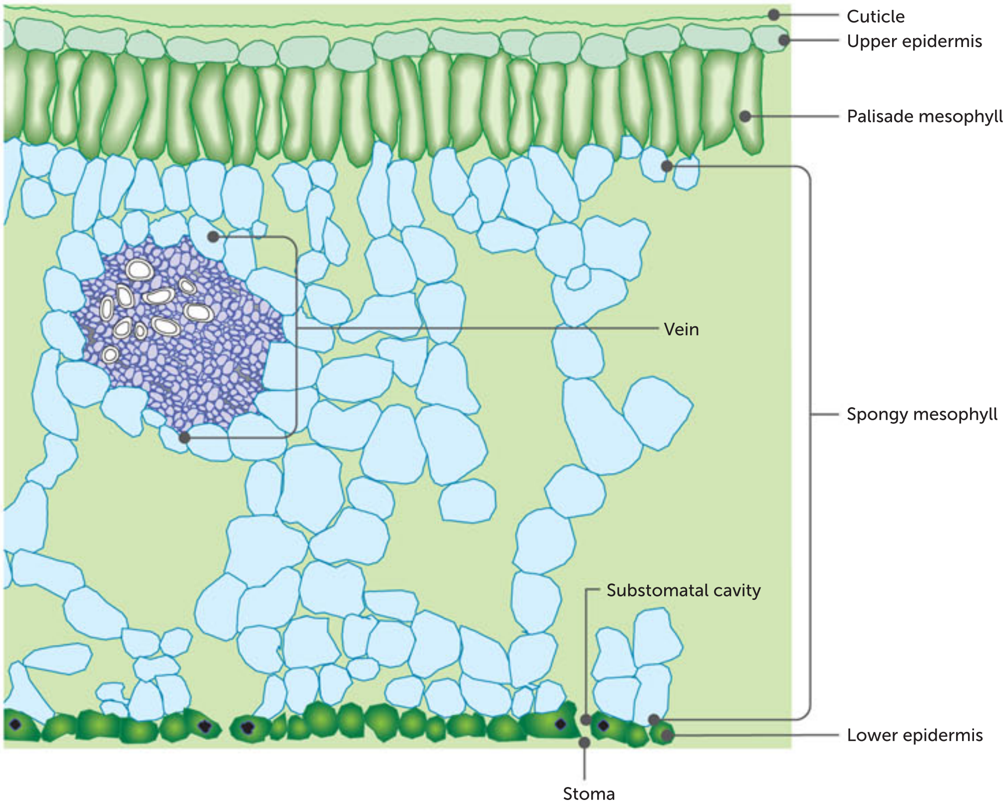


FIGURE 13.25 A generalised cross-section of a leaf

are mostly situated. Explain how you came to your conclusions.

4 Compare the thickness of the cuticle on the upper and lower leaf surfaces. Account for any differences.

5 Identify the layer of photosynthetic cells that has the most air spaces between its cells.

6 During photosynthesis, green cells in plants take up carbon dioxide (CO_2) and release oxygen (O_2). Illustrate the pathway along which a green cell in the leaf could:

  a obtain carbon dioxide from the air

  b lose oxygen to the air

  c obtain water and mineral ions.

7 Explain how the external and cellular structure of a leaf assists it in carrying out the function of photosynthesis.

Taking it further

1 Make transverse sections of a *Eucalyptus* leaf and examine them under the microscope. How does this leaf differ from the soft herbaceous ones?

2 A video microscope can be used to view a prepared slide. A camera attached to the microscope could record an image of the leaf section.

WS Chapter 13 Activity sheet

CHAPTER 13 SUMMARY

- Vascular plants possess vascular tissue which is involved in the transport of substances in plants. Vascular tissue is composed of two different types of tissues: xylem and phloem.
- Vascular plants consist of a root system and a shoot system.
- Gas exchange in vascular plants occurs mostly across stomata found in leaves.
- Plants transport water and nutrients through xylem and phloem, which are found together in vascular bundles. Transport is powered by the processes of osmosis and water pressure, capillary action and evaporation.
- Xylem is a water-conducting tissue composed of elongated tubular cells. When xylem cells mature, they die.
- Phloem tissue transports sugars and other plant products around the plant from a source to a sink. Sieve tube cells and companion cells are the components of phloem, and both kinds are living cells.
- Roots absorb water and minerals from the soil, support and anchor a plant, and are often used for storage.
- Root hairs greatly increase the surface area for water absorption.
- Water and minerals are absorbed into roots through a combination of osmosis, water pressure and active uptake.
- Water and minerals move through the xylem by a combination of root pressure, capillary action and transpiration.
- Sugars (in solution) and other plant products are transported through the phloem by a process called translocation. This requires energy.
- Leaves and their distribution play a major role in the collection of light for photosynthesis.
- Movement of gases in leaves depends on simple diffusion.
- Guard cells control the movement of gases by opening and closing stomata.
- Plants absorb carbon dioxide through their stomata, but they also lose water during this process.
- Terrestrial Australian plants that live in arid environments are adapted to minimise water loss. They may have structural and/or physiological adaptations that help them survive.
- Adaptations such as altered stomatal opening times, sunken or hairy stomata, reduced leaves, thick waxy cuticles and special locations for stomata enable plants to reduce water loss.

CHAPTER 13 GLOSSARY

Absorption the movement of water and dissolved substances into a cell, organ or organism

Active transport the process whereby cells actively transport substances across a membrane from a low concentration to higher concentration of the substance; characterised by the fact that the process consumes energy

Adaptation any change in the characteristics of an organism that makes it better able to survive in its environment

Adhesion the strong forces that exist between water molecules and other substances, due to the polar nature of the water molecules

Arid describes a climate that has little or no rain

Capillary action the combined forces of adhesion and cohesion which act to move water along a thin column

Cohesion the strong forces that exist between water molecules

Companion cell a type of cell found in phloem next to the sieve tube cells; provides most of the cell functions of the sieve tube cells, which lack most organelles

Epidermis the surface layer of cells of a plant or animal; generally responsible for separating and protecting the organism from its environment

Flaccid describes a cell when it has shrunk due to loss of water

Guard cells pairs of cells surrounding and controlling the action of stomata

Humidity the concentration of water vapour in the air

Humus-rich soil the complex organic material resulting from the decomposition of plant and animal debris (detritus)

Lignin a complex compound found in xylem cells; provides strength and structure to the cell wall and plant

Mesophyll cell a type of cell found in the middle of leaves, packed with chloroplasts and essential for photosynthesis

Nitrogen-fixing bacteria bacteria found in the roots of certain plants that are able to capture atmospheric nitrogen and convert it to usable compounds

Non-vascular describes plants that do not have roots but do have simple leaves; they lack vascular tissue

Nutrient a substance required by living organisms, generally including dissolved salts and vitamins in the case of animals, rather than substances taken up to provide energy

Osmosis the passive movement of water across a selectively permeable membrane from regions of low solute concentration to high solute concentration

Palisade cell an elongated cell packed with chloroplasts

Phloem a plant tissue that transports sugars, in the form of sucrose, and other photosynthesis products from one part of a plant (usually where they are made, the leaves, or where they are stored, the roots) to where they are needed; transport can therefore be in two directions; consists of conductive tissue composed of thin-walled cells

Root hair a tube-like outgrowth of a root epidermal cell that increases the surface area of the root; responsible for absorbing water and nutrients

Root pressure the force that pushes water up the stem from the roots

Sieve tube cell a long, tubular plant cell without a nucleus that is found in phloem and joins with others to form sieve tubes, through which sugar and other solutes travel

Sink a plant organ that uses sugar for active growth or stores sugar, such as growing roots, stems and fruits

Source a plant organ that produces (by photosynthesis) or releases sugar for translocation; leaves are the primary sugar source

Stomata (singular stoma) the openings in leaves, and some stems, that control the movement of gases into and out of the plant

Tissue a group of specialised cells working together to perform a specific function

Translocation the active, multidirectional movement of organic nutrients (sugars) in solution, from source to sink, through the phloem of vascular plants

Transpiration the loss of water vapour by evaporation from the surface of a plant, especially via stomata on the underside of leaves

Transpirational pull the force arising from the evaporation of water from leaves which pulls water up through the xylem

Transpiration stream a continuous column of water in the xylem that runs the length of the stem of a plant

Turgid describes a cell that is full of water and has a swollen appearance, such as a guard cell next to an open stoma

Turgor the state of a plant cell that is full of water

Vascular bundle a combined bundle of xylem and phloem tissues in a plant

Vascular plants plants that have vascular tissue, the tissue that transports water, nutrients, sugars and other substances around the plant body

Vascular tissue (in plants) the tissue devoted to the bulk transport of water, nutrients, sugars and other substances; comprises the xylem and the phloem

Xylem the plant tissue responsible for the transport of water, along with mineral nutrients, from the roots to the leaves; made of elongated, tubular dead cells

CHAPTER 13 REVIEW QUESTIONS

Remembering

1 List the major resources that plants must exchange with their environment.
2 Name the two types of vascular tissues in plants.
3 List the factors in the external environment of a plant that affect the rate of transpiration.

Understanding

4 Outline the major difference between transport systems in animals and in plants.
5 Using Figure 13.26, explain the pathway of oxygen and carbon dioxide through the leaf cells. Indicate what processes these gases would be used or produced in, and where these processes occur.

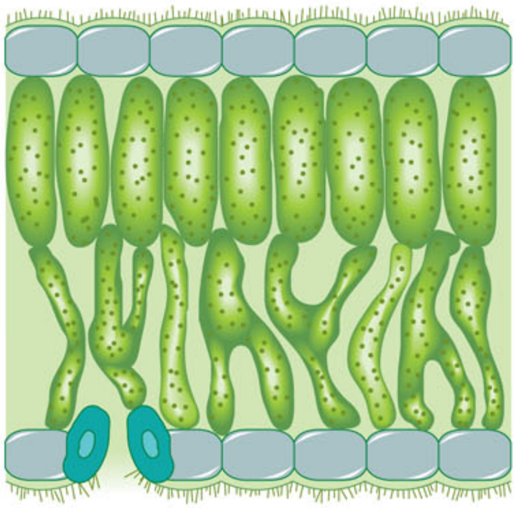


FIGURE 13.26 A leaf cross-section

6 Explain how sugars are moved through the phloem.
7 Explain why the function of the phloem depends on having xylem tissue nearby.

Applying

8 Plants are able to use oxygen produced by photosynthesis for the process of respiration, and carbon dioxide produced by respiration for photosynthesis.
  a Suggest under what circumstances the plant would be able to supply its own gaseous requirements.
  b Predict when the plant would need to take in oxygen or carbon dioxide from the outside environment.
  c Explain why a plant will lose weight when kept in the dark.
9 If stomata could be manipulated to always stay open, predict the effect on a plant. Suggest what would happen to a plant if stomata always stayed shut.
10 Suggest what the energy source is for the following processes.
  a the transport of water from the roots to the crown of a tall tree
  b the transport of sugars from the leaf to other parts of a tree
11 Discuss which characteristic of non-vascular plants such as mosses limits how large they can grow.

Analysing

12 Explain how the uptake of mineral ions differs from the uptake of water from the soil.

13 In most plants, the xylem is mostly comprised of dead tissue while phloem is always comprised of living cells. Account for this difference in terms of the different mechanisms used to move substances through the xylem and phloem vascular systems.

Evaluating

14 Transpiration has been described as a 'necessary evil'. Explain the costs and benefits of transpiration to a plant.

Creating

15 Plants are continuously losing water as they open their stomata to absorb carbon dioxide. Consider and discuss how the rising levels of carbon dioxide in the atmosphere, due to human activity, might affect plants. Present your conclusions in a poster.

PRACTICE EXAM QUESTIONS

1 Xylem does not:

A transport water.
B support the plant.
C respire.
D occur in vascular bundles.

[Q4 2010 Stage 2 WACE SCSA]

2 Phloem moves:

A starches down from the leaves.
B minerals from the leaves to the roots.
C water upward to create a transpiration stream.
D sugars throughout the plant.

[Q7 2010 Stage 2 WACE SCSA]

3 Leaf cells performing photosynthesis will most likely:

A lack mitochondria but have chloroplasts.
B lack chloroplasts but have mitochondria.
C have both chloroplasts and mitochondria.
D have neither chloroplasts nor mitochondria.

[Q12 2010 Stage 2 WACE SCSA]

4 Radioactive sugars were injected into the stem of a 2 m tall tree, approximately 1 m above the ground. After a few hours, you would expect to detect radioactive sugars in only the:

A living parts of the plant.
B stem above the injection and in the leaves.
C stem below the injection and in the roots.
D parts of the plant with chloroplasts.

[Q18 2010 Stage 2 WACE SCSA]

5 What is the best definition of osmosis? Osmosis is:

A diffusion of a solute across a semipermeable membrane.
B random movement of solute molecules.
C active uptake of water molecules.
D diffusion of water across a semipermeable membrane.

[Q28 2010 Stage 2 WACE SCSA]

6 A biology student made an artificial cell using a balloon that was permeable to water but not to sucrose. The student filled the balloon with 10% sucrose solution and placed it in a tank of 5% sucrose solution. The apparatus was then left overnight.
A likely outcome the next day would be that the balloon would:

A gain water.
B lose water.
C gain sucrose.
D lose sucrose.

[Q29 2010 Stage 2 WACE SCSA]

7 Many Australian plants living in arid environments have leaf adaptations that enable them to survive dry, hot conditions.

Which of these adaptations would limit gas exchange the most?

A a waxy cuticle
B a reduced number of stomata
C a thick, waxy cuticle
D changing the angle of the leaf to reduce direct sunlight

8 Indicate whether each of the following statements about water transport in plants is true or false, and give a reason for your answers.

a Plants transport water from their roots to their leaves in the phloem. (2 marks)
b In plants, root hairs, which take up substances from the soil, have a high surface-area-to-volume ratio. (2 marks)

[Q31d 2011 Stage 2 WACE SCSA]

9 **a** Distinguish between diffusion and osmosis. (2 marks)
b Provide an example of diffusion in plants. (1 mark)
c Provide an example of osmosis in plants. (1 mark)

[Q31e 2011 Stage 2 WACE SCSA]

10 Plants require water to perform photosynthesis. Plants also need to transport the organic products of photosynthesis around inside them in order to perform many functions. Recall and relate the structures and processes required for the transport of water and products of photosynthesis within a plant's systems. (10 marks)

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