BIOZONE

Student Workbook

YEAR 11 BIOLOGY



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Student Workbook

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Cover Photograph

Seven species of sea turtles exist today, four of which have a threatened conservation status. Entanglement in fishing gear, loss of habitat, hunting, and pollution are the main reasons for the decline in their numbers. Sea turtles are widely distributed, and are found in nearly every ocean. Once hatched, a male sea turtle will spend its entire life at sea, while females return to land every two to five years to lay their eggs.

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Note to the Student

This year's edition of Year 11 Biology has been written specifically to help you develop the skills and knowledge to achieve success in your biology programme. We have provided a wide range of activities that will enable you to build on what you know already, explore new topics, work with your classmates, and practise your skills in data handling and interpretation and in answering free response questions as required in examinations. We hope that you find the workbook valuable and that you make full use of its features.

To use this workbook most effectively, take note of the features outlined in this introduction. Understanding the activity coding system and using the external resources we provide will help to scaffold your learning so that you understand the principles and processes involved in each topic of study.

Look out for these features and know how to use them:

- A guide to answering essay style questions is provided at the end of this introduction. Use it to help you when completing the synoptic questions that conclude each area of study.
- The chapter introduction provides you with the learning aims for the topic. Use the check boxes to identify and then mark off the objectives as you complete them. The chapter introduction also provides you with a list of key terms for the chapter, from which you can construct your own glossary as you work through the activities. See *Using this Workbook* on page 1 for more information.
- The activities form the bulk of this workbook. They have codes assigned to them according to the skills they emphasise. Each has a short introduction to the topic and provides some relevant background. Most of the information is associated with pictures and diagrams, and your understanding of the content is reviewed through the questions. Some of the activities involved modelling and group work.
- The free response questions allow you to use the information on the page to answer a question about the core ideas of the activity. They may require you to apply your understanding to a new situation where the same principles operate.
- A coding system on the page tab identifies the type of activity. For example, is it primarily information-based (*KNOW*), or does it involve modelling (*PRAC*) or data handling (*DATA*)? A full list of codes is given on page 1 but the codes themselves are relatively self explanatory.
- ***Link*** tabs at the bottom the activity page identify connections across the curriculum and pages covering similar or related concepts in different situations.
- The **Weblinks** resource provides you with external, online support material in the form of animations, video clips, and quizzes. Bookmark the page (see details on page 2) and visit it frequently as you progress through the workbook.
- ***VOCAB*** activities enable you to test your understanding of the key terms used in the chapter. Being able to define scientific terms accurately and use them appropriately in your exam answers will help you to achieve better results in exams.

Meet the writing team

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Using This Workbook

This workbook is designed to increase your understanding and enjoyment of biology. It addresses the requirements of the Year 11 syllabuses for biology in Australia, including Victoria (VCE), Western Australia, Queensland, and South Australia. Use it as a stand-alone or complementary resource for your course work and home study.

Introduction

- A check list of learning aims
- A list of key terms

Activities

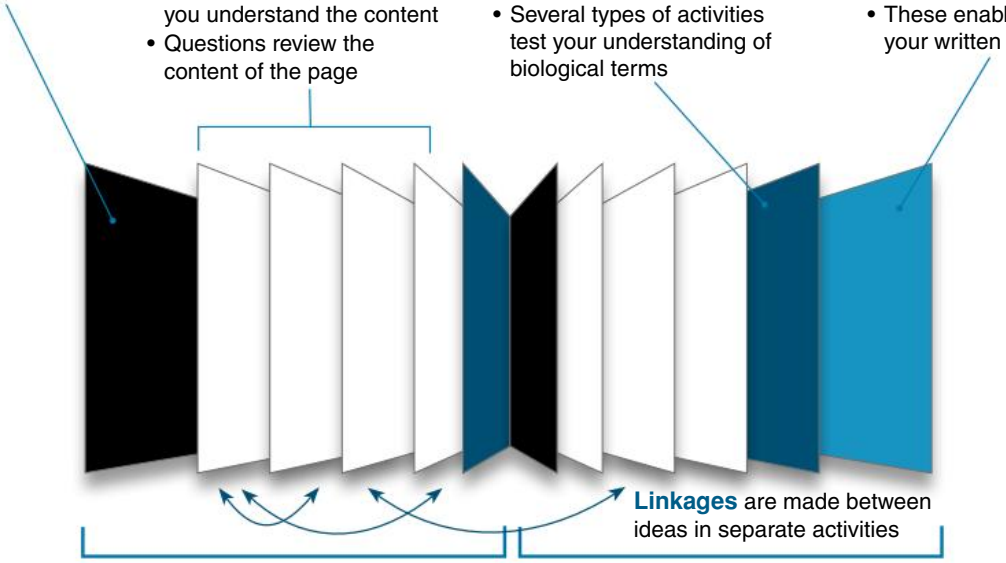
- The KEY IDEA provides your focus for the activity
- Annotated diagrams help you understand the content
- Questions review the content of the page

Literacy

- Most chapters have a literacy activity based on the introductory key terms list
- Several types of activities test your understanding of biological terms

Synoptic Question

- Synoptic questions conclude the four broad areas of study covered in the workbook.
- These enable you to practise your written exam skills



▶ The activities make up most of this workbook. Each one has a similar structure and they are organised through the chapter in a way that unpacks the material in a series of steps.

Activity number

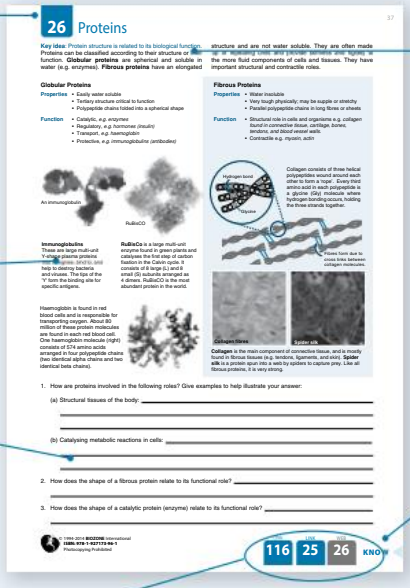
Activities are numbered to make it easy to navigate through the workbook and to find related activities.

Content explained

The main ideas of the activity are explained with short paragraphs and clear, informative diagrams, illustrations, and photos.

Direct questioning style

The questions help you consolidate your understanding of biological vocabulary, processes, and principles around the key idea.



Key Idea

The key idea provides the message for the activity. It helps you to understand what is important on the page.

Page tabs

The **page tabs** at the bottom of an activity page indicate the type of activity, related activities and external weblinks.



Link

Connections are made between activities in different sections of the syllabus that are related through content or because they build on prior knowledge.

Weblinks

Bookmark the weblinks page: www.biozone.com.au/weblink/au11-3961/

Access the external URL for the activity by clicking on its number

Activities are coded

- ***COMP*** = comprehension of text
- ***DATA*** = data handling and interpretation
- ***KNOW*** = content you need to know
- ***PRAC*** = a paper practical or a practical focus
- ***REFER*** = reference - use this for information
- ***REVISE*** = review the material in the section
- ***TEST*** = test your understanding
- ***VOCAB*** = learning your biological vocabulary

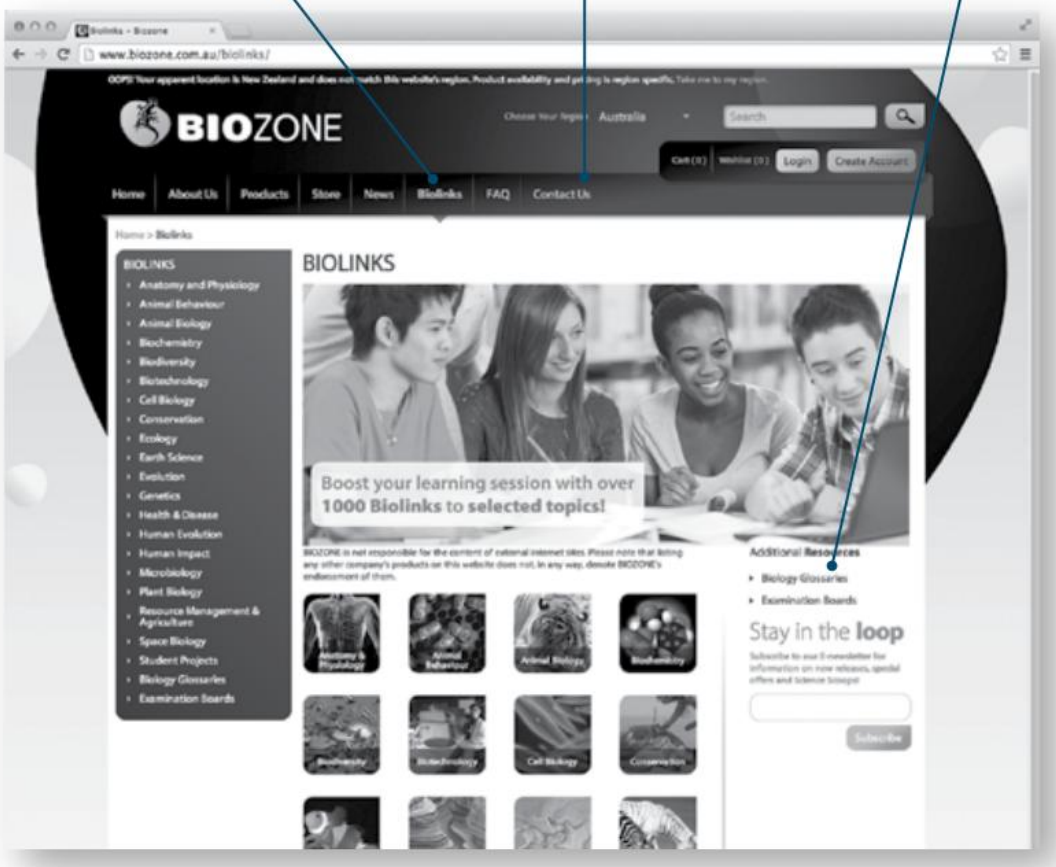
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Using BIOZONE's Website

Access the **BIOLINKS** database of web sites directly from the homepage of our new website. Biolinks is organised into easy-to-use sub-sections relating to general areas of interest. It's a great way to quickly find out more on topics of interest.

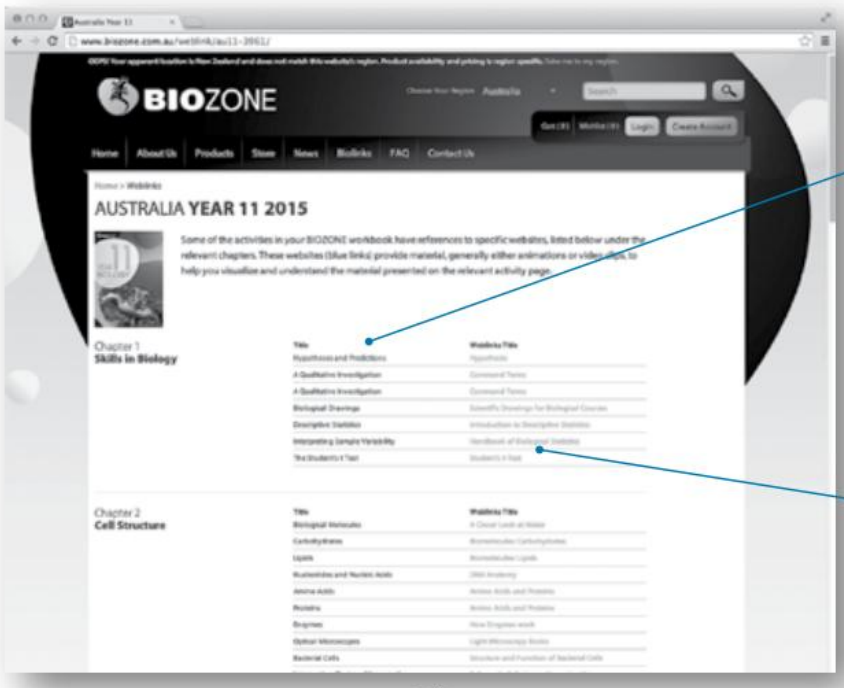
Contact us with questions, feedback, ideas, and critical commentary. We welcome your input.

Make use of additional resources, such as course information through your own state's examination board.



Weblinks: www.biozone.com.au/weblink/au11-3961/

***Bookmark the Weblinks page by typing in the address**. It is not accessible directly from BIOZONE's website*



Throughout this workbook, there are references to **Weblinks** that are relevant to the activity on which they are cited. These are video clips, animations, or quizzes that support your understanding of the concepts on the page:

Weblink: Provides a link to an **external web site** with supporting information for the activity. If there are any additional activities, these are also listed here as links.

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Answering Exam Questions

- Exams require you to demonstrate your understanding of a particular concept by providing a written paragraph or essay.
- Open answer questions (meaning there is no definitive answer) are designed so that you can demonstrate your level of understanding. The question may give you some guidance as to what you should include in your answer, such as definitions of certain terms or to provide specific examples.
- In order to gain the highest possible mark in these questions, you need to lay out your answer in a clear and logical way so that the examiner can easily see how you have demonstrated your understanding of the topic.
- The difference between you obtaining a low, mid, or high grade depends on how well you demonstrate your understanding of a concept.
  - Defining, drawing, annotating, or giving a description demonstrates a basic understanding of the material.
  - Explaining how a process works, why it works, and how changes to it may affect an outcome shows a deeper understanding of how the system works in that situation.
  - Linking biological ideas, comparing and contrasting, analysing, or justifying ideas shows both a deep understanding and an ability to translate that understanding to a new situation.
- The following example shows how an answer can be built up from a simple definition, through explanation, to comparisons and linking of ideas.

For the animal group mammals, discuss the relationship between the gas exchange system and the internal transport system. You should clearly show how they are linked and the role each plays in supporting a mammal's active lifestyle

How gas exchange is physically linked to transport system.

The gas exchange system in mammals is linked to the internal transport system at the gas exchange surface in the alveoli of the lungs. Inhaled air passes through the trachea to the bronchi, to the bronchioles and finally into the alveoli, microscopic sac-like structures at the terminal ends of bronchioles. Oxygen from the air diffuses through the gas exchange surface into the blood and binds to haemoglobin in the red blood cells. It is then transported to the body's cells. Haemoglobin greatly increases the amount of oxygen the blood can carry and supports a high oxygen demand (as in mammals).

Description of the gas exchange system.

Description of how oxygen is exchanged and carried through the transport system.

Carbon dioxide (CO_2) is picked up at the respiring tissues and is transported in the blood to the lungs where it diffuses into the alveoli and is exhaled. The diffusion of respiratory gases into and out of the blood proceeds because the diffusion gradients are maintained by the transport of gases to and from the gas exchange surface and continual exchange of air between the lungs and the external environment.

Explanation of how the diffusion of gases is maintained.

Why the system supports the mammal's lifestyle.

This system supports a mammal's active lifestyle (high metabolic rate) by continually supply oxygen to fuel metabolism and removing CO_2 (its waste product). The system can also adapt to increases in oxygen demand by increasing the volume of air breathed (more rapid breathing and deeper breaths) and increasing the speed at which the blood circulates (increasing heart rate to pump more blood per unit time).

How the system can adjust to changes in demand.

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QLD As required
VCE Skills
WA Skills
SA Skills

Skills in Biology

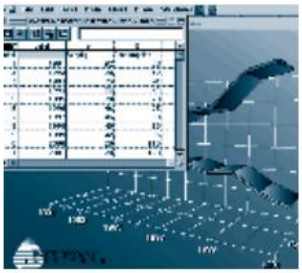
Key terms

biological drawing
chi-squared test
control
controlled variable
data
dependent variable
descriptive statistics
graph
histogram
hypothesis
independent variable
mean
measurement
median
mode
observation
prediction
qualitative data
quantitative data
raw data
sample
scientific method
standard deviation
statistic
Student's *t* test
systematically record
table
transformation (of data)
trend (of data)
variable
X axis
Y axis

The collection and presentation of data

Learning aims and skills

		Activity number
☐	1 Describe and explain the principles of the scientific method, including the role of observations as a prelude to making hypotheses from which testable predictions are generated.	1 2
☐	2 Explain the difference between qualitative data and quantitative data and give examples of their appropriate use.	3
☐	3 Describe an experiment for which qualitative data are collected and describe its outcome. Describe the limitations of qualitative data and explain why the collection of quantitative data is preferable in most scientific studies.	4
☐	4 Describe an experiment for which quantitative data are collected. Identify your dependent and independent variables, their range, and how you will measure them. Identify controlled variables and their significance.	5
☐	5 Demonstrate an ability to systematically record data. Critically evaluate the accuracy and precision of any recording or measurements you make.	6
☐	6 Demonstrate an ability to process raw data. Calculate percentages, rates, and frequencies for raw data and explain the reason for these manipulations.	7
☐	7 Present your data appropriately in a table, including any calculated values.	8
☐	8 Recognise the benefits of graphing data and present your processed data appropriately in a graph format. Recognise any patterns or trends evident.	8-12
☐	9 Demonstrate an ability to make accurate biological drawings.	13





Basic data analysis

Learning aims and skills

		Activity number
☐	10 Calculate basic descriptive statistics (e.g. sample mean, median, mode and standard deviation) to summarise trends or differences in your data. If required, perform an appropriate statistical analysis to test the significance of any trends or differences you have observed.	14 15
☐	11 Use the Student's *t* test to determine the significance of differences between the means of two sets of data. State the criteria for using the *t* test. Recognise that such tests provide an objective standard for statements about the data and the findings they support.	16
☐	12 Use the chi-squared test to determine the significance of differences between two or more sets of categorical data (e.g. habitat type) where the data are frequencies (counts) and not measurements. Distinguish statistical tests for difference between data sets (e.g. Student's *t* test, chi-squared) from tests for a trend or relationship between variables (correlation and regression).	17



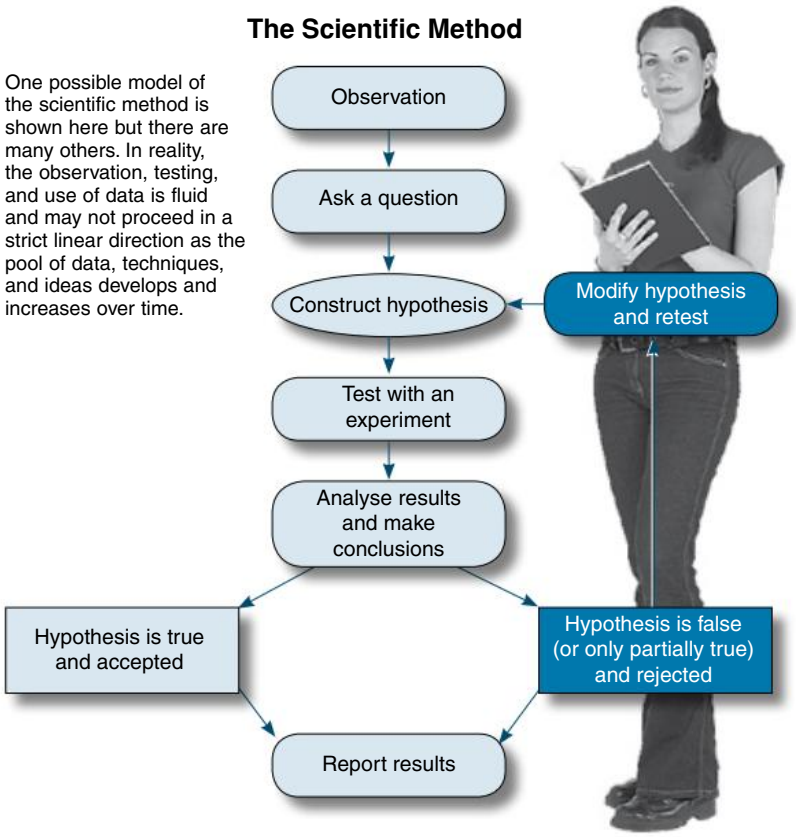
1 The Scientific Method

Key Idea: The scientific method is a rigorous process of observation, measurement, and analysis that helps us to explain phenomena and predict changes in a system.

Scientific knowledge grows through a process called the **scientific method**. This process involves observation and measurement, hypothesising and predicting, and planning and executing investigations designed to test formulated **hypotheses**. A scientific hypothesis is a tentative explanation for an observation, which is capable of being tested by experimentation. Hypotheses lead to **predictions** about the system involved and they are accepted or rejected on the basis of the investigation's findings. Acceptance of the hypothesis is not necessarily permanent: explanations may be rejected later in light of new findings.

The Scientific Method

One possible model of the scientific method is shown here but there are many others. In reality, the observation, testing, and use of data is fluid and may not proceed in a strict linear direction as the pool of data, techniques, and ideas develops and increases over time.



Forming a Hypothesis

Features of a sound hypothesis:

- It is based on observations and prior knowledge of the system.
- It offers an explanation for an observation.
- It refers to only one independent variable.
- It is written as a definite statement and not as a question.
- It is testable by experimentation.
- It leads to predictions about the system.

Testing a Hypothesis

Features of a sound method:

- It tests the validity of the hypothesis.
- It is repeatable.
- It includes a control which does not receive treatment.
- All variables are controlled where possible.
- The method includes a dependent and independent variable.
- Only the independent variable is changed (manipulated) between treatment groups.



Hypothesis Involving Manipulation
Used when the effect of manipulating a variable on a biological entity is being investigated. **Example**: The composition of applied fertiliser influences the rate of growth of plant A.



Hypothesis of Choice
Used when investigating species preference, e.g. for a particular habitat type or microclimate. **Example**: Woodpeckers (species A) show a preference for a certain tree type when nesting.



Hypothesis Involving Observation
Used when organisms are being studied in their natural environment and conditions cannot be changed. **Example**: Fern abundance is influenced by the amount of canopy.

1. Why might an accepted hypothesis be rejected at a later date? _____

2. Explain why a method must be repeatable: _____

3. In which situation(s) is it difficult, if not impossible, to control all the variables? _____

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2 Hypotheses and Predictions

Key Idea: Observations are the basis for forming hypotheses and making predictions about systems. An assumption is something that is accepted as true but is not tested.

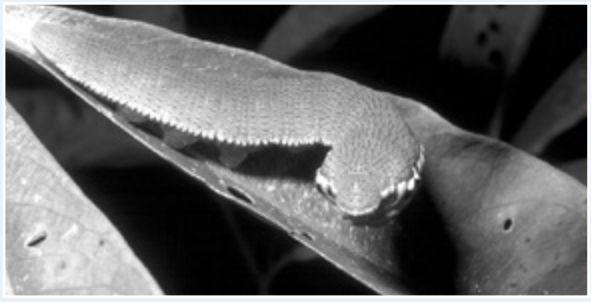
A **hypothesis** offers a tentative explanation to questions generated by observations and leads to one or more predictions about the way a biological system will behave. For every hypothesis, there is a corresponding **null hypothesis**: a hypothesis of no difference or no effect. A null hypothesis allows a hypothesis to be tested using statistical tests. If the experimental results are statistically significant, the null hypothesis can be rejected. If a hypothesis is accepted, anyone should be able to test the predictions with the same methods and get a similar result. Scientific hypotheses may be modified as more information becomes available.

Observations, Hypotheses, and Predictions

Observation is the basis for formulating hypotheses and making predictions. An observation may generate a number of plausible hypotheses, and each hypothesis will lead to one or more predictions, which can be tested by further investigation.



Observation 1: Some caterpillar species are brightly coloured and appear to be conspicuous to predators such as insectivorous (insect-eating) birds. Predators appear to avoid these species. These caterpillars are often found in groups, rather than as solitary animals.



Observation 2: Some caterpillar species are cryptic in their appearance or behaviour. Their camouflage is so convincing that, when alerted to danger, they are difficult to see against their background. Such caterpillars are usually found alone.



Assumptions

Any biological investigation requires you to make **assumptions** about the biological system you are working with. Assumptions are features of the system (and your investigation) that you assume to be true but do not (or cannot) test. Possible assumptions about the biological system described above include:

- Insectivorous birds have colour vision.
- Caterpillars that look bright or cryptic to us, also appear that way to insectivorous birds.
- Insectivorous birds can learn about the palatability of prey by tasting them.



1. Study the example above illustrating the features of cryptic and conspicuous caterpillars, then answer the following:

   (a) Generate a hypothesis to explain the observation that some caterpillars are brightly coloured and conspicuous while others are cryptic and blend into their surroundings:

   Hypothesis: _____

   _____

   _____

   (b) State the null form of this hypothesis: _____

   _____

   (c) Describe one of the **assumptions** being made in your hypothesis: _____

   _____

   _____

   (d) Based on your hypothesis, generate a **prediction** about the behaviour of insectivorous birds towards caterpillars:

   _____

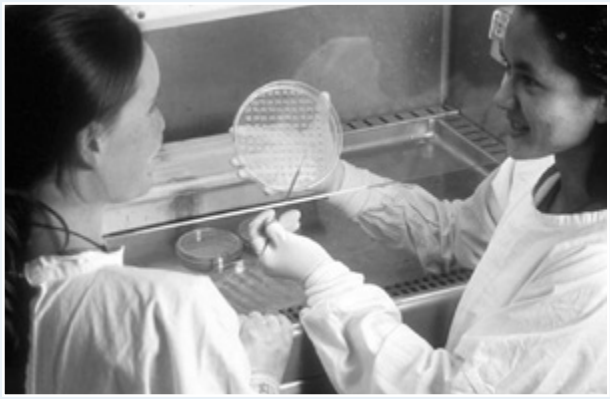
   _____

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2. During the course of any investigation, new information may arise as a result of observations unrelated to the original hypothesis. This can lead to the generation of further hypotheses about the system. For each of the incidental observations described below, formulate a prediction, and an outline of an investigation to test it. *The observation described in each case was not related to the hypothesis the experiment was designed to test:*

(a) **Bacterial cultures**

Prediction: _____

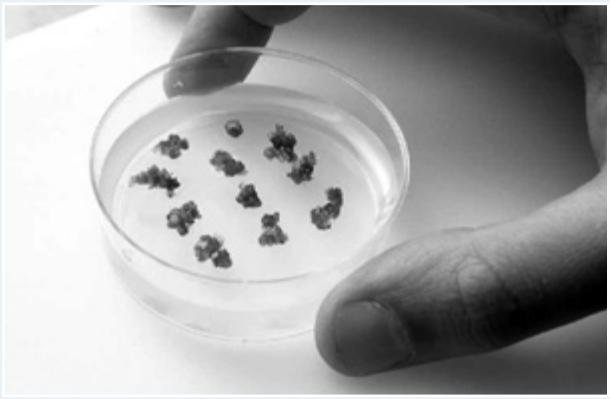


Observation: During an experiment on bacterial growth, these girls noticed that the cultures grew at different rates when the dishes were left overnight in different parts of the laboratory.

Outline of the investigation:

(b) **Plant cloning**

Prediction: _____



Observation: During an experiment on plant cloning, a scientist noticed that the root length of plant clones varied depending on the concentration of a hormone added to the agar.

Outline of the investigation:

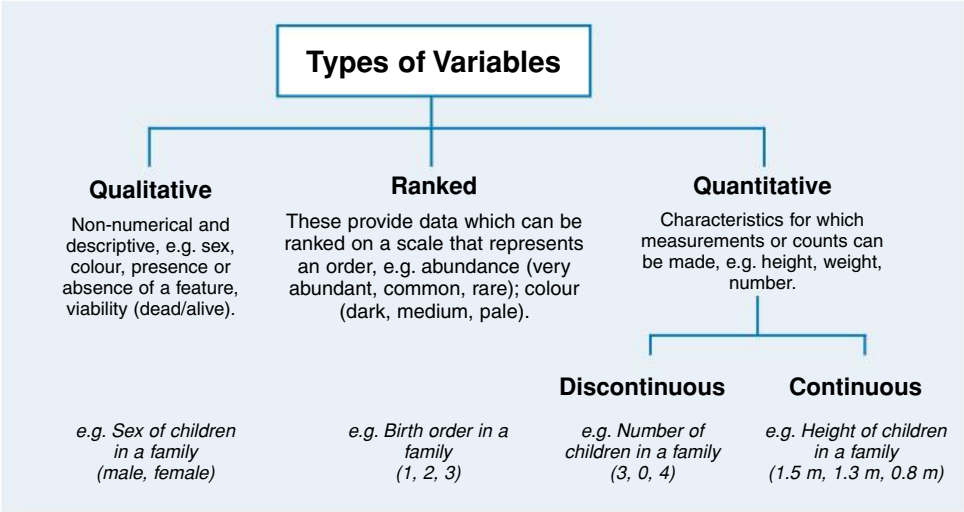
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3 Variables and Data

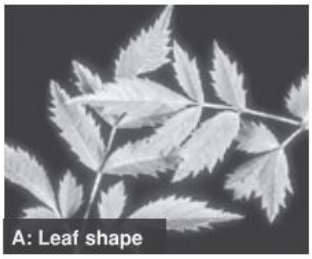
Key Idea: The type of data collected and how it is recorded are important for later data manipulation and transformation.

When planning a biological investigation, it is important to consider the type of data that will be collected. It is best to collect quantitative (numerical) data, because they are easier to analyse in a meaningful way. Recording data in a systematic way as you collect it, e.g. using a table or spreadsheet, is important too, especially if data manipulation and transformation are required. It is also useful to calculate summary, descriptive statistics (e.g. mean, median) as you proceed. These will help you to recognise important trends and features in your data as they become apparent.





The values for monitored or measured variables, collected during the course of the investigation, are called data. Like their corresponding variables, data may be quantitative, qualitative, or ranked.







BH

1. For each of the photographic examples (A – C above), classify the variables as quantitative, ranked, or qualitative:

   (a) Leaf shape: _____

   (b) Number per litter: _____

   (c) Fish length: _____

2. Why is it desirable to collect quantitative data where possible in biological studies? _____

3. How could you measure the colour of light (red, blue, green) quantitatively? _____

4. (a) Give an example of data that could not be collected in a quantitative manner, explaining your answer:

   (b) Sometimes, ranked data are given numerical values, e.g. rare = 1, occasional = 2, frequent = 3, common = 4, abundant = 5. Suggest why these data are sometimes called **semi-quantitative**:

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4 A Qualitative Investigation

Key Idea: Qualitative data is non-numerical and descriptive.
Qualitative data is more difficult to analyse and interpret objectively than quantitative data. It is also more likely to be biased. However, sometimes it is appropriate to collect qualitative data, e.g. when recording colour changes in simple tests for common components of foods. Two common tests for carbohydrates are the iodine/potassium iodide test for starch and the Benedict's test for reducing sugars, such as glucose. These tests indicate the presence of a substance with a colour change. All monosaccharides are reducing sugars as are the disaccharides, lactose and maltose. The monosaccharide fructose is a ketose, but it gives a positive test because it is converted to glucose in the reagent. When a starchy fruit ripens, the starch is converted to reducing sugars.

The Aim

To investigate the effect of ripening on the relative content of starch and simple sugars in bananas.

The Tests

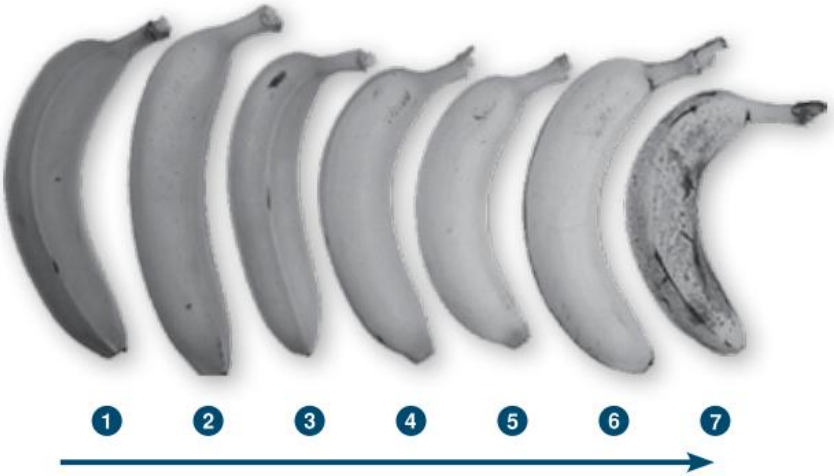
Iodine-potassium iodide test for starch
The sample is covered with the iodine in potassium iodide solution. The sample turns blue-black if starch is present.

Benedict's test for reducing sugars
The sample is heated with the reagent in a boiling water bath. After 2 minutes, the sample is removed and stirred, and the colour recorded immediately after stirring. A change from a blue to a brick red colour indicates a reducing sugar.

Summary of the Method

Two 1 cm thick slices of banana from each of seven stages of ripeness were cut and crushed to a paste. One slice from each stage was tested using the I/KI test for starch, and the other was tested using the Benedict's test.

The colour changes were recorded in a table. Signs (+/–) were used to indicate the intensity of the reaction relative to those in bananas that were either less or more ripe.



Stage of ripeness	Starch-iodine test		Benedict's test	
1	blue-black	+++++	blue clear	–
2	blue-black	++++	blue clear	–
3	blue-black	+++	green	+
4	blue-black	++	yellow cloudy	++
5	slight darkening	+	orange thick	+++
6	no change	–	orangey-red thick	++++
7	no change	–	brick-red thick	+++++

1. Explain why each of the following protocols was important:

   (a) All samples of banana in the Benedict's reagent were heated for 2 minutes: _____

   _____

   (b) The contents of the banana sample and Benedict's reagent were stirred after heating: _____

   _____

2. Explain what is happening to the relative levels of starch and glucose as bananas ripen: _____

   _____

   _____

3. Fructose is a ketose sugar (not an aldose with an aldehyde functional group like glucose).

   (a) Explain why fructose also gives a positive result in a Benedict's test: _____

   _____

   (b) What could this suggest to you about the results of this banana test? _____

   _____

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5 A Quantitative Investigation

Key Idea: Practical work carried out in a careful and methodical way makes analysis of the results much easier.

The next stage after planning an experiment is to collect the data. Practical work may be laboratory or field based. Typical laboratory based experiments involve investigating how a biological response is affected by manipulating a particular **variable**, e.g. temperature. The data collected for a quantitative practical task should be recorded systematically, with due attention to safe practical techniques, a suitable quantitative method, and accurate measurements to an appropriate degree of precision. If your quantitative practical task is executed well, and you have taken care throughout, your evaluation of the experimental results will be much more straightforward and less problematic.

Carrying Out Your Practical Work







Preparation

Familiarise yourself with the equipment and how to set it up. If necessary, calibrate equipment to give accurate measurements.

Read through the methodology and identify key stages and how long they will take.

Execution

Identify any **assumptions** you make about your set up. Assumptions are features of the system that you assume to be true but do not (or cannot) test. Know how you will take your measurements, how often, and to what degree of precision.

Recording

Record your results systematically, in a hand-written table or on a spreadsheet.

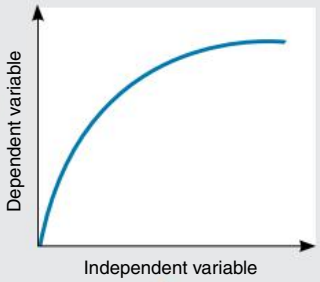
Record your results to the appropriate number of significant figures according to the precision of your measurement.

Identifying Variables

A variable is any characteristic or property able to take any one of a range of values. Investigations often look at the effect of changing one variable on another. It is important to identify all variables in an investigation: independent, dependent, and controlled, although there may be nuisance factors of which you are unaware. In all fair tests, only one variable is changed by the investigator.

Dependent variable

- Measured during the investigation.
- Recorded on the y axis of the graph.



Controlled variables

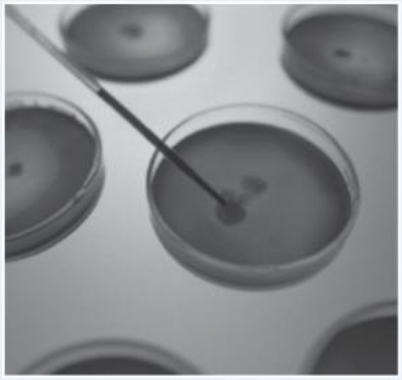
- Factors that are kept the same or controlled.
- List these in the method, as appropriate to your own investigation.

Independent variable

- Set by the experimenter.
- Recorded on the graph's x axis.

Experimental Controls

A control refers to standard or reference treatment or group in an experiment. It is the same as the experimental (test) group, except that it lacks the one variable being manipulated by the experimenter. Controls are used to demonstrate that the response in the test group is due a specific variable (e.g. temperature). The control undergoes the same preparation, experimental conditions, observations, measurements, and analysis as the test group. This helps to ensure that responses observed in the treatment groups can be reliably interpreted.



The experiment above tests the effect of a certain nutrient on microbial growth. All the agar plates are prepared in the same way, but the control plate does not have the test nutrient applied. Each plate is inoculated from the same stock solution, incubated under the same conditions, and examined at the same set periods. The control plate sets the baseline; any growth above that seen on the control plate is attributed to the presence of the nutrient.

Examples of Investigations

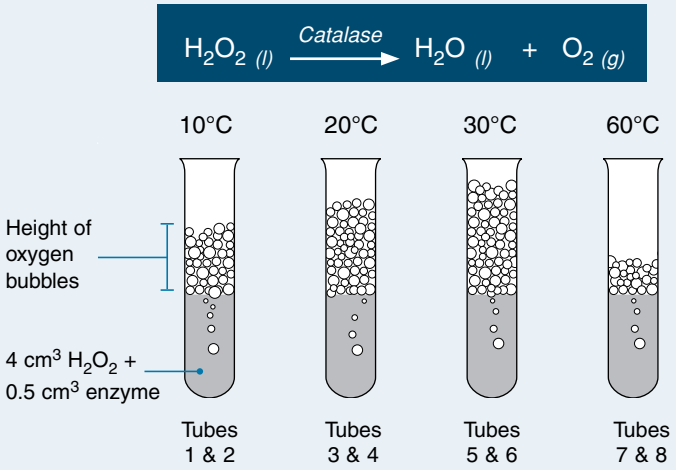
Aim		Variables	
Investigating the effect of varying...	**on the following...**	**Independent variable**	**Dependent variable**
Temperature	Leaf width	Temperature	Leaf width
Light intensity	Activity of woodlice	Light intensity	Woodlice activity
Soil pH	Plant height at age 6 months	pH	Plant height

KNOW
LINK 1
LINK 75
LINK 113

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Case Study: Catalase Activity

Catalase is an enzyme that converts hydrogen peroxide (H_2O_2) to oxygen and water. An experiment investigated the effect of temperature on the rate of the catalase reaction. Small (10 cm^3) test tubes were used for the reactions, each containing 0.5 cm^3 of enzyme and 4 cm^3 of hydrogen peroxide. Reaction rates were assessed at four temperatures (10°C, 20°C, 30°C, and 60°C). For each temperature, there were two reaction tubes (e.g. tubes 1 and 2 were both kept at 10°C). The height of oxygen bubbles present after one minute of reaction was used as a measure of the reaction rate; a faster reaction rate produced more bubbles. The entire experiment, involving eight tubes, was repeated on two separate days.



1. Write a suitable aim for this experiment: _____

_____

2. Write a suitable hypothesis for this experiment: _____

_____

3. (a) What is the **independent variable?** _____

   (b) What is the range of values for the independent variable? _____

   (c) Name the unit for the independent variable: _____

   (d) List the equipment needed to set the independent variable, and describe how it was used: _____

   _____

4. (a) What is the **dependent variable**? _____

   (b) Name the unit for the dependent variable: _____

   (c) List the equipment needed to measure the dependent variable, and describe how it was used: _____

   _____

5. (a) Each temperature represents a treatment/sample/trial (circle one):

   (b) How many tubes are at each temperature? _____

   (c) What is the sample size for each treatment? _____

   (d) How many times was the whole investigation repeated? _____

6. Why would it have been desirable to have included an extra tube containing no enzyme? _____

   _____

7. Identify three variables that might have been controlled in this experiment, and how they could have been monitored:

   (a) _____

   (b) _____

   (c) _____

8. Why should controlled variables be monitored carefully? _____

   _____

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6 Recording Results

Key Idea: Accurately recording results in a table makes it easier to understand and analyse your data later. A table is a good way to record your results systematically, both during the course of your experiment and in presenting your results. A table can also be used to show calculated values, such as rates or means. An example of a table for recording results is shown below. It relates to an investigation of the net growth of plants at three pH levels, but it represents a relatively standardised layout. The labels on the columns and rows are chosen to represent the design features of the investigation. The first column shows the entire range of the independent variable. There are spaces for multiple sampling units, repeats (trials), and calculated mean values. A version of this table would be given in the write-up of the experiment.

Dependent variable and its units

Space for repeats of the experimental design (in this case, three trials).

All masses are in grams and to the nearest 0.1 g.

		Trial 1 (plant mass in grams)						**Trial 2** (plant mass in grams)						**Trial 3** (plant mass in grams)					
		Day No.						Day No.						Day No.					
		0	2	4	6	8	10	0	2	4	6	8	10	0	2	4	6	8	10
pH 3	1	0.5	1.1																
	2	0.6	1.2																
	3	0.7	1.3																
	Mean	0.6	1.2																
pH 5	1	0.6	1.4																
	2	0.8	1.7																
	3	0.5	1.9																
	Mean	0.6	1.7																
pH 7	1	0.7	1.3																
	2	0.8	1.3																
	3	0.4	1.7																
	Mean	0.6	1.4																

Space for three plants at each pH

The range of values for the independent variable are in this column

Recordings of the dependent variable

Space for calculated means

1. In the box (below) design a table to collect data from the case study below. Include space for individual results and averages from the three set ups (use the table above as a guide).

CO_2 Levels in a Respiration Chamber

A datalogger was used to monitor the concentrations of carbon dioxide (CO_2) in respiration chambers containing five green leaves from one plant species. The entire study was performed in conditions of full light (quantified) and involved three identical set-ups.
The CO_2 concentrations were measured every minute, over a period of 10 minutes, using a CO_2 sensor. A mean CO_2 concentration (for the three set-ups) was calculated. The study was carried out two more times, two days apart.

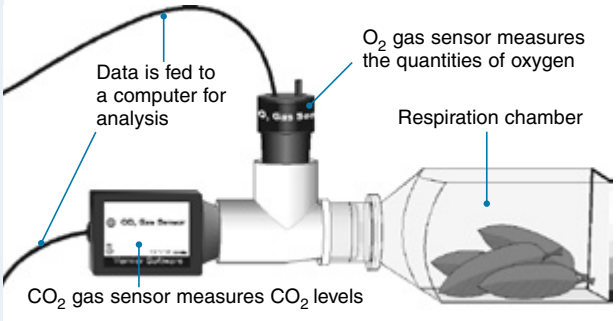


Image courtesy of Vernier

2. Next, the effect of various light intensities (low light, half-light, and full light) on CO_2 concentration was investigated. How would the results table for this investigation differ from the one you have drawn above (for full light only):

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7 Manipulating Raw Data

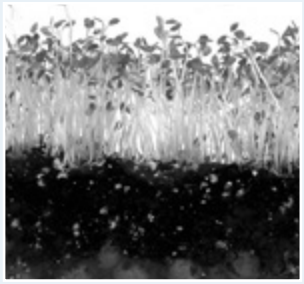
Key Idea: The manipulation (transformation) of raw data makes it easier to identify trends and patterns. Simple transformations include frequencies, rates, and percentages. The data collected in the field or laboratory are called **raw data**. It is often helpful, especially with large data sets, to transform or otherwise summarise the data to identify trends and patterns. Some basic calculations, such as totals, are made to compare replicates or as a prelude to other transformations. The calculation of **rate** (amount per unit time) is also common and is appropriate for many biological situations (e.g. measuring growth or weight loss or gain). Biological investigations often compare the rates of events in different situations. Other typical transformations include frequencies and percentages.

Tally Chart

Records the number of times a value occurs in a data set

HEIGHT (cm)	TALLY	TOTAL
0–0.99	III	3
1–1.99	~~IIII~~ I	6
2–2.99	~~IIII~~ ~~IIII~~	10
3–3.99	~~IIII~~ ~~IIII~~ II	12
4–4.99	III	3
5–5.99	II	2

- A useful first step in analysis; a neatly constructed tally chart doubles as a simple histogram.
- Cross out each value on the list as you tally it to prevent double entries. Check all values are crossed out at the end and that totals agree.



Example: Height of 6 d old seedlings

Percentages

Expressed as a fraction of 100

Women	Body mass (kg)	Lean body mass (kg)	% lean body mass
Athlete	50	38	76.0
Lean	56	41	73.2
Normal weight	65	46	70.8
Overweight	80	48	60.0
Obese	95	52	54.7

- Percentages provide a clear expression of what proportion of data fall into any particular category, e.g. for pie graphs.
- Allows meaningful comparison between different samples.
- Useful to monitor change (e.g. % increase from one year to the next).



Example: Percentage of lean body mass in women

Rates

Expressed as a measure per unit time

Time (minutes)	Cumulative sweat loss (mL)	Rate of sweat loss (mL min^{-1})
0	0	0
10	50	5
20	130	8
30	220	9
60	560	11.3

- Rates show how a variable changes over a standard time period (e.g. one second, one minute, or one hour).
- Rates allow meaningful comparison of data that may have been recorded over different time periods.
- For a line graph, with time as the independent variable, the slope of the line is a measure of the rate.



Example: Rate of sweat loss during cycling

1. Why might you perform a basic data transformation? _____

_____

2. (a) Describe a transformation for data relating to the relative abundance of plant species in different habitats:

_____

(b) Explain your answer: _____

_____

3. Complete the transformations on the table (right). The first value is given for you.

Table: ***Incidence of cyanogenic clover in different areas***

Working: 120 ÷ 158 = 0.76 = 76%

This is the number of cyanogenic clover out of the total.

Incidence of cyanogenic clover in different areas

Clover plant type	Frost free area		Frost prone area		Totals
	Number	%	Number	%	
Cyanogenic	120	76	22		
Acyanogenic	38		120		
Total	158				

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8 Constructing Tables and Graphs

Key Idea: Tables and graphs provide a way to organise and visualise data in a way that helps to identify trends.

Tables and graphs are ways to present data and they have different purposes. **Tables** provide an accurate record of numerical values and allow you to organise your data so that relationships and trends are apparent. **Graphs** provide a visual image of trends in the data in a minimum of space. It is useful to plot your data as soon as possible, even during your experiment, as this will help you to evaluate your results as you proceed and make adjustments as necessary (e.g. to the sampling interval). The choice between graphing or tabulation in the final report depends on the type and complexity of the data and the information that you are wanting to convey. Usually, both are appropriate.

Presenting Data in Tables

An accurate, descriptive title.

Table 1: Length and growth of the third internode of bean plants receiving three different hormone treatments (data are given ± standard deviation).

Treatment	Sample size	Mean rate of internode growth (mm day^{-1})	Mean internode length (mm)	Mean mass of tissue added (g day^{-1} ± SD)
Control	50	0.60 ± 0.025	32.3 ± 2.3	0.36 ± 0.025
Hormone 1	46	1.52 ± 0.030	41.6 ± 3.4	0.51 ± 0.030
Hormone 2	98	0.82 ± 0.018	38.4 ± 0.9	0.56 ± 0.028
Hormone 3	85	2.06 ± 0.019	50.2 ± 1.4	0.68 ± 0.020

Independent variable in left column.

Control values (if present) should be placed at the beginning of the table.

Each row should show a different experimental treatment, organism, sampling site etc.

Heading and subheadings identify each set of data and show units of measurement.

Tables can show a calculated measure of data variability (e.g. standard deviation).

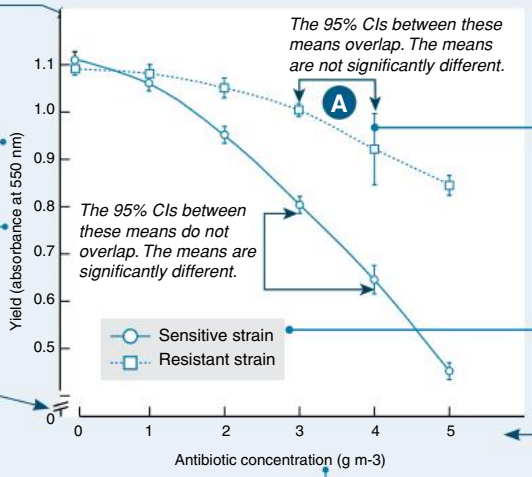
Show values only to the level of significance allowable by your measuring technique.

Columns that need to be compared should be placed alongside each other.

Organise the columns so that each category of like numbers or attributes is listed vertically.

Presenting Data in Graph Format

Fig. 1: Yield of two bacterial strains at different antibiotic levels (± 95% confidence intervals, n= 6)



Plot points accurately. Different responses can be distinguished using different symbols, lines or bar colours.

Label both axes (provide SI units of measurement if necessary).

Place the dependent variable, e.g. biological response, on the vertical (y) axis (if you are drawing a scatter graph it does not matter).

A break in an axis allows economical use of space if there are no data in the "broken" area. A floating axis (where zero points do not meet) allows data points to be plotted away from the vertical axis.

Graphs (called figures) should have a concise, explanatory title. If several graphs appear in your report they should be numbered consecutively.

Measures of spread about the plotted mean value can be shown on the graph. Such measures include standard deviation and 95% confidence intervals (CI). The values are plotted as **error bars** and give an indication of the reliability of the mean value. If the 95% confidence intervals do not overlap between points, then these means will be significantly different.

A key identifies symbols. This information sometimes appears in the title or the legend.

Each axis should have an appropriate scale. Decide on the scale by finding the maximum and minimum values for each variable.

Place the independent variable, e.g. treatment, on the horizontal (x) axis.

1. What can you conclude about the difference (labelled A) between the two means plotted above? Explain your answer:

2. Explain the reasons for including both graphs and tables in a final report:

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9 Drawing Bar Graphs

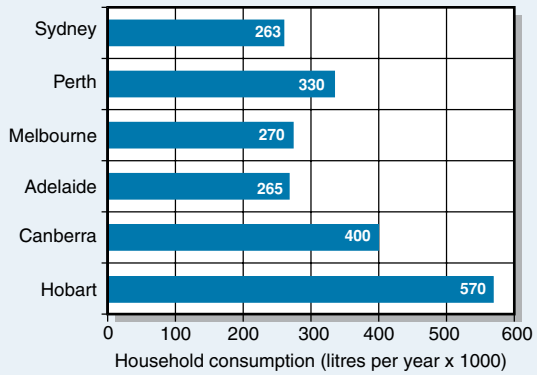
Key Idea: Bar graphs are used to plot data that is non-numerical or discrete for at least one variable.

Guidelines for Bar Graphs

Bar graphs are appropriate for data that are non-numerical and **discrete** for at least one variable, i.e. they are grouped into categories. There are no dependent or independent variables. Important features of this type of graph include:

- Data are collected for discontinuous, non-numerical categories (e.g. colour, species), so the bars do not touch.
- Data values may be entered on or above the bars.
- Multiple sets of data can be displayed side by side for comparison (e.g. males and females).
- Axes may be reversed so that the categories are on the x axis, i.e. bars can be vertical or horizontal. When they are vertical, these graphs are called column graphs.

Average household water consumption in Australian cities



1. Counts of eight mollusc species were made from a series of quadrat samples at two sites on a rocky shore. The summary data are presented here.
   (a) Tabulate the mean (**average**) numbers per square metre at each site in Table 1 (below left).
   (b) Plot a **bar graph** of the tabulated data on the grid below. For each species, plot the data from both sites side by side using different colours to distinguish the sites.

Mean abundance of 8 molluscan species from two sites along a rocky shore.

Species	Mean (no m^{-2})	
	Site 1	Site 2

Field data notebook

Total counts at site 1 (11 quadrats) and site 2 (10 quadrats). Quadrats 1 sq m.

	Site 1		Site 2	
	No m^{-2}		No m^{-2}	
Species	Total	Mean	Total	Mean
Ornate limpet	232	21	299	30
Radiate limpet	68	6	344	34
Limpet sp. A	420	38	0	0
Cats-eye	68	6	16	2
Top shell	16	2	43	4
Limpet sp. B	628	57	389	39
Limpet sp. C	0	0	22	2
Chiton	12	1	30	3

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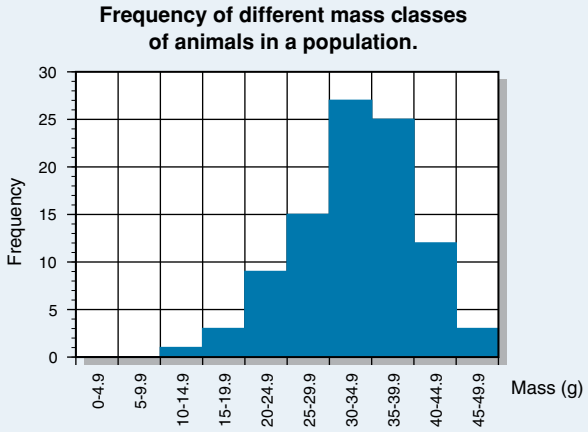
10 Drawing Histograms

Key Idea: Histograms graphically show the frequency distribution of continuous data.

Guidelines for Histograms

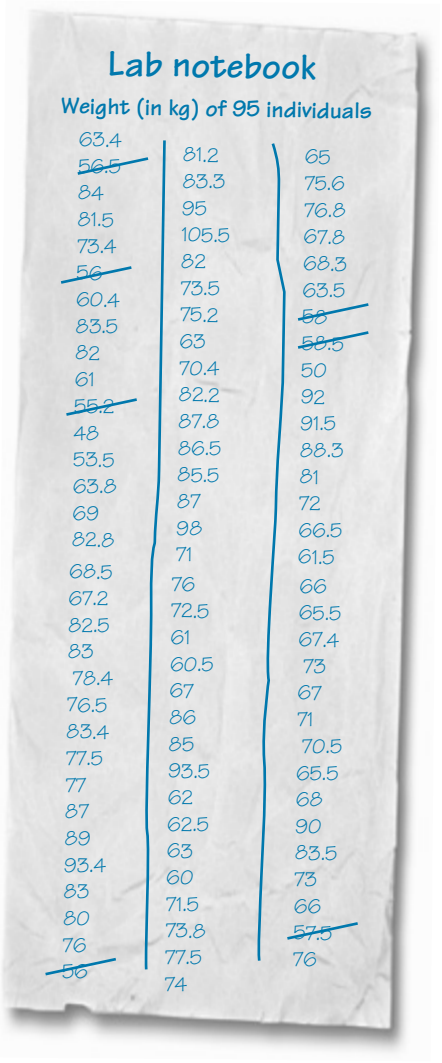
Histograms are plots of **continuous** data and are often used to represent frequency distributions, where the y-axis shows the number of times a particular measurement or value was obtained. For this reason, they are often called frequency histograms. Important features of this type of graph include:

- The data are numerical and continuous (e.g. height or weight), so the bars touch.
- The x-axis usually records the class interval. The y-axis usually records the number of individuals in each class interval (frequency).



1. The weight data provided below were recorded from 95 individuals (male and female), older than 17 years.
   (a) Create a tally chart (frequency table) in the frame provided, organising the weight data into a form suitable for plotting. An example of the tally for the weight grouping 55-59.9 kg has been completed for you as an example. Note that the raw data values, once they are recorded as counts on the tally chart, are crossed off the data set in the notebook. It is important to do this in order to prevent data entry errors.
   (b) Plot a **frequency histogram** of the tallied data on the grid provided below.

Weight (kg)	Tally	Total
45-49.9		
50-54.9		
55-59.9	𝍸 II	7
60-64.9		
65-69.9		
70-74.9		
75-79.9		
80-84.9		
85-89.9		
90-94.9		
95-99.9		
100-104.9		
105-109.9		



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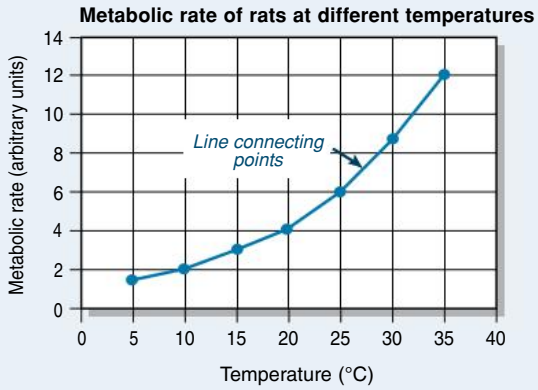
11 Drawing Line Graphs

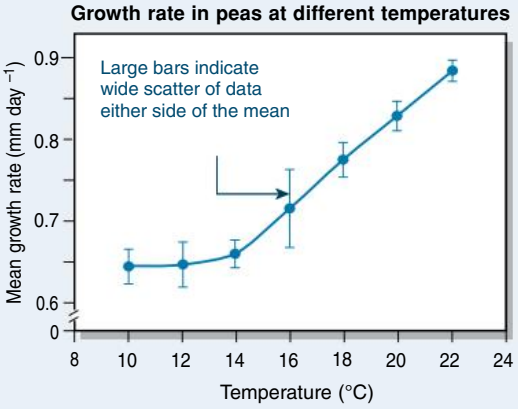
Key Idea: Line graphs are used to plot continuous data in which one variable (the independent variable) directly affects the other (dependent) variable. They are appropriate for data in which the independent variable is manipulated.

Guidelines for Line Graphs

Line graphs are used when one variable (the independent variable) affects another, the dependent variable. Line graphs can be drawn without a measure of spread (top figure, right) or with some calculated measure of data variability (bottom figure, right). Important features of line graphs include:

- The data must be continuous for both variables.
- The dependent variable is usually the biological response.
- The independent variable is often time or experimental treatment.
- In cases where there is an implied trend (e.g. one variable increases with the other), a line of best fit is usually plotted through the data points to show the relationship.
- If fluctuations in the data are likely to be important (e.g. with climate and other environmental data) the data points are usually connected directly (point to point).
- Line graphs may be drawn with measure of error. The data are presented as points (which are the calculated means), with bars above and below, indicating a measure of variability or spread in the data (e.g. standard error, standard deviation, or 95% confidence intervals).
- Where no error value has been calculated, the scatter can be shown by plotting the individual data points vertically above and below the mean. By convention, bars are not used to indicate the range of raw values in a data set.





1. The results (shown right) were collected in a study investigating the effect of temperature on the activity of an enzyme.

   (a) Using the results provided (right), plot a line graph on the grid below:

   (b) Estimate the rate of reaction at 15°C: _____

Lab Notebook

An enzyme's activity at different temperatures

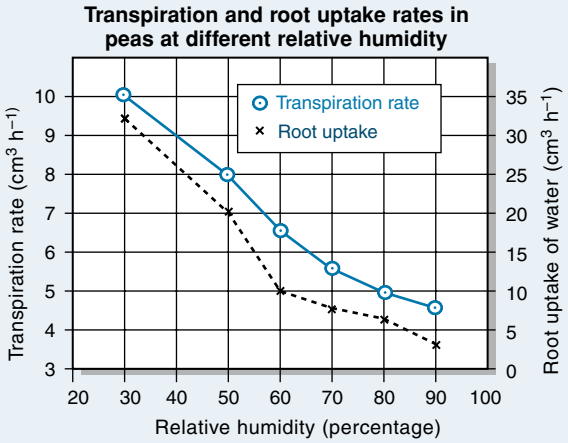
Temperature (°C)	Rate of reaction (mg of product formed per minute)
10	1.0
20	2.1
30	3.2
35	3.7
40	4.1
45	3.7
50	2.7
60	0

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Plotting Multiple Data Sets

A single figure can be used to show two or more data sets, i.e. more than one curve can be plotted per set of axes. This type of presentation is useful when comparing the trends for two or more treatments, or the response of one species against the response of another. Important points regarding this format are:

- If the two data sets use the same measurement units and a similar range of values for the independent variable, one scale on the y axis is used.
- If the two data sets use different units and/or have a very different range of values for the independent variable, two scales for the y axis are used (see example provided). The scales can be adjusted if necessary to avoid overlapping plots
- The two curves must be distinguished with a key.



2. The number of perch and trout in a hydro-electric reservoir were monitored over 19 years. A colony of black shag was also present. Shags feed on perch and (to a lesser extent) trout. In 1960-61, 424 shags were removed from the lake during the nesting season and nest counts were made every spring in subsequent years. In 1971, 60 shags were removed from the lake, and all existing nests dismantled. The results of the population survey are tabulated below.

   (a) Plot a line graph (joining the data points) for the survey results. Use one scale (on the left) for numbers of perch and trout and another scale for the number of shag nests. Use different symbols to distinguish the lines and include a key.

   (b) Use a vertical arrow to indicate the point at which shags and their nests were removed.

Year	Mean number of fish per haul		Shag nest numbers
	Trout	Perch	
1960	–	–	16
1961	–	–	4
1962	1.5	11	5
1963	0.8	9	10
1964	0	5	22
1965	1	1	25
1966	1	2.9	35
1967	2	5	40
1968	1.5	4.6	26
1969	1.5	6	32

Year (continued)	Mean number of fish per haul		Shag nest numbers
	Trout	Perch	
1970	1.5	6	1.5
1971	0.5	0.7	1.5
1972	1	0.8	0
1973	0.2	4	0
1974	0.5	6.5	0
1975	0.6	7.6	2
1976	1	1.2	10
1977	1.2	1.5	32
1978	0.7	1.2	28

Source: Data adapted from 1987 Bursary Examination

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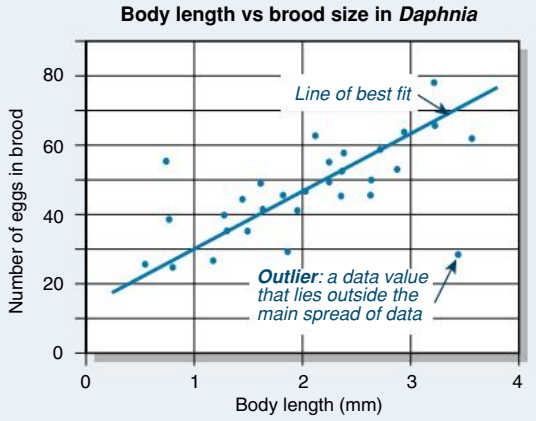
12 Drawing Scatter Plots

Key Idea: Scatter graphs are used to plot continuous data where there is a relationship between two interdependent variables.

Guidelines for Scatter Graphs

A scatter graph is used to display continuous data where there is a relationship between two interdependent variables.

- The data must be continuous for both variables.
- There is no independent (manipulated) variable, but the variables are often correlated, i.e. they vary together in some predictable way.
- Scatter graphs are useful for determining the relationship between two variables.
- The points on the graph need not be connected, but a line of best fit is often drawn through the points to show the relationship between the variables (this may be drawn by eye or computer generated).



1. In the example below, metabolic measurements were taken from seven Antarctic fish *Pagothenia borchgrevinski.* The fish are affected by a gill disease, which increases the thickness of the gas exchange surfaces and affects oxygen uptake. The results of oxygen consumption of fish with varying amounts of affected gill (at rest and swimming) are tabulated below.

Oxygen consumption of fish with affected gills

Fish number	Percentage of gill affected	Oxygen consumption ($cm^3\ g^{-1}\ h^{-1}$)	
		At rest	Swimming
1	0	0.05	0.29
2	95	0.04	0.11
3	60	0.04	0.14
4	30	0.05	0.22
5	90	0.05	0.08
6	65	0.04	0.18
7	45	0.04	0.20

(a) Using **one** scale only for oxygen consumption, plot the data on the grid below to show the relationship between oxygen consumption and the amount of gill affected by disease. Use different symbols or colours for each set of data (at rest and swimming).

(b) Draw a line of best fit through each set of points.

2. Describe the relationship between the amount of gill affected and oxygen consumption in the fish:

(a) For the **at rest** data set:

(b) For the **swimming** data set:

3. How does the gill disease affect oxygen uptake in resting fish? _____

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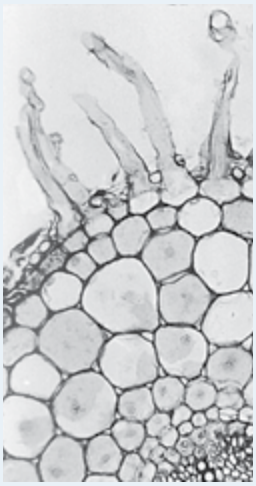
13 Making a Biological Drawing

Key Idea: Good biological drawings provide an accurate record of the specimen you are studying, and enable you to record its important features.

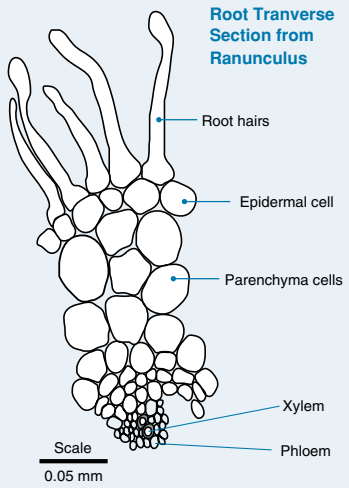
Biological drawings should include as much detail as you need to distinguish different structures and types of tissue, but avoid unnecessary detail. Tissue preparations are rarely neat and tidy and there may be areas where you cannot see detail and where cells overlie one another. In these cases you will need to infer detail from adjacent cells. Avoid shading as this can smudge and obscure detail. Labelling involves interpretation based on your knowledge and labels should be away from the drawing with label lines pointing to the structures identified. Add a title and any details of the image such as magnification. In this activity, you will practise the skills required to translate what is viewed into a good biological drawing.



***Above**: Use relaxed viewing when drawing at the microscope. Use one eye (the left for right handers) to view and the right eye to view and direct your drawing.*



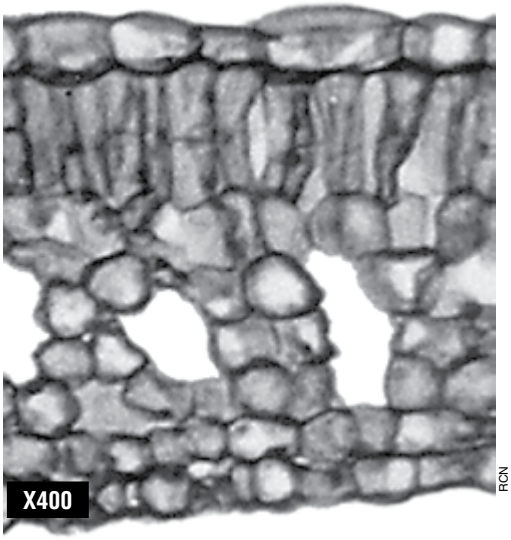
Above: Light micrograph TS through a *Ranunculus* root.



Above: A biological drawing of the same *Ranunculus* section. A biological drawing is different from a diagram, which is idealised and may contain more structure than can be seen in one section.

TASK

Complete the biological drawing of a cross section through a dicot leaf (below). Use the example above of the *Ranunculus* root as a guide to the detail required in your drawing.



Light micrograph of a cross section through a leaf.

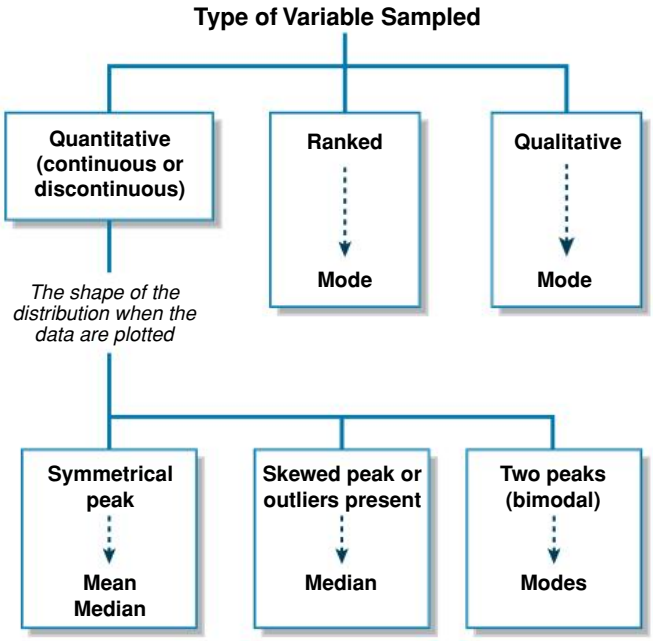
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14 Descriptive Statistics

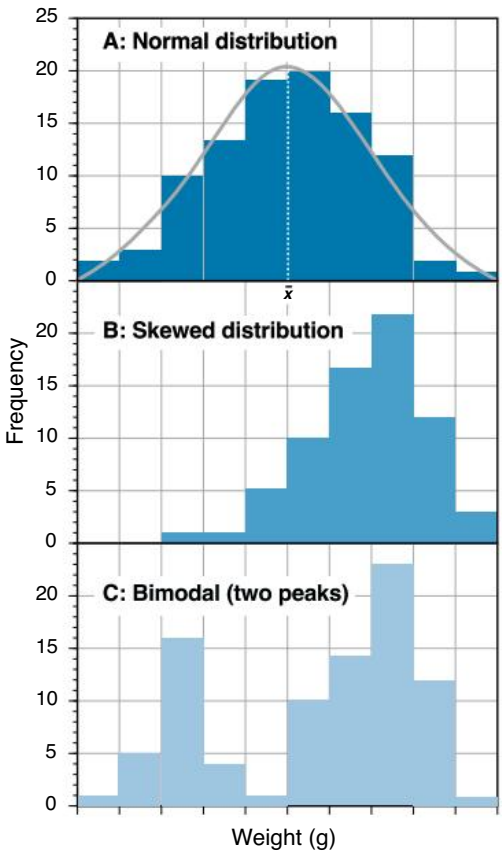
Key Idea: Descriptive statistics provide a way to summarise data and provide information about its distribution and spread. For most investigations, measures of the biological response are made from more than one sampling unit. In lab based investigations, the sample size (the number of sampling units) may be as small as three or four (e.g. three test-tubes in each of four treatments). In field studies, each individual may be a sampling unit, and the sample size can be very large (e.g. 100 individuals). It is useful to summarise the data collected using **descriptive statistics.** Descriptive statistics, such as mean, median, and mode, can identify the central tendency of a data set. Each of these statistics is appropriate to certain types of data or distribution (as indicated by a frequency distribution). Standard deviation and standard error are statistics used to quantify the variability around the central value and evaluate the reliability of estimates of the true (population) mean.

Variation in Data

Whether they are obtained from observation or experiments, most biological data show variability. In a set of data values, it is useful to know the value about which most of the data are grouped; the centre value. This value can be the mean, median, or mode depending on the type of variable involved (see schematic below). The main purpose of these statistics is to summarise important features your data and to provide the basis for statistical analyses.



The shape of the distribution will determine which statistic (mean, median, or mode) best describes the central tendency of the sample data.



A **frequency distribution** will indicate whether the data are normal, skewed, or bimodal.

Total of data entries / Number of entries = 5221 / 29 = 180 cm

Mean

Height of swimmers (in rank order)		
174	177	185
175	177	185
175	178	185
175	178	186
176	178	186
176	178	186
176	180	188
176	180	188
176	180	189
177	181	

Mode

Median

Height (cm)	Tally	Total
174	✔	1
175	✔✔✔	3
176	✔✔✔✔✔	5
177	✔✔✔	3
178	✔✔✔✔	4
179		0
180	✔✔✔	3
181	✔	1
182		0
183		0
184		0
185	✔✔✔	3
186	✔✔✔	3
187		0
188	✔✔	2
189	✔	1



Case Study: Height of Swimmers

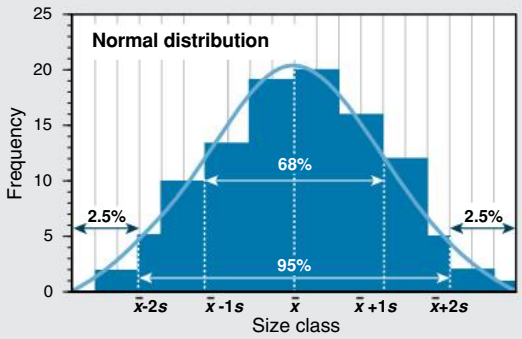
Data (below) and descriptive statistics (left) from a survey of the height of 29 members of a male swim squad.

Raw data: Height (cm)

178	177	188	176	186	175
180	181	178	178	176	175
180	185	185	175	189	174
178	186	176	185	177	176
176	188	180	186	177	

1. Give a reason for the difference between the mean, median, and mode for the swimmers' height data:

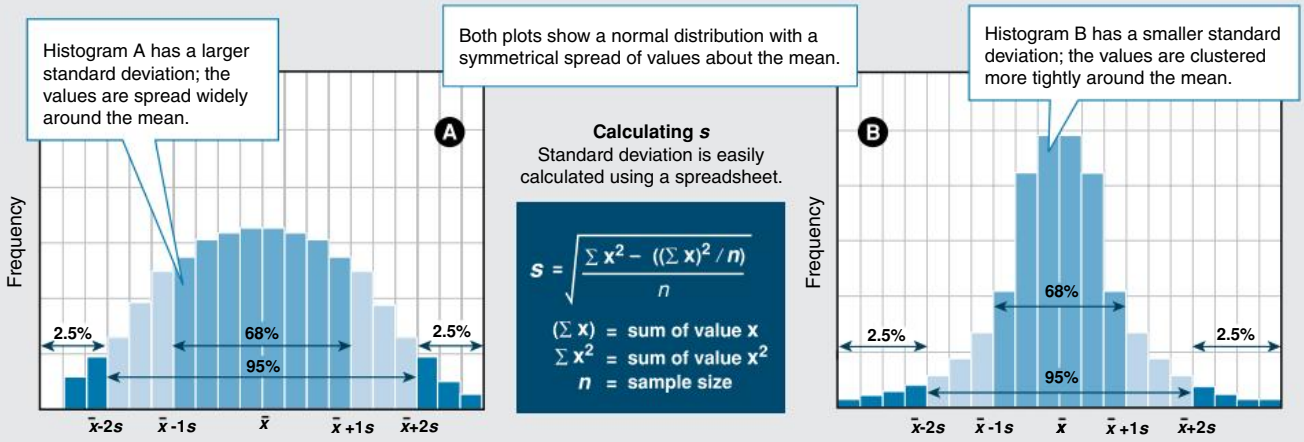
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Measuring Spread

The **standard deviation** is a frequently used measure of the variability (spread) in a set of data. It is usually presented in the form $\bar{x} \pm s$. In a normally distributed set of data, 68% of all data values will lie within one standard deviation (s) of the mean ($\bar{x}$) and 95% of all data values will lie within two standard deviations of the mean (left).

Two different sets of data can have the same mean and range, yet the distribution of data within the range can be quite different. In both the data sets pictured in the histograms below, 68% of the values lie within the range $\bar{x} \pm 1s$ and 95% of the values lie within $\bar{x} \pm 2s$. However, in B, the data values are more tightly clustered around the mean.

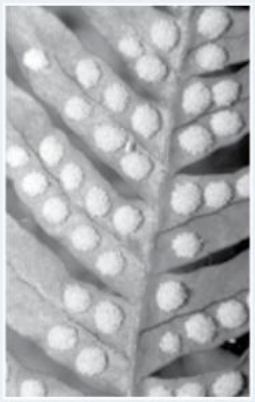


Calculating *s*

Standard deviation is easily calculated using a spreadsheet.

$$s = \sqrt{\frac{\sum x^2 - ((\sum x)^2 / n)}{n}}$$

$(\sum x)$ = sum of value x
$\sum x^2$ = sum of value x^2
n = sample size



Fern spores

Case Study: Fern Reproduction

Raw data (below) and descriptive statistics (right) from a survey of the number of sori found on the fronds of a fern plant.

Raw data: Number of sori per frond							
64	60	64	62	68	66	66	63
69	70	63	70	70	63	63	62
71	69	59	70	66	61	61	70
67	64	63	64				

$$\frac{\text{Total of data entries}}{\text{Number of entries}} = \frac{1641}{25} = 66 \text{ sori}$$

Mean

Number of sori per frond (in rank order)	
59	66
60	66
61	67
62	68
62	69
63	69
63	70
63	70
63	70
64	70
64	70
64	71
64	

Median

Mode

Sori per frond	Tally	Total
59	✔	1
60	✔	1
61	✔	1
62	✔✔	2
63	✔✔✔✔	4
64	✔✔✔✔	4
65		0
66	✔✔	2
67	✔	1
68	✔	1
69	✔✔	2
70	✔✔✔✔✔	5
71	✔	1

2. Give a reason for the difference between the mean, median, and mode for the fern sori data:

3. Calculate the mean, median, and mode for the data on ladybird masses below. Draw up a tally chart and show all calculations:

Ladybird mass (mg)		
10.1	8.2	7.7
8.0	8.8	7.8
6.7	7.7	8.8
9.8	8.8	8.9
6.2	8.8	8.4





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15 Interpreting Sample Variability

Key Idea: The sampling method can affect the results of a study, especially if it has an unknown bias.

The description of a data set requires that we know something about both central tendency (e.g. mean) and the spread of the data values around that central measure. The **standard deviation** (s) gives a simple measure of the spread or **dispersion** in data. It is usually preferred over the **variance** (s^2) because it is expressed in the original units. Two data sets could have the same mean, but very different values of dispersion. If we simply used the mean to compare these data sets, the results would (incorrectly) suggest that they were alike. The inferences we make about a population will be affected by what the sample data tell us. This is why it is important that sample data are unbiased (e.g. collected by random sampling) and that the sample set is as large as practicable. This exercise will help to illustrate this principle.

Random Sampling, Sample Size, and Dispersion in Data

Sample size and sampling bias can both affect the information we obtain when we sample a population. In this exercise you will calculate some descriptive statistics for some sample data.

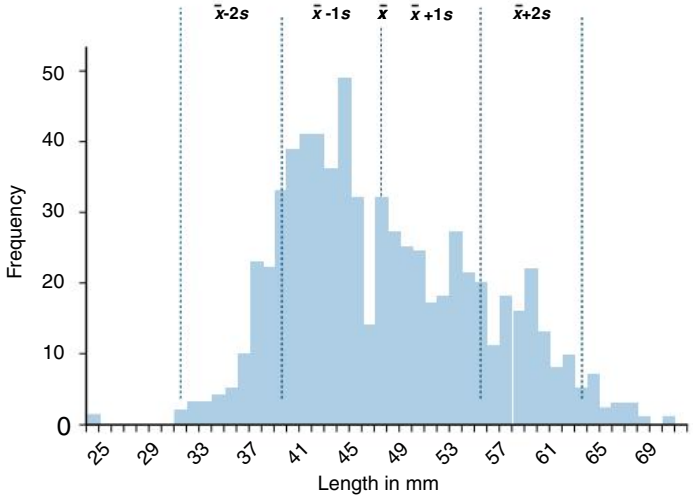
The complete set of sample data we are working with comprises 689 length measurements of year zero (young of the year) perch (column left). Basic descriptive statistics for the data have bee calculated for you below and the frequency histogram has also been plotted.

Look at this data set and then complete the exercise to calculate the same statistics from each of two smaller data sets (tabulated right) drawn from the same population. This exercise shows how random sampling, large sample size, and sampling bias affect our statistical assessment of variation in a population.

Complete sample set
n = 689 (random)

Length in mm	*Freq*
25	1
26	0
27	0
28	0
29	0
30	0
31	0
32	2
33	3
34	3
35	4
36	5
37	10
38	23
39	22
40	33
41	39
42	41
43	41
44	36
45	49
46	32
47	14
48	32
49	27
50	25
51	24
52	17
53	18
54	27
55	21
56	20
57	11
58	18
59	16
60	22
61	13
62	8
63	10
64	5
65	7
66	2
67	3
68	3
69	1
70	0
71	1
	689

Length of year zero perch



Descriptive statistics

MEAN	48
MEDIAN	47
MODE	45
VARIANCE	61.03
STANDARD DEVIATION	7.81



Small sample set
n = 30 (random)

Length in mm	*Freq*
25	1
26	0
27	0
28	0
29	0
30	0
31	0
32	0
33	0
34	0
35	2
36	0
37	0
38	3
39	2
40	1
41	3
42	0
43	0
44	0
45	0
46	1
47	0
48	2
49	0
50	0
51	1
52	3
53	0
54	0
55	0
56	0
57	1
58	0
59	3
60	2
61	2
62	0
63	0
64	0
65	0
66	0
67	2
68	1
	30

This population was sampled randomly to obtain this data set

This column records the number of fish of each size

Number of fish in the sample

Small sample set
n = 50 (bias)

Length in mm	*Freq*
46	1
47	0
48	0
49	1
50	0
51	0
52	1
53	1
54	1
55	1
56	0
57	2
58	2
59	4
60	1
61	0
62	8
63	10
64	13
65	2
66	0
67	2
	50

The person gathering this set of data was biased towards selecting larger fish because the mesh size on the net was too large to retain small fish

1. For the complete data set (n = 689) calculate the percentage of data falling within:

   (a) ± one standard deviation of the mean: _____

   (b) ± two standard deviations of the mean: _____

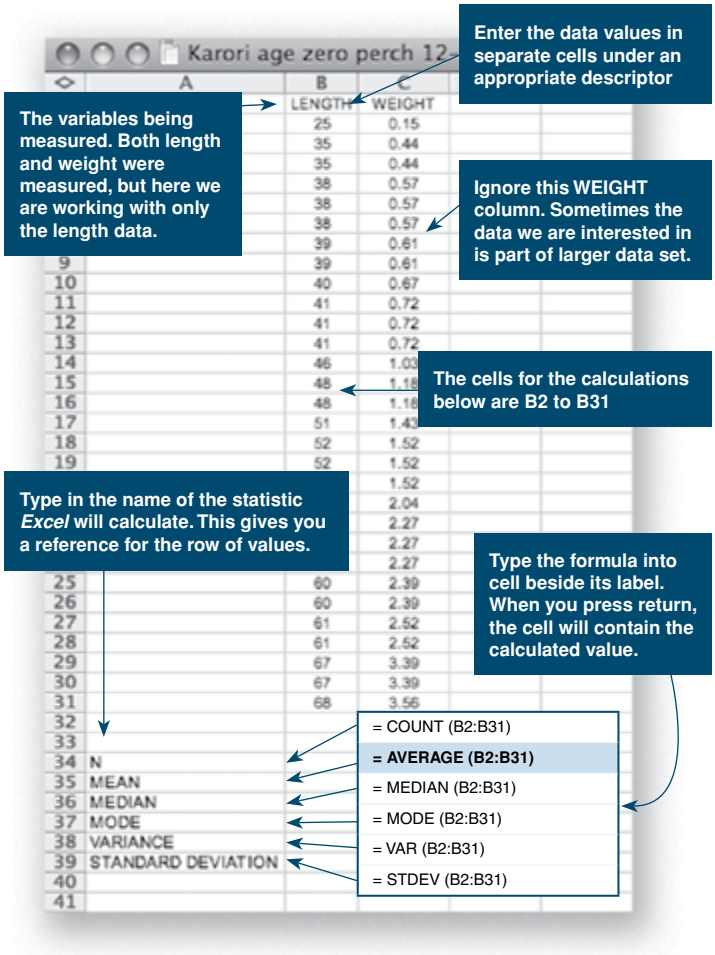
   (c) Explain what this information tells you about the distribution of year zero perch from this site: _____

   _____

2. Give another reason why you might reach the same conclusion about the distribution: _____

   _____

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Calculating Descriptive Statistics Using *Excel*®

You can use *Microsoft Excel*® or other similar spreadsheet program to easily calculate descriptive statistics for sample data.

In this first example, the smaller data set (n = 30) is shown as it would appear on an *Excel*® spreadsheet, ready for the calculations to be made. Use this guide to enter your data into a spreadsheet and calculate the descriptive statistics as described.

When using formulae in *Excel*®, = indicates that a formula follows. The cursor will become active and you will be able to select the cells containing the data you are interested in, or you can type the location of the data using the format shown. The data in this case are located in the cells B2 through to B31 (B2:B31).

3. For this set of data, use a spreadsheet to calculate:

   (a) Mean: _____

   (b) Median: _____

   (c) Mode: _____

   (d) Sample variance: _____

   (e) Standard deviation: _____

   Staple the spreadsheet into your workbook.

4. Repeat the calculations for the second small set of sample data (n = 50) on the previous page. Again, calculate the statistics as indicated below and staple the spreadsheet into your workbook:

   (a) Mean: _____ (b) Median: _____ (c) Mode: _____

   (d) Variance: _____ (e) Standard deviation: _____

5. On a separate sheet, plot **frequency histograms** for each of the two small data sets. Label them *n* = 30 and *n* = 50. Staple them into your workbook. If you are proficient in *Excel*® and you have the "Data Analysis" plug in loaded, you can use *Excel*® to plot the histograms for you once you have entered the data.

6. Compare the descriptive statistics you calculated for each data set with reference to the following:

   (a) How close the median and mean to each other in each sample set: _____

   _____

   (b) The size of the standard deviation in each case: _____

   _____

   (c) How close each small of the sample sets resembles the large sample set of 689 values: _____

   _____

   _____

7. (a) Compare the two frequency histograms you have plotted for the two smaller sample data sets: _____

   _____

   _____

   (b) Why do you think two histograms look so different? _____

   _____

   _____

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16 The Student's *t* Test

Key Idea: The Student's *t* test can be used to determine if differences between two sample means are significant.

The Student's *t* test is a commonly used test when comparing two sample means, e.g. means for a treatment and a control in an experiment, or the means of some measured characteristic between two animal or plant populations. It is a good test for distinguishing real but marginal differences between samples. The *t* test is only valid for certain situations. It is a two-group test so you must have only two sample means to compare. The test assumes that the data have a normal distribution and that the standard deviation is similar for both samples. Below is a simple example outlining the general steps involved in the Student's *t* test. The example uses a set of data from a fictitious experiment involving a treatment and a control (the units are not relevant in this case, only the values). A portion of the Student's *t* table is provided, sufficient to carry out the test. Follow the example through, making sure that you understand each step.

Steps in performing a Student's *t* test	Explanatory notes
Step 1 ***Calculate basic summary statistics for your two data sets*** Control (A): 6.6, 5.5, 6.8, 5.8, 6.1, 5.9 $n_A = 6$, $\bar{x}_A = 6.12$, $s_A = 0.496$ Treatment (B): 6.3, 7.2, 6.5, 7.1, 7.5, 7.3 $n_B = 6$, $\bar{x}_B = 6.98$, $s_B = 0.475$	n_A and n_B are the number of values in the first and second data sets respectively (these need not be the same). $\bar{x}$ is the mean. ***s*** is the standard deviation (a measure of scatter in the data).
Step 2 ***Set up and state your null hypothesis (H_0)*** H_0: there is no treatment effect. The differences in the data sets are the result of chance variation only and they are not really different	The alternative hypothesis is that there is a treatment effect and the two sets of data are truly different.
Step 3 ***Decide if your test is one or two tailed*** This tells you what section of the *t* table to consult. Most biological tests are two-tailed. Very few are one-tailed.	A one-tailed test looks for a difference only in one particular direction. A two-tailed test looks for any difference (+ or –).
Step 4 ***Calculate the t statistic*** For our sample data above the calculated value of *t* is –3.09. The degrees of freedom (df) are $n_1 + n_2 - 2 = 10$. Calculation of the *t* value uses the variance which is simply the square of the standard deviation (s^2). You may compute the *t* value by entering your data onto a computer and using a simple statistical program.	It does not matter if your calculated *t* value is a positive or negative (the sign is irrelevant). If you do not have access to a statistical program, computation of *t* is not difficult. Step 4 (calculating *t*) is described in the following *t* test exercises.
Step 5 ***Consult the t table of critical values*** Selected critical values for Student's t statistic (two-tailed test) Degrees of freedom / $P = 0.05$ / $P = 0.01$ / $P = 0.001$ 5 / 2.57 / 4.03 / 6.87 10 / 2.23 / 3.17 / 4.59 15 / 2.13 / 2.95 / 4.07 20 / 2.09 / 2.85 / 3.85 Critical value of *t* for 10 degrees of freedom. The calculated *t* value must exceed this	The absolute value of the *t* statistic (3.09) well exceeds the critical value for $P = 0.05$ at 10 degrees of freedom. *We can reject H_0 and conclude that the means are different at the 5% level of significance.* If the calculated absolute value of *t* had been less than 2.23, we could not have rejected H_0.

1. (a) In an experiment, data values were obtained from four plants in experimental conditions and three plants in control conditions. The mean values for each data set (control and experimental conditions) were calculated. The *t* value was calculated to be 2.16. The null hypothesis was: "The plants in the control and experimental conditions are not different". State whether the calculated *t* value supports the null hypothesis or its alternative (consult *t* table above):

   _____

   (b) The experiment was repeated, but this time using 6 control and 6 "experimental" plants. The new *t* value was 2.54. State whether the calculated *t* value supports the null hypothesis or its alternative now:

   _____

2. Explain why, in terms of applying Student's *t* test, extreme data values (outliers) are often excluded from the data set(s):

   _____

   _____

3. Explain what you understand by statistical significance (for any statistical test): _____

   _____

   _____

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17 Student's *t* Test Exercise

Key Idea: Differences between two populations can be tested for significance using the Student's *t* test.

Data from two flour beetle populations are given below. Ten samples were taken from each population and the number of beetles in each sample were counted. The Student's *t* test is used to find out if the densities of the two populations were significantly different. The exercise below uses a workbook computation to determine a *t* value. The calculations are also very simple to do using a spreadsheet programme such as *Excel*® (see opposite).

1. (a) Complete the calculations to perform the *t* test for these two populations. Some calculations are provided for you.

x (counts)		**x – x̄** (deviation from the mean)		**(x – x̄)²** (deviation from mean)²	
Popn A	**Popn B**	**Popn A**	**Popn B**	**Popn A**	**Popn B**
465	310	9.3	-10.6	86.5	112.4
475	310	19.3	-10.6	372.5	112.4
415	290				
480	355				
436	350				
435	335				
445	295				
460	315				
471	316				
475	330				
$n_A = 10$	$n_B = 10$			$(x - \bar{x})^2$	$(x - \bar{x})^2$

The number of samples in each data set

The sum of each column is called the sum of squares

(b) The variance for population A: $s^2_A =$

The variance for population B: $s^2_B =$

(c) The difference between the population means

$(\bar{x}_A - \bar{x}_B) =$

(d) $t_{(calculated)} =$

(e) Determine the degrees of freedom (d.f.)

d.f. $(n_A + n_B - 2) =$

(f) $P =$

$t_{(critical value)} =$

(g) Your decision is:

Step 1: Summary statistics

Tabulate the data as shown in the first 2 columns of the table (left). Calculate the mean and give the n value for each data set. Compute the standard deviation if you wish.

Popn A $\bar{x}_A = 455.7$, $n_A = 10$, $s_A = 21.76$

Popn B $\bar{x}_B = 320.6$, $n_B = 10$, $s_B = 21.64$

Step 2: State your null hypothesis

Step 3: Decide if your test is one or two tailed

Calculating the t value

Step 4a: Calculate sums of squares

Complete the computations outlined in the table left. The sum of each of the final two columns (left) is called the sum of squares.

Step 4b: Calculate the variances

Calculate the variance (s^2) for each set of data. This is the sum of squares divided by $n - 1$ (number of samples in each data set – 1). In this case the n values are the same, but they need not be.

$$s^2_A = \frac{\sum(x - \bar{x})^2_{(A)}}{n_A - 1} \qquad s^2_B = \frac{\sum(x - \bar{x})^2_{(B)}}{n_B - 1}$$

Step 4c: Differences between means

Calculate the *actual* difference between the means

$$(\bar{x}_A - \bar{x}_B)$$

Step 4d: Calculate t

Calculate the *t* value. Ask for assistance if you find interpreting the lower part of the equation difficult

$$t = \frac{(\bar{x}_A - \bar{x}_B)}{\sqrt{\frac{s^2_A}{n_A} + \frac{s^2_B}{n_B}}}$$

Step 4e: Determine the degrees of freedom

Degrees of freedom (d.f.) are defined by the number of samples (e.g. counts) taken: d.f. = $n_A + n_B - 2$ where n_A and n_B are the number of counts in each of populations A and B.

Step 5: Consult the t table

Consult the *t*-tables (opposite page) for the critical *t* value at the appropriate degrees of freedom and the acceptable probability level (e.g. P = 0.05).

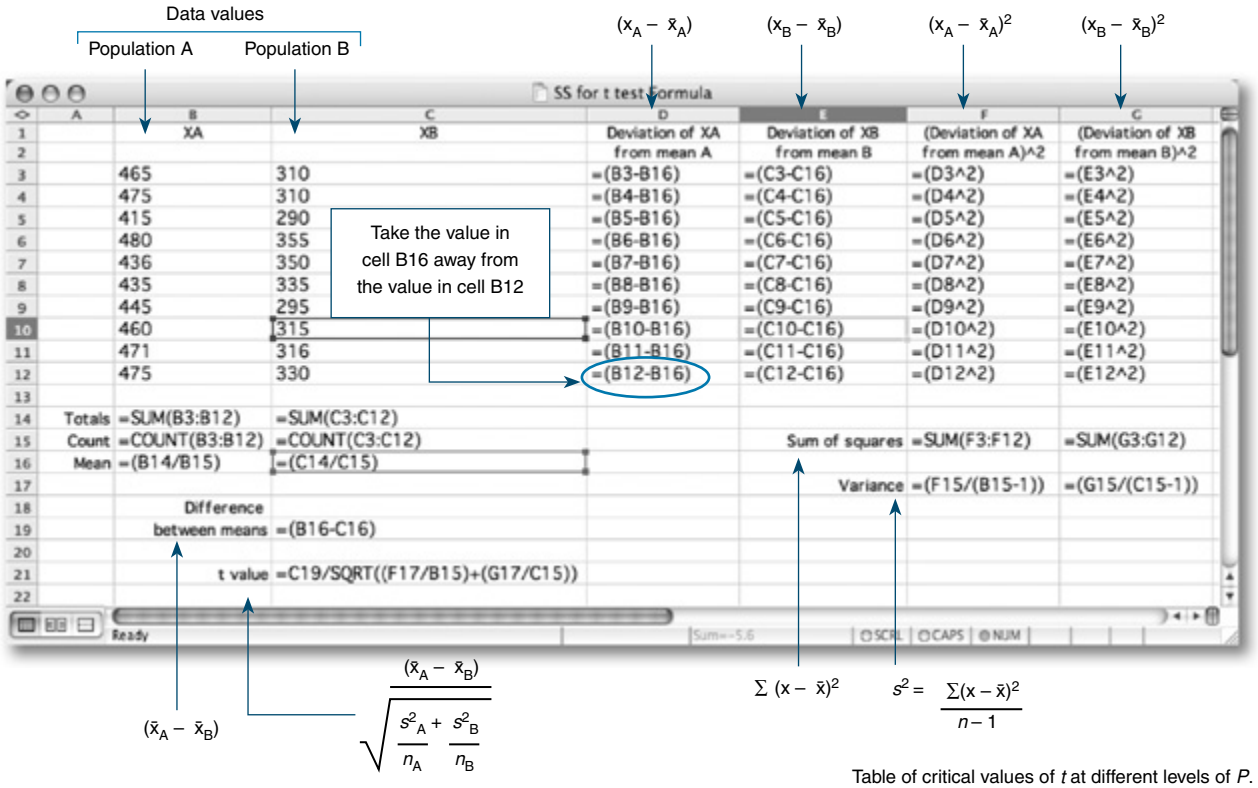
Step 5a: Make your decision

Make your decision whether or not to reject H_0. If your *t* value is large enough you may be able to reject H_0 at a lower *P* value (e.g. 0.001), increasing your confidence in the alternative hypothesis.

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2. The previous example is repeated below using a spreadsheet (created in *Microsoft Excel®*). The spreadsheet has been shown in a special mode with the formulae displayed. Normally, the calculated values will appear as the calculation is completed (entered) and a formula is visible only when you click into an individual cell. When setting up a spreadsheet, you can arrange your calculating cells wherever you wish. What is important is that you accurately identify the cells being used for each calculation. Also provided below is a summary of the spreadsheet notations used and a table of critical values of *t* at different levels of *P*. For brevity, only some probability values have been shown. To be significant at the appropriate level of probability, calculated values must be greater than those in the table for the appropriate degrees of freedom.

   (a) Using the data in question 1, set up a spreadsheet as indicated below to calculate *t*. Save your spreadsheet. Print it out and staple the print-out into your workbook.



Notation	Meaning
Columns and rows	Columns are denoted A, B, C ... at the top of the spreadsheet, rows are 1, 2, 3, ... on the left. Using this notation a cell can be located e.g. C3
=	An "equals" sign before other entries in a cell denotes a formula.
( )	Parentheses are used to group together terms for a single calculation. This is important for larger calculations (see cell C21 above)
C3:C12	Cell locations are separated by a colon. C3:C12 means "every cell between and including C3 and C12"
SUM	Denotes that what follows is added up. =SUM(C3:C12) means "add up the values in cells C3 down to C12"
COUNT	Denotes that the number of values is counted =COUNT(C3:C12) means "count up the number of values in cells C3 down to C12"
SQRT	Denotes "take the square root of what follows"
^2	Denotes an exponent e.g. x^2 means that value x is squared.

Above is a table explaining some of the spreadsheet notations used for the calculation of the *t* value for the exercise on the previous page. It is not meant to be an exhaustive list for all spreadsheet work, but it should help you to become familiar with some of the terms and how they are used. This list applies to *Microsoft Excel®* . Different spreadsheets may use different notations. These will be described in the spreadsheet manual.

Table of critical values of *t* at different levels of *P*.

Degrees of freedom	Level of Probability		
	0.05	0.01	0.001
1	12.71	63.66	636.6
2	4.303	9.925	31.60
3	3.182	5.841	12.92
4	2.776	4.604	8.610
5	2.571	4.032	6.869
6	2.447	3.707	5.959
7	2.365	3.499	5.408
8	2.306	3.355	5.041
9	2.262	3.250	4.781
10	2.228	3.169	4.587
11	2.201	3.106	4.437
12	2.179	3.055	4.318
13	2.160	3.012	4.221
14	2.145	2.977	4.140
15	2.131	2.947	4.073
16	2.120	2.921	4.015
17	2.110	2.898	3.965
18	2.101	2.878	3.922
19	2.093	2.861	3.883
20	2.086	2.845	3.850

   (b) Save your spreadsheet under a different name and enter the following new data values for population B: **425, 478, 428, 465, 439, 475, 469, 445, 421, 438**. Notice that, as you enter the new values, the calculations are updated over the entire spreadsheet. Re-run the *t*-test using the new *t* value. State your decision for the two populations now:

   New *t* value: Decision on null hypothesis (delete one): Reject / Do not reject

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18 Using the Chi-Squared Test in Ecology

Key Idea: The chi-squared test for difference is used to compare sets of categorical data and evaluate if differences between them are statistically significant or due to chance.

The **chi-squared test** (χ^2), is used when you are working with frequencies (counts) rather than measurements. It is a simple test to perform but the data must meet the requirements of the test. Firstly, it can only be used for data that are raw counts (not measurements or transformed data such as percentages). Secondly, it is used to compare an experimental result with an expected theoretical outcome (e.g. an expected Mendelian ratio or a theoretical value indicating "no difference" between groups in a response such as habitat preference). Thirdly, it is not a valid test when sample sizes are small (<20). Like all statistical tests, it aims to test the null hypothesis. The following exercise is a worked example using the chi-squared test for difference to test habitat preference.



Using χ^2 in Ecology

In an investigation of the ecological niche of the mangrove, *Avicennia marina var. resinifera*, the density of pneumatophores was measured in regions with different substrate. The mangrove trees were selected from four different areas: mostly sand, some sand, mostly mud, and some mud. Note that the variable, substrate type, is categorical in this case. Quadrats (1 m by 1 m) were placed around a large number of trees in each of these four areas and the numbers of pneumatophores were counted. Chi-squared was used to compare the observed results for pneumatophore density (as follows) to an expected outcome of no difference in density between substrates.

Mangrove pneumatophore density in different substrate areas

Mostly sand	**85**	Mostly mud	**130**
Some sand	**102**	Some mud	**123**

Using χ^2, the probability of this result being consistent with the expected result could be tested. Worked example as follows:

Step 1: Calculate the expected value (E)

In this case, this is the sum of the observed values divided by the number of categories.

$$\frac{440}{4} = 110$$

Step 2: Calculate O – E

The difference between the observed and expected values is calculated as a measure of the deviation from a predicted result. Since some deviations are negative, they are all squared to give positive values. This step is usually performed as part of a tabulation (right, darker blue column).

Step 3: Calculate the value of χ^2

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

Where: O = the observed result
E = the expected result
Σ = sum of

The calculated χ^2 value is given at the bottom right of the last column in the tabulation.

Step 4: Calculating degrees of freedom

The probability that any particular χ^2 value could be exceeded by chance depends on the number of degrees of freedom. This is simply ***one less than the total number of categories*** (this is the number that could vary independently without affecting the last value). ***In this case: 4–1 = 3.***

Category	O	E	O - E	$(O - E)^2$	$\frac{(O - E)^2}{E}$
Mostly sand	85	110	-25	625	5.68
Some sand	102	110	-8	64	0.58
Mostly mud	130	110	20	400	3.64
Some mud	123	110	13	169	1.54
Total = 440				χ^2 →	Σ = 11.44

Step 5a: Using the χ^2 table

On the χ^2 table (part reproduced in Table 1 below) with 3 degrees of freedom, the calculated value for χ^2 of 11.44 corresponds to a probability of between 0.01 and 0.001 (see arrow). *This means that by chance alone a χ^2 value of 11.44 could be expected between 1% and 0.1% of the time.*

Step 5b: Using the χ^2 table

The probability of between 0.1 and 0.01 is lower than the 0.05 value which is generally regarded as significant. The null hypothesis can be rejected and we have reason to believe that the observed results differ significantly from the expected (at P = 0.05).

Table 1: Critical values of χ^2 at different levels of probability. By convention, the critical probability for rejecting the null hypothesis (H_0) is 5%. If the test statistic is less than the tabulated critical value for P = 0.05 we cannot reject H_0 and the result is not significant. If the test statistic is greater than the tabulated value for P = 0.05 we reject H_0 in favour of the alternative hypothesis.

Degrees of freedom	Level of probability (*P*)									
	0.98	0.95	0.80	0.50	0.20	0.10	0.05	0.02	0.01	0.001
1	0.001	0.004	0.064	0.455	1.64	2.71	3.84	5.41	6.64	10.83
2	0.040	0.103	0.466	1.386	3.22	4.61	5.99	7.82	9.21	13.82
3	0.185	0.352	1.005	2.366	4.64	6.25	7.82	9.84	11.35	16.27
4	0.429	0.711	1.649	3.357	5.99	7.78	9.49	11.67	13.28	18.47
5	0.752	0.145	2.343	4.351	7.29	9.24	11.07	13.39	15.09	20.52
				← *Do not reject H_0*				*Reject H_0* →		

(χ^2 → 11.35 / 16.27)

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19 Chi-Squared Exercise in Ecology

Key Idea: Chi-squared can be used to study habitat preference using the counts of organisms.

This exercise illustrates the use of chi-squared (χ^2) in ecological studies of habitat preference. In the first example, it is used for determining if the flat periwinkle *(Littorina littoralis)* shows significant preference for any of the four species of seaweeds with which it is found. Using quadrats, the numbers of periwinkles associated with each seaweed species were recorded. The data from this investigation are provided for you in Table 1. In the second example, the results of an investigation into habitat preference in woodlice (also called pillbugs, or slaters) are presented in Table 2.

1. (a) State your null hypothesis for this investigation (H_0):

_____

_____

_____

(b) State the alternative hypothesis (H_A): _____

_____

_____

Table 1: Number of periwinkles associated with different seaweed species

Seaweed species	Number of periwinkles
Spiral wrack	9
Bladder wrack	28
Toothed wrack	19
Knotted wrack	64

2. Use the chi-squared test to determine if the differences observed between the samples are significant or if they can be attributed to chance alone. The table of critical values of χ^2 is provided in "*The Chi-Squared Test*".

(a) Enter the observed values (no. of periwinkles) and complete the table to calculate the χ^2 value:

Category	O	E	O - E	$(O - E)^2$	$\frac{(O - E)^2}{E}$
Spiral wrack					
Bladder wrack					
Toothed wrack					
Knotted wrack					
	Σ				Σ

(b) Calculate χ^2 value using the equation:

$$\chi^2 = \sum \frac{(O - E)^2}{E} \qquad \chi^2 = _____$$

(c) Calculate the degrees of freedom: _____

(d) Using the χ^2, state the *P* value corresponding to your calculated χ^2 value:

_____

(e) State whether or not you reject your null hypothesis:

reject H_0 / do not reject H_0 (*circle one*)



3. Students carried out an investigation into habitat preference in woodlice. In particular, they were wanting to know if the woodlice preferred a humid atmosphere to a dry one, as this may play a part in their choice of habitat. They designed a simple investigation to test this idea. The woodlice were randomly placed into a choice chamber for 5 minutes where they could choose between dry and humid conditions (atmosphere). The investigation consisted of five trials with ten woodlice used in each trial. Their results are shown on Table 2 (right):

Table 2: Habitat preference in woodlice

Trial	Atmosphere	
	Dry	Humid
1	2	8
2	3	7
3	4	6
4	1	9
5	5	5

(a) State the null and alternative hypotheses (H_0 and H_A) :

_____

_____

Use a separate piece of paper (or a spreadsheet) to calculate the chi-squared value and summarise your answers below:

(b) Calculate χ^2 value: _____

(c) Calculate the degrees of freedom and state the *P* value corresponding to your calculated χ^2 value: _____

(d) State whether or not you reject your null hypothesis: reject H_0 / do not reject H_0 (*circle one*)

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20 KEY TERMS: Mix and Match

INSTRUCTIONS: Test your vocabulary by matching each term to its definition, as identified by its preceding letter code.

biological drawing	**A**	A factor in an experiment that is subject to change.
chi-squared test	**B**	A variable whose values are set, or systematically altered, by the investigator.
control	**C**	A diagram drawn to accurately show what has been seen by the observer.
controlled variable	**D**	Facts collected for analysis.
data	**E**	The value that occurs most often in a data set.
dependent variable	**F**	A pattern observed in processed data showing that data values may be linked.
descriptive statistics	**G**	A standard (reference) treatment that helps to ensure that the responses to the other treatments can be reliably interpreted.
graph	**H**	The sum of the data divided by the number of data entries (*n*).
histogram	**I**	A variable whose values are determined by another variable.
hypothesis	**J**	Data able to be expressed in numbers. Numerical values derived from counts or measurements.
independent variable	**K**	Variable that is fixed at a specific amount as part of the design of experiment.
mean	**L**	A type of column graph used to display frequency distributions.
measurement	**M**	A tentative explanation of an observation, capable of being tested by experimentation.
median	**N**	The number that occurs in the middle of a set of sorted numbers. It divides the upper half of the number data set from the lower half.
mode	**O**	A representation of data, often summarised, organised in rows and columns.
observation	**P**	The sampling of an object or substance to record numerical data that describes some aspect of the it, e.g. length or temperature.
qualitative data	**Q**	Data that have not been processed or manipulated in any way.
quantitative data	**R**	A diagram that displays information (most usually numerical data), often in a way that can be used to identify trends and relationships.
raw data	**S**	The act of seeing and noting an occurrence in the object or substance being studied.
sample	**T**	The use of an ordered, repeatable method to investigate, manipulate, gather, and record data.
scientific method	**U**	Data described in descriptors or terms rather than by numbers.
Student's *t* test	**V**	A sub-set of a whole used to estimate the values that might have been obtained if every individual or response was measured.
table	**W**	A statistical test for determining the significance of departures of observed data from an expected result.
trend (of data)	**X**	A test used to determine if the difference between two sample means is significant.
variable	**Y**	Calculated values that summarise the main features of a collection of data.

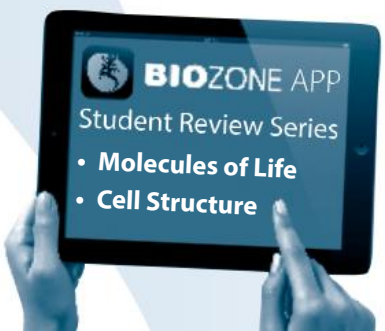
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QLD As required
VCE Unit 1 (1)
WA ATAR Unit 2
SA Theme C

Cell Structure

Key terms

activation energy
active site
amino acid
carbohydrate
cell wall
centrioles
chloroplast
cilia
cytoplasm
electron micrograph
endoplasmic reticulum (ER)
eukaryotic cell
flagella
Golgi apparatus
light (=optical) microscope
lipid
lysosome
magnification
mitochondrion
nuclear envelope
nuclear pore
nucleic acid
nucleolus
nucleus
organelles
plasma membrane
prokaryotic cell
protein
resolution
ribosome
rough ER (rER)
smooth ER (sER)
specificity
stain
vacuole

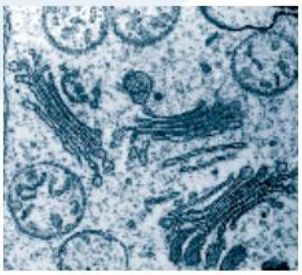
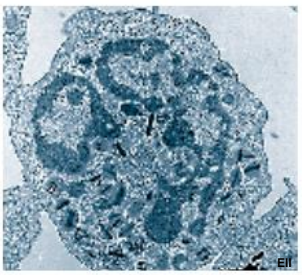


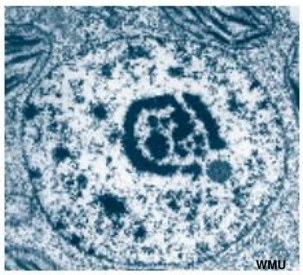
Biological molecules

Learning aims and skills

Activity number

- ☐ 1 Describe the basic biochemical components of cells. Describe the importance of organic molecules and inorganic ions in biological systems. — 21
- ☐ 2 Using examples, describe the basic structure and roles of carbohydrates, amino acids, proteins, lipids, and nucleic acids. — 22-26
- ☐ 3 Describe the properties and mode of action of enzymes, including the role of the active site and specificity, and activation energy. Recognise that most enzymes are proteins. — 27
- ☐ 4 Describe how chromatography is used to separate and identify biological molecules such as proteins and pigments. — 28



Microscopy

Learning aims and skills

Activity number

- ☐ 5 Describe the structure and basic principles of light (optical) microscopes. Appreciate that microscopy has a long history and its development was important in the development of cell theory. — 34 35
- ☐ 6 Distinguish between the structure and use of compound and dissecting (stereo) light microscopes. Use dissecting and compound light microscopes to locate material and focus images. — 35
- ☐ 7 Explain the purpose of stains when preparing specimens for viewing with an optical microscope. Use simple staining techniques to show features of cells. — 36
- ☐ 8 Explain the difference between magnification and resolution. Compare the magnification and resolution achieved using different microscopes. Calculate the linear magnification of images viewed with a microscope. — 35 37

Cells as living entities

Learning aims and skills

Activity number

- ☐ 9 Outline the cell theory and explain its development. — 29
- ☐ 10 Describe the characteristics of living organisms and explain why viruses do not fulfil the criteria for being living cells. Describe the main differences between the cells of fungi, plants, protists, animals, and bacteria. — 29 30 31
- ☐ 11 Describe the requirements of cells in terms of their immediate environment. — 32
- ☐ 12 Describe the range of cell sizes. Express cell sizes in different units of measurement (mm, μm, nm). Calculate the linear magnification of images viewed with a microscope. — 33
- ☐ 13 Use drawings and electron micrographs to compare and contrast the structure of prokaryotic cells and eukaryotic cells. — 39-44
- ☐ 14 Use drawings and photomicrographs to compare and contrast the structure and ultrastructure of plant cells and animal cells. — 38 40-44

21 Biological Molecules

Key Idea: Water, carbohydrates, lipids, proteins, and nucleic acids are the molecules that make up living things.

Water is the main component of organisms and provides an environment in which metabolic reactions can occur. Water molecules attract each other, forming large numbers of hydrogen bonds. It is this feature that gives water many of its unique properties (e.g. low viscosity and its chemical behaviour as a universal solvent). The organic (carbon containing) macromolecules that make up living things are carbohydrates, lipids, proteins, and nucleic acids. These larger molecules are built up from smaller components in anabolic reactions and broken down by catabolic reactions. The sum total of anabolic and catabolic reactions in the cell or organism is metabolism.

Important Properties of Water



Water is a liquid at room temperature and many substances dissolve in it. It is a medium inside cells and for aquatic life.



A lot of energy is required before water will change state so aquatic environments are thermally stable and sweating and transpiration cause rapid cooling.



Ice is less dense than water. Consequently ice floats, insulating the underlying water and providing valuable habitat.



Water has a high surface tension and low viscosity. It forms droplets on surfaces and can flow freely through narrow vessels.



Water is colourless, with a high transmission of visible light, so light penetrates tissue and aquatic environments.

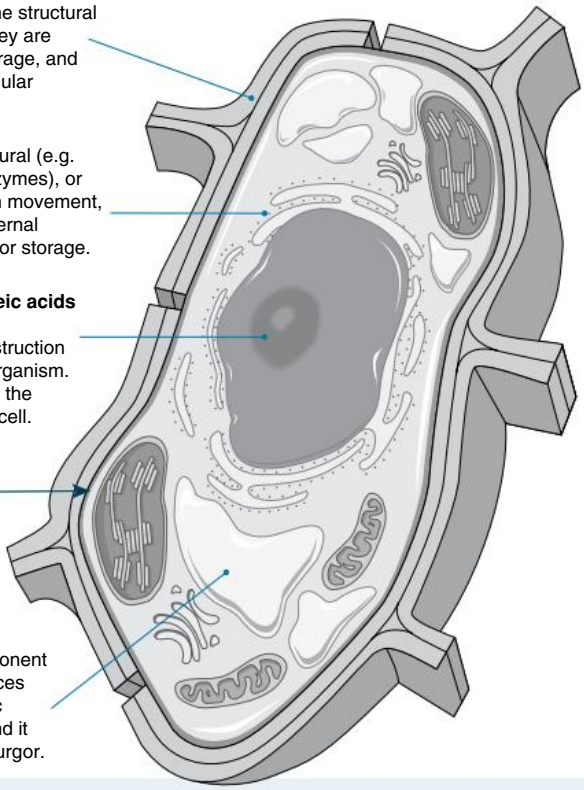
Carbohydrates form the structural components of cells, they are important in energy storage, and they are involved in cellular recognition.

Proteins may be structural (e.g. collagen), catalytic (enzymes), or they may be involved in movement, message signalling, internal defence and transport, or storage.

Nucleotides and nucleic acids Nucleic acids encode information for the construction and functioning of an organism. The nucleotide, ATP, is the energy currency of the cell.

Lipids provide insulation and a concentrated source of energy. Phospholipids are a major component of cellular membranes.

Water is a major component of cells: many substances dissolve in it, metabolic reactions occur in it, and it provides support and turgor.



1. What is the biological significance of each of the following physical properties of water?

   (a) Low viscosity: _____

   (b) Colourless and transparent: _____

   (c) Universal solvent: _____

   (d) Ice is less dense than water: _____

2. Describe the biologically important role of each of the following molecules:

   (a) Lipids: _____

   (b) Carbohydrates: _____

   (c) Proteins: _____

   (d) Nucleic acids: _____

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22 Carbohydrates

Key Idea: Carbohydrates are a family of organic molecules made up of carbon, hydrogen, and oxygen atoms only.

Carbohydrates are organic molecules made up of carbon, hydrogen, and oxygen atoms. The simplest carbohydrates are sugars (monosaccharides such as glucose and fructose and disaccharides such as sucrose). These may join together by **condensation** to form polymers called polysaccharides, releasing water in the process. Polysaccharides and disaccharides are broken down into their constituent monosaccharides by the opposite reaction (**hydrolysis**). Sugars play a central role in cells, providing energy for metabolism and joining together to form carbohydrate macromolecules, such as starch and cellulose (in plants) and glycogen (in animals).

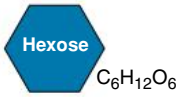
Monosaccharides (simple sugars)

Monosaccharides are used as the main energy source for fuelling cell metabolism. The most common ones have a ring structure with either six (hexoses) or five (pentoses) carbon atoms in each molecule. Examples include glucose (grape sugar and blood sugar) and fructose (honey and fruit juices).

e.g. ribose, deoxyribose



e.g. glucose, fructose, galactose



Disaccharides (compound sugars)

Disaccharides are used as energy sources and as building blocks for larger molecules. They contain two linked monosaccharides, which can either be the same (e.g. maltose) or different (e.g. lactose).

Example	Components	Where found
maltose	glucose + glucose	germinating seeds
lactose	glucose + galactose	milk
sucrose	glucose + fructose	plant sap

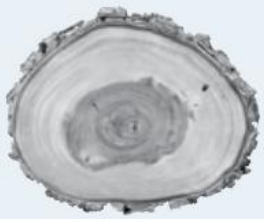




During the fruit ripening process, starch is converted to fructose and/or glucose. This provides the sweetness which attracts animals that might assist in seed dispersal.

Polysaccharides

Cellulose



Cellulose comprises unbranched chains of up to 10,000 glucose molecules. Cellulose is a major structural component of plants, forming their **cell walls**, xylem vessel elements and **wood** (photo above). It is the most abundant carbohydrate.

Starch



Starch, a branched polysaccharide, is made up of chains of about 1000 glucose molecules. It is an energy storage molecule, concentrated in **starch granules** within the cells of plants (e.g. potatoes, above). It is converted into glucose when required for energy production.

Chitin

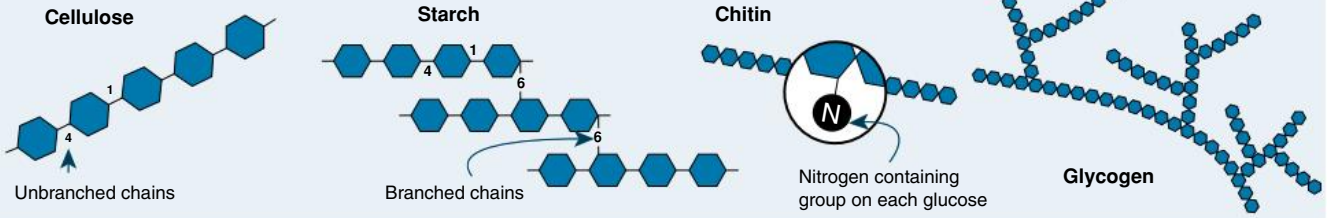


Chitin is made up of unbranched chains of modified glucose molecules. It is chemically similar to cellulose, but each glucose has a nitrogen containing group attached. Chitin occurs in the cell walls of fungi and it makes up the **exoskeleton** of arthropods (above).

Glycogen



Glycogen, like starch, is a branched polysaccharide. It is composed of 2000 to 60,000 glucose molecules. Glycogen is more highly branched, and is more soluble in water, than starch. It is a storage compound in animal tissues and is found in the cells of **liver** and **muscle** (above).



1. Name one biological function of monosaccharides, providing an example: _____

   _____

2. Describe the structure and biological role of each of the following polysaccharides:

   (a) Starch: _____

   (b) Glycogen: _____

   (c) Cellulose: _____

   (d) Chitin: _____

3. (a) What reaction produces polysaccharides from monosaccharides? _____

   (b) What reaction breaks down polysaccharides into simple sugars? _____

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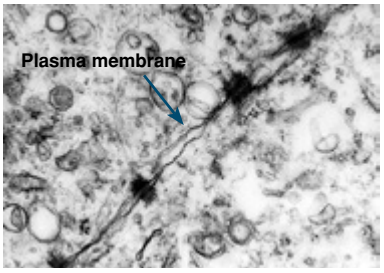
23 Lipids

Key Idea: Lipids are non-polar, hydrophobic organic molecules, which have many important biological functions.

Lipids are a group of organic compounds with an oily, greasy, or waxy consistency. They are relatively insoluble in water and tend to be water-repelling. Fats and oils have a higher proportion of hydrogen than either carbohydrates or protein, making them a more concentrated energy source and important as energy storage molecules. As well as their role as fuels, lipids are important as hormones, as part of plasma membranes, and as a source of fatty acids. Proteins and carbohydrates can be converted into fats by enzymes and stored. When food is short, stored fat can provide energy.

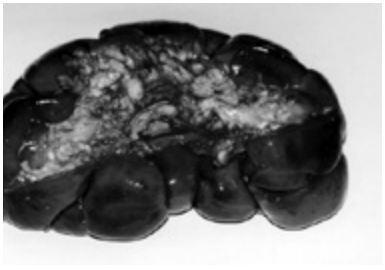


Lipids are concentrated sources of energy and provide fuel for aerobic respiration.



WMU

Phospholipids form the structural framework of cellular membranes.

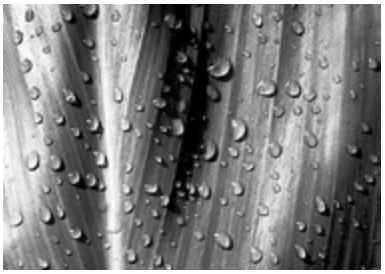


TG

Fat absorbs shocks. Organs that are prone to bumps and shocks (e.g. kidneys) are cushioned with a relatively thick layer of fat.



Lipids can provide metabolic water. During respiration, stored lipids are metabolised for energy, producing water and carbon dioxide.



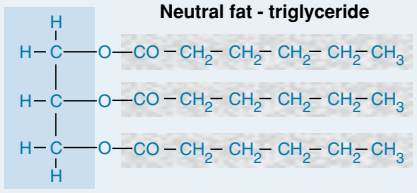
Waxes and oils secreted on to surfaces provide waterproofing in plants and animals.



Stored lipids provide insulation, reducing the amount of heat lost to the environment.

Lipid Structure

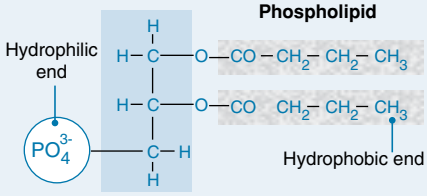
Neutral fat - triglyceride



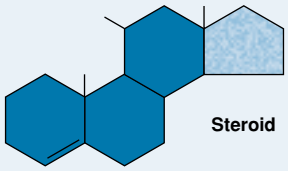
Glycerol — Three fatty acids

Neutral fats and oils are the most abundant lipids in living things. They consist of a glycerol attached to one (mono-), two (di-) or three (tri-) fatty acids. They provide more than twice as much energy as the same quantity of carbohydrate.

Phospholipid



Most phospholipids consist of a glycerol attached to two fatty acid chains and a phosphate group. The phosphate end of the molecule is attracted to water while the fatty acid end is water repellent.



Steroids have a basic structure of three 6C rings and a fourth 5C ring.

1. (a) Describe the basic structure of a neutral fat (triglyceride): _____

   _____

   (b) How does this structure differ from the structure of a phospholipid: _____

   _____

   _____

2. Why do lipids have such a high energy content? _____

   _____

3. Discuss the various biological roles of lipids: _____

   _____

   _____

   _____

   _____

   _____

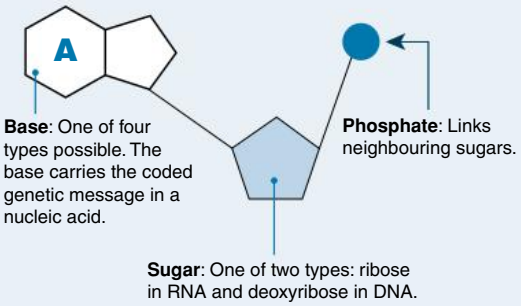
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24 Nucleotides and Nucleic Acids

Key Idea: Nucleotides are the building blocks of DNA and RNA. Nucleic acids are long chains of nucleotides, which store and transmit genetic information.

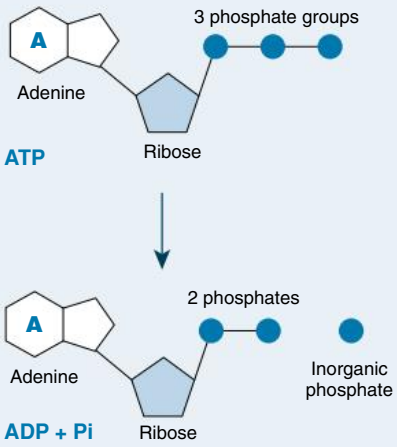
A nucleotide has three components: a base, a sugar, and a phosphate group. They are the building blocks of nucleic acids (DNA and RNA), which are involved in the transmission of inherited information. Nucleic acids such as deoxyribonucleic acid (**DNA**) have the capacity to store the information that controls cellular activity. Ribonucleic acids (**RNA**) are involved in the 'reading' of the DNA information. All nucleic acids are made up of **nucleotides** linked together to form chains or strands. The strands vary in the sequence of the bases found on each nucleotide. It is this sequence which provides the 'genetic code' for the cell.

Nucleotide Structure



Nucleotides are the building blocks of DNA. Their precise sequence in a DNA molecule provides the genetic instructions for the organism. Mutations are changes in the nucleotide sequence.

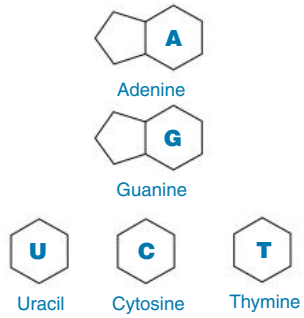
Nucleotide Derivatives
Adenosine Triphosphate (ATP)



ATP is a **nucleotide derivative** (a nucleoside triphosphate) used in cells as a coenzyme. ATP transports chemical energy within cells for metabolism. It consists of an adenine linked to a ribose sugar and 3 phosphate groups. It males energy available for work when it transfers a phosphate group to an intermediate.

Nucleic Acids

Bases in Nucleotides

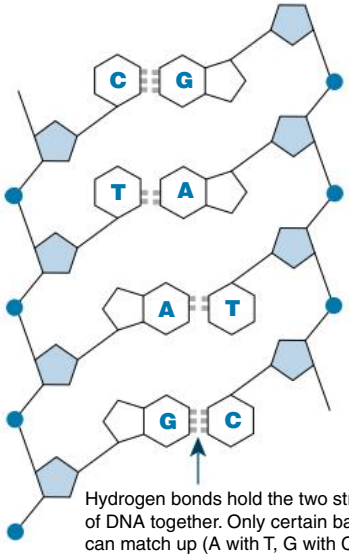


Nucleotides have four kinds of bases making up part of their structure. DNA contains A, T, G, and C. RNA contains A, U, G, and C (U replaces T).



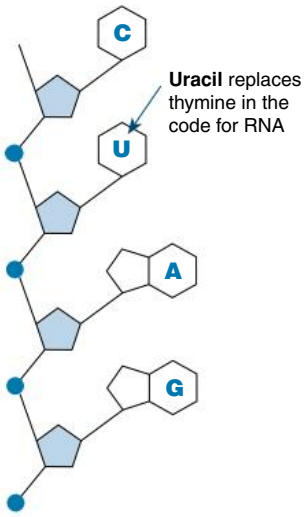
Individual chromosomes (above) are visible with a light microscope only during cell division when they are condensed.

DNA Molecule



Deoxyribonucleic acid (DNA) consists of a double strand of nucleotides linked together, forming a **double helix**.

RNA Molecule



Ribonucleic acid (RNA) consists of a single strand of nucleotides linked together.

1. (a) What is the basic repeating unit of nucleic acids? _____

   (b) Describe the structure of this repeating unit: _____

   _____

2. (a) What is the base pairing rule in DNA? _____

   (b) How does RNA differ from DNA in this respect? _____

3. How is information encoded in DNA? _____

   _____

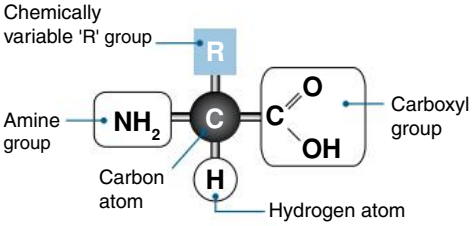
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25 Amino Acids

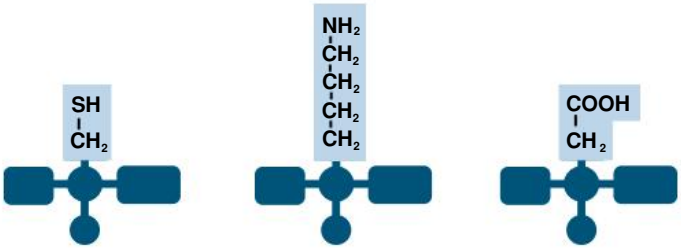
Key Idea: Amino acids can be joined together by condensation reactions to form polypeptides. Proteins are made up of one or more polypeptide molecules.

Amino acids are the basic units from which proteins are made. Twenty amino acids commonly occur in proteins and they can be linked in many different ways by peptide bonds to form a huge variety of polypeptides. Peptide bonds are formed by **condensation reactions** between amino acids.

The Structure and Properties of Amino Acids



All amino acids have a common structure (above), but the R group is different in each kind of amino acid (right). The property of the R group determines how it will interact with other amino acids and ultimately determines how the amino acid chain folds up into a functional protein. For example, the hydrophobic R groups of soluble proteins are folded into the protein's interior, while the hydrophilic groups are arranged on the outside.

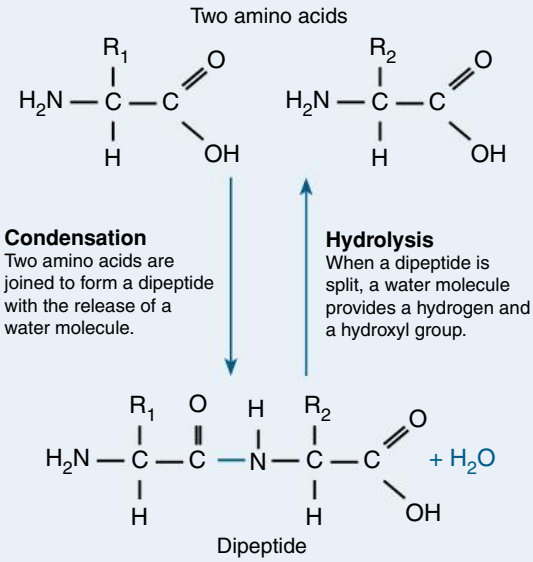


Cysteine
This 'R' group can form **disulfide bridges** with other cysteines to create cross linkages in a polypeptide chain.

Lysine
This 'R' group gives the amino acid an **alkaline** property.

Aspartic acid
This 'R' group gives the amino acid an **acidic** property.

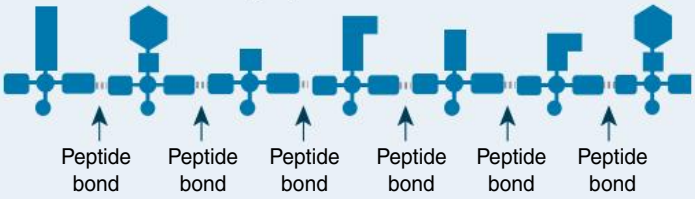
Condensation and Hydrolysis Reactions



Amino acids are linked by **peptide bonds** to form long **polypeptide chains** of up to several thousand amino acids. Peptide bonds form between the carboxyl group of one amino acid and the amine group of another (left). Water is formed as a result of this bond formation.

The sequence of amino acids in a polypeptide is called the **primary structure** and is determined by the order of nucleotides in DNA and mRNA. The linking of amino acids to form a polypeptide occurs on ribosomes in the cytoplasm. Once released from the ribosome, a polypeptide will fold into a secondary structure determined by the composition and position of the amino acids making up the chain.

A Polypeptide Chain



1. (a) What makes each of the amino acids in proteins unique? _____

   (b) What is the primary structure of a protein? _____

   (c) What determines the primary structure? _____

   _____

   (d) How do the sequence and composition of amino acids in a protein influence how a protein folds up? _____

   _____

   _____

2. (a) What type of bond joins neighbouring amino acids together? _____

   (b) How is this bond formed? _____

   (c) Circle this bond in the dipeptide above: _____

   (d) How are di- and polypeptides broken down? _____

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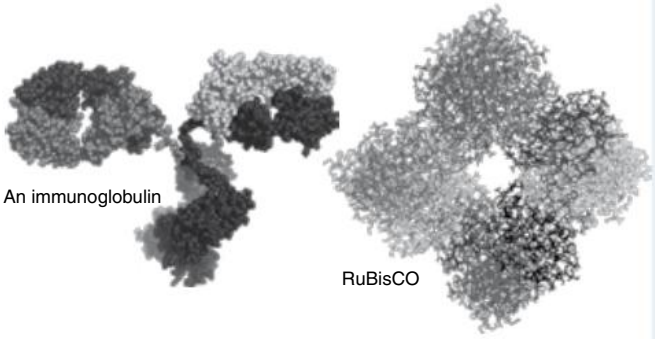
26 Proteins

Key Idea: Protein structure is related to its biological function. Proteins can be classified according to their structure or their function. **Globular proteins** are spherical and soluble in water (e.g. enzymes). **Fibrous proteins** have an elongated structure and are not water soluble. They are often made up of repeating units and provide stiffness and rigidity to the more fluid components of cells and tissues. They have important structural and contractile roles.

Globular Proteins

Properties
- Easily water soluble
- Tertiary structure critical to function
- Polypeptide chains folded into a spherical shape

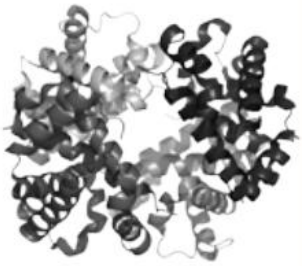
Function
- Catalytic, *e.g. enzymes*
- Regulatory, *e.g. hormones (insulin)*
- Transport, *e.g. haemoglobin*
- Protective, *e.g. immunoglobulins (antibodies)*



Immunoglobulins
These are large multi-unit Y-shape plasma proteins that recognise, bind to, and help to destroy bacteria and viruses. The tips of the 'Y' form the binding site for specific antigens.

RuBisCo is a large multi-unit enzyme found in green plants and catalyses the first step of carbon fixation in the Calvin cycle. It consists of 8 large (L) and 8 small (S) subunits arranged as 4 dimers. RuBisCO is the most abundant protein in the world.

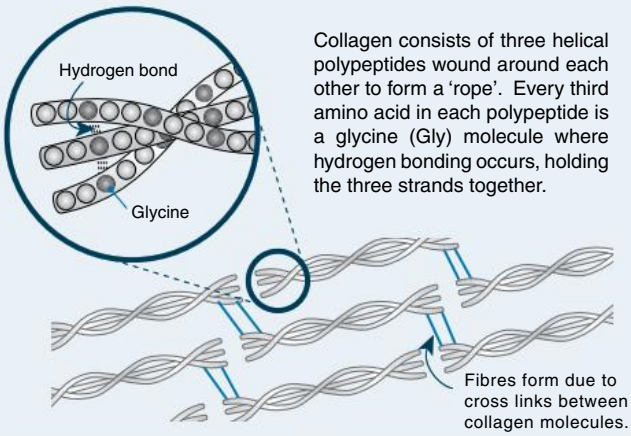
Haemoglobin is found in red blood cells and is responsible for transporting oxygen. About 80 million of these protein molecules are found in each red blood cell. One haemoglobin molecule (right) consists of 574 amino acids arranged in four polypeptide chains (two identical alpha chains and two identical beta chains).



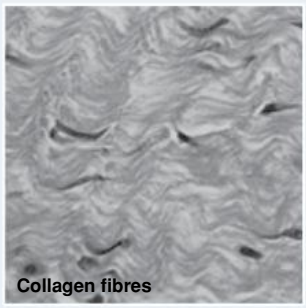
Fibrous Proteins

Properties
- Water insoluble
- Very tough physically; may be supple or stretchy
- Parallel polypeptide chains in long fibres or sheets

Function
- Structural role in cells and organisms e.g. *collagen found in connective tissue, cartilage, bones, tendons, and blood vessel walls.*
- Contractile e.g. *myosin, actin*



Collagen consists of three helical polypeptides wound around each other to form a 'rope'. Every third amino acid in each polypeptide is a glycine (Gly) molecule where hydrogen bonding occurs, holding the three strands together.





Collagen is the main component of connective tissue, and is mostly found in fibrous tissues (e.g. tendons, ligaments, and skin). **Spider silk** is a protein spun into a web by spiders to capture prey. Like all fibrous proteins, it is very strong.

1. How are proteins involved in the following roles? Give examples to help illustrate your answer:

   (a) Structural tissues of the body: _____

   _____

   _____

   (b) Catalysing metabolic reactions in cells: _____

   _____

   _____

2. How does the shape of a fibrous protein relate to its functional role? _____

   _____

3. How does the shape of a catalytic protein (enzyme) relate to its functional role? _____

   _____

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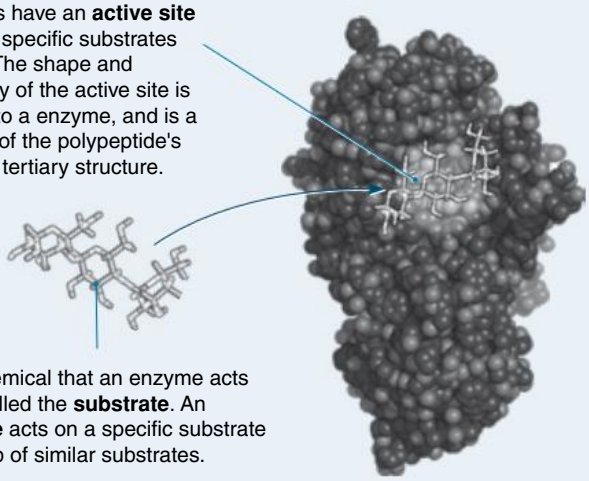
27 Enzymes

Key Idea: Enzymes are biological catalysts. They speed up biological reactions.

All metabolic reactions require the presence of enzymes. **Enzymes** are biological catalysts, that is, they speed up the chemical reactions in cells without being used up. They are unchanged at the end of a reaction and, because each enzyme molecule can be reused many times over, enzymes are effective in low concentrations. Enzymes differ from other catalysts in that they work faster, are specific (catalysing only one kind of reaction), are inactivated (**denatured**) by extremes of heat or pH which disrupt the active site and prevent the enzyme from functioning.

The Active Site

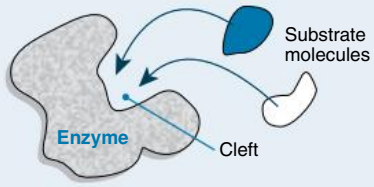
Enzymes have an **active site** to which specific substrates bind to. The shape and chemistry of the active site is specific to a enzyme, and is a function of the polypeptide's complex tertiary structure.



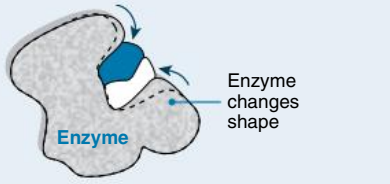
The chemical that an enzyme acts on is called the **substrate**. An **enzyme** acts on a specific substrate or group of similar substrates.

A Model of Enzyme Activity

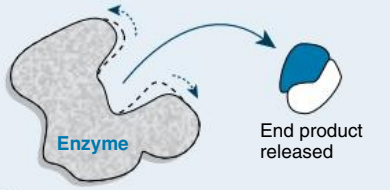
An enzyme fits to its substrate somewhat like a lock and key. The shape of the enzyme changes when the substrate fits into the cleft (called the **induced fit**):



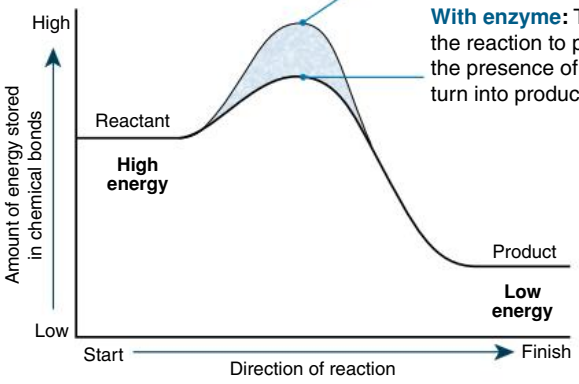
1. Two substrate molecules are drawn into the cleft of the enzyme.



2. The enzyme changes shape, forcing the substrate molecules to combine.



3. The resulting end product is released by the enzyme which returns to its normal shape, ready to receive more.



Without enzyme: The activation energy needed to make the reaction proceed in the forward direction is high without the enzyme present.

With enzyme: The energy required for the reaction to proceed is reduced by the presence of the enzyme. Reactants turn into products more readily.

How Enzymes Work

Enzyme are biological catalysts. They speed up reactions by influencing the **stability of bonds** in the reactants, lowering the **activation energy** needed for a reaction to occur (left). The reactants bind to the enzyme, usually by weak chemical bonds. The binding can weaken bonds within the reactants themselves, allowing the reaction to proceed more readily. Various factors, including temperature, substrate concentration, and pH may affect an enzyme's activity.

1. Name three ways in which enzymes differ from other catalysts:

   (a) _____

   (b) _____

   (c) _____

2. Why are enzymes so effective at low concentrations? _____

3. How do enzymes catalyse reactions? _____

   _____

   _____

4. How does heat denature enzymes? _____

   _____

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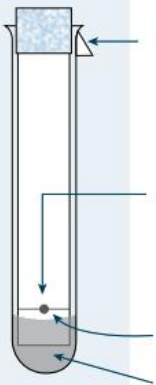
28 Paper Chromatography

Key Idea: Photosynthetic pigments can be separated from a mixture using paper chromatography.

Chromatography is a technique used to separate a mixture of molecules. Chromatography involves passing a mixture dissolved in a mobile phase (a solvent) through a stationary phase, which separates the molecules according to their specific characteristics (e.g. size or charge). Paper chromatography is a simple technique in which porous paper serves as the stationary phase, and a solvent, either water or ethanol, serves as the mobile phase.

Paper Chromatography

Set Up and Procedure



The chromatography paper is folded so it can be secured by the bung inside the test tube. The bung also prevents the solvent evaporating.

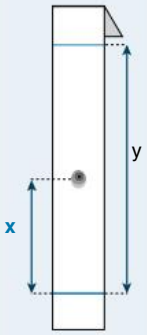
Chromatography paper may be treated with chemicals to stain normally invisible pigments.

A spot of concentrated sample is added using a pipette and suspended above the solvent. As the solvent travels up the paper it will carry the sample with it. The distance the sample travels depends on its solubility.

A pencil line is used to show the starting point.

Solvent

Determining R_f Values



To identify the substances in a mixture an Rf value is calculated using the equation:

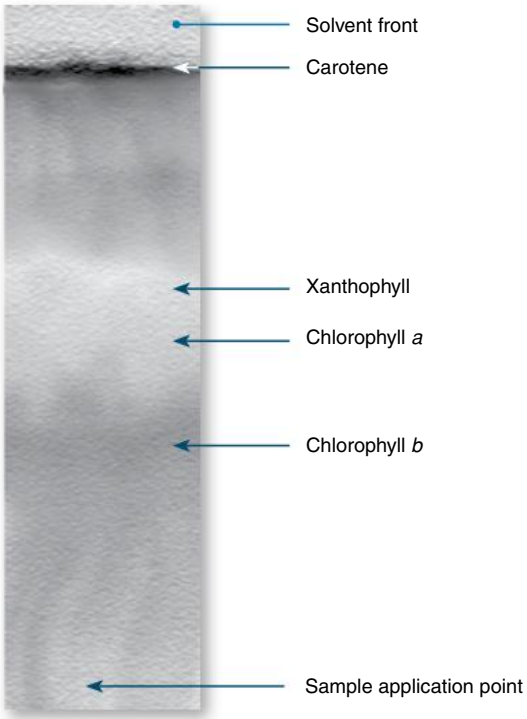
$$R_f = \frac{\text{Distance travelled by the spot (x)}}{\text{Distance travelled by the solvent (y)}}$$

These Rf values can then be compared with Rf values from known samples or standards, for example Rf values for the the following amino acids are:

Glycine's Rf value	= 0.50
Alanine's Rf value	= 0.70
Arginine's Rf value	= 0.72
Leucine's Rf value	= 0.91

Separation of Photosynthetic Pigments

The four primary pigments of green plants can easily be separated and identified using paper chromatography. The pigments from the leaves are first extracted with acetone before being separated. During paper chromatography the pigments separate out according to differences in their relative solubilities. Two major classes of pigments are detected: the two greenish chlorophyll pigments and two yellowish carotenoid pigments.



1. Calculate the R_f value for **spot X** in the example given above left (show your working): _____

2. Why is the R_f value of a substance always less than 1? _____

3. When is it appropriate to use chromatography instead of a simple food test? _____

4. Predict what would happen if a sample was immersed in the chromatography solvent, instead of suspended above it:

5. With reference to their R_f values, rank the four amino acids (listed above) in terms of their solubility: _____

6. Why must lipids be mixed in ethanol before they will form an emulsion in water? _____

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29 The Cell Theory

Key Idea: All living organisms are composed of cells. The cell is the basic unit of life.

The cell theory is a fundamental idea of biology. This idea, that all living things are composed of cells, developed over many years and is strongly linked to the invention and refinement of the microscope in the 1600s. The term cell was coined by Robert Hooke after observing a thin piece of cork under a microscope in which he saw cell-like walled compartments.

The Cell Theory

The idea that cells are fundamental units of life is part of the cell theory. The basic principles of the theory (as developed by early biologists) are:

- All living things are composed of cells and cell products.
- New cells are formed only by the division of pre-existing cells.
- The cell contains inherited information (genes) that are used as instructions for growth, functioning, and development.
- The cell is the functioning unit of life; all chemical reactions of life take place within cells.

Life Functions

All cells show the functions of life. They use food (e.g. glucose) to maintain a stable internal environment, grow, reproduce, and produce wastes.

Nutrition: All cells require food to provide energy to power chemical reactions and nutrients to build cell components.

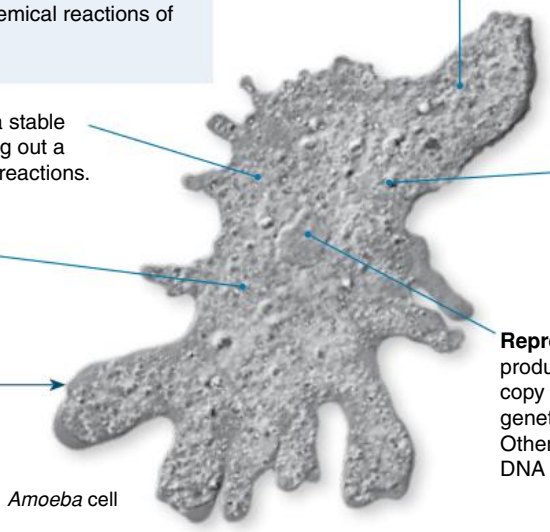
Homeostasis: Cells maintain a stable internal environment by carrying out a continuousl series of chemical reactions.

Growth: Cells grow bigger over time. When they get big enough and acquire enough materials they may divide.

Metabolism: Life is a continual series of chemical reactions. Cells sustain these reactions by using the energy in food molecules (e.g. glucose).

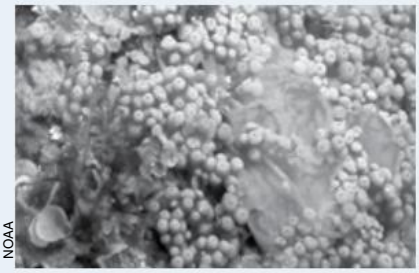
Reproduction: Cells divide to produce new cells. Some cells may copy their DNA and produce a genetically identical daughter cell. Other specialized cells divide their DNA to produce gametes.

Response: All cells respond to their environment. Receptors in the plasma membrane detect molecules in the environment and send signals to the internal machinery of the cell.



Amoeba cell

Exceptions to the Cell Theory



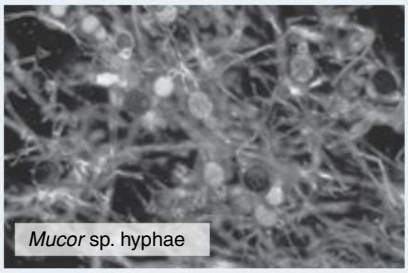
NOAA

The alga ***Caulerpa*** consists of one multi-nucleated cell, yet it grows to the size of a large plant. Its shape is maintained by the cell wall and microtubules, but there are no separate cells.



EII

Muscle fibres form from the fusion of many myoblasts (individual muscle stem cells), producing a large multi-nucleated fibre. These fibres can be 20 cm or more long.



EII

Mucor sp. hyphae

Some **fungi** produce hyphae that lack cross walls dividing the hyphae into cells. They are known as aseptate hyphae (as opposed to septate hyphae that do contain cross walls).

1. Cells are the fundamental unit of life. Explain what this means: _____

2. To what extent is an organism such as *Caulerpa* an exception to the cell theory? _____

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30 Types of Living Things

Key Idea: There are two broad types of cells, prokaryotic (or bacterial) cells and eukaryotic cells.

Living things (organisms) are made up of one or more cells. They are divided into two broad groups, **prokaryotic** (bacterial) **cells** and the more complex **eukaryotic cells**. Plant cells, animals cells, fungal cells, and protists are all eukaryotic cells. Viruses are classed as non-cellular as they have no cellular machinery of their own. All cells need energy to carry out their metabolic processes. **Autotrophs** are able to meet their energy requirements using light or chemical energy from the physical environment. **Heterotrophs** obtain their energy from the consumption of other organisms.

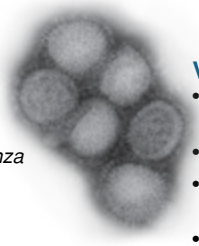
Living things

? ?

Cells

Prokaryotic (bacterial) cells
- Lack a membrane-bound nucleus or membrane-bound organelles
- Cells 0.5-10 µm
- Circular chromosome

Non-cellular



Influenza virus

Viruses
- Non-cellular. Typical size range: 20-300 nm.
- Contain no cytoplasm or organelles.
- No chromosome, just RNA or DNA strands.
- Enclosed in a protein coat.
- Depend on cells for metabolism and reproduction (replication).



Bacterial cell

Bacterial cells
- Single-celled. Lack a distinct membrane-bound nucleus and have no membrane-bound organelles.
- DNA a single, circular chromosome. There may be small accessory chromosomes called plasmids.
- Cell walls containing peptidoglycan. Some secrete a capsule.

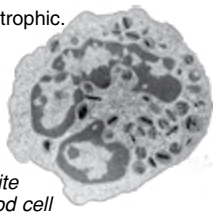
Eukaryotic cells
- Have a membrane-bound nucleus, and other membrane-bound organelles
- Cells 30-150 µm
- Linear chromosomes

Plant cells
- Exist as part of multicellular organism with specialisation of cells into many types.
- Possess nucleus and membrane-bound organelles.
- Autotrophic: photosynthetic cells with chloroplasts.
- Cell walls of cellulose.



Generalised plant cell

Animal cells
- Exist as part of multicellular organism with specialisation of cells into many types.
- Possess nucleus and membrane-bound organelles.
- Lack cell walls. Exhibit many cell types.
- Heterotrophic.



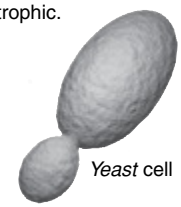
White blood cell

Protist cells
- Mainly single-celled or exist as cell colonies.
- Possess nucleus and membrane-bound organelles.
- Some are autotrophic and carry out photosynthesis.
- Some are heterotrophic.



Amoeba cell

Fungal cells
- Rarely discrete cells, except for some unicellular forms (e.g. yeasts)
- Possess nucleus and membrane-bound organelles.
- Plant-like, but lack chlorophyll.
- Rigid cell walls containing chitin.
- Heterotrophic.



Yeast cell

1. What are the characteristic features of a prokaryotic cell? _____

_____

2. What are the characteristic features of a eukaryotic cell? _____

_____

3. Why are viruses considered to be non-cellular (non-living)? _____

_____

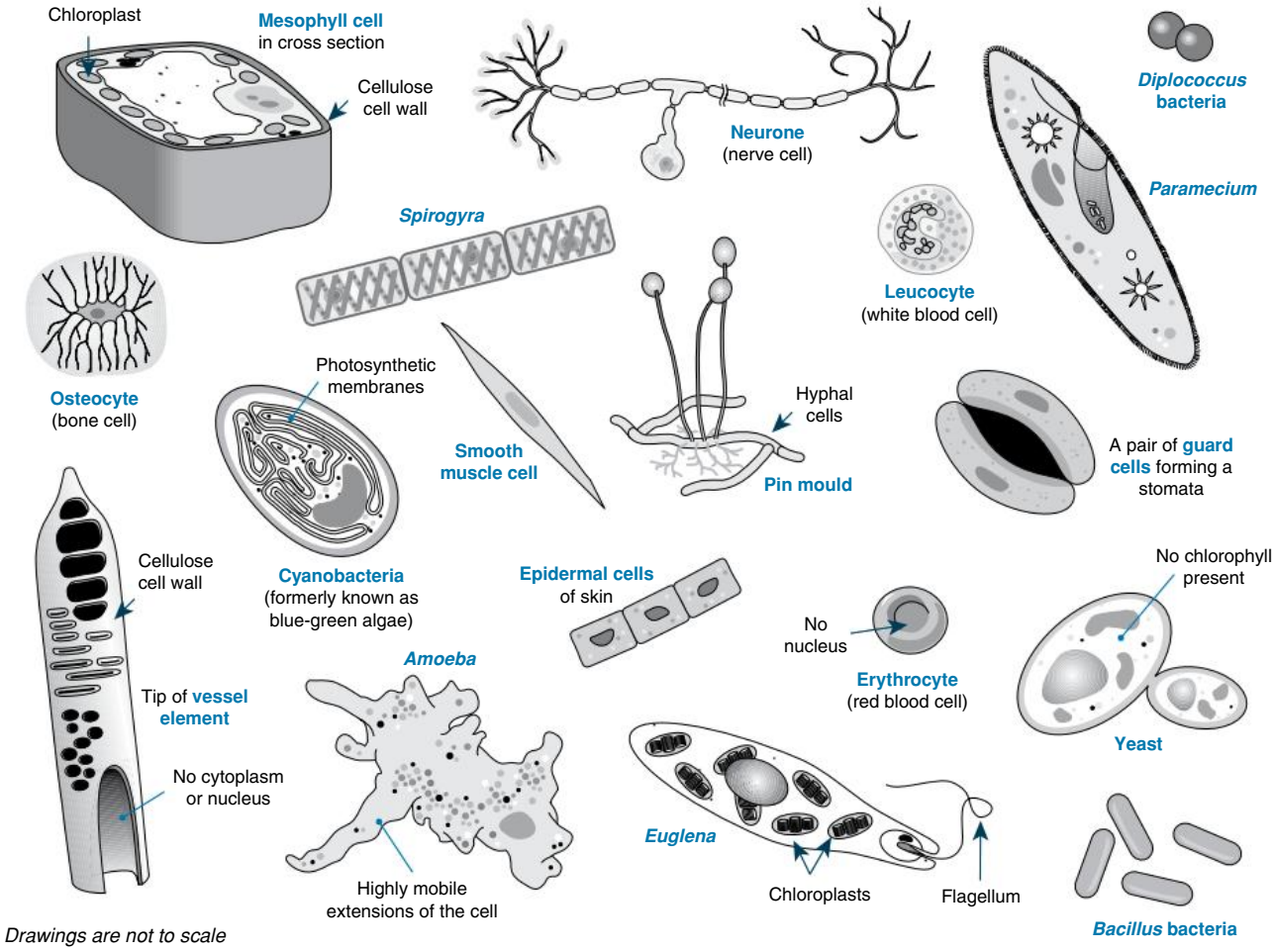
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31 Types of Cells

Key Idea: Cells come in a wide range of shapes and sizes. Each cell type is adapted for a specific role.

Cells come in a wide range of types and forms. The diagram below shows a selection of cell types from the five kingdoms. The variety that results from specialisation of undifferentiated cells is enormous. In the following exercise, identify which of the cell types belongs to each of the kingdoms and list the major distinguishing characteristics of their cells.



Drawings are not to scale

1. (a) **Plant** cell examples: _____

   (b) Major distinguishing characteristics: _____

   _____

2. (a) **Animal** cell examples: _____

   (b) Major distinguishing characteristics: _____

   _____

3. (a) **Protist** cell examples: _____

   (b) Major distinguishing characteristics: _____

   _____

4. (a) **Fungal** cell examples: _____

   (b) Major distinguishing characteristics: _____

   _____

5. (a) **Prokaryote** examples: _____

   (b) Major distinguishing characteristics: _____

   _____

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32 Cellular Environments

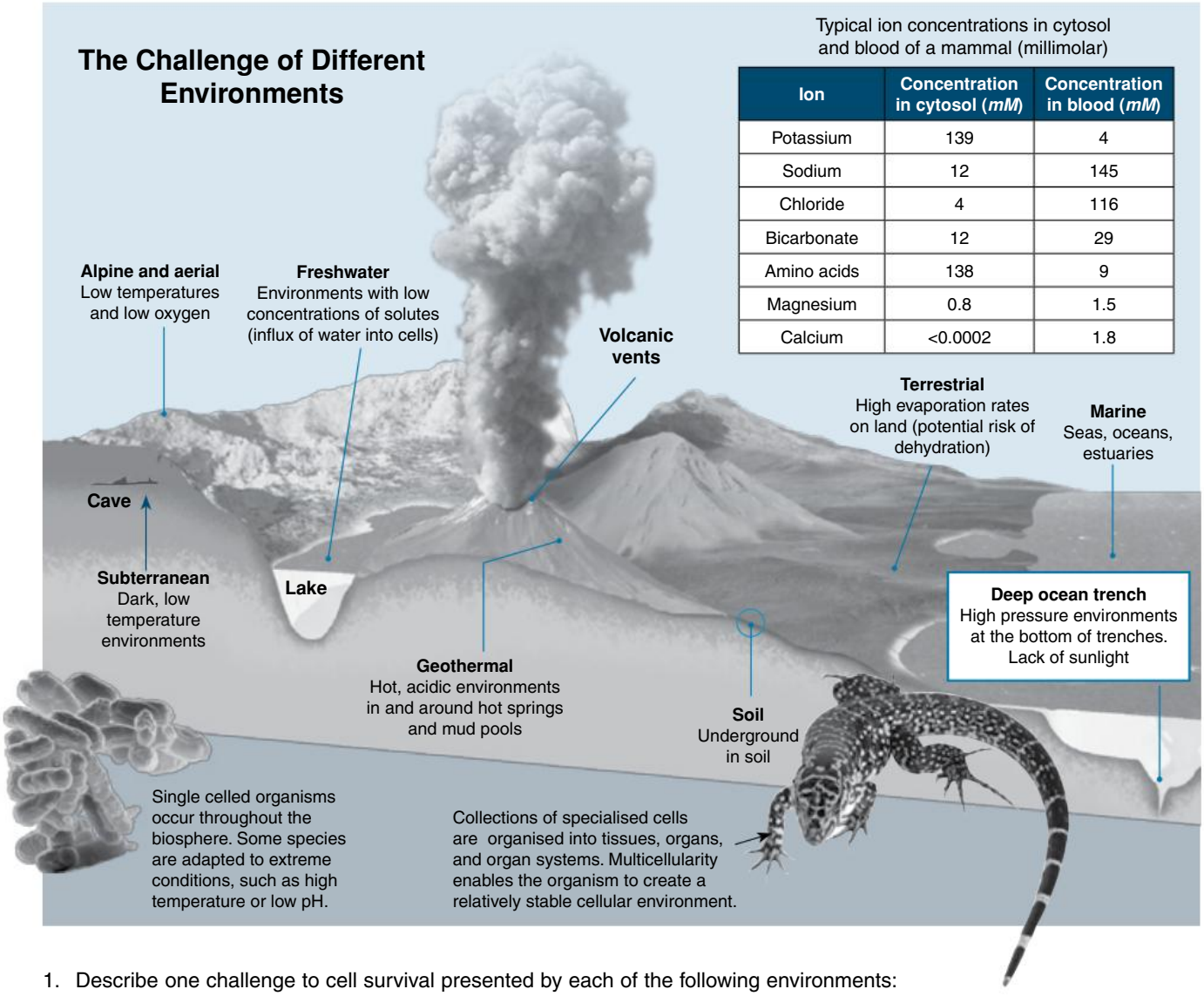
Key Idea: Cell specialisation and organisation has allowed organisms to survive in a wide variety of environments.

Organisms are found in a wide variety of physically different environments. Each environment has its own challenges (e.g. ion concentration, temperature, pH, oxygen availability), and to survive, organisms must maintain a relatively stable internal environment so their vital life processes can be carried out. The evolution of **multicellularity** (consisting of many cells) provided some independence from the external environment, because specialised cells could be organised into protective tissues, such as skin. Cell specialisation and organisation has enabled multicellular organisms to grow larger and provide the cells within their bodies with the optimum environment for cellular function.

The Challenge of Different Environments

Typical ion concentrations in cytosol and blood of a mammal (millimolar)

Ion	Concentration in cytosol (*mM*)	Concentration in blood (*mM*)
Potassium	139	4
Sodium	12	145
Chloride	4	116
Bicarbonate	12	29
Amino acids	138	9
Magnesium	0.8	1.5
Calcium	<0.0002	1.8



1. Describe one challenge to cell survival presented by each of the following environments:

   (a) Freshwater: _____

   (b) Ocean trench: _____

   (c) Terrestrial: _____

2. What are the biological consequences of multicellularity? _____

   _____

   _____

   _____

3. What do the differences between the ion concentrations in the cytosol (within the cell) and the blood (in the table above) tell you about the functioning of a multicellular organism such as a mammal?

   _____

   _____

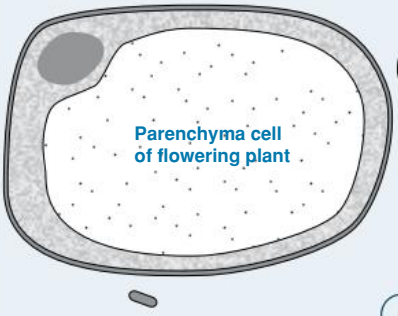
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33 Cell Sizes

Key Idea: Cells vary in size (2-100 µm), with prokaryotic cells being approximately 10 times smaller than eukaryotic cells.

Cells can only be seen properly when viewed through the magnifying lenses of a microscope. The images below show a variety of cell types, including a multicellular microscopic animal and a virus (non-cellular) for comparison. For each of these images, note the scale and relate this to the type of microscopy used.

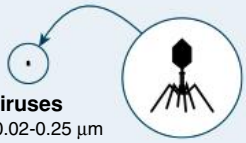




Human white blood cell

Eukaryotic cells
(e.g. plant and animal cells)
Size: 10-100 µm diameter. Cellular organelles may be up to 10 µm.

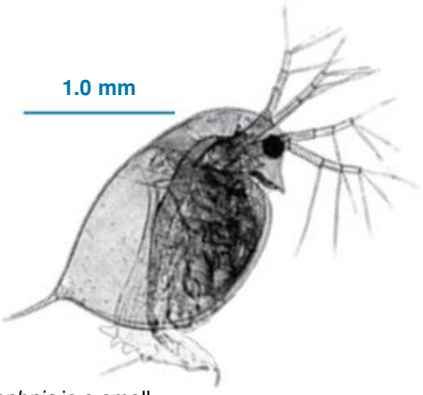
Prokaryotic cells
Size: Typically 2-10 µm length, 0.2-2 µm diameter. Upper limit 30 µm long.



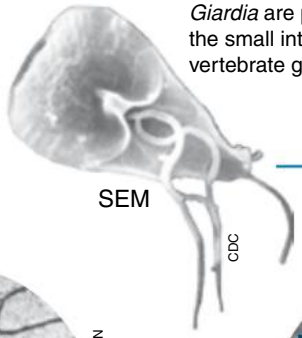
Viruses
Size: 0.02-0.25 µm (20-250 nm)

Unit of Length (International System)		
Unit	**Metres**	**Equivalent**
1 metre (m)	1 m	= 1000 millimetres
1 millimetre (mm)	10^{-3} m	= 1000 micrometres
1 micrometre (µm)	10^{-6} m	= 1000 nanometres
1 nanometre (nm)	10^{-9} m	= 1000 picometres

Micrometres are sometime referred to as microns. Smaller structures are usually measured in nanometres (nm) e.g. molecules (1 nm) and plasma membrane thickness (10 nm).



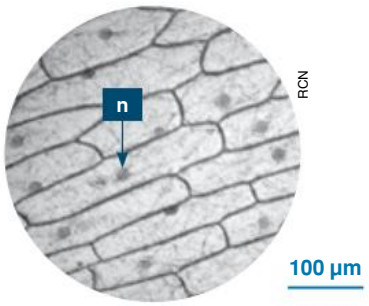
Daphnia is a small crustacean found as part of the zooplankton of lakes and ponds.



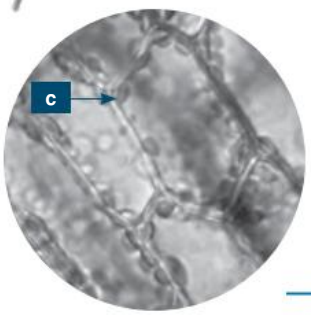
Giardia are protozoa that infect the small intestines of many vertebrate groups.



Paramecium is a protozoan commonly found in ponds and stagnant water.



Onion epidermal cells: the nucleus (n) is visible.



Elodea is an aquatic plant. In these leaf cells, the chloroplasts (c) can be seen around the inner edge of the cells.

1. Using the measurement scales provided on each of the photographs above, determine the longest dimension (length or diameter) of the cell/animal/organelle indicated in µm and mm. Attach your working:

   (a) *Daphnia*: _____ µm _____ mm
   (b) *Giardia*: _____ µm _____ mm
   (c) Nucleus _____ µm _____ mm
   (d) *Elodea* leaf cell: _____ µm _____ mm
   (e) Chloroplast: _____ µm _____ mm
   (f) *Paramecium*: _____ µm _____ mm

2. (a) List a-f in question 1 in order of size, from the smallest to the largest:

   _____

   (b) Study your ruler. Which one of the above could you see with your unaided eye? _____

3. Calculate the equivalent length in millimetres (mm) of the following measurements:

   (a) 0.25 µm: _____ (b) 450 µm: _____ (c) 200 nm: _____

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34 History of Microscopy

Key Idea: Microscopes are used to view objects that cannot be viewed in detail with the naked eye. Microscopes have become increasingly sophisticated over time with improvements in both magnification and resolution.

Lenses of various descriptions have been used for around 4000 years to view objects, but it is only in the last few hundred years that techniques have developed to build sophisticated devices for viewing microscopic objects. Early microscopes suffered from image distortion such as chromatic aberration (the production of images with the light split into the different colours). The development of more sophisticated techniques in lens and microscope production reduced this problem. The development of electron microscopes has made it possible to image objects to the atomic level.

Milestones in Microscopy

1500 Convex lenses with a magnification greater than x5 became available.

1595 **Zacharias Janssen** of Holland has been credited with the first compound microscope (more than one lens).

1662 **Robert Hooke** of England used the term 'cell' in describing the microscopic structure of cork.

1675 **Antoni van Leeuwenhoek** of Holland produced over 500 single lens microscopes that had a magnification of 270 times.

1800s The discovery that lenses combining two types of glass reduced chromatic aberration (the production of images with the light split into the different colours) allows clear images to be viewed.

1830 **Joseph Jackson Lister** demonstrated that spherical aberration (the focussing of light rays at different points due to the curve of the lens) could be reduced by using different lenses at precise distances from each other.

1878 **Ernst Abbe** produced a formula for correlating resolution to the wavelength of light, and so describes the maximum resolution of a light microscope.

1903 **Richard Zsigmondy** developed the ultramicroscope allowing objects smaller than the wavelength of light to be viewed.

1932 **Frits Zernike** invented the phase-contrast microscope making transparent or colourless objects easier to view.

1938 **Ernst Ruska** developed the transmission electron microscope (TEM). Electrons pass through an object and are focused by magnets. The short wavelength of electrons allows study of incredibly small objects. **Manfred von Ardenne** developed the scanning electron microscope (SEM) around the same time allowing the surface of objects to be imaged.

1981 **Gerd Binning** and **Heinrich Rohrer** invented the scanning tunneling electron microscope (STM), producing three dimensional images at the atomic level.

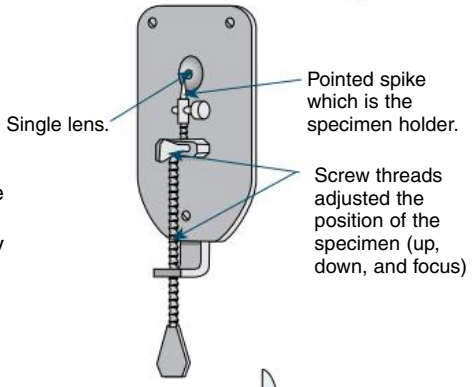
1595

The first compound microscope (the Janssen microscope, left) consisted of three draw tubes with lenses inserted into the tubes. The microscope was focussed by sliding the draw tube in or out.



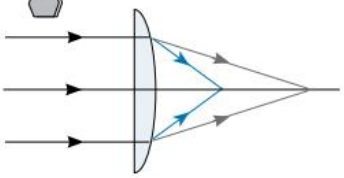
1675

A Leeuwenhoek microscope c. 1673 (right) was only a glorified magnifying glass by today's standards.



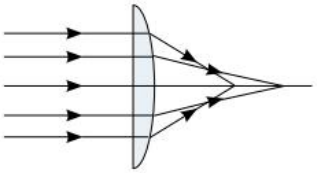
1800s

Chromatic aberration. Blue light refracts more than red light producing different focal points.

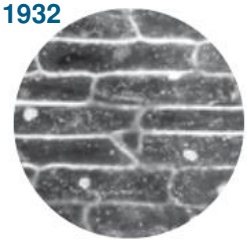


1830

Spherical aberration. Light entering at the edge of the lens focuses closer to the lens than light entering near the centre of the lens.

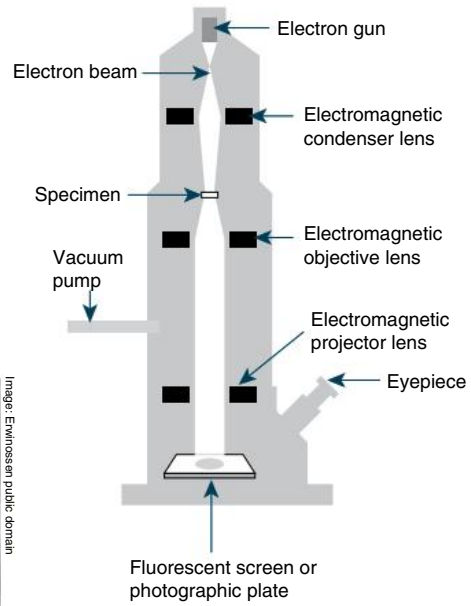


1932

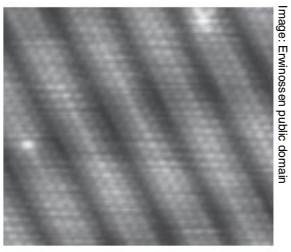


Onion cells viewed by phase contrast.

1938 TEM



1981



Gold atoms imaged with an STM

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35 Optical Microscopes

Key Idea: Optical microscopes use light focussed through a series of lenses to magnify objects up to several 100 times.

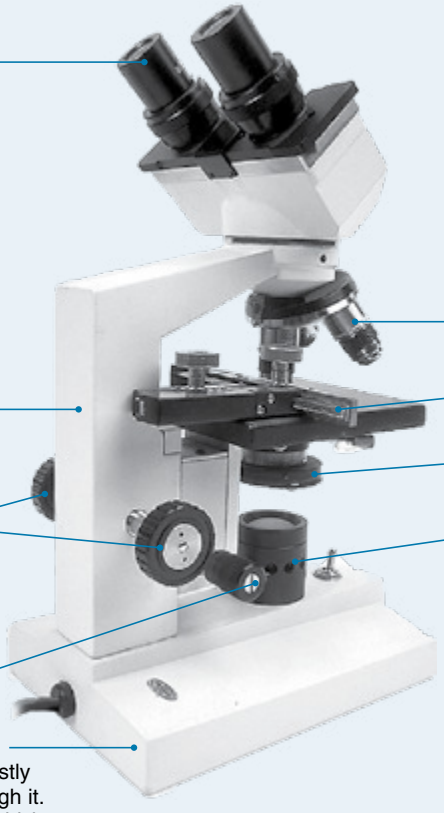
The light (or optical) microscope is an important tool in biology and using it correctly is an essential skill. High power compound light microscopes use visible light and a combination of lenses to magnify objects up to several 100 times. The resolution of light microscopes is limited by the wavelength of light. Electron microscopes use a beam of electrons, instead of light, to produce an image. Their higher resolution is due to the shorter wavelengths of electrons.


RCN

Stoma in leaf epidermis

Typical compound light microscope

Word list: *In-built light source, arm, coarse focus knob, fine focus knob, condenser, mechanical stage, eyepiece lens, objective lens*



(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

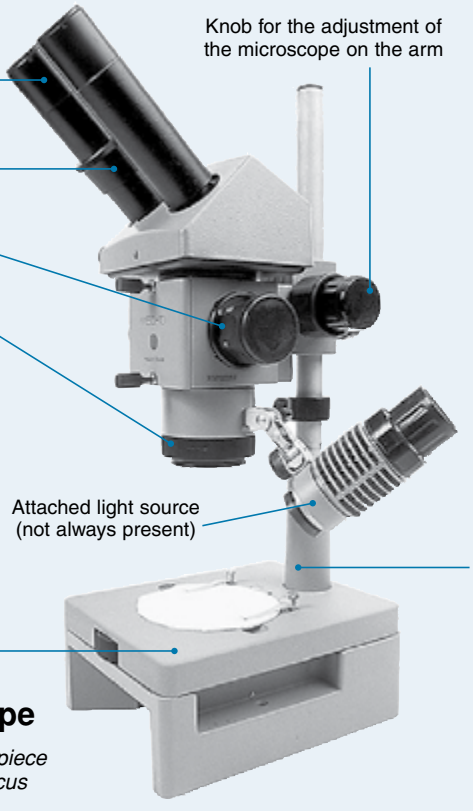
A specimen viewed with a **compound light microscope** must be thin and mostly transparent so that light can pass through it. No detail will be seen if specimens are thick or opaque. Modern microscopes are binocular, i.e. they have two adjustable eyepieces.

What is Magnification?

Magnification refers to the number of times larger an object appears compared to its actual size.

Magnification is calculated as follows:

Objective lens power **X** Eyepiece lens power



Knob for the adjustment of the microscope on the arm

Attached light source (not always present)

(i)

(j)

(k)

(l)

(m)


RCN

Drosophila

Dissecting microscope

Word list: *Focus knob, stage, eyepiece lens, objective lens, eyepiece focus*

What is Resolution?

Resolution is the ability to distinguish between close together but separate objects. Examples of high and low resolution for separating two objects viewed under the same magnification are given below.

High resolution

Low resolution

Dissecting microscopes are a special type of binocular microscope used for observations at low total magnification (X4 to X50), where a large working distance between the objectives and stage is required.

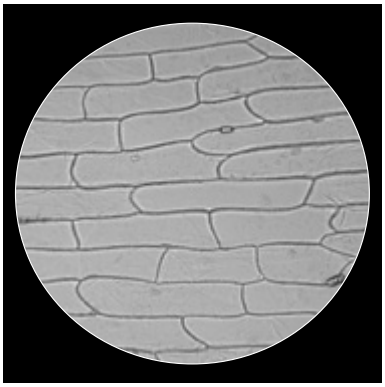
A dissecting microscope has two separate lens systems, one for each eye. Such microscopes produce a 3-D view of the specimen and are sometimes called stereo microscopes for this reason.

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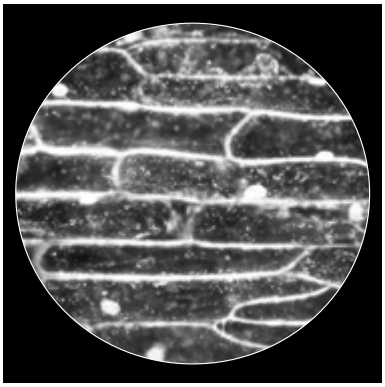


JDG

Dissecting microscopes are used for identifying and sorting organisms, observing microbial cultures, and dissections.



These onion epidermal cells are viewed with standard **bright field** lighting. Very little detail can be seen (only cell walls) and the cell nuclei are barely visible.



Photos: EII

Dark field illumination is excellent for viewing specimens that are almost transparent. The nuclei of these onion epidermal cells are clearly visible.

1. Label the two photographs on the previous page, the compound light microscope (a) to (h) and the dissecting microscope (i) to (m). Use words from the lists supplied for each image.

2. Determine the magnification of a microscope using:

   (a) 15 X eyepiece and 40 X objective lens: _____ (b) 10 X eyepiece and 60 X objective lens: _____

3. Describe the main difference between a compound light microscope and a dissecting microscope: _____

   _____

   _____

4. What type of microscope would you use to:

   (a) Count stream invertebrates in a sample: _____ (b) Observe cells in mitosis: _____

5. (a) Distinguish between **magnification** and **resolution**: _____

   _____

   (b) Explain the benefits of a higher resolution: _____

   _____

   _____

6. Below is a list of ten key steps taken to set up a microscope and optimally view a sample. The steps have been mixed up. Put them in their **correct order** by numbering each step:

☐ Focus and centre the specimen using the high objective lens. Adjust focus using the fine focus knob only.

☐ Adjust the illumination to an appropriate level by adjusting the iris diaphragm and the condenser. The light should appear on the slide directly below the objective lens, and give an even amount of illumination.

☐ Rotate the objective lenses until the shortest lens is in place (pointing down towards the stage).
This is the lowest / highest power objective lens (delete one).

☐ Place the slide on the microscope stage. Secure with the sample clips.

☐ Fine tune the illumination so you can view maximum detail on your sample.

☐ Focus and centre the specimen using the medium objective lens. Focus firstly with the coarse focus knob, then with the fine focus knob (if needed).

☐ Turn on the light source.

☐ Focus and centre the specimen using the low objective lens. Focus firstly with the coarse focus knob, then with the fine focus knob.

☐ Focus the eyepieces to adjust your view.

☐ Adjust the distance between the eyepieces so that they are comfortable for your eyes.

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36 Microscopy Techniques

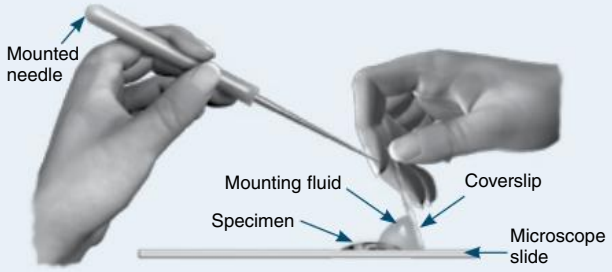
Key Idea: Correct sample preparation and use of an appropriate stain help to view material under a microscope.

Preparation of specimens can help to highlight features of samples for microscopy. Techniques such as wet mounts improve a sample's appearance and enhance visible detail. Stains can be used to highlight specific features. Most stains are used on dead specimens. These are called non-viable stains. Stains applied to living material are called vital stains.

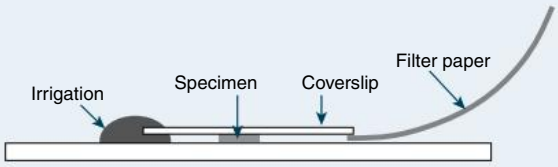
Making a Temporary Wet Mount

A wet mount is a temporary preparation in which a specimen and a drop of fluid are trapped under a thin coverslip. Wet mounts are used to view live microscopic organisms or suspensions such as blood.

1. **Sectioning:** Very thin sections of fresh material are cut with a razorblade.
2. **Mounting:** The thin section(s) are placed in the centre of a clean glass microscope slide and covered with a drop of mounting liquid (e.g. water, glycerol, or stain). A coverslip is placed on top to exclude air (below).
3. If too much liquid is added the coverslip will sit too high, and it will be difficult to focus on the sample. If not enough liquid is used, it may quickly evaporate and the sample may dry up before it can be fully examined.



A mounted needle is used to support the coverslip and lower it gently over the specimen. This avoids including air in the mount.



If a specimen is already mounted, a drop of stain can be placed at one end of the coverslip and drawn through using filter paper (above). Water can be drawn through in the same way to remove excess stain.

Staining Techniques

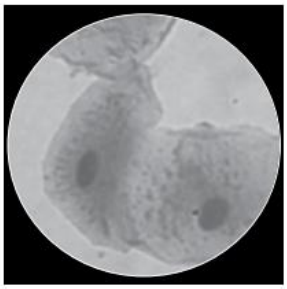
Some commonly used stains

Stain	Final color	Used for
Iodine solution	blue-black	Starch
Crystal violet	purple	Gram staining
Aniline sulfate	yellow	lignin
Methylene blue	blue	Nuclei



Mnolf

Iodine solution stains starch containing organelles, such as **potato amyloplasts**, blue-black.

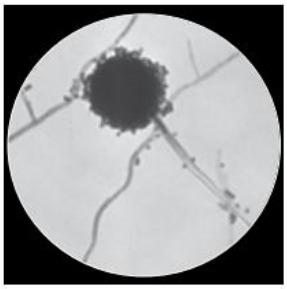


Methylene blue is a commonly used temporary stain for animal cells. It makes **nuclei** more visible.



CDC

The gram stain contains **crystal violet**, which binds strongly to the peptidoglycan component in the cell walls of **gram positive bacteria**, turning them purple.



CDC: Dr Lucille K. Georg

Vital (or viable) **stains** do not immediately harm living cells. **Trypan blue** distinguishes living and dead cells, and is used to study fungal hyphae (above).

1. Why are many microscope samples wet mounted prior to viewing under a microscope? _____

2. What is the main purpose of using a stain? _____

3. What is the difference between a **vital** and **non-viable** stain? _____

4. Identify a stain that would be appropriate for improving identification of the following:

   (a) Fungal hyphae: _____ (d) Lignin in a plant root section: _____

   (b) Starch in potato cells: _____ (e) Nuclei in cheek cells: _____

   (c) Cell wall of bacteria: _____

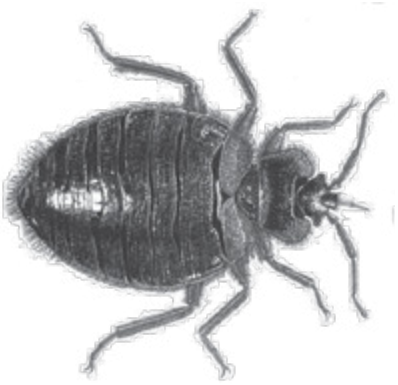
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37 Calculating Linear Magnification

Key Idea: Magnification is how much larger an object appears compared to its actual size. It can be calculated from the ratio of image height to object height.

Microscopes produce an enlarged (magnified) image of an object allowing it to be observed in greater detail than is possible with the naked eye. **Magnification** refers to the number of times larger an object appears compared to its actual size. Linear magnification is calculated by taking a ratio of the image height to the object's actual height. If this ratio is greater than one, the image is enlarged. If it is less than one, it is reduced. To calculate magnification, all measurements are converted to the same units. Often, you will be asked to calculate an object's actual size, in which case you will be told the size of the object and the magnification.

Calculating Linear Magnification: A Worked Example



1. Measure the body length of the bed bug image (right). Your measurement should be 40 mm (***not*** including the body hairs and antennae).

2. Measure the length of the scale line marked 1.0 mm. You will find it is 10 mm long. The magnification of the scale line can be calculated using equation 1 (below right).

   The magnification of the scale line is **10** (10 mm / 1 mm)

   **NB: The magnification of the bed bug image will also be 10x because the scale line and image are magnified to the same degree.*

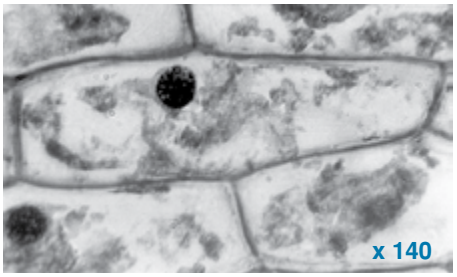
3. Calculate the actual (real) size of the bed bug using equation 2 (right):

   The actual size of the bed bug is **4 mm**
   (40 mm / 10 x magnification)

Microscopy Equations

1. $\text{Magnification} = \dfrac{\text{measured size of the object}}{\text{actual size of the object}}$

2. $\text{Actual object size} = \dfrac{\text{size of the image}}{\text{magnification}}$



1. The bright field microscopy image on the left is of onion epidermal cells. The measured length of the onion cell in the centre of the photograph is 52,000 µm (52 mm). The image has been magnified 140 x. Calculate the actual size of the cell:



2. The image of the flea (left) has been captured using light microscopy.

   (a) Calculate the magnification using the scale line on the image:

   (b) The body length of the flea is indicated by a line. Measure along the line and calculate the actual length of the flea:



3. The image size of the *E.coli* cell (left) is 43 mm, and its actual size is 2 µm. Using this information, calculate the magnification of the image:

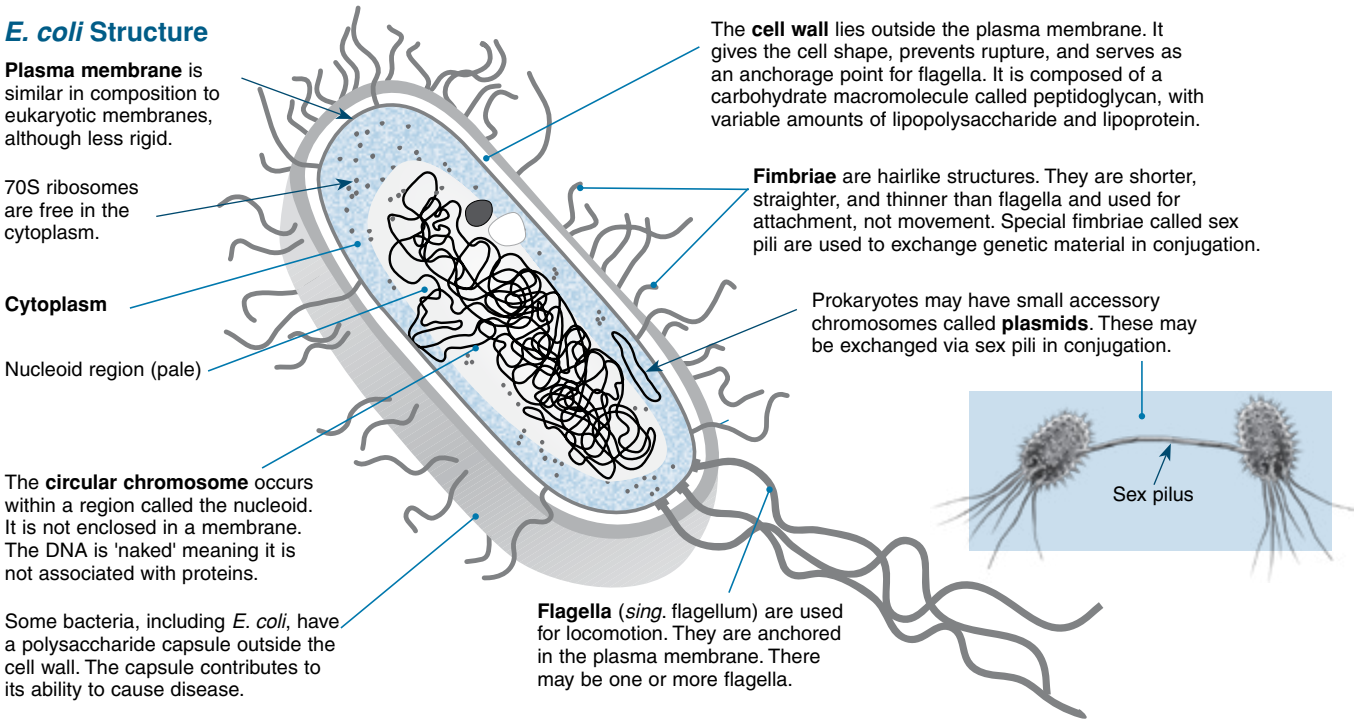
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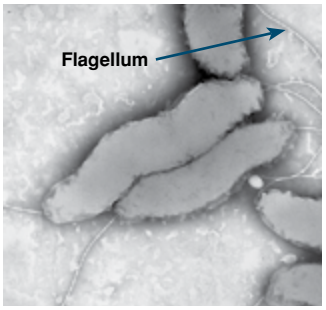
38 Bacterial Cells

Key Idea: Bacterial cells have a simpler cell structure than eukaryotic cells.

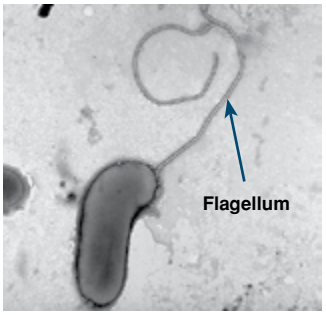
Bacterial (prokaryotic) cells are much smaller than eukaryotic cells and lack many eukaryotic features, such as a distinct nucleus and membrane-bound cellular organelles. The cell wall is an important feature. It is a complex, multi-layered structure and has a role in the organism's ability to cause disease. A generalised prokaryote, *E. coli*, is shown below.

E. coli Structure



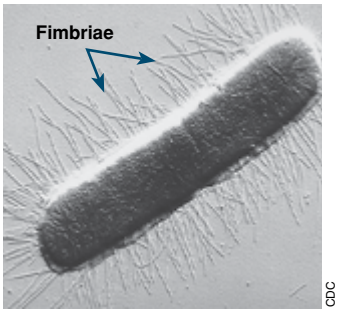


A spiral shape is one of four bacterial shapes (the others being rods, commas, and spheres). These *Campylobacter* cells also have flagella.



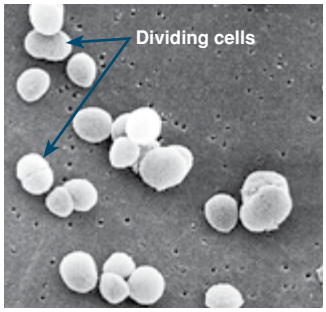
EII

Helicobacter pylori, is a comma-shaped vibrio bacterium that causes stomach ulcers in humans. It moves by means of polar flagella.



CDC

Escherichia coli is a rod-shaped bacterium, common in the human gut. The fimbriae surrounding the cell are used to adhere to the intestinal wall.



Bacteria usually divide by binary fission. During this process, DNA is copied and the cell splits into two cells, as in these round (cocci) cells.

1. Describe three features distinguishing prokaryotic cells from eukaryotic cells:

   (a) _____

   (b) _____

   (c) _____

2. (a) Describe the function of flagella in bacteria: _____

   _____

   (b) Explain how fimbriae differ structurally and functionally from flagella: _____

   _____

   _____

3. Describe the location and general composition of the bacterial cell wall: _____

   _____

   _____

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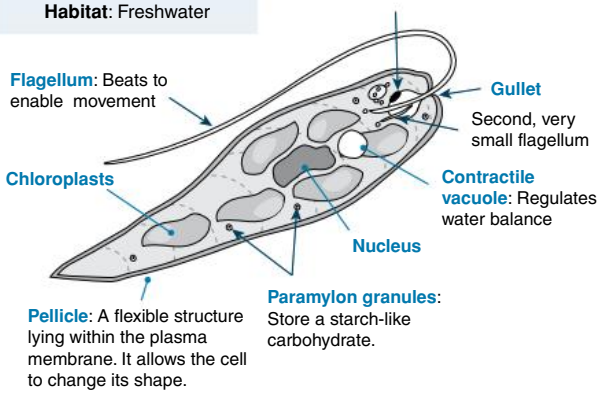
39 Unicellular Eukaryotes

Key Idea: Most of the eukaryote kingdom Protista is made up of unicellular organisms. They show great variation in the ways in which they carry out the functions of life.

Unicellular (single-celled) **eukaryotes** make up most of the kingdom, Protista. They are found almost anywhere there is water, including within larger organisms (as parasites or symbionts). The protists are a diverse group, showing some features typical of generalised eukaryotic cells, as well as specialised features. Note that even within the genera below there is considerable variation in size and appearance. *Amoeba* and *Paramecium* are both **heterotrophic**, ingesting food, which accumulates inside a **vacuole**. *Euglena and Chlamydomonas* are autotrophic algae, although *Euglena* is heterotrophic when deprived of light.

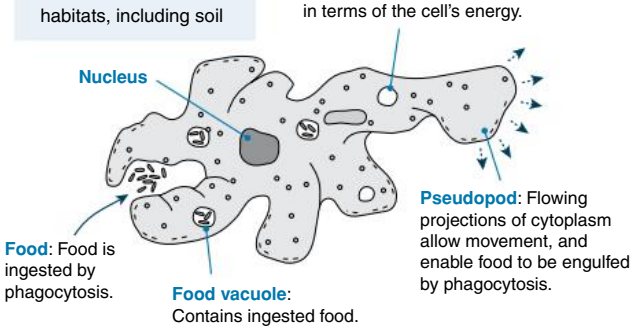
Euglena

Size: 130 x 50 µm (varies considerably with species)
Habitat: Freshwater



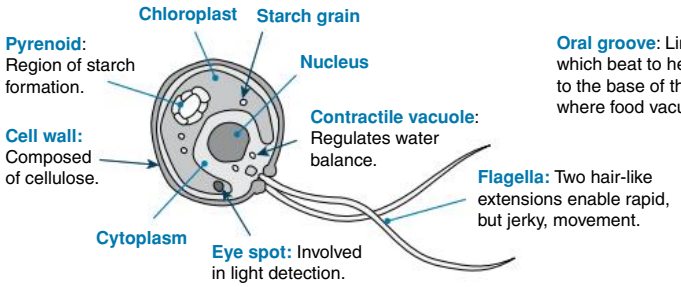
Amoeba

Size: up to 800 x 400 µm (varies with species)
Habitat: Most moist habitats, including soil



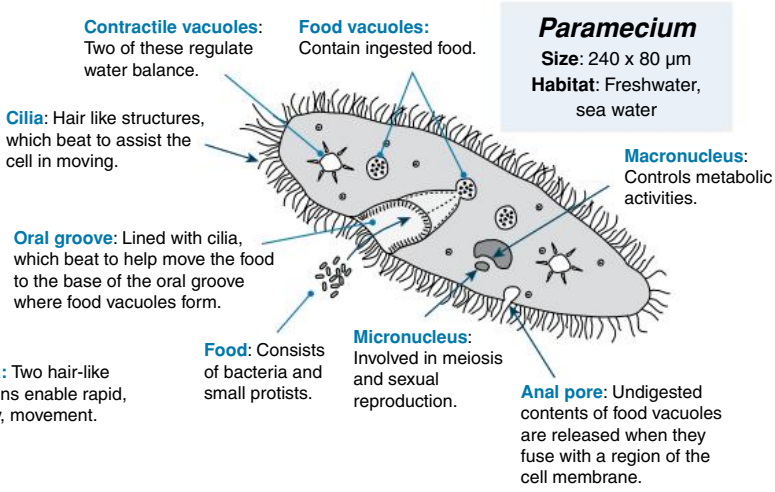
Chlamydomonas

Size: 20 x 10 µm
Habitat: Freshwater



Paramecium

Size: 240 x 80 µm
Habitat: Freshwater, sea water



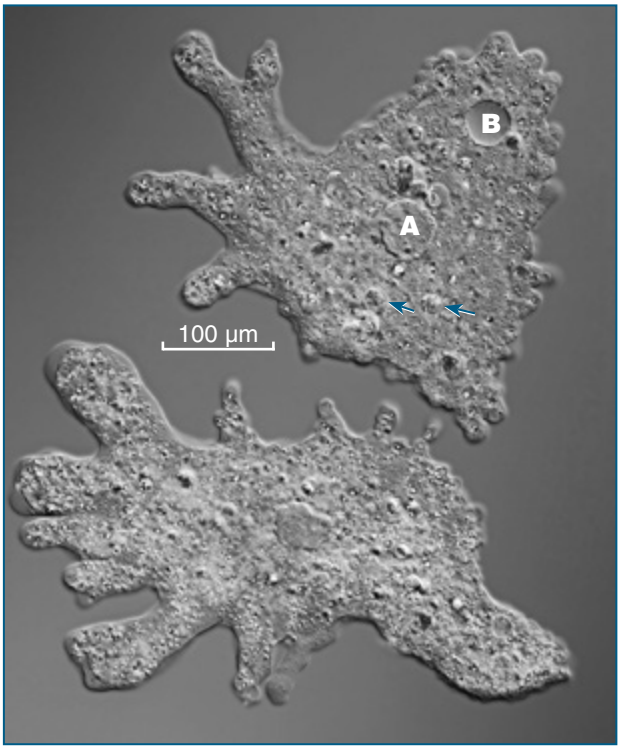
1. Fill in the table below to summarise differences in some of the features and life functions of the protists shown above:

Organism	Nutrition	Movement	Osmoregulation	Eye spot present / absent	Cell wall present / absent
Amoeba					
Paramecium					
Euglena					
Chlamydomonas					

2. List the four organisms shown above in order of size (largest first): _____

3. Explain why an autotroph would have an eye spot: _____

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istock

4. (a) Identify the structure labelled **A**:

(b) Circle the same structure in the unlabelled specimen:

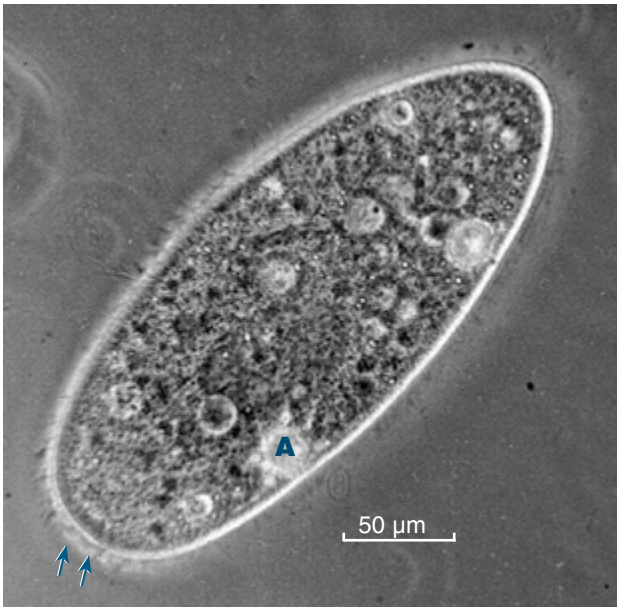
(c) What feature(s) helped you identify this organelle?

(d) Identify the structure labelled **B**:

(e) Describe the function of this structure:

(f) Identify the structures labelled with arrows:

(g) Describe the function of these structures:



Barfooz CC 3.0

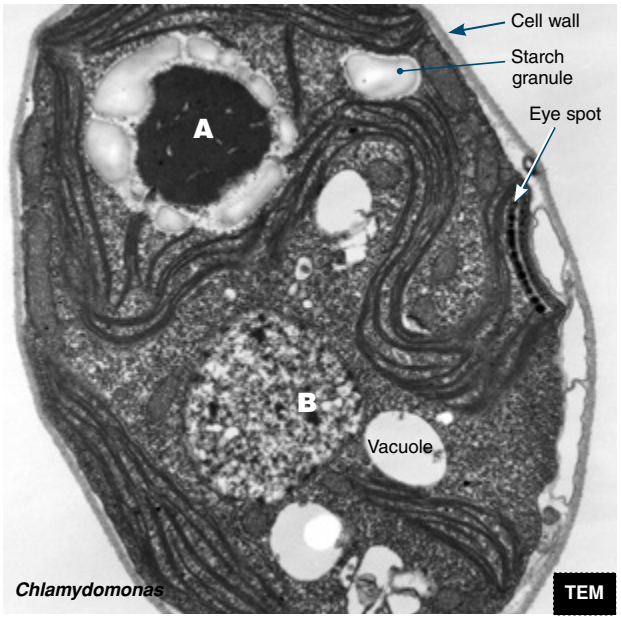
5. (a) Identify this organism:

(b) What feature(s) helped you make your identification?

(c) Identify the organelle labelled **A**:

(d) Circle another organelle with the same function:

(e) Identify the structures indicated by the arrows and describe their purpose:



Dartmouth College

6. (a) Identify the organelle labelled **A**:

(b) Describe the function of this organelle:

(c) Identify the organelle labelled B. What is the dark granular material you can see?

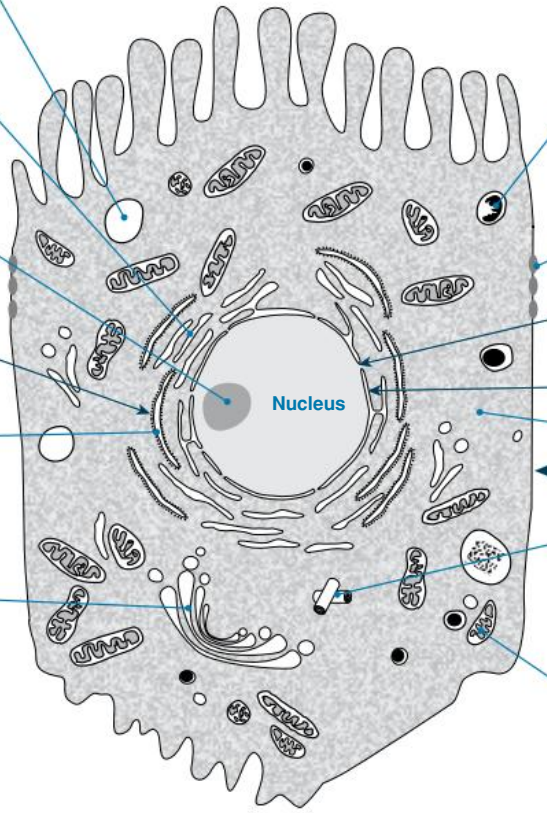
(d) Identify the ribbon-like structures in this image, and explain how you came to your conclusion about what they are:

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40 Animal Cells

Key Idea: Animal cells are eukaryotic cells. They have many features in common with plant cells, but also have a number of unique features.

Animal cells, unlike plant cells, do not have a regular shape. In fact, some animal cells (such as phagocytes) are able to alter their shape for various purposes (e.g. engulfing foreign material). The diagram below shows the structure and organelles of a liver cell. It contains organelles common to most relatively unspecialised human cells. Note the differences between this cell and the generalised plant cell. The plant cells activity provides further information on the organelles listed here but not described.



Vacuoles: Smaller than those found in plant cells.

Smooth endoplasmic reticulum: ER without ribosomes. It is a site for lipid and carbohydrate metabolism, including hormone synthesis.

Nucleolus: A dense, solid structure composed of crystalline protein and nucleic acid. They are involved in ribosome synthesis.

Ribosomes: These small structures may be free in the cytoplasm or associated with the endoplasmic reticulum (ER).

Rough endoplasmic reticulum: A site of protein synthesis.The rough ER also synthesises new membranes, growing in place by adding proteins and phospholipids.

Golgi apparatus: A series of flattened, disc-shaped sacs, stacked one on top of the other and connected with the ER. The Golgi stores, modifies, and packages proteins. It 'tags' proteins so that they go to their correct destination.

Lysosome: A sac bounded by a single membrane. They are pinched off from the Golgi apparatus and contain and transport enzymes that break down food and foreign matter. Lysosomes show little internal structure but often contain fragments of material being broken down. Specialised lysosomes are generally absent from plant cells.

Tight junctions: Join cells together in the formation of tissues.

Nuclear pore: A hole in the nuclear membrane allowing the nucleus to communicate with the rest of the cell.

Nuclear membrane: Double layered

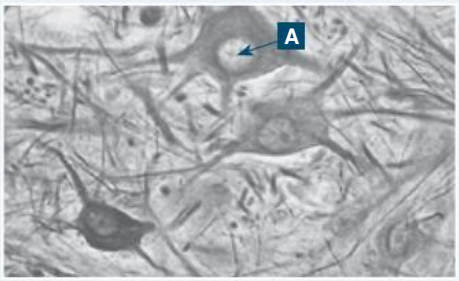
Cytoplasm

Plasma membrane

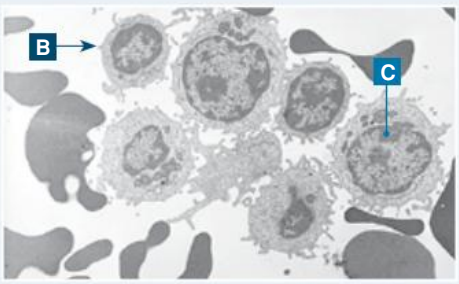
Centrioles: Structures associated with nuclear division. They are composed of microtubules, but appear as small, featureless particles, 0.25 µm diameter, under a light microscope. They are absent in higher plant cells and some protists.

Mitochondrion (*pl.* mitochondria): An organelle bounded by a double membrane system. The number in a cell depends on its metabolic activity.

Generalised Animal Cell



Neurones (nerve cells) in the spinal cord



White blood cells and red blood cells (blood smear)

Photos: EII

1. The two photomicrographs (left) show several types of animal cells. Identify the features indicated by the letters **A-C**:

   A: _____

   B: _____

   C: _____

2. White blood cells are mobile, phagocytic cells, whereas red blood cells are smaller than white blood cells and, in humans, lack a nucleus.

   (a) In the photomicrograph (lower, left), circle a white blood cell and a red blood cell:

   (b) With respect to the features that you can see, explain how you made your decision.

   _____

   _____

   _____

   _____

3. Name and describe one structure or organelle present in generalised animal cells but absent from plant cells:

   _____

   _____

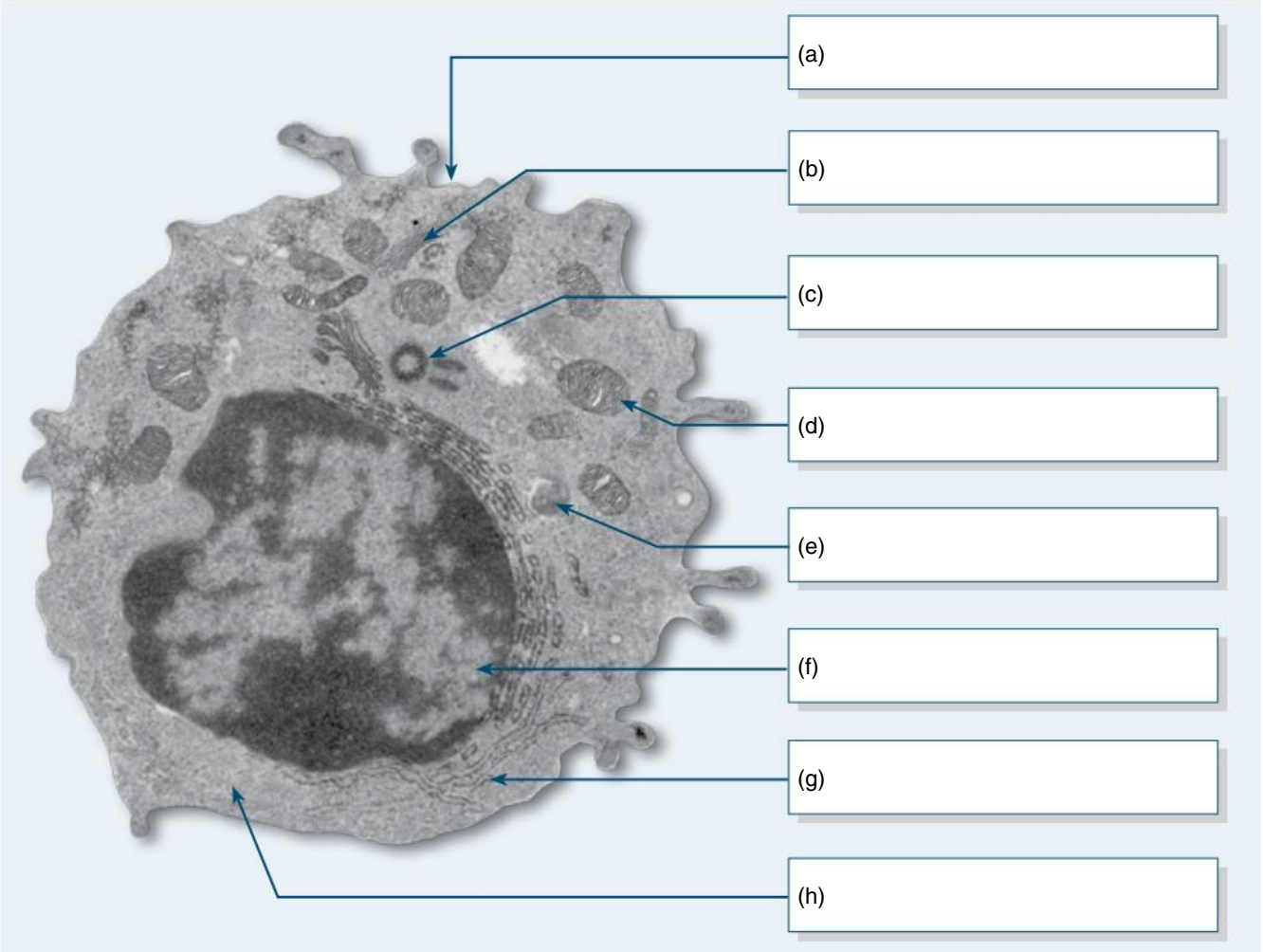
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41 Identifying Structures in an Animal Cell

Key Idea: The position of the organelles in an electron micrograph can result in variations in their appearance.

Transmission electron microscopy (TEM) is the most frequently used technique for viewing cellular organelles. When viewing TEMs, the cellular organelles may appear to be quite different depending on whether they are in transverse or longitudinal section.

1. Identify and label the structures in the animal cell below using the following list of terms: *cytoplasm, plasma membrane, rough endoplasmic reticulum, mitochondrion, nucleus, centriole, Golgi apparatus, lysosome*



2. Which of the organelles in the EM above are shown in both transverse and longitudinal section?

3. Why do plants lack any of the mobile phagocytic cells typical of animal cells?

4. The animal cell pictured above is a lymphocyte. Describe the features that suggest to you that:

   (a) It has a role in producing and secreting proteins:

   (b) It is metabolically very active:

5. What features of the lymphocyte cell above identify it as eukaryotic?

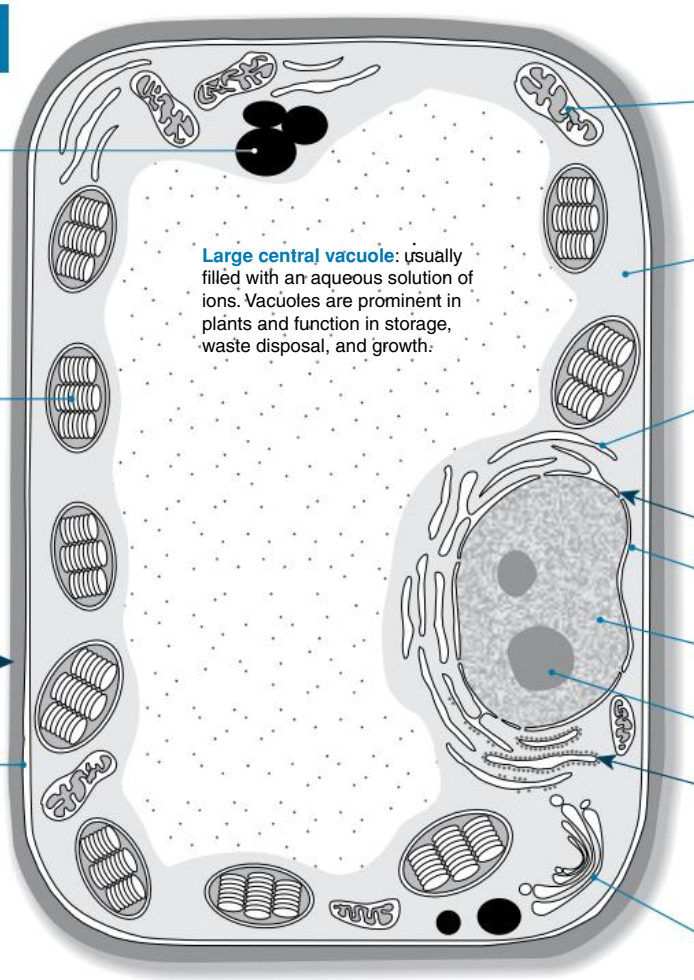
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42 Plant Cells

Key Idea: Plant cells are eukaryotic cells. They have many features in common with animal cells, but they also have several unique features.

Plant cells are enclosed in a cellulose cell wall which protects the cell, maintains its shape, and prevents excessive water uptake. It does not interfere with the passage of materials into and out of the cell. The diagram below shows the structure and function of a typical plant cell and its organelles. The animal cells activity provides further information on the organelles listed here but not described.

Generalised Plant Cell



Starch granule: Carbohydrate stored in amyloplasts (plastids specialised for storage). Plastids are unique to plants. Non-photosynthetic plastids usually store materials.

Chloroplast: Specialised plastids, 2 µm x 5 µm, containing the green pigment chlorophyll. They contain dense stacks of membranes (grana) within a colourless stroma. They are the sites for photosynthesis and occur mainly in leaves.

Cell wall: A semi-rigid structure outside the plasma membrane, 0.1 µm to several µm thick. It is composed mainly of cellulose. It supports the cell and limits its volume.

Plasma membrane: Located inside the cell wall in plants, 3 to 10 nm thick.

Large central vacuole: usually filled with an aqueous solution of ions. Vacuoles are prominent in plants and function in storage, waste disposal, and growth.

Mitochondrion: 1.5 µm X 2–8 µm. Mitochondria are ovoid structures bounded by a double membrane. They are the cell energy transformers, converting chemical energy into ATP.

Cytoplasm: A watery solution containing dissolved substances, enzymes, and the cell organelles and structures. The site of translation in the cell.

Endoplasmic reticulum (ER): Comprises a network of tubes and flattened sacs. ER is continuous with the plasma membrane and the nuclear membrane and may be smooth or have attached ribosomes (rough ER).

Nuclear pore: 100 nm diameter.

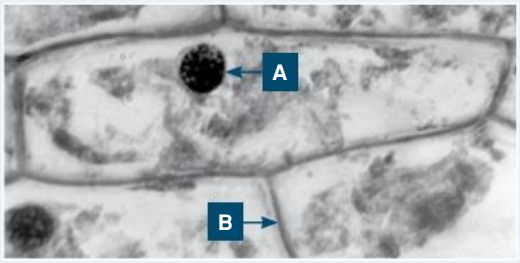
Nuclear membrane: A double layered structure penetrated by holes (nuclear pores).

Nucleus: A conspicuous organelle containing most of the cell's DNA, 5 µm diameter.

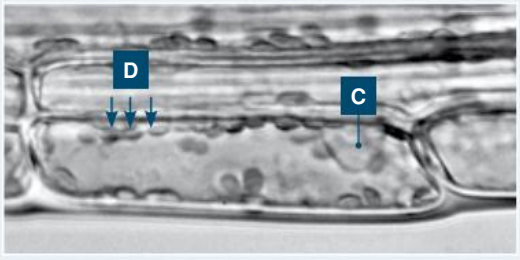
Nucleolus

Ribosomes: These small (20 nm) structures manufacture proteins. Ribosomes are made of ribosomal RNA and protein. They may be free in the cytoplasm or associated with the surface of the endoplasmic reticulum.

Golgi apparatus



Onion epidermal cells



Elodea cells

1. The two photographs (left) show plant cells as seen by a light microscope. Identify the basic features labelled **A-D**:

   A: _____

   B: _____

   C: _____

   D: _____

2. Identify four structures or organelles present in generalised plant cells but absent from animal cells:

   _____

   _____

   _____

   _____

3. Identify four membrane-bound organelles that plant cells have in common with animal cells:

   (a) _____ (c) _____

   (b) _____ (d) _____

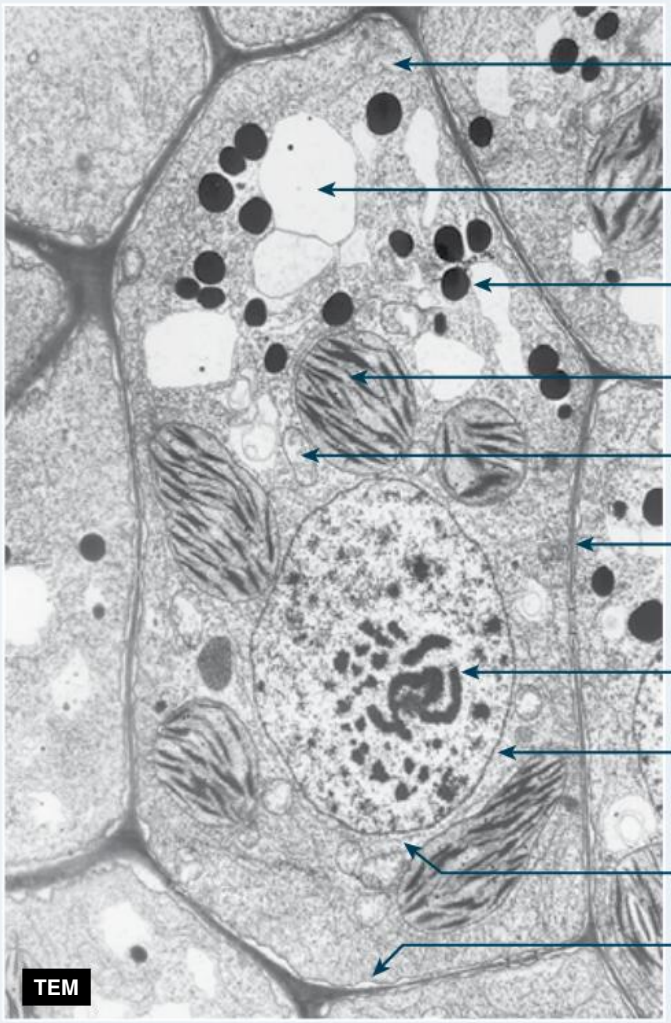
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43 Identifying Structures in a Plant Cell

Key Idea: The position and appearance of the organelles in an electron micrograph can be used to identify them.

1. Study the diagrams on the other pages in this chapter to familiarise yourself with the structures found in eukaryotic cells. Identify and label the ten structures in the cell below using the following list of terms: *nuclear membrane, cytoplasm, endoplasmic reticulum, mitochondrion, starch granules, chromosome, vacuole, plasma membrane, cell wall, chloroplast*



(a) _____

(b) _____

(c) _____

(d) _____

(e) _____

(f) _____

(g) _____

(h) _____

(i) _____

(j) _____

2. State how many cells, or parts of cells, are visible in the electron micrograph above: _____

3. Describe the features that identify this cell as a plant cell: _____

_____

_____

4. (a) Explain where cytoplasm is found in the cell: _____

_____

(b) Describe what cytoplasm is made up of: _____

_____

5. Describe two structures, pictured in the cell above, that are associated with storage:

(a) _____

_____

(b) _____

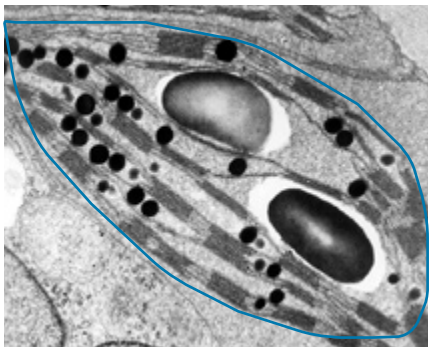
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44 Interpreting Electron Micrographs

Key Idea: Cellular organelles can be identified in electron micrographs by their specific features.

Electron microscopes produce a magnified image at high resolution (distinguish between close together but separate objects). The transmission electron microscope (TEM) images below show the ultrastructure of some organelles.



WMU

1. (a) Name the circled organelle: _____

   (b) Which kind of cell(s) would this organelle be found in?

   _____

   (c) Describe the function of this organelle: _____

   _____

   _____

   _____



WMU

2. (a) Name this organelle (arrowed): _____

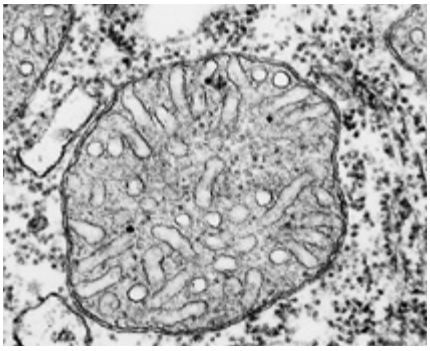
   (b) State which kind of cell(s) this organelle would be found in:

   _____

   (c) Describe the function of this organelle: _____

   _____

   _____



WMU

3. (a) Name the large, circular organelle: _____

   (b) State which kind of cell(s) this organelle would be found in:

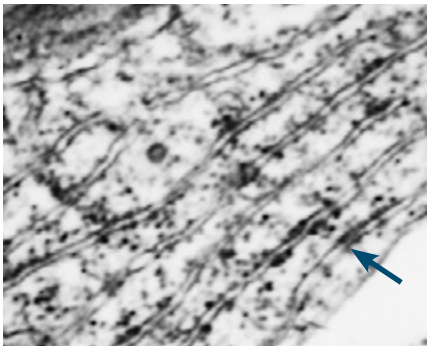
   _____

   (c) Describe the function of this organelle: _____

   _____

   _____

   (d) Label **two** regions that can be seen **inside** this organelle.



WMU

4. (a) Name and label the ribbon-like organelle in this photograph (arrowed):

   _____

   (b) State which kind of cell(s) this organelle is found in:

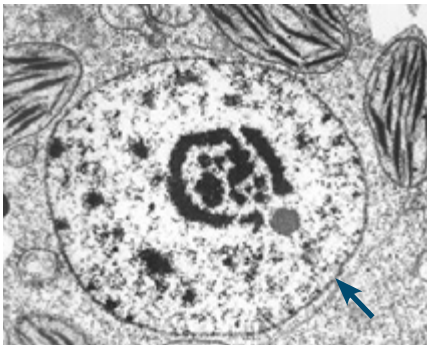
   _____

   (c) Describe the function of this organelle: _____

   _____

   (d) Name the dark 'blobs' attached to the organelle you have labelled:

   _____



BF

5. (a) Name this large circular organelle (arrowed): _____

   (b) State which kind of cell(s) this organelle would be found in: _____

   _____

   (c) Describe the function of this organelle: _____

   _____

   (d) Label three features relating to this organelle in the photograph.

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45 KEY TERMS: Word Find

Use the clues below to find the relevant key terms in the WORD FIND grid

V	G	Z	H	L	Z	R	E	S	O	L	U	T	I	O	N	J	V	S	K	D	F	Y	J	I	P	N	C
N	T	A	Y	B	G	R	S	N	O	H	K	X	Z	H	W	Y	L	Y	D	S	Y	W	S	V	O	K	F
S	N	E	I	X	S	T	A	I	N	E	T	G	T	M	N	B	C	Y	T	O	P	L	A	S	M	B	O
I	B	S	C	F	M	I	T	O	C	H	O	N	D	R	I	A	C	W	B	H	F	Z	O	H	X	X	R
I	S	A	E	L	K	Z	J	P	L	A	S	M	A	M	E	M	B	R	A	N	E	F	N	Y	Q	L	G
E	G	J	L	A	G	Y	I	S	S	W	H	R	Y	X	V	W	P	Q	L	I	J	B	L	S	Q	F	A
A	R	R	L	G	L	Y	S	O	S	O	M	E	S	B	A	C	E	N	Z	Y	M	E	S	T	K	I	N
P	W	F	W	E	M	B	L	S	Q	S	T	W	J	E	T	F	W	A	N	V	T	F	K	I	O	F	E
D	A	A	A	L	V	O	A	D	O	P	Z	S	K	C	W	E	U	K	A	R	Y	O	T	E	S	Y	L
U	T	X	L	L	I	G	C	B	Q	A	Y	A	G	O	L	G	I	A	P	P	A	R	A	T	U	S	L
E	E	Y	L	A	F	J	I	D	A	R	I	K	I	A	U	W	B	R	L	Y	P	K	I	L	L	Y	E
K	R	J	C	H	M	G	U	I	W	R	M	V	C	V	Y	R	A	N	M	V	V	Y	J	W	E	Q	Q
Y	Y	C	B	P	R	T	P	R	I	M	A	R	Y	S	T	R	U	C	T	U	R	E	E	O	A	R	G
O	P	T	I	C	A	L	M	I	C	R	O	S	C	O	P	E	Y	K	Y	O	L	R	F	M	Q	Z	P
S	L	J	S	Y	Z	Z	D	I	R	P	Z	K	H	S	T	A	R	C	H	U	Q	Y	Q	K	T	P	X
D	E	D	L	R	I	B	O	S	O	M	E	S	F	R	I	R	I	J	R	P	B	C	A	F	W	E	R
J	Q	C	S	H	D	O	L	B	P	R	O	K	A	R	Y	O	T	E	L	B	X	T	C	C	D	J	P
X	Q	N	U	C	L	E	U	S	D	Y	A	C	T	I	V	E	S	I	T	E	D	C	X	P	B	S	T
H	U	H	D	S	Z	E	N	D	O	P	L	A	S	M	I	C	R	E	T	I	C	U	L	U	M	R	P
N	U	C	L	E	O	L	U	S	Y	P	H	O	S	P	H	O	L	I	P	I	D	S	W	S	T	F	S

Known as the universal solvent.

A storage polymer in plants made up of long chains of alpha-glucose.

A chemical that binds to parts of the cell and allows those parts to be seen more easily under a microscope.

Small structures comprising RNA and protein that are found in all cells. They function in translation of the genetic code (genes into proteins).

The degree to which two objects can be distinguished as separate by an instrument such as a microscope.

Describing cells that lack a membrane-bound nucleus or organelles.

The sequence of amino acids in a protein is called this (2 words).

The watery contents of the cell within the plasma membrane, but excluding the contents of the nucleus.

These are biological catalysts.

Lipid bilayered membrane surrounding the cell. It regulates the passage of molecules into and out of the cell (2 words).

These lipid molecules naturally form bilayers.

A structural and functional part of the cell usually bound within its own membrane. Examples include the mitochondria and lysosomes.

A type of microscope in which lenses use light to magnify objects (2 words).

Membrane bound area within a eukaryotic cell where the chromosomes are found.

An organelle found within the nucleus that contains ribosomal RNA and is associated with the part of the chromosome that codes for rRNA.

Organelles responsible for producing the cell's energy. Oval in shape with an outer double membrane and a convoluted interior membrane.

Membrane-bound vacuolar organelles that contain enzymes that form part of the intracellular digestive system.

Organelle resembling a series of flattened sacs. It modifies and packages proteins and also performs a secretory function by budding vesicles (2 words).

Filamentous appendages in bacteria used for locomotion.

Describing cells with a membrane-bound nucleus and organelles.

An organelle comprising a convoluted membranous stack and divided into rough and smooth regions. It plays a part in protein synthesis and membrane synthesis (2 words).

The region of an enzyme responsible for substrate binding and reaction catalysis (2 words).

A structure in plants, fungi, and bacteria, which is found outside the plasma membrane and gives rigidity to the cell (2 words).

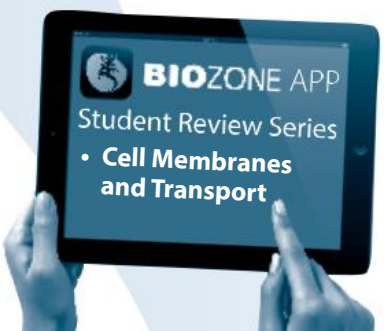
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VCE Unit 1 (1)
WA ATAR Unit 2
SA Theme C, O

Cellular Processes

Key terms

active transport
carrier protein
cellular differentiation
channel protein
cholesterol
concentration gradient
cytokinesis
diffusion
endocytosis
exocytosis
facilitated diffusion
fluid mosaic model
glycolipid
glycoprotein
hypertonic
hypotonic
interphase
ion pump
isotonic
meiosis
metaphase
mitosis
multicellular
osmosis
partially permeable
passive transport
phagocytosis
phospholipid
pinocytosis
plasma membrane
plasmolysis
prophase
surface area: volume ratio
telophase
turgor

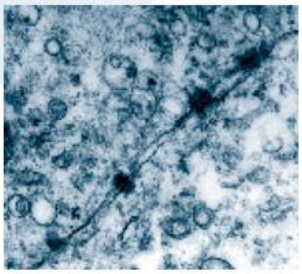
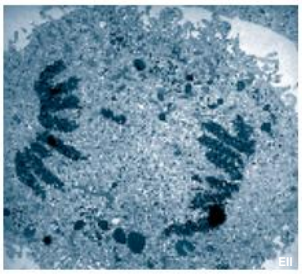
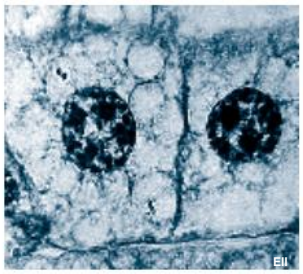


Cellular membranes

Learning aims and skills

Activity number

- ☐ 1 Describe the various roles of membranes in cells, including the role of the plasma membrane as a partially permeable barrier to the movement of substances into and out of the cell. — 46
- ☐ 2 Describe the fluid mosaic model of membrane structure. Include reference to the significance of phospholipid orientation and the role of transmembrane proteins in the integral structure of the membrane. — 47
- ☐ 3 Describe the roles of the phospholipids, cholesterol, glycolipids, proteins, and glycoproteins in the plasma membrane. Include reference to membrane stability, fluidity, cellular communication, and cellular transport. Describe and explain the effects of temperature changes on membrane structure and permeability. — 47

Cellular transport processes

Learning aims and skills

Activity number

- ☐ 4 Describe diffusion, facilitated diffusion, and osmosis, identifying them as passive transport processes. Explain factors affecting diffusion rates across membranes: membrane thickness, surface area, and concentration gradient. — 48 49
- ☐ 5 With respect to solutions of differing solute concentration, explain hypotonic, isotonic, and hypertonic. Estimate osmolarity in cells using solutions of known solute concentration. — 50
- ☐ 6 Explain turgor and plasmolysis in plant cells. Understand the role of the cell wall in turgor pressure and the role of turgor pressure in plant support. — 51
- ☐ 7 Explain why cell size is limited by the rate of diffusion. Explain the significance of surface area to volume ratio to cells and relate this to organism size. — 52
- ☐ 8 Distinguish between passive transport and active transport, identifying the involvement of membrane proteins and energy in active transport processes. — 53
- ☐ 9 Using examples, describe and explain active transport processes in cells, including ion pumps, endocytosis, and exocytosis. — 54 55

Cellular division and differentiation

Learning aims and skills

Activity number

- ☐ 10 Distinguish between mitosis and meiosis in terms of their cellular outcomes and role in the life cycle of organisms. — 56
- ☐ 11 Describe the cell cycle, identifying the events occurring in interphase, mitosis, and cytokinesis. Describe the main stages in mitosis: prophase, metaphase, anaphase, and telophase. Explain where mitosis occurs in plants and in animals. — 57 61
- ☐ 12 Describe the role of cell differentiation in the development of tissues and organs in multicellular organisms. — 58-61
- ☐ 13 Describe levels of organisation in multicellular organisms. Explain how specialised tissues and organs increase the efficiency of function and describe examples in plants and animals. — 62 63 64

46 The Role of Membranes in Cells

Key Idea: Membranes create compartments, control entry and exit of substances from the cell and organelles, and enable cell communication.

Many cell organelles are composed of membranes. Membranes within eukaryotic cells share the same basic structure as the plasma membrane that encloses the entire cell. Membranes have many functions (below) and create compartments within the cell where reactions can be localised.

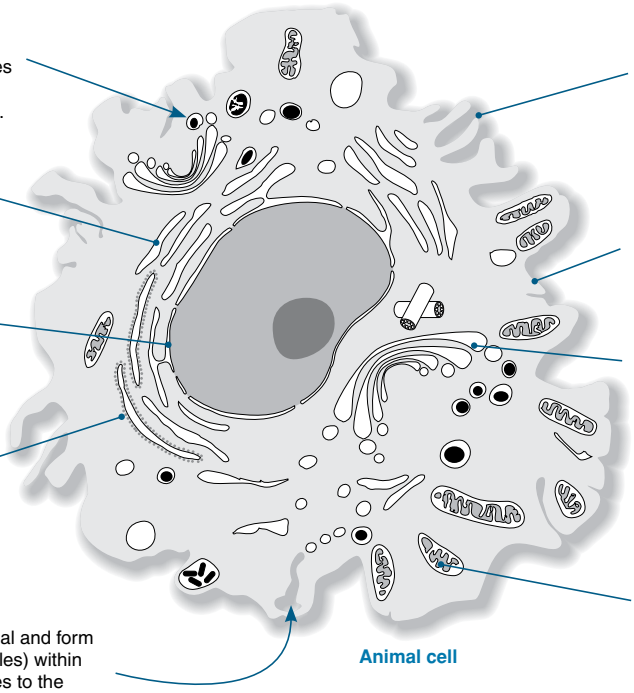
Isolating enzymes
Membrane-bound lysosomes contain enzymes to destroy wastes and foreign material.

Lipid synthesis
Lipids and steroids are ed in the smooth endoplasmic reticulum.

Containing DNA
The nucleus is surrounded by a nuclear envelope of two membranes, forming a separate compartment for the cell's genetic material. The nuclear envelope is continuous with the ER.

Protein synthesis
Some protein synthesis occurs on free ribosomes, but much occurs on membrane-bound ribosomes on the rough endoplasmic reticulum. The protein is synthesised directly into the space within the ER membranes.

Entry and export of substances
The plasma membrane may take up material and form membrane-bound vesicles (or larger vacuoles) within the cell. Transport vesicles move substances to the inner surface of the cell where they can be exported from the cell by exocytosis.



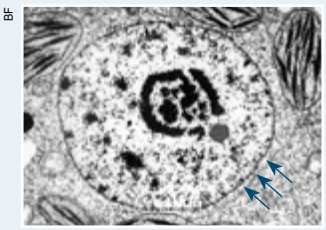
Animal cell

Cell communication and recognition
Proteins in the membrane act as receptors for signal molecules like hormones. Glycoproteins and glycolipids act as cell identity markers, helping cells to organise themselves into tissues.

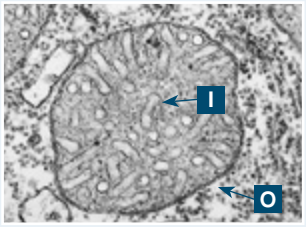
Transport
Channel and carrier proteins are involved in selective transport across the plasma membrane.

Packaging and secretion
The Golgi apparatus is a specialised membrane-bound organelle, producing lysosomes and modifying, packaging, and secreting substances such as proteins and hormones.

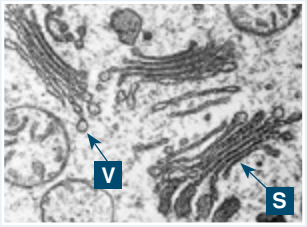
Energy transfer
The reactions of cellular respiration take place in the membrane-bound mitochondria. In plant cells, the reactions of photosynthesis are located in specialised membranous organelles called chloroplasts.



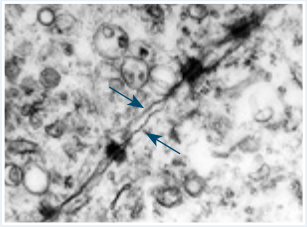
The **nuclear membrane** that surrounds the nucleus helps to control the passage of genetic information to the cytoplasm. It may also serve to protect the DNA.



Mitochondria have an outer membrane (**O**) which controls the entry and exit of materials involved in aerobic respiration. Inner membranes (**I**) provide attachment sites for enzyme activity



The **Golgi apparatus** comprises stacks of membrane-bound sacs (**S**). It is involved in packaging materials for transport or export from the cell as secretory vesicles (**V**).



The cell is surrounded by a **plasma membrane** which controls the movement of most substances into and out of the cell. This photo shows the plasma membranes of two neighbouring cells (arrows).

1. Explain the crucial role of membrane systems and organelles in the following:

   (a) Providing compartments within the cell: _____

   _____

   _____

   (b) Increasing the total membrane surface area within the cell: _____

   _____

   _____

2. (a) Name a membrane-bound cellular organelle: _____

   (b) What is the function of the organelle? _____

   (c) What is the membrane's role in this organelle? _____

   _____

   _____

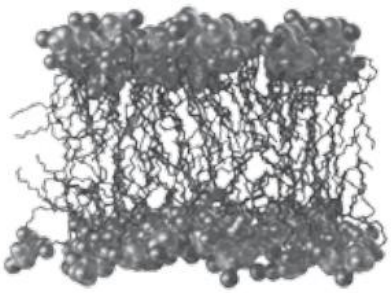
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47 The Structure of Membranes

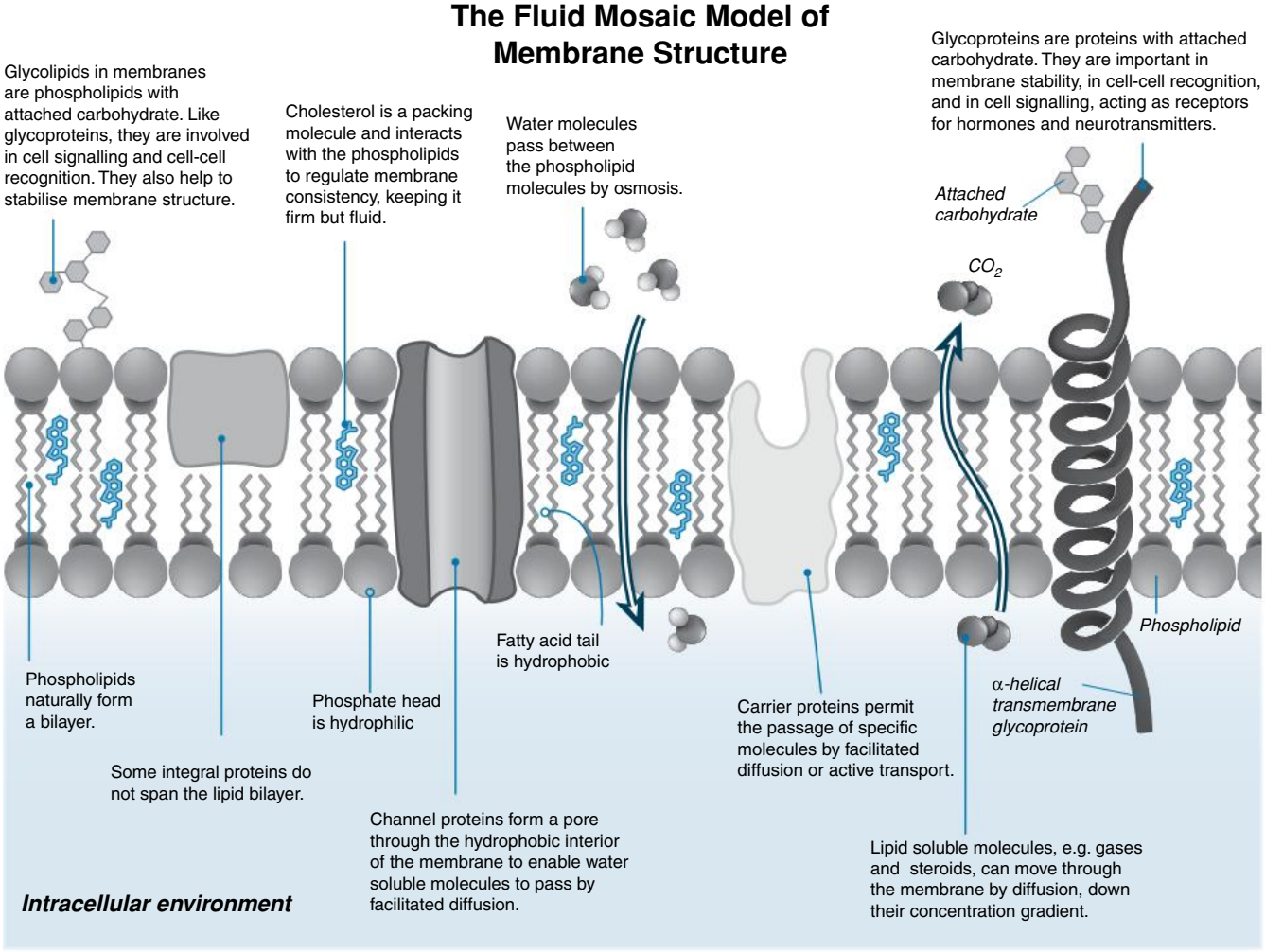
Key Idea: The plasma membrane is composed of a lipid bilayer with proteins moving freely within it.

All cells have a plasma membrane that forms the outer limit of the cell. A cell wall, if present, lies outside this, and it is quite distinct from it. Membranes are also found inside eukaryotic cells as part of membranous **organelles**. The original model of membrane structure, proposed by Davson and Danielli, was the unit membrane (a lipid bilayer coated with protein). This model was later modified after the discovery that the protein molecules were embedded *within* the bilayer rather than coating the outside. The now-accepted **fluid-mosaic model** of membrane structure (below) satisfies the observed properties of membranes. The self-orientating properties of the phospholipids allows cellular membranes to reseal themselves when disrupted. The double layer of lipids is also quite fluid, and proteins move quite freely within it.



Molecular model showing how phospholipid molecules naturally orientate to form a bilayer.

The Fluid Mosaic Model of Membrane Structure



Based on a diagram in Biol. Sci. Review, Nov. 2009, pp. 20-21

1. Identify the component(s) of the plasma membrane involved in:

   (a) Facilitated diffusion: _____ (c) Cell signalling: _____

   (b) Active transport: _____ (d) Regulating membrane fluidity: _____

2. How do the properties of phospholipids contribute to their role in forming the structural framework of membranes?

   _____

   _____

3. (a) Describe the modern fluid mosaic model of membrane structure: _____

   _____

   _____

   _____

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(b) Explain how the fluid mosaic model accounts for the observed properties of cellular membranes:

4. Explain the importance of each of the following to cellular function:

   (a) Carrier proteins in the plasma membrane:

   (b) Channel proteins in the plasma membrane:

5. Non-polar (lipid-soluble) molecules diffuse more rapidly through membranes than polar (lipid-insoluble) molecules:

   (a) Explain the reason for this:

   (b) Discuss the implications of this to the transport of substances into the cell through the plasma membrane:

6. Describe the purpose of cholesterol in plasma membranes:

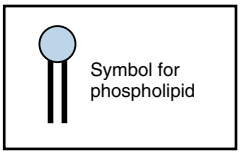
7. List three substances that need to be transported **into** all kinds of animal cells, in order for them to survive:

   (a) (b) (c)

8. List two substances that need to be transported **out** of all kinds of animal cells, in order for them to survive:

   (a) (b)

9. Use the symbol for a phospholipid molecule (below) to draw a **simple labelled diagram** to show the structure of a plasma membrane (include features such as lipid bilayer and various kinds of proteins):



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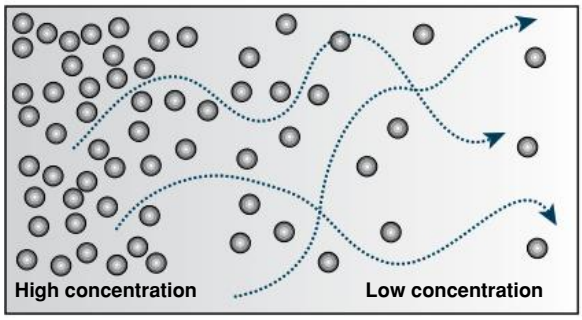
48 Diffusion

Key Idea: Diffusion is the movement of molecules from higher concentration to a lower concentration (i.e. down a concentration gradient).

The molecules that make up substances are constantly moving about in a random way. This random motion causes molecules to disperse from areas of high to low concentration. This dispersal is called **diffusion** and it requires no energy. Each type of molecule moves down its own concentration gradient. Diffusion is important in allowing exchanges with the environment and in the regulation of cell water content.

What is Diffusion?

Diffusion is the movement of particles from regions of high concentration to regions of low concentration. Diffusion is a **passive process**, meaning it needs no input of energy to occur. During diffusion, molecules move randomly about, becoming evenly dispersed.



Concentration gradient

If molecules are free to move, they move from high to low concentration until they are evenly dispersed.

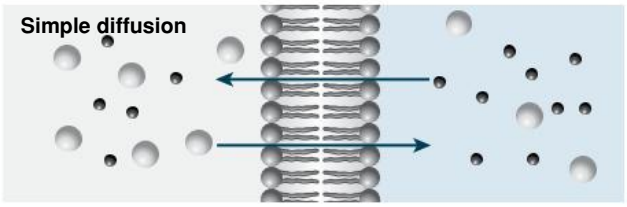
Factors Affecting the Rate of Diffusion

Concentration gradient	The rate of diffusion is higher when there is a greater difference between the concentrations of two regions.
The distance moved	Diffusion over shorter distance occurs at a greater rate than over a larger distance.
The surface area involved	The larger the area across which diffusion occurs, the greater the rate of diffusion.
Barriers to diffusion	Thick barriers have a slower rate of diffusion than thin barriers.
Temperature	Particles at a high temperature diffuse at a greater rate than at a low temperature.

Types of Diffusion

Simple Diffusion

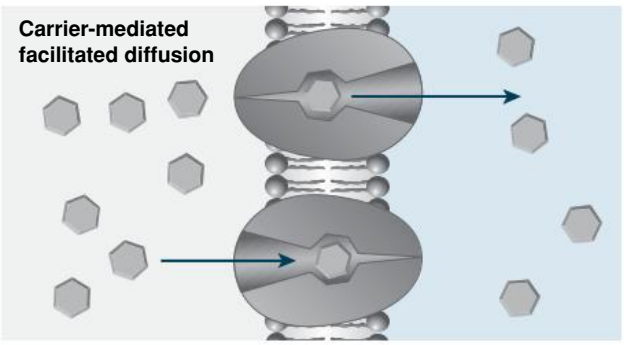
Molecules move directly through the membrane without assistance.
Example: O_2 diffuses into the blood and CO_2 diffuses out.



Facilitated Diffusion

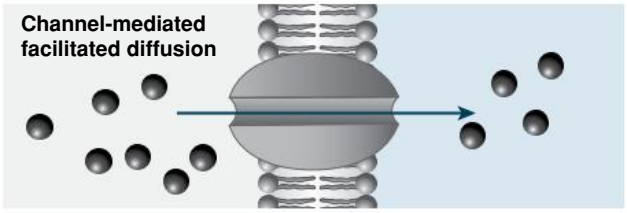
Carrier-Mediated Facilitated Diffusion

Carrier proteins allow large lipid-insoluble molecules that cannot cross the membrane by simple diffusion to be transported into the cell. Example: the transport of glucose into red blood cells.



Channel-Mediated Facilitated Diffusion

Channels (hydrophilic pores) in the membrane allow inorganic ions to pass through the membrane. Example: K^+ ions exiting nerve cells to restore resting potential.



1. What is diffusion? _____

2. What do the three types of diffusion described above all have in common?

3. What would happen in each of the following situations described? In each situation, a 1 cm^3 volume of salt is placed into 50 mL of tap water at 20ºC.

   (a) The water is heated to 40ºC: _____

   (b) The water has two teaspoons of salt dissolved in it before the volume of salt is added: _____

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49 Osmosis

Key Idea: Osmosis is the diffusion of water molecules from a lower solute concentration to a higher solute concentration across a partially permeable membrane.

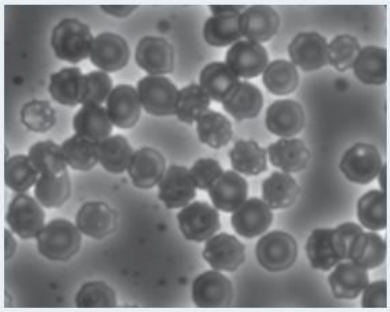
Osmosis is the diffusion of water molecules from regions of lower solute concentration (higher free water concentration) to regions of higher solute concentration (lower free water concentration) across a partially permeable membrane. A partially permeable membrane allows some molecules, but not others, to pass through. Water molecules will diffuse across a partially permeable membrane until an equilibrium is reached and net movement is zero. The plasma membrane of a cell is an example of a partially permeable membrane. Osmosis is a passive process and does not require any energy input.

Osmotic Potential

The presence of solutes (dissolved substances) in a solution increases the tendency of water to move into that solution. This tendency is called the osmotic potential or osmotic pressure. The greater a solution's concentration (i.e. the more total dissolved solutes it contains) the greater the osmotic potential.

Osmosis is important when handling body tissues for medical transport or preparation. The tissue must be bathed a solution with and osmolarity equal to the tissue's to avoid a loss of gain of fluid in the tissue.

The red blood cells below were placed into a solution with lower osmolarity than the internal environment of the cells (a **hypertonic** solution). As a result the cells have lost water and begun to shrink, losing their usual discoid shape.



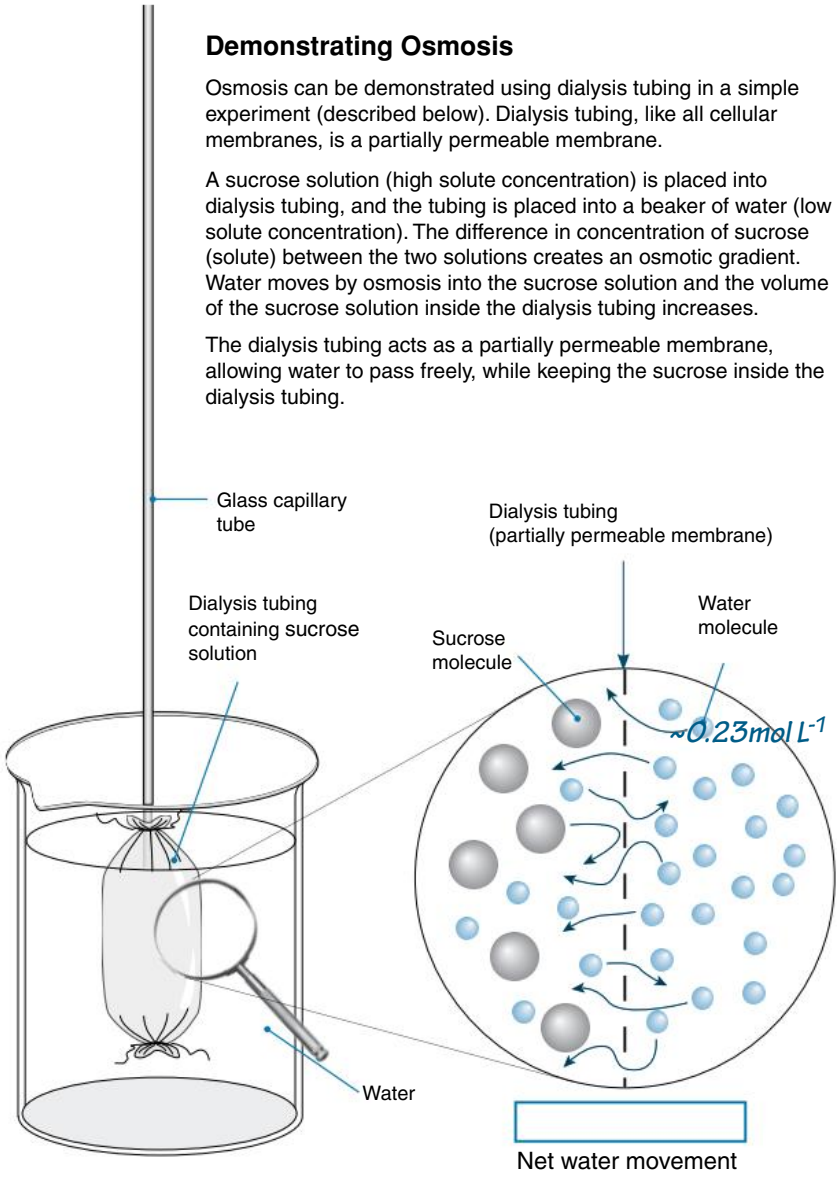
Zephyris

Demonstrating Osmosis

Osmosis can be demonstrated using dialysis tubing in a simple experiment (described below). Dialysis tubing, like all cellular membranes, is a partially permeable membrane.

A sucrose solution (high solute concentration) is placed into dialysis tubing, and the tubing is placed into a beaker of water (low solute concentration). The difference in concentration of sucrose (solute) between the two solutions creates an osmotic gradient. Water moves by osmosis into the sucrose solution and the volume of the sucrose solution inside the dialysis tubing increases.

The dialysis tubing acts as a partially permeable membrane, allowing water to pass freely, while keeping the sucrose inside the dialysis tubing.



1. What is osmosis? _____

_____

_____

2. (a) In the blue box on the diagram above, draw an arrow to show the direction of net water movement.

   (b) Why did water move in this direction? _____

_____

_____

3. What would happen to the height of the water in the capillary tube if the sucrose concentration was increased?

_____

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50 Estimating Osmolarity

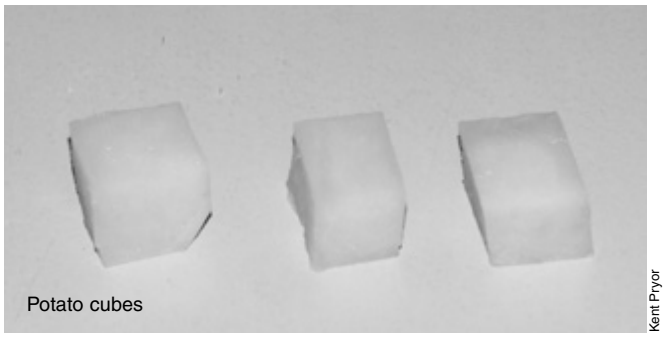
Key Idea: A cell placed in a hypotonic solution will gain water while a cell placed in a hypertonic solution will lose water.
The osmolarity (a measure of solute concentration) of a cell or tissue can be estimated by placing part of the cell or tissue into a series of solutions of known concentration and observing if the tissue loses (hypertonic solution) or gains (hypertonic solution) water. The solution in which the tissue remains unchanged indicates the osmolarity of the tissue.

The Aim

To investigate the osmolarity of potatoes by placing cubes of potato in varying solutions of sucrose, $C_{12}H_{22}O_{11}$ (table sugar).

The Method

Fifteen identical 1.5 cm^3 cubes of potato where cut and weighed in grams to two decimal places. Five solutions of sucrose were prepared in the following range (in mol L^{-1}): 0.00, 0.25, 0.50, 0.75, 1.00. Three potato cubes were placed in each solution for two hours, stirring every 15 minutes. The cubes were then retrieved, patted dry on blotting paper and weighed again.



Potato cubes

Kent Pryor

The Results

Sucrose concentration (mol L-1)	Potato sample	Initial mass (I) (g)	Final mass (F) (g)
0.00	1	5.11	6.00
	2	5.15	6.07
	3	5.20	5.15
Total			
Change (C) (F-I) (g)			
% Change (C/I x 100)			
0.25	1	6.01	4.98
	2	6.07	5.95
	3	7.10	7.00
Total			
Change (C) (F-I) (g)			
% Change (C/I x 100)			
0.50	1	6.12	5.10
	2	7.03	6.01
	3	5.11	5.03
Total			
Change (C) (F-I) (g)			
% Change (C/I x 100)			
0.75	1	5.03	3.96
	2	7.10	4.90
	3	7.03	5.13
Total			
Change (C) (F-I) (g)			
% Change (C/I x 100)			
1.00	1	5.00	4.03
	2	5.04	3.95
	3	6.10	5.02
Total			
Change (C) (F-I) (g)			
% Change (C/I x 100)			

1. Complete the table (left) by calculating the total mass of the potato cubes, the total change in mass, and the total % change in mass for all the sucrose concentrations:

2. Use the grid below to draw a line graph of the sucrose concentration vs total % change in mass:

3. Use the graph to estimate the osmolarity of the potato (the point where there is no change in mass):

_____

4. Identify which of the solutions are hypotonic and which are hypertonic.

_____

_____

_____

_____

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LINK 52 LINK 49 DATA

51 Water Relations in Plants

Key Idea: Plant cells in a hypertonic solution lose water and undergo plasmolysis. In a hypotonic solution, they gain water creating turgor pressure.

Osmosis across the partially permeable cell membrane is the main way by which water enters and leaves the cell. When the external concentration of free water molecules is the same as that of the cytoplasm there is no net movement of water. Changing the tonicity of the external environment will cause a net movement of water into or out of the cell as water moves down its concentration gradient.

Osmosis and tonicity

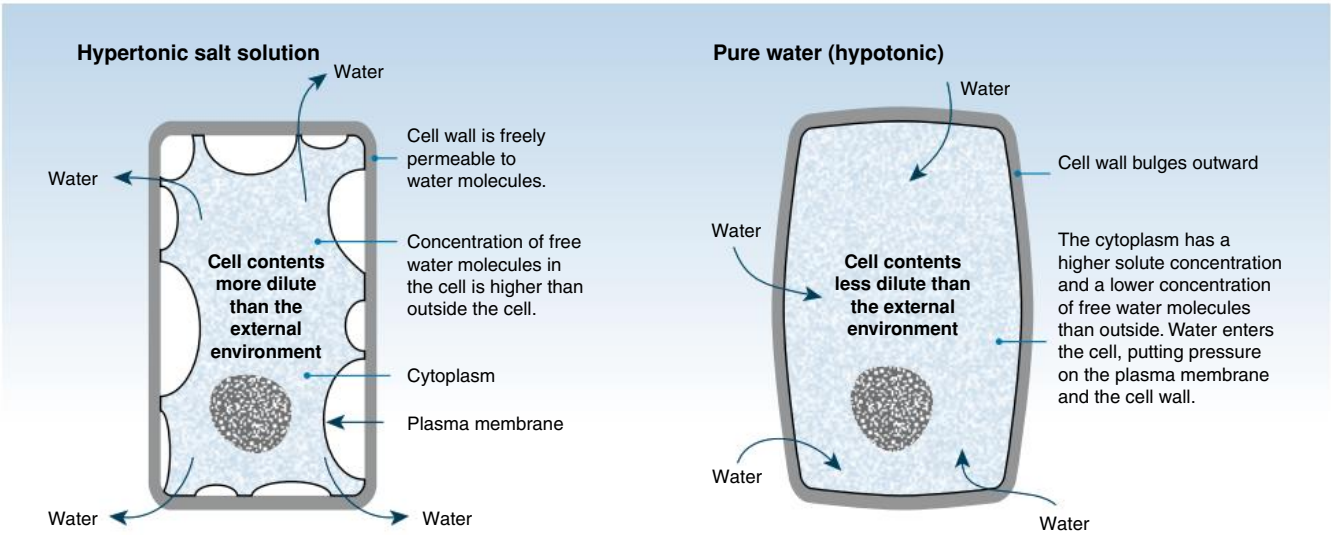
When the watery contents of a plant cell push against the cell wall they create turgor (tightness) which helps to provide support for the plant body. When cells lose water, there is a loss of cell turgor and the plant will wilt. Complete loss of turgor from a cell is called plasmolysis and is irreversible. Two systems (cell and environment) with the same effective osmotic pressure are termed isotonic and there is no net movement of water molecules. However, when there is an osmotic gradient between the cell and environment there will be a net movement of water molecules down their concentration gradient. The diagram below shows two different situations: when a plant cell is in a hypertonic solution and when it is in a hypotonic solution.



Wilted plant (cells have lost turgor)



Plant cells are turgid



Plasmolysis in a plant cell

Tonicity is a measure of the osmotic pressure of a solution. In a hypertonic solution, the external free water concentration is lower than the free water concentration of the cell. Water leaves the cell and, because the cell wall is rigid, the cell membrane shrinks away from the cell wall. This is called **plasmolysis** and the cell becomes flaccid.

Turgor in a plant cell

In a hypotonic solution, the external free water concentration is higher than the cell cytoplasm. Water enters the cell, causing it to swell tight. A wall (turgor) pressure is generated when the cell contents press against the cell wall. Turgor pressure increases until no more water enters the cell (the cell is **turgid**).

1. Identify the outcome of the following situations:

   (a) A plant cell is placed in a hypertonic solution: _____

   (b) A plant cell is placed in a hypotonic solution: _____

   (c) A plant cell in an isotonic solution: _____

2. (a) Explain the role of cell wall pressure in generating cell turgor in plants: _____

   _____

   _____

   (b) Discuss the role of cell turgor in plants: _____

   _____

   _____

   _____

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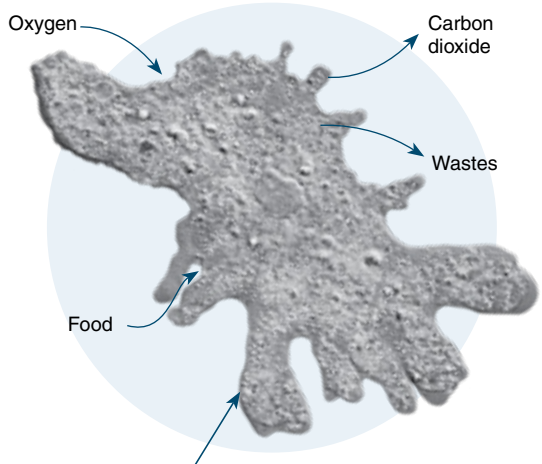
52 Limitations to Cell Size

Key Idea: Diffusion is less efficient in cells with a small surface area relative to their volume than in cells with a large surface area relative to their volume.

When an object (e.g. a cell) is small it has a large surface area in comparison to its volume. Diffusion is an effective way to transport materials (e.g. gases) into the cell. As an object becomes larger, its surface area compared to its volume is smaller. Diffusion is no longer an effective way to transport materials to the inside. This places a physical limit on the size a cell can grow, with the effectiveness of diffusion being the controlling factor. Larger organisms overcome this constraint by becoming multicellular.

Single-Celled Organisms

Single-celled organisms (e.g. *Amoeba*), are small and have a large surface area relative to the cell's volume. The cell's requirements can be met by the diffusion or active transport of materials into and out of the cell (below).

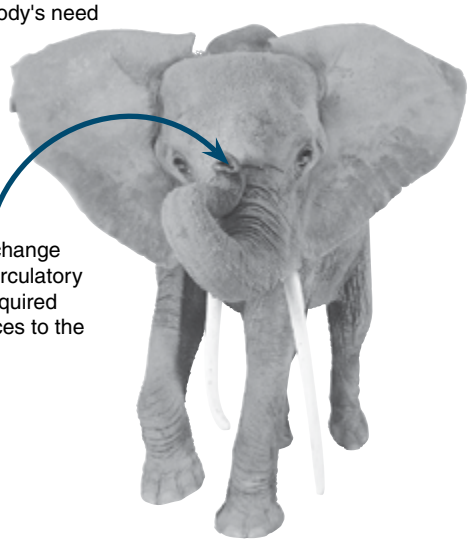


The **plasma membrane**, which surrounds every cell, regulates movements of substances into and out of the cell. For each square micrometre of membrane, only so much of a particular substance can cross per second.

Multicellular Organisms

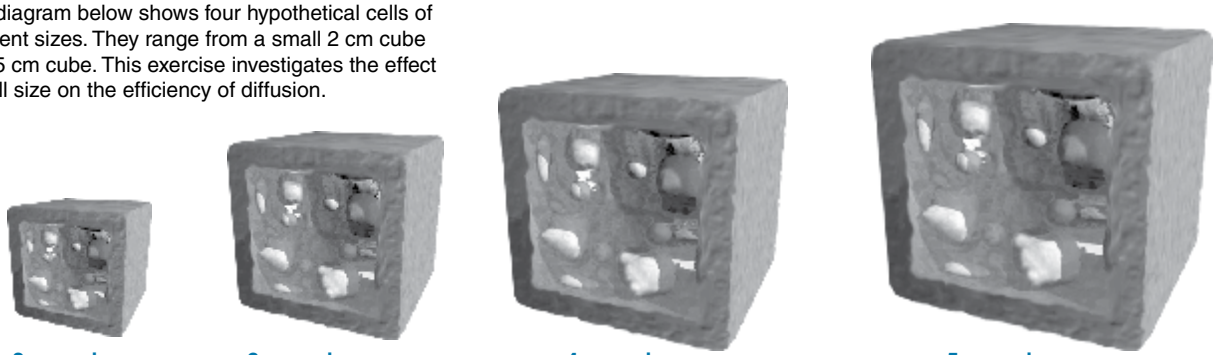
Multicellular organisms (e.g. plants and animals) are often quite large and large organisms have a small surface area compared to their volume. They require specialized systems to transport the materials they need to and from the cells and tissues in their body.

In a multicellular organism, such as an elephant, the body's need for respiratory gases cannot be met by diffusion through the skin.



A specialised gas exchange surface (lungs) and circulatory (blood) system are required to transport substances to the body's cells.

The diagram below shows four hypothetical cells of different sizes. They range from a small 2 cm cube to a 5 cm cube. This exercise investigates the effect of cell size on the efficiency of diffusion.



2 cm cube **3 cm cube** **4 cm cube** **5 cm cube**

1. Calculate the volume, surface area and the ratio of surface area to volume for each of the four cubes above (the first has been done for you). When completing the table below, show your calculations.

Cube size	Surface area	Volume	Surface area to volume ratio
2 cm cube	$2 \times 2 \times 6 = 24\ cm^2$ (2 cm x 2 cm x 6 sides)	$2 \times 2 \times 2 = 8\ cm^3$ (height x width x depth)	24 to 8 = 3:1
3 cm cube			
4 cm cube			
5 cm cube			

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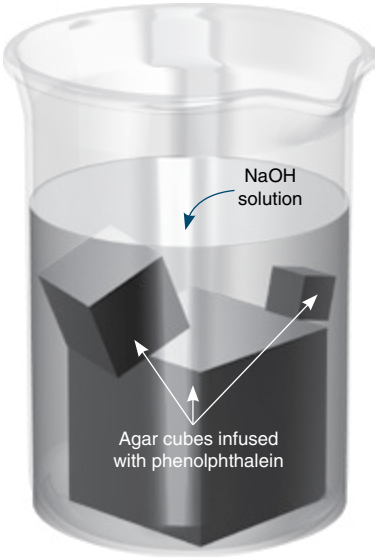
2. Create a graph, plotting the surface area against the volume of each cube, on the grid on the right. Draw a line connecting the points and label axes and units.

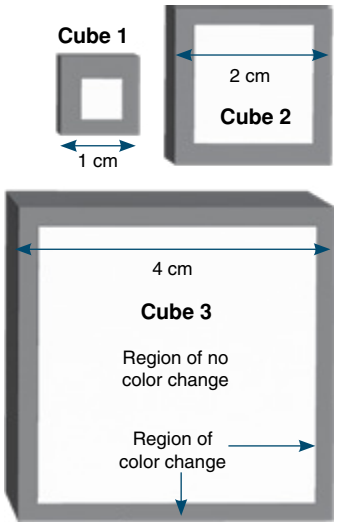
3. Which increases the fastest with increasing size: the **volume** or the **surface area**?

4. Explain what happens to the ratio of surface area to volume with increasing size.

5. The diffusion of molecules into a cell can be modelled by using agar cubes infused with phenolphthalein indicator and soaked in sodium hydroxide (NaOH). Phenolphthalein turns a pink colour when in the presence of a base. As the NaOH diffuses into the agar, the phenolphthalein changes to pink and thus indicates how far the NaOH has diffused into the agar. By cutting an agar block into cubes of various sizes, it is possible to show the effect of cell size on diffusion.

   (a) Use the information below to fill in the table on the right:





Cubes shown to same scale

Cube	1	2	3
1. Total volume (cm^3)			
2. Volume not pink (cm^3)			
3. Diffused volume (cm^3) (subtract value 2 from value 1)			
4. Percentage diffusion			

   (b) Diffusion of substances into and out of a cell occurs across the plasma membrane. For a cuboid cell, explain how increasing cell size affects the effective ability of diffusion to provide the materials required by the cell:

6. Explain why a single large cell of 2 cm x 2 cm x 2 cm is less efficient in terms of passively acquiring nutrients than eight cells of 1 cm x 1 cm x 1 cm:

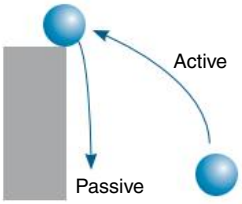
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53 Active Transport

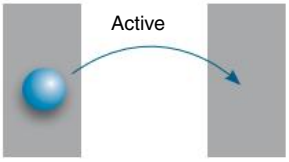
Key Idea: Active transport uses energy to transport molecules against their concentration gradient across a partially permeable membrane.

Active transport is the movement of molecules (or ions) from regions of low concentration to regions of high concentration across a cellular membrane by a transport protein. Active transport needs energy to proceed because molecules are being moved against their concentration gradient.

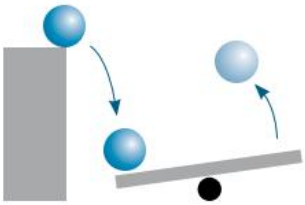
- The energy for active transport comes from **ATP** (adenosine triphosphate). Energy is released when ATP is hydrolysed (water is added) forming ADP (adenosine diphosphate) and inorganic phosphate (Pi).
- Transport (carrier) proteins in the membrane are used to actively transport molecules from one side of the membrane to the other (below).
- Active transport can be used to move molecules into and out of a cell.
- Active transport can be either primary or secondary. Primary active transport directly uses ATP for the energy to transport molecules. In secondary active transport, energy is stored in a concentration gradient. The transport of one molecule is coupled to the movement of another down its concentration gradient, ATP is not directly involved in the transport process.



A ball falling is a passive process (it requires no energy input). Replacing the ball requires active energy input.

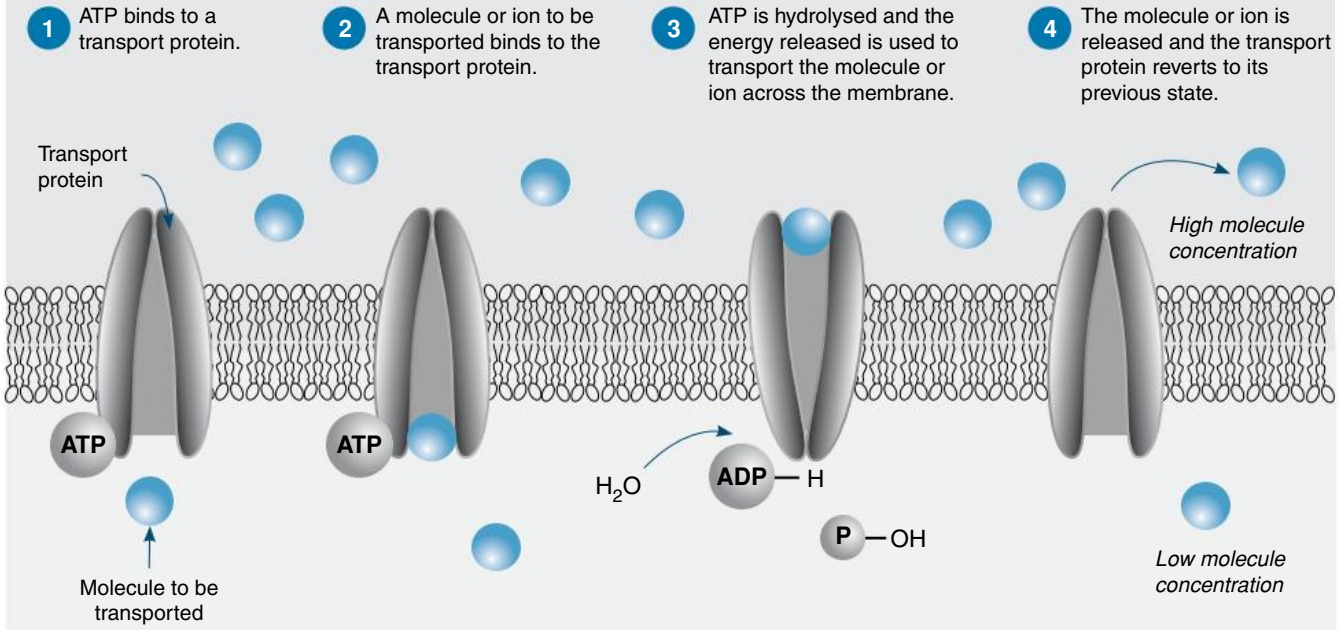


It requires energy to actively move an object across a physical barrier.



Sometimes the energy of a passively moving object can be used to actively move another. For example, a falling ball can be used to catapult another (left).

Active Transport



1. What is **active transport**? _____

_____

_____

_____

2. Where does the energy for active transport come from? _____

3. What is the difference between primary active transport and secondary active transport? _____

_____

_____

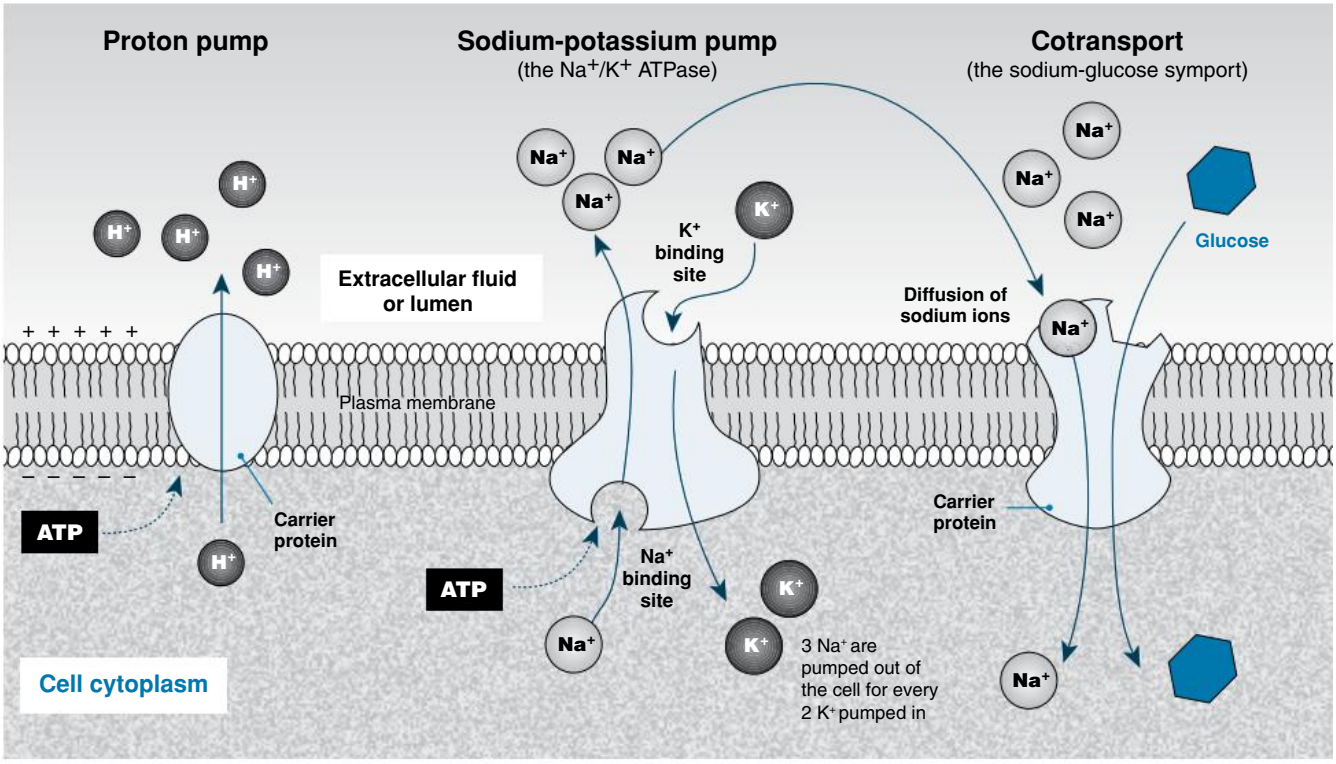
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54 Ion Pumps

Key Idea: Ion pumps are transmembrane proteins that use energy to move ions and molecules across a membrane against their concentration gradient.

Sometimes molecules or ions are needed in concentrations that diffusion alone cannot supply to the cell, or they cannot diffuse through the plasma membrane. In this case ion pumps move ions (and some molecules) across the plasma membrane. The sodium-potassium pump (below, right) is found in almost all animal cells and is common in plant cells also. The concentration gradient created by ion pumps is often coupled to the transport of other molecules such as glucose across the membrane.



Proton Pumps

ATP driven proton pumps use energy to remove hydrogen ions (H^+) from inside the cell to the outside. This creates a large difference in the proton concentration either side of the membrane, with the inside of the plasma membrane being negatively charged. This potential difference can be coupled to the transport of other molecules.

Sodium-potassium Pump

The sodium-potassium pump is a specific protein in the membrane that uses energy in the form of ATP to exchange sodium ions (Na^+) for potassium ions (K^+) across the membrane. The unequal balance of Na^+ and K^+ across the membrane creates large concentration gradients that can be used to drive transport of other substances (e.g. cotransport of glucose).

Cotransport (coupled transport)

A gradient in sodium ions drives the active transport of **glucose** in intestinal epithelial cells. The specific transport protein couples the return of Na^+ down its concentration gradient to the transport of glucose into the intestinal epithelial cell. A low intracellular concentration of Na^+ (and therefore the concentration gradient) is maintained by a sodium-potassium pump.

1. Why is ATP required for membrane pump systems to operate? _____

2. (a) Explain what is meant by cotransport: _____

   (b) How is cotransport used to move glucose into the intestinal epithelial cells? _____

   (c) What happens to the glucose that is transported into the intestinal epithelial cells? _____

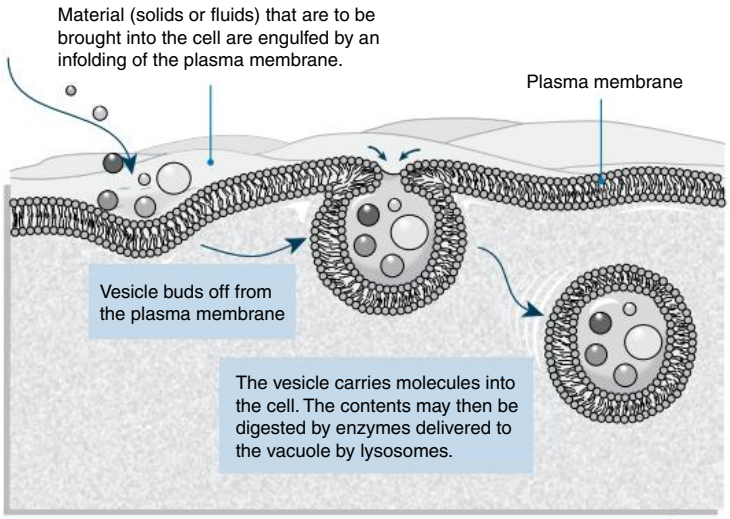
3. Describe two consequences of the extracellular accumulation of sodium ions: _____

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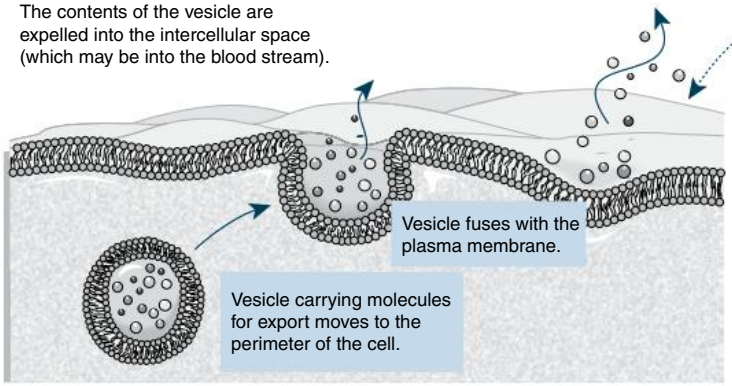
55 Exocytosis and Endocytosis

Key Idea: Endocytosis and exocytosis are active transport processes. Endocytosis involves the cell engulfing material. Exocytosis involves the cell expelling material.

Most cells carry out **cytosis**, a type of active transport in which the plasma membrane folds around a substance to transport it across the plasma membrane. The ability of cells to do this is a function of the flexibility of the plasma membrane. Cytosis results in bulk transport of substances into or out of the cell and is achieved through the localised activity of the cell cytoskeleton. **Endocytosis** involves material being engulfed and taken into the cell. It typically occurs in protozoans and some white blood cells of the mammalian defence system (phagocytes). **Exocytosis** is the reverse of endocytosis and involves expelling material from the cell in vesicles or vacuoles that have fused with the plasma membrane. Exocytosis is common in cells that export material (secretory cells).



Both endocytosis and exocytosis require energy in the form of ATP

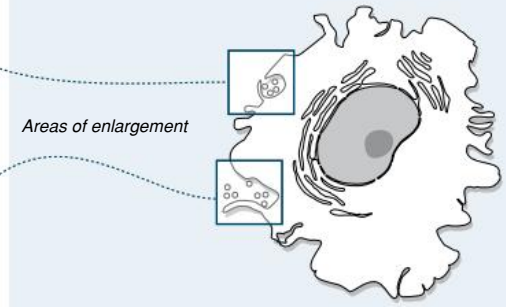


Endocytosis

Endocytosis (left) occurs by invagination (infolding) of the plasma membrane, which then forms vesicles or vacuoles that become detached and enter the cytoplasm. There are two main types of endocytosis:

Phagocytosis: 'cell-eating'
Phagocytosis involves the cell engulfing **solid material** to form large vesicles or vacuoles (e.g. food vacuoles). Examples: Feeding in *Amoeba*, phagocytosis of foreign material and cell debris by neutrophils and macrophages. Some endocytosis is **receptor mediated** and is triggered when receptor proteins on the extracellular surface of the plasma membrane bind to specific substances. Examples include the uptake of lipoproteins by mammalian cells.

Pinocytosis: 'cell-drinking'
Pinocytosis involves the non-specific uptake of **liquids** or fine suspensions into the cell to form small pinocytic vesicles. Pinocytosis is used primarily for absorbing extracellular fluid. Examples: Uptake in many protozoa, some cells of the liver, and some plant cells.



Exocytosis

Exocytosis (left) is the reverse process to endocytosis. In multicellular organisms, various types of cells are specialised to manufacture and export products, such as proteins, from the cell to elsewhere in the body or outside it. Exocytosis occurs by fusion of the vesicle membrane and the plasma membrane, followed by release of the vesicle contents to the outside of the cell.

1. Distinguish between **phagocytosis** and **pinocytosis**: _____

_____

_____

2. Describe an example of phagocytosis and identify the cell type involved: _____

_____

3. Describe an example of exocytosis and identify the cell type involved: _____

_____

4. How does each of the following substances enter a living macrophage:

(a) Oxygen: _____ (c) Water: _____

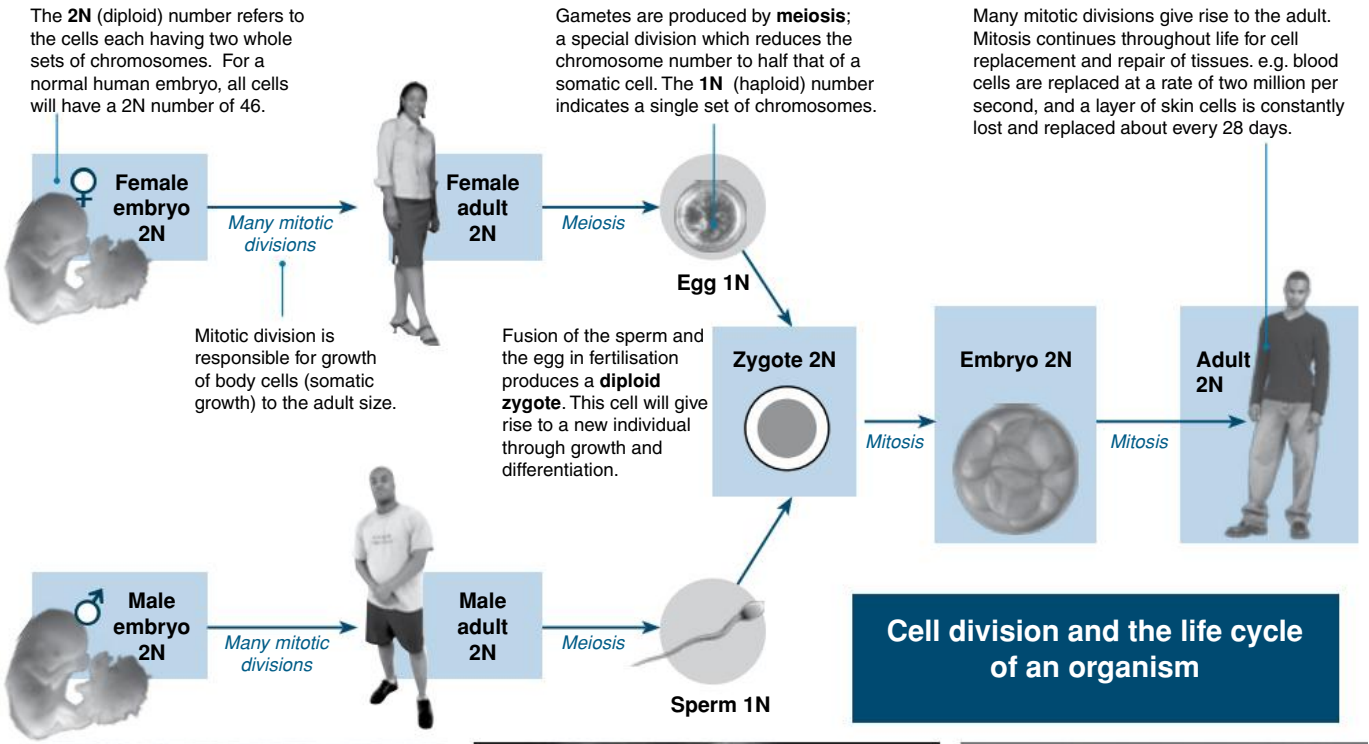
(b) Cellular debris: _____ (d) Glucose: _____

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56 Cell Division

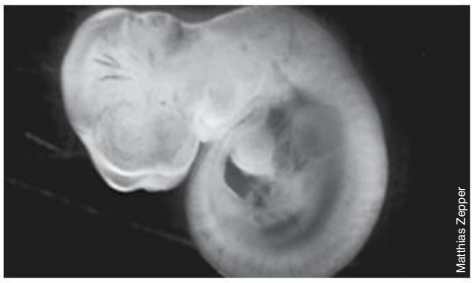
Key Idea: New cells arise from the division of existing cells. There are two types of cell division, mitosis and meiosis.

New cells are formed when existing cells divide. In eukaryotes, cell division begins with the replication of a cell's DNA followed by division of the nucleus. There are two forms of cell division. **Mitosis** produces two identical daughter cells from each parent cell. Mitosis is responsible for growth and repair processes in multicellular organisms, and asexual reproduction in some eukaryotes, e.g. yeasts. **Meiosis** is a special type of cell division concerned with producing sex cells (gametes or haploid spores) for sexual reproduction. It occurs in the sex organs of plants and animals.

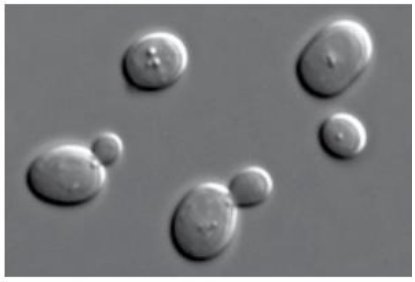




Mitosis for repair: Mitosis is vital in the repair and replacement of damaged cells. When you break a bone, or graze your skin, new cells are generated to repair the damage. Some organisms, such as sea stars, can generate new limbs if they are broken off.



Mitosis for growth: Multicellular organisms develop from a single cell. Organisms, such as this 12 day old mouse embryo, grow by increasing their cell number. Cell growth is highly regulated and once the mouse reaches its adult size, physical growth stops.



Mitosis for reproduction: Sexually reproducing organisms produce haploid gametes by meiosis, but some eukaryotes, such as these yeast cells, can reproduce asexually by budding. The parent cell buds to form a daughter cell, which grows and then separates from the parent cell.

1. (a) Where does mitosis take place in animals? _____

   (b) What is the purpose of mitosis? _____

   _____

   _____

2. (a) Where does meiosis take place in animals? _____

   (b) What is the purpose of meiosis? _____

   _____

3. Why do gametes produced by meiosis have a haploid chromosome number? _____

   _____

   _____

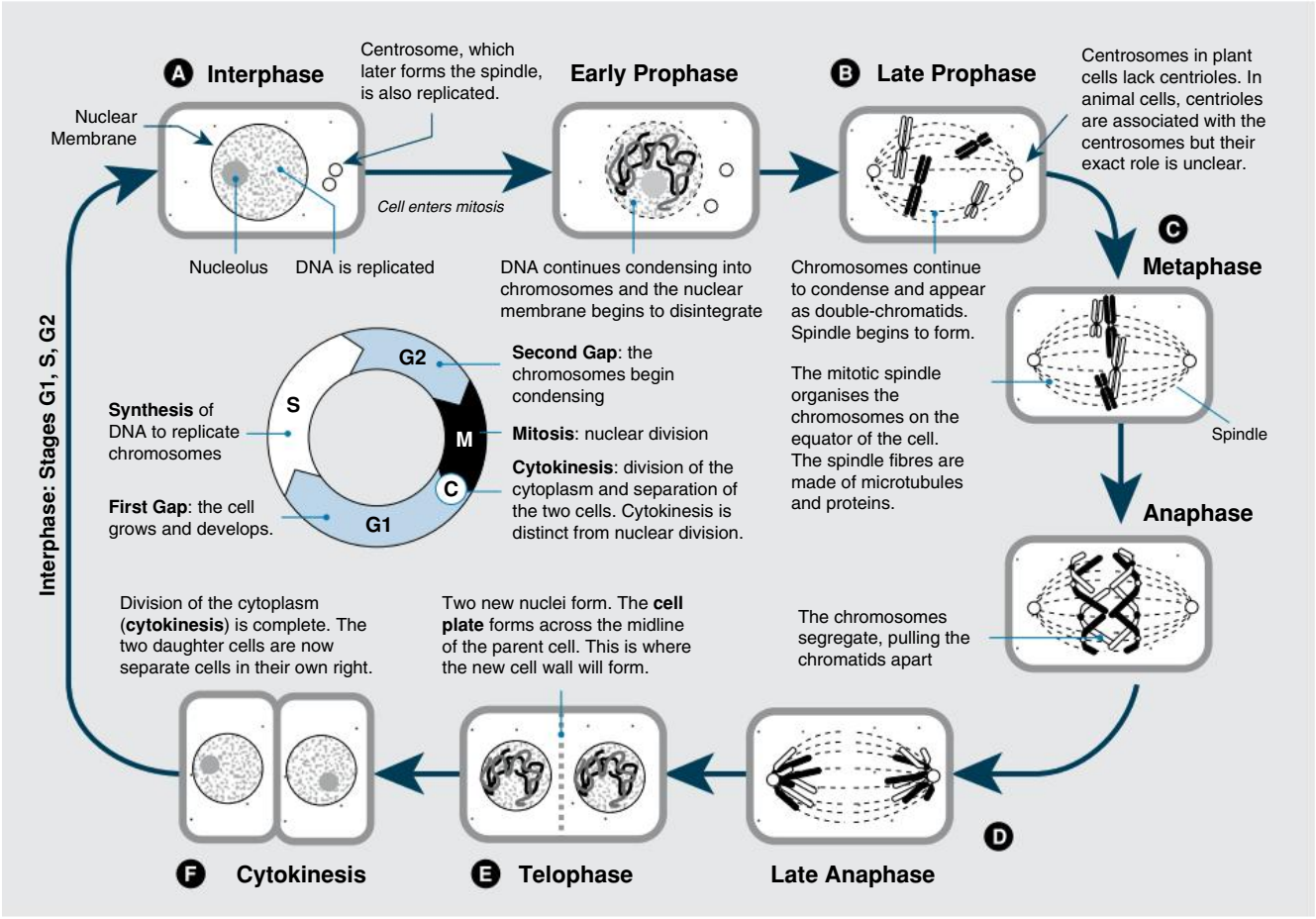
KNOW LINK 57 LINK 159 LINK 163

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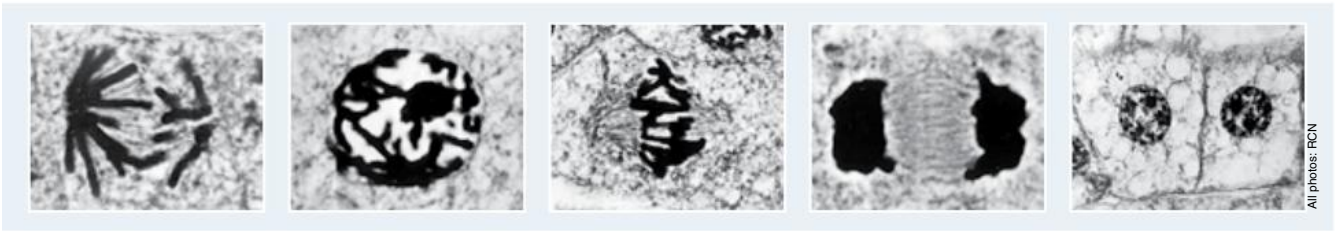
57 Mitosis and the Cell Cycle

Key Idea: Mitosis is the part of the cell cycle in which the replicated chromosomes are separated and the cell divides, producing two new identical cells.

Mitosis is part of the cell cycle in which an existing parent cell divides into two new identical daughter cells. Although mitosis is part of a continuous cell cycle, it is divided into stages (below). The example below illustrates the cell cycle in a plant cell. Note that in animal cells, cytokinesis involves the formation of a constriction that divides the cell in two. It does not involve the formation of a cell plate.



1. The five photographs below were taken at various stages through the process of mitosis in a plant cell. They are not in any particular order. Study the diagram above and determine the stage that each photograph represents (e.g. anaphase).



(a) _____ (b) _____ (c) _____ (d) _____ (e) _____

2. State two important changes that chromosomes must undergo before cell division can take place:

_____

3. Briefly summarise the stages of the cell cycle by describing what is happening at the points (**A-F**) in the diagram above:

A. _____

B. _____

C. _____

D. _____

E. _____

F. _____

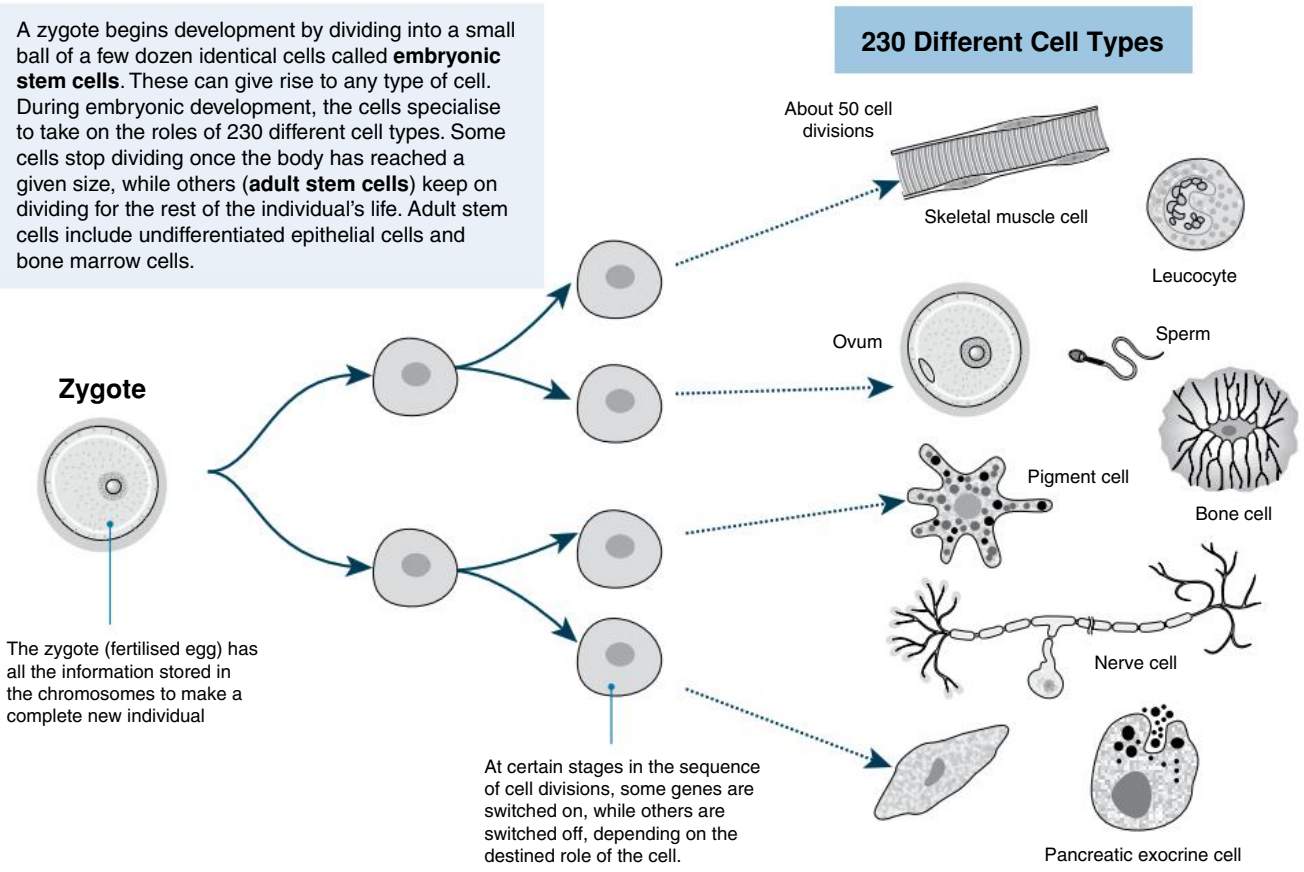
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58 Cellular Differentiation

Key Idea: Many different cell types arise during development of the embryo. Activation of specific genes determines what type of cell will develop.

Mitosis produces genetically identical cells, yet a multicellular organism is made up of many different types of cells, each specialised to carry out a particular role. The variety of cell types arise through **cellular differentiation**, a process by which cells become specialised. Although each cell has the same genetic material (genes) different genes are turned on (activated) or off in different patterns during development in particular types of cells. The differences in gene activation controls what type of cell forms. Once the developmental pathway of a cell is determined, it cannot alter its path and change into another cell type.

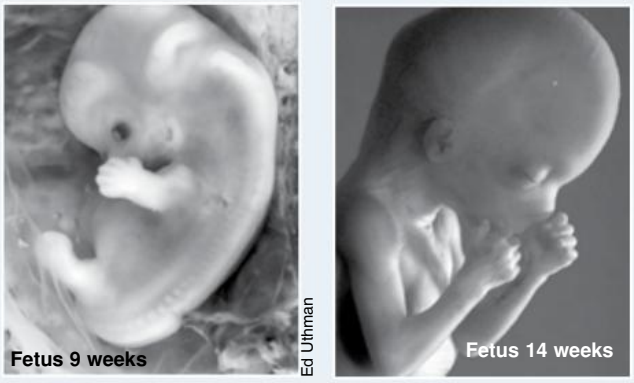
A zygote begins development by dividing into a small ball of a few dozen identical cells called **embryonic stem cells**. These can give rise to any type of cell. During embryonic development, the cells specialise to take on the roles of 230 different cell types. Some cells stop dividing once the body has reached a given size, while others (**adult stem cells**) keep on dividing for the rest of the individual's life. Adult stem cells include undifferentiated epithelial cells and bone marrow cells.



Development

Development is the process of progressive change through the lifetime of an organism. It involves growth (increase in size), cell division (to generate the multicellular body), **cellular differentiation** (to produce specialised cells) and **morphogenesis** (creating the shape and form of the body).

Selective cell proliferation combined with programmed cell death sculpts the tissues in all vertebrates. In a human embryo, mesoderm forms between the fingers and toes giving the appearance of a webbed, paddle like structure (right). As the embryo develops, this webbing is selectively destroyed. At 14 weeks, each of the individual digits are visible (far right).



1. How can so many different types of cell arise from one unspecialised cell (the zygote)? _____

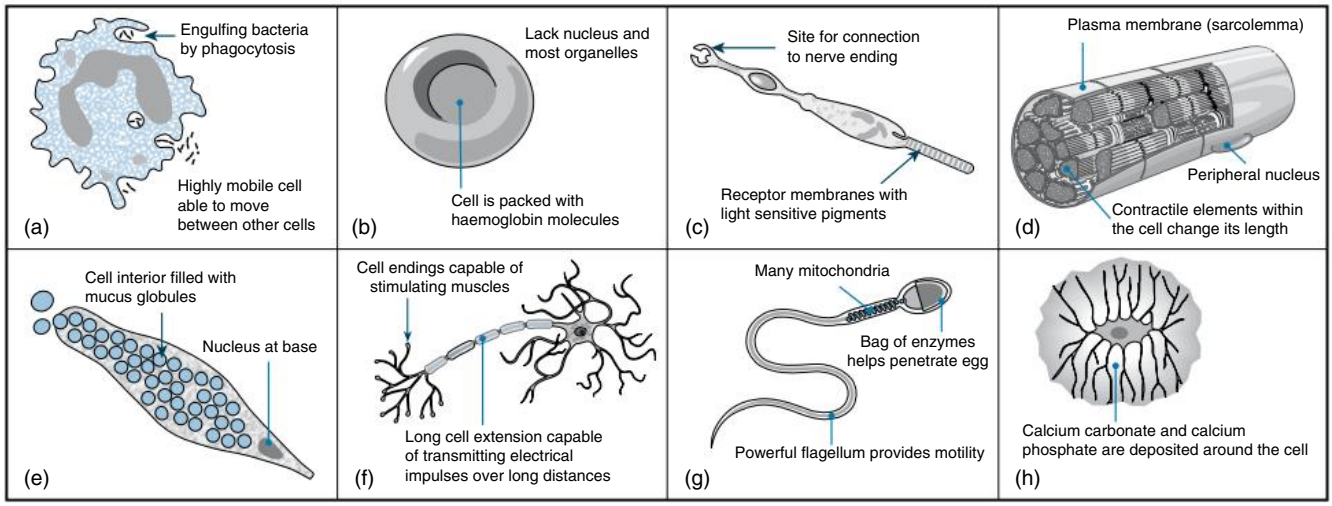
2. Why can't a differentiated cell change into another cell type? _____

KNOW LINK 59 LINK 60 LINK 61 LINK 63 LINK 64

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59 Specialisation in Human Cells

Key Idea: Specialised cells carry out specific roles in animals. Humans have at least 230 specialised cell types, each with features that enable it to perform its designated role. The eight cell types below are a representative sample of these.



1. Identify each of the cells (b) to (h) pictured above, and describe their **specialised features** and **role** in the body:

(a) Type of cell: Phagocytic white blood cell (neutrophil)

Specialised features: Engulfs bacteria and other foreign material by phagocytosis

Role of cell within body: Destroys pathogens and other foreign material as well as cellular debris

(b) Type of cell: _____

Specialised features: _____

Role of cell within body: _____

(c) Type of cell: _____

Specialised features: _____

Role of cell within body: _____

(d) Type of cell: _____

Specialised features: _____

Role of cell within body: _____

(e) Type of cell: _____

Specialised features: _____

Role of cell within body: _____

(f) Type of cell: _____

Specialised features: _____

Role of cell within body: _____

(g) Type of cell: _____

Specialised features: _____

Role of cell within body: _____

(h) Type of cell: _____

Specialised features: _____

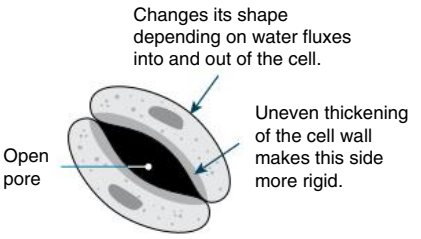
Role of cell within body: _____

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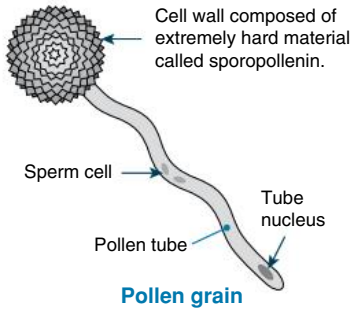
LINK 63 KNOW

60 Specialisation in Plant Cells

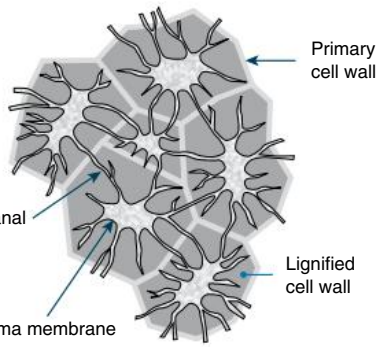
Key Idea: The specialised cells in a plant have specific features associated with their particular roles in the plant.
The differentiation of cells gives rise to specialised cell types that fulfil specific roles in the plant, e.g. support, transport, or photosynthesis. Each of the cell types illustrated below has features that set it apart from other cell types.



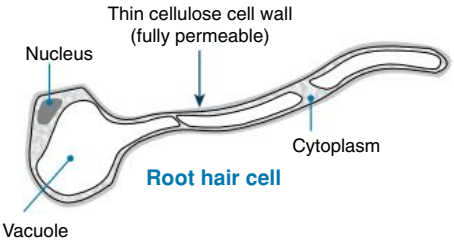
A pair of **guard cells** forming a stoma



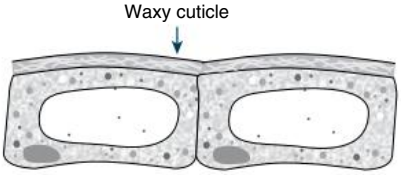
Pollen grain



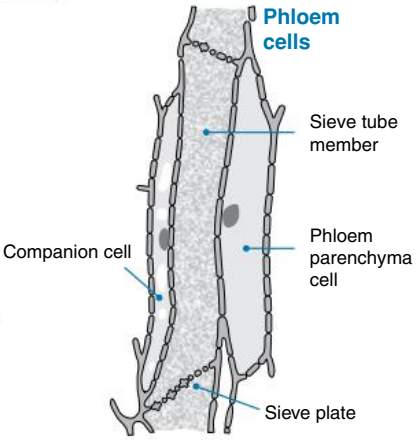
Stone cells (sclereids) covering the seed in stone fruit

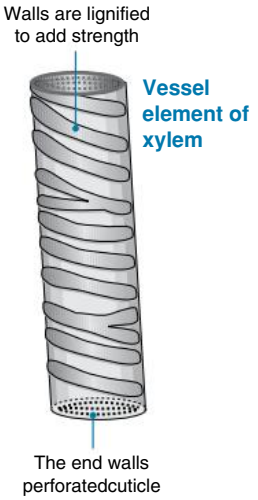


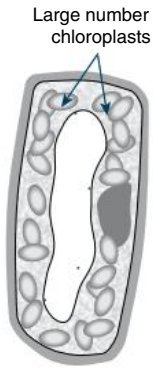
Root hair cell



Epidermal cells







Palisade parenchyma cell of the mesophyll

1. Using the information given above, describe the **specialised features** and **role** of each of the cell types (b)-(h) below:

(a) **Guard cell**: Features: Curved, sausage shaped cell, unevenly thickened.

Role in plant: Turgor changes alter the cell shape to open or close the stoma.

(b) **Pollen grain**: Features: _____

Role in plant: _____

(c) **Palisade parenchyma cell**: Features: _____

Role in plant: _____

(d) **Epidermal cell**: Features: _____

Role in plant: _____

(e) **Vessel element**: Features: _____

Role in plant: _____

(f) **Stone cell**: Features: _____

Role in plant: _____

(g) **Sieve tube member** (of phloem): Features: _____

Role in plant: _____

(h) **Root hair cell**: Features: _____

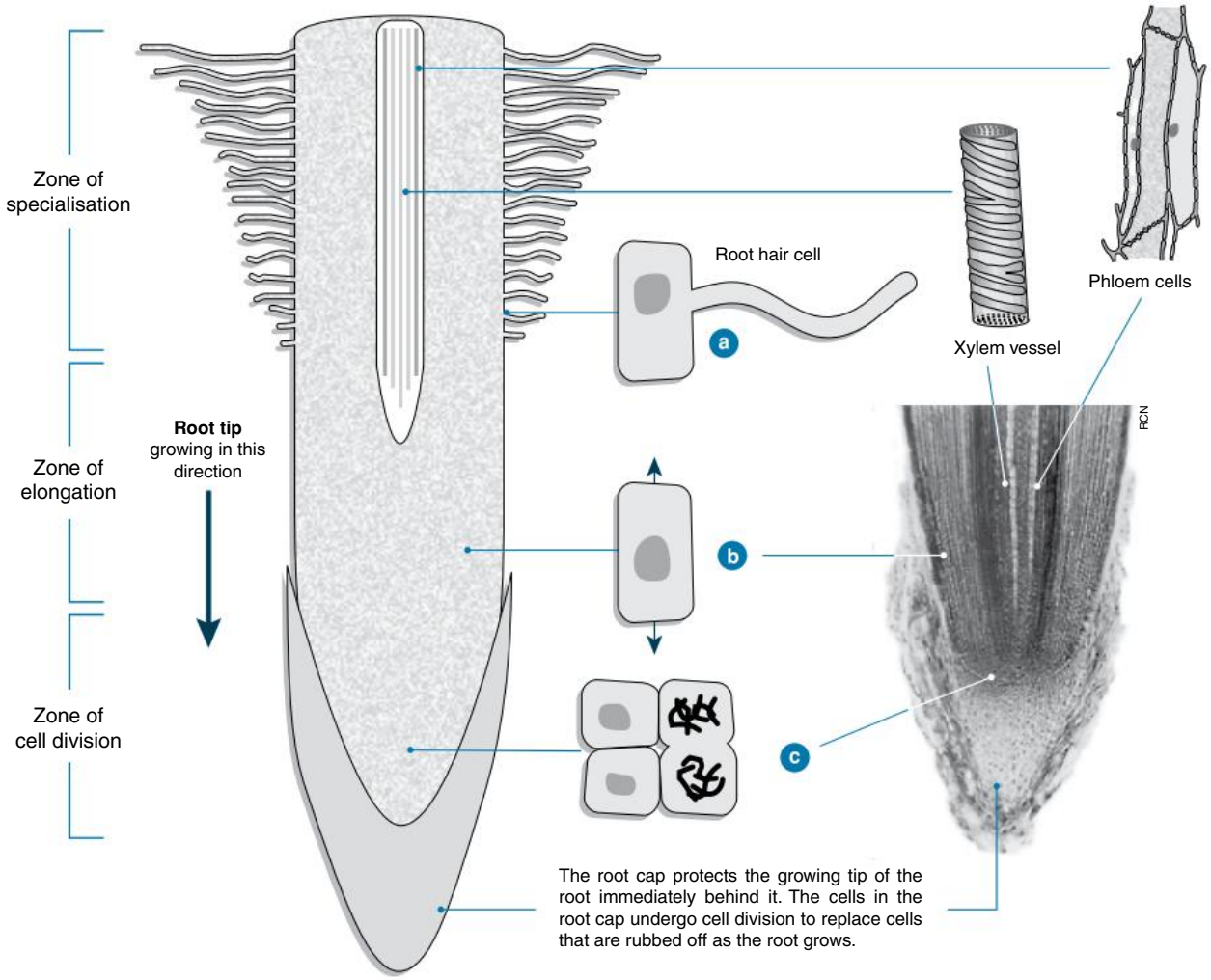
Role in plant: _____

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61 Root Cell Development

Key Idea: In plants, mitosis is restricted to areas called meristems. These occur at the root and shoot tips.

In plants, mitotic division occurs only in zones of meristematic (undifferentiated) tissue. Growth in length (primary growth) occurs in the growing tips (**apical meristems**) of every stem and root. Plants that show lateral growth also have lateral meristems (cambium), where growth in diameter occurs. The diagram below shows the zones of dividing, expanding, and developing cells in a root. Similar zones occur in the growing stem tips, which give rise to all above-ground plant organs.



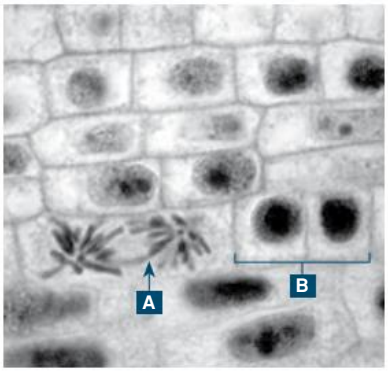
1. What is happening to the plant cells at each of the points labelled (**a**) to (**c**) in the diagram above?

   (a) _____

   (b) _____

   (c) _____

2. The light micrograph (below) shows a section of the cells of an onion root tip, stained to show up the chromosomes.



   (a) State the mitotic stage of the cell labelled **A** and explain your answer:

   _____

   (b) State the mitotic stage just completed in the cells labelled **B** and explain:

   _____

   _____

   (c) If, in this example, 250 cells were examined and 25 were found to be in the process of mitosis, what proportion of the cell cycle is occupied by mitosis:

   _____

3. Identify the cells that divide and specialise when a tree increases its girth (diameter): _____

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LINK 64 LINK 63 KNOW

62 Levels of Organisation

Key Idea: Structural organisation in multicellular organisms is hierarchical, with new properties arising at each level.

Organisation and the emergence of novel properties in complex systems are two of the defining features of living organisms. Organisms are organised according to a hierarchy of structural levels, each level building on the one before it. At each level, new properties arise that were absent at the simpler level. Hierarchical organisation allows specialised cells to group together into tissues and organs to perform a specific function. This improves efficiency in the organism.

All multicellular organisms are organised in a hierarchy of structural levels, where each level builds on the one below it. It is traditional to start with the simplest components (parts) and build from there. Higher levels of organisation are more complex than lower levels.

Hierarchical organisation enables **specialisation** so that individual components perform a specific function or set of related functions. Specialisation enables organisms to function more efficiently.

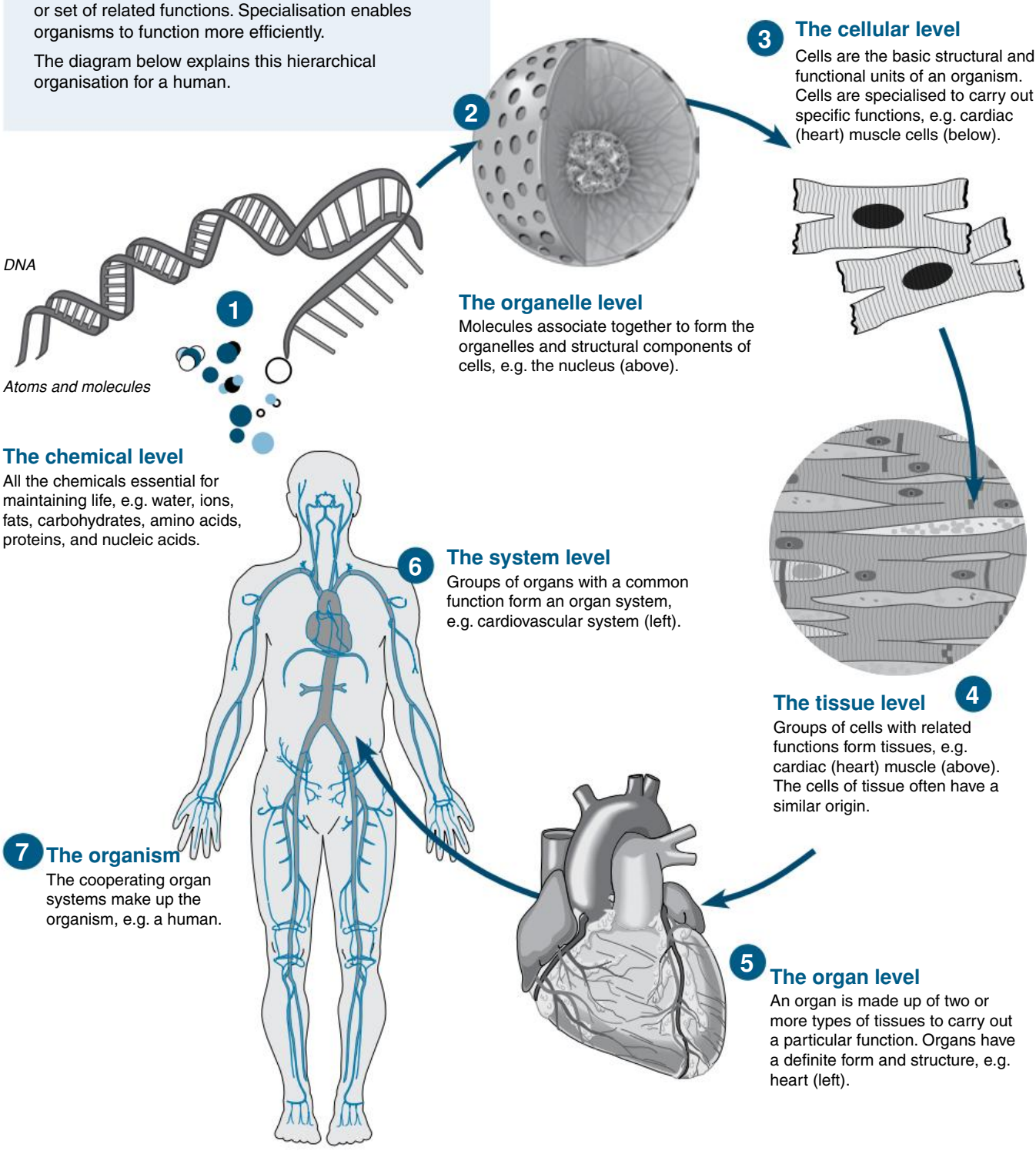
The diagram below explains this hierarchical organisation for a human.

1. Assign each of the following emergent properties to the level at which it first appears:

   (a) Metabolism: _____

   (b) Behaviour: _____

   (c) Replication: _____



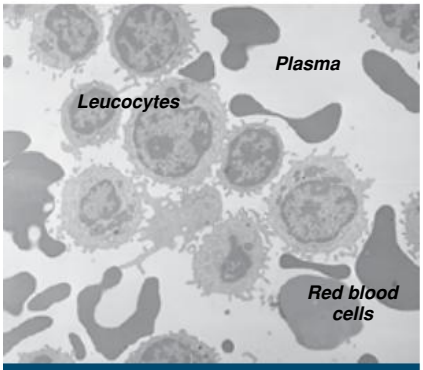
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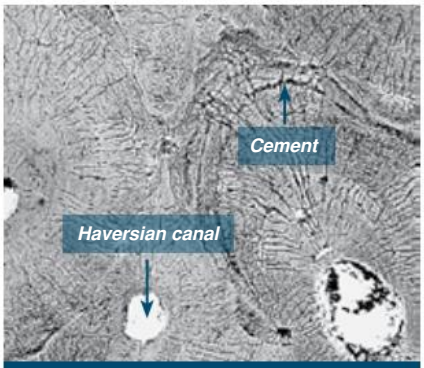
63 Animal Tissues

Key Idea: A tissue is a collection of related cell types that work together to carry out a specific function. Four main tissue types make up the animal body.

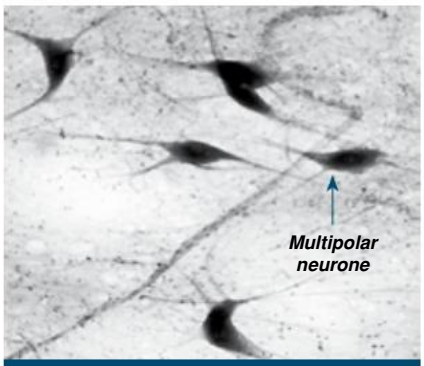
Tissues are formed from related cell types that carry out a specific function. They improve functional efficiency because tasks can be shared amongst specialised cells. Animal tissues fall into four broad groups: epithelial, connective, muscle, and nervous tissues. Different tissues come together to form organs. For example, the heart consists of cardiac muscle tissue, but also has epithelial tissue, which lines the heart chambers, connective tissue for strength and elasticity, and nervous tissue, which directs muscle contraction.



Blood



Dense bone tissue



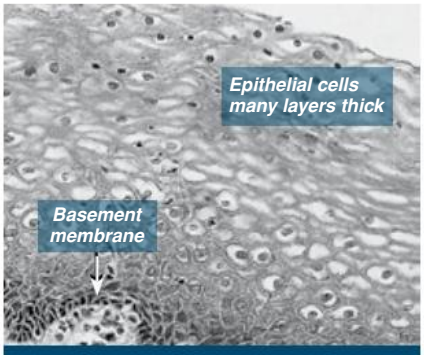
Nervous tissue

Connective tissues form the major supporting tissue of the body made up of cells within a semi-fluid matrix. Connective tissues bind structures together and provide support and protection. They include dentine (teeth), adipose (fat) tissue, bone (above) and cartilage, and the tissues around the organs and blood vessels.
Blood is a specialised liquid tissue, made up of cells floating in a liquid matrix.

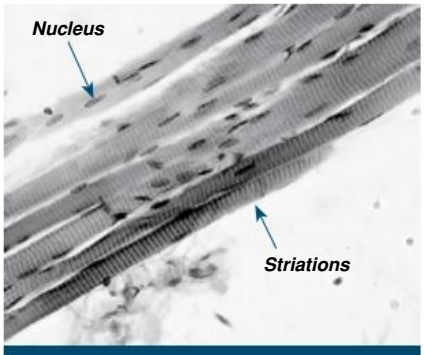
Nervous tissue contains densely packed nerve cells (neurones) which transmit information in the form of nerve impulses. There may also be supporting connective tissue and blood vessels.



Simple columnar epithelium: gall bladder



Compound stratified epithelium: vagina



Skeletal (striated) muscle fibres

Epithelial tissue is organised into single or layered sheets. It lines internal and external surfaces (e.g. blood vessels, ducts, gut lining) and protects the structures underneath from wear, infection, or pressure. The cells may be specialised for absorption, secretion, or excretion. Examples: stratified (compound) epithelium of vagina, ciliated epithelium of respiratory tract, cuboidal epithelium of kidney ducts, and the columnar epithelium of the intestine.

Muscle tissue consists of specialised cells called fibres, held together by connective tissue. The three muscle types are cardiac, skeletal, and smooth muscle. Muscles bring about movement of body parts by contracting.

1. Explain how the development of tissues improves functional efficiency: _____

_____

_____

2. Describe the general function of each of the following broad tissue types:

(a) Epithelial tissue: _____ (c) Muscle tissue: _____

(b) Nervous tissue: _____ (d) Connective tissue: _____

3. Identify the particular features that contribute to the particular functional role of each of the following tissue types:

(a) Muscle tissue: _____

_____

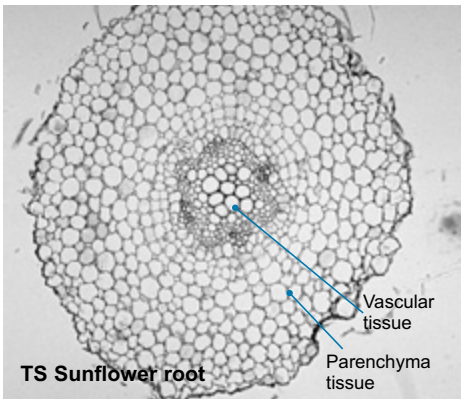
(b) Nervous tissue: _____

_____

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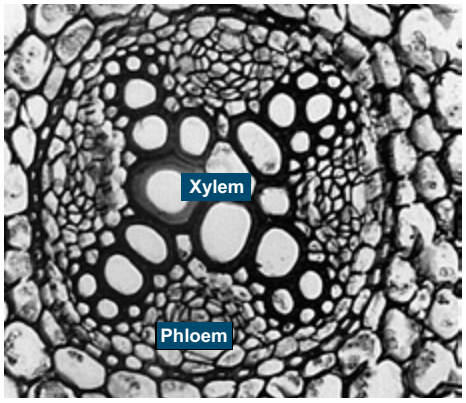
64 Plant Tissues

Key Idea: Plant tissues are either simple or complex tissues. Plant tissues are divided into simple and complex tissues. **Simple tissues** contain only one cell type and form packing and support tissues. **Complex tissues** contain more than one cell type and form the conducting and support tissues of plants. Tissues are grouped into tissue systems which make up the plant body. Vascular plants have dermal, vascular, and ground tissue systems. The dermal system covers the plant providing protection and reducing water loss. Vascular tissue provides the water and nutrient transport system of the plant. The ground tissue system carries out a variety of roles within the plant (e.g. photosynthesis, storage, and support).



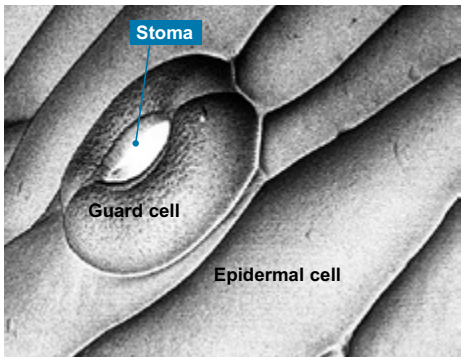
EII

Simple tissues consists of only one or two cell types. **Parenchyma tissue** is the most common and involved in storage, photosynthesis, and secretion. **Collenchyma tissue** comprises thick-walled collenchyma cells alternating with layers of intracellular substances to provide flexible support. The fibres and sclereids of **sclerenchyma** tissue have rigid cell walls which provide support.



RCN

Complex tissues comprise more than two cell types. Xylem and phloem, which make up the plant **vascular tissue** system, are complex tissues. Each is made up of several cell types: tracheids, vessels, parenchyma, and fibres in xylem, and sieve tube members, companion cells, parenchyma and sclerenchyma in phloem.



EII

Dermal tissue covers the outside of the plant. Its composition varies depending on its location. The leaf epidermis has a waxy cuticle to reduce water loss and guard cells to regulate water loss and gas exchange via pores in the leaf (stomata).

Simple tissue	Cell type(s)	Role within the plant
Parenchyma	Parenchyma cells	Photosynthesis, storage and secretion.
Collenchyma		
Sclerenchyma		
Root endodermis	Endodermal cells	
Pericycle		

Complex tissue	Cell type(s)	Role within the plant
Leaf mesophyll	Spongy mesophyll cells, palisade mesophyll cells	
Xylem		
Phloem		
Epidermis		

1. Identify the three tissue systems of plants:_____

2. The tables above list the major types of simple and complex plant tissues. Complete the tables by filling in the cell types that make up the tissue and the role that each tissue has within the plant. The first example has been completed for you. Use the weblinks sites to help you.

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65 KEY TERMS: Mix and Match

Test your vocabulary by matching each term to its definition, as identified by its preceding letter code.

active transport

channel proteins

cholesterol

concentration gradient

differentiation

diffusion

endocytosis

exocytosis

facilitated diffusion

fluid mosaic model

glycolipids

glycoproteins

hypertonic

hypotonic

interphase

ion pump

isotonic

metaphase

mitosis

osmosis

partially permeable membrane

passive transport

phagocytosis

plasma membrane

plasmolysis

prophase

surface area: volume ratio

turgor

A Passive movement of water molecules across a partially permeable membrane down a concentration gradient.

B The model for membrane structure which proposes a double phospholipid bilayer in which proteins and cholesterol are embedded.

C A type of passive transport, facilitated by transport proteins.

D A stage of mitosis in which condensed chromosomes align in the middle of the cell.

E The process in plant cells where the plasma membrane pulls away from the cell wall as a result of the loss of water through osmosis.

F The energy-requiring movement of substances across a biological membrane against a concentration gradient.

G A common term in animal biology for a solution with a lower total solute concentration relative to another solution (across a membrane).

H Active transport in which molecules are engulfed by the plasma membrane, forming a phagosome or food vacuole within the cell.

I A stage of mitosis in a eukaryotic cell in which the chromatin condenses into chromosomes and becomes visible.

J The force exerted outward on a plant cell wall by the water contained in the cell.

K Lipids with attached carbohydrates which serve as markers for cellular recognition.

L In animal biology, solutions of equal solute concentration are often termed this.

M This relationship determines capacity for effective diffusion in a cell.

N The phase of a cell cycle resulting in nuclear division.

O The passive movement of molecules from high to low concentration.

P Movement of substances across a biological membrane without energy expenditure.

Q A common term in animal biology for a solution with a higher total solute concentration relative to another solution (across a membrane).

R A sterol lipid that forms part of the plasma membrane and helps regulate its fluidity.

S A partially-permeable phospholipid bilayer forming the boundary of all cells.

T A transmembrane protein that moves ions across a plasma membrane against their concentration gradient.

U Active transport process by which cells take in molecules (such as proteins) from outside the cell by engulfing it with their plasma membrane.

V Gradual change in the concentration of solutes as a function of distance through the solution. In biology, this usually results from unequal distribution of ions across a membrane.

W Pore-forming proteins that facilitate the flow of ions across the plasma membrane.

X Membrane-bound proteins with attached carbohydrates, involved in cell to cell interactions.

Y Active transport process by which membrane-bound secretory vesicles fuse with the plasma membrane and release the vesicle contents into the external environment.

Z A membrane that acts selectively to allow some substances, but not others, to pass.

AA The phase of the cell cycle prior to cell division in which all the DNA in the nucleus is copied.

BB The process by which a less specialised cell becomes a more specialised cell type.

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66 Cells in Action Synoptic Question

1. Plant and animal cells are eukaryotic cells and share several common features. They also have features unique to each cell type. Compare and contrast the features of plant and animal cells. You may use extra paper if required:

   In your answer you should:
   - Discuss features common to plant and animal cells
   - Discuss features unique to plant and animal cells
   - Briefly describe and contrast the roles of the plasma membrane and cell wall

2. Explain the roles of osmosis and active transport in cells and give examples of where they may occur in an organism:

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QLD As required
VCE Unit 1 (2)
WA ATAR Unit 2
SA Theme C, O

Plant and Animal Nutrition

Key terms

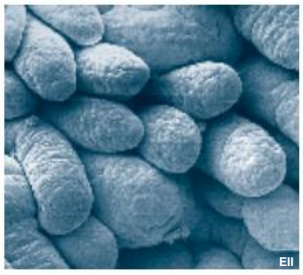
absorption
assimilation
autotrophic
bulk feeding
chlorophyll
chloroplasts
dentition
deposit feeding
digestion
egestion
enzyme
extracellular digestion
feeding
filter feeding
fluid feeding
gastric (adj)
grana
heterotrophic
holozoic
ingestion
intracellular digestion
large intestine
mutualistic nutrition
mycorrhizae
nitrogen fixation
parasite/parasitic
parasitoid
photosynthesis
saprophytic
small intestine
stroma
thylakoids
villi (intestinal)

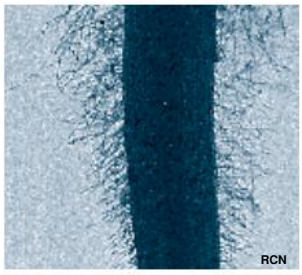
Autotrophic nutrition

Learning aims and skills

		Activity number
☐	1 Distinguish between autotrophic and heterotrophic nutrition.	67
☐	2 Describe the role of ATP as an energy carrier in cells. Show in a diagram the relationship between photosynthesis and cellular respiration.	68
☐	3 Describe the ecological role and importance of plants as producers. Summarise photosynthesis in a simple word equation. Identify the form in which the food is produced and what it is used for. Describe features of the chloroplasts that are related to their role in photosynthesis.	69 70
☐	4 Describe the features of leaves that facilitate photosynthesis and describe adaptations to maximise photosynthetic rates in different environments.	71 72
☐	5 Describe factors in the environment that affect photosynthetic rate, including light and level of carbon dioxide. Explain how humans can use controlled environments to maximise rates of photosynthesis in crop plants.	73 74
☐	6 Describe the mineral requirements of plants. Using examples, describe adaptations in plants for increasing nutrient uptake: mycorrhizae, nitrogen fixation symbioses, and insectivory.	76 77







Diversity in heterotrophic nutrition

Learning aims and skills

		Activity number
☐	7 Describe modes of heterotrophic nutrition: parasitic, saprotrophic, and holozoic.	67 78
☐	8 Recognise different modes of holozoic nutrition including bulk feeding, filter feeding, fluid feeding, and deposit feeding and describe examples of each.	79
☐	9 Compare and contrast intracellular and extracellular digestion.	80
☐	10 Describe the stages in processing food in a tube gut. Explain how food is moved through the gut by peristalsis. Distinguish between absorption and assimilation.	81
☐	11 Describe and explain diversity in mouthparts or dentition in specific taxa, for example fish, birds (beak size and shape), insects, or mammals.	82 83 84
☐	12 Describe and explain structural and functional diversity in animal digestive systems, using examples from representative taxa.	85 86 87
☐	13 Describe adaptations for cellulose digestion in a various taxa.	87 88 89
☐	14 Explain the role of enzymes in the extracellular digestion of ingested food in holozoic animals. Describe the source, substrate, products, and optimum pH for one amylase, protease, and lipase enzyme involved in digestion.	90
☐	15 Describe adaptations to increase the surface area for nutrient absorption in the guts of holozoic animals and explain why this is important.	91 92 93
☐	16 Describe the nutritional and lifestyle adaptations of predatory and parasitic insects, fish, and mammals. Distinguish between parasites and parasitoids.	94 95



67 Modes of Nutrition

Key Idea: Heterotrophs (feeders on others) feed on other things to gain energy and carbon. Autotrophs (self feeders) use light or chemical energy to make their own food.

The nutritional mode of an organism describes how it obtains its energy and carbon. **Autotrophs** make their food from simple inorganic substances using the free energy in sunlight or chemical energy. **Heterotrophs** feed on other organisms to obtain their energy. They depend either directly on other organisms (dead or alive) or their by-products (e.g. faeces, cell walls, or food stores).

1. Distinguish between photoautotrophs, chemoautotrophs, and chemoheterotrophs in terms of their sources of energy and carbon:

   (a) Photoautotroph

   Source of energy: _____

   _____

   Source of carbon: _____

   _____

   (b) Chemoautotrophs

   Source of energy: _____

   _____

   Source of carbon: _____

   _____

   (c) Chemoheterotroph

   Source of energy: _____

   _____

   Source of carbon: _____

   _____

2. Describe the three main nutritional modes of chemoheterotrophs:

   _____

   _____

   _____

   _____

   _____

   _____

   _____

3. What is the main difference between the way in which parasites and saprotrophs obtain their nutrition?

   _____

   _____

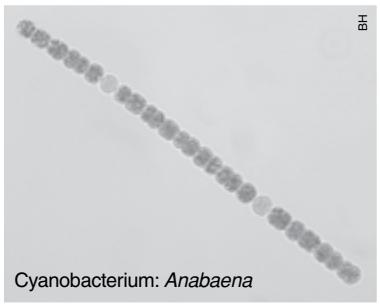
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   _____

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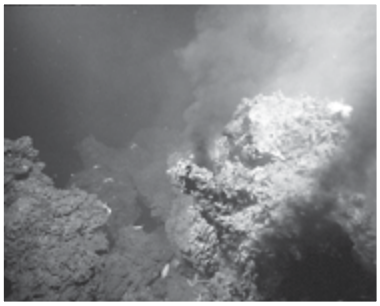
Autotrophic Nutrition (Autotrophs)

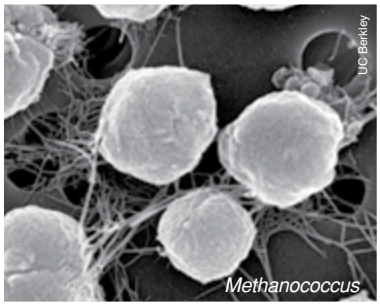

Green plant


BH

Cyanobacterium: *Anabaena*

Photoautotrophs (photosynthetic organisms) use light as their energy source, and carbon dioxide as a source of carbon to make their own food. They include bacteria, cyanobacteria, algae (photosynthetic protists), and green plants.

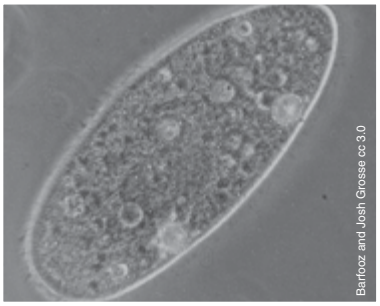



UC Berkley

Methanococcus

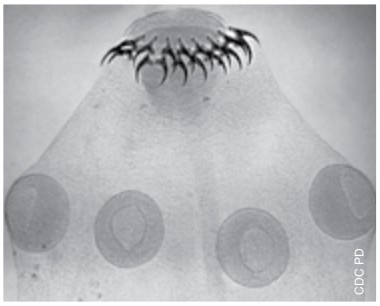
Chemoautotrophs (chemosynthetic organisms) use inorganic compounds (e.g. elemental hydrogen) for energy, and CO_2 as a source of carbon. Most are bacteria or archaea that live in hostile environments, such as geothermal and deep sea vents, e.g. *Methanococcus* (above) uses hydrogen to reduce CO_2 to methane.

Heterotrophic Nutrition (Chemoheterotrophs)


Barfooz and Josh Grosse cc 3.0


Brett Taylor cc 2.0

Heterotrophs need an organic source of carbon and energy (this is usually glucose). Many bacteria and many protists, e.g. *Paramecium* (above left) are heterotrophic. All fungi (above right) are chemoheterotrophs and most are decomposers (**saprotrophs**), obtaining nutrition from the extracellular digestion of dead organic material.


CDC PD


NJR-ZA cc 3.0

All animals are heterotrophs, relying on glucose (from plants, dead material, or other animals) for energy and carbon. **Parasites**, e.g. tapeworms (above left), live on or within their living host organism for part or all of their life. Bacteria, fungi, protists, and animals all have parasitic representatives. The ingestion of solid or liquid organic material from other organisms (**holozoic nutrition**) is the main feeding mode of animals.

KNOW
LINK 39 LINK 70 LINK 78 LINK 79

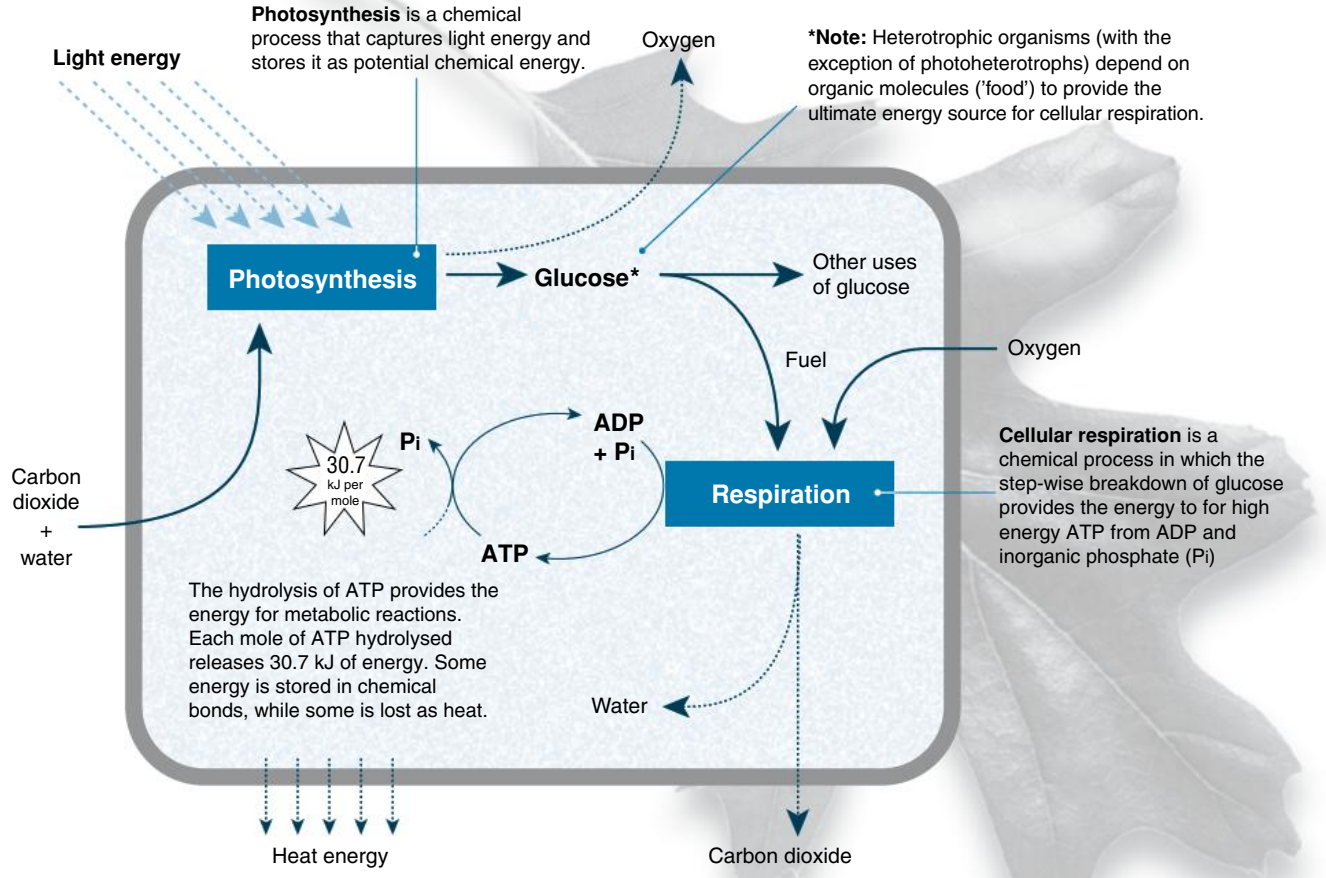
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68 Energy in Cells

Key Idea: The energy from sunlight is captured and stored as glucose, which powers the production of ATP. ATP provides the energy for the chemical reactions in living systems.

Energy flow in the cell of a green plant (an autotroph) is shown below. Note the central role of ATP in the pathways. The energy flow in the cells of animals is similar, except that glucose is supplied by food instead of photosynthesis. Energy is used to make energy-rich molecules or is lost as heat.

Energy Transformations in a Photosynthetic Plant Cell



It takes energy to break bonds, so how does the hydrolysis of ATP provide energy for metabolic reactions?

The hydrolysis of ATP is coupled to the formation of a phosphorylated intermediate, which can be used to do cellular work. The reactions that make the energy in ATP available occur virtually simultaneously, so are usually simplified to omit the intermediates:



1. How does ATP acts as a supplier of energy to power metabolic reactions? _____

2. (a) Identify the **ultimate** source of energy for most autotrophs: _____

   (b) Identify a group of autotrophic organisms that do not use this source of energy: _____

3. Identify the **ultimate** source of energy for most heterotrophs: _____

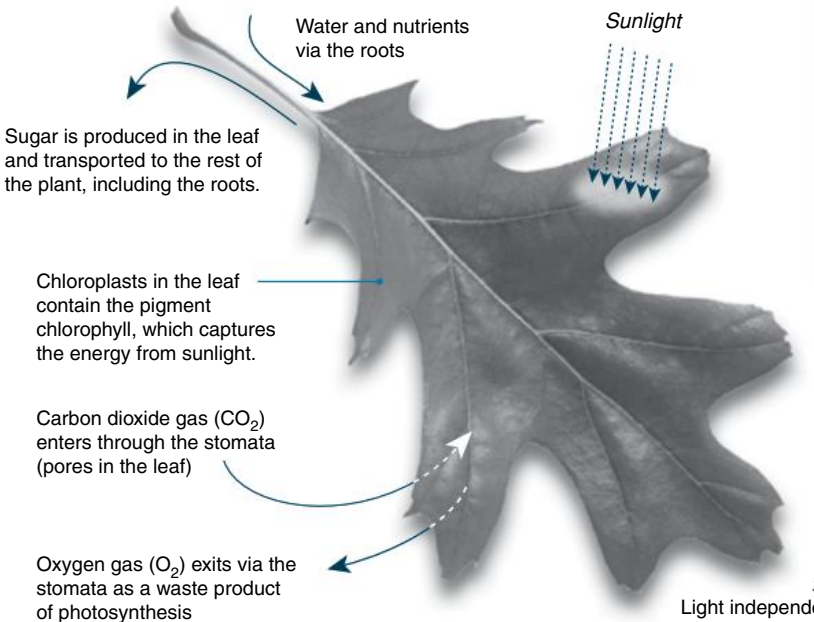
4. Outline the differences between **photosynthesis** and **cellular respiration**, including reference to the raw materials used and the waste products produced:

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69 Plants as Producers

Key Idea: Photosynthesis by producers (photoautotrophs) directly and indirectly sustains heterotrophic life on Earth.

Life on earth is solar-powered. Plants, algae, and some bacteria are producers (photoautotrophs). They capture light energy and convert it into sugars through a process called photosynthesis. The chemical energy stored in this food fuels the reactions that sustain life. Heterotrophs rely on producers directly or indirectly for their energy. The photosynthesis that occurs in the oceans is vital to the Earth's functioning, providing oxygen and absorbing carbon dioxide.

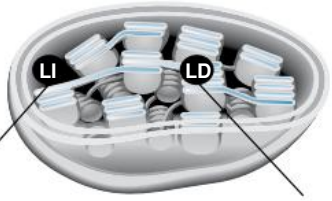


Requirements for Photosynthesis

Plants need only a few raw materials to make their own food:

- Light energy from the sun
- Chlorophyll absorbs light energy
- CO_2 gas is reduced to carbohydrate
- Water is split to provide the electrons for the fixation of carbon

Photosynthesis is not a single process but two complex processes (the light dependent and light independent reactions) each with multiple steps.



Light independent reactions (carbon fixation) occur in the fluid stroma of chloroplast.

Light dependent reactions (energy capture) occur in the stacked inner membranes of the chloroplast.

Photosynthesis Equation

$$6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$



The photosynthesis of marine algae supplies a substantial portion of the world's oxygen. The oceans also act as sinks for absorbing large amounts of carbon dioxide.



Macroalgae, like this giant kelp, are important marine producers. Algae living near the ocean surface get access to light used in photosynthesis (the red wavelength).



On land, vascular plants (such as trees with transport vessels) are the main producers of food. Plants at different levels in a forest receive different intensity and quality of light.

1. Write the overall chemical equation for photosynthesis: _____

2. Describe three things of fundamental biological importance provided by photosynthesis:

   (a) _____

   (b) _____

   (c) _____

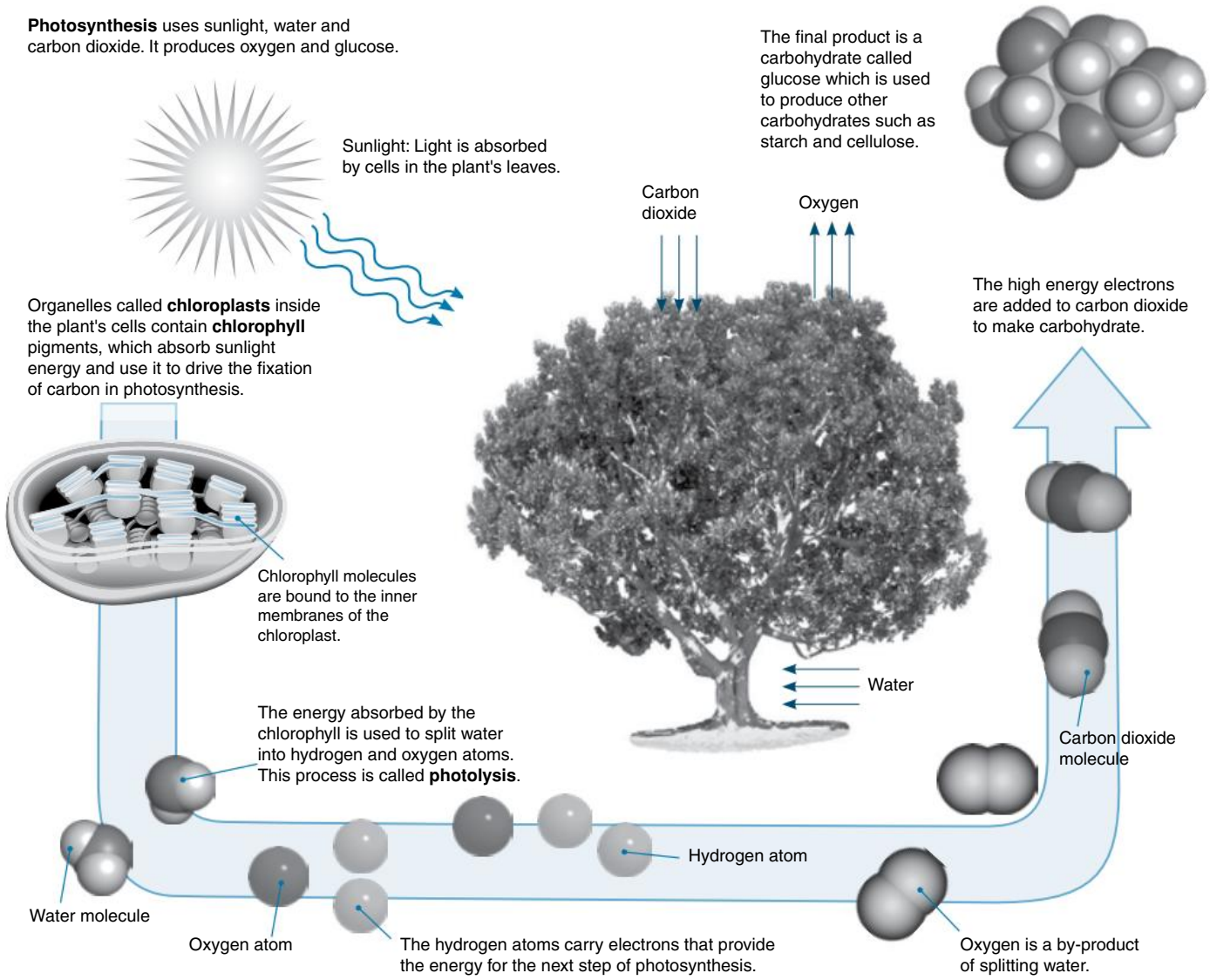
3. How does light limit the distribution of algae in the ocean? _____

REFER LINK 70 LINK 71 LINK 72

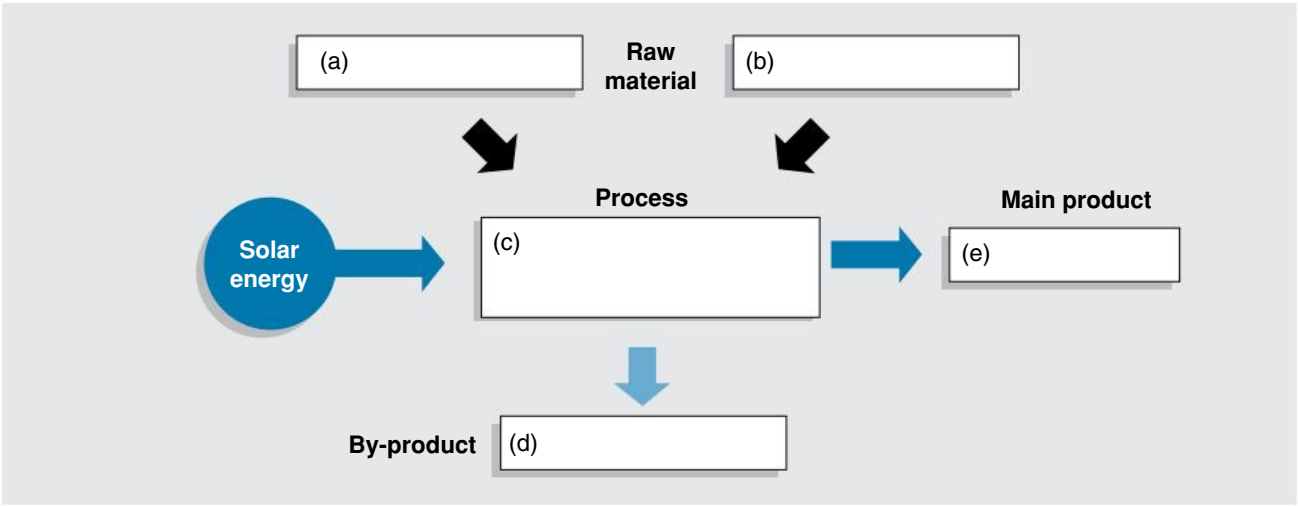
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70 Photosynthesis

Key Idea: Photosynthesis is the process of converting sunlight, carbon dioxide, and water into glucose and oxygen. **Photosynthesis** is of fundamental importance to living things because it transforms sunlight energy into chemical energy stored in molecules, releases free oxygen gas, and absorbs carbon dioxide (a waste product of cellular metabolism). Photosynthetic organisms use special pigments, called **chlorophylls**, to absorb light of specific wavelengths and capture the light energy. Like cellular respiration, photosynthesis is a redox process, but in photosynthesis, water is split and electrons are transferred together with hydrogen ions from water to CO_2, reducing it to glucose.



1. Complete the schematic diagram of photosynthesis below:



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71 Leaf Structure

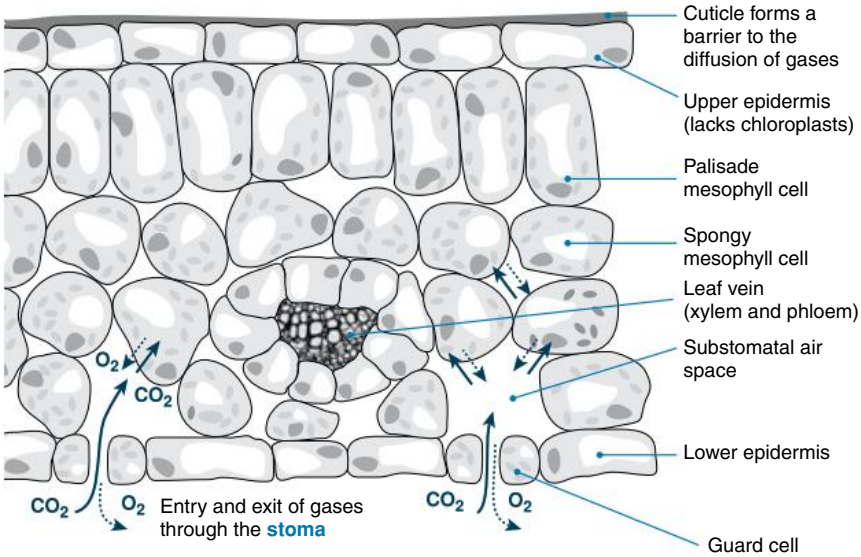
Key Idea: Leaves are the main site for photosynthesis in plants. Leaf structure aids the photosynthetic process.

The main function of leaves is as photosynthetic organs in which light energy is collected and used in photosynthesis. Leaf structure is organised in such a way as to maximise the capture of sunlight energy and facilitate the diffusion of gases into and out of the leaf tissue. Gases enter and leave the leaf by way of **stomata** (small pores) on the leaf. Inside the leaf the large air spaces and loose arrangement of the spongy mesophyll provide a large surface area for gas exchange.

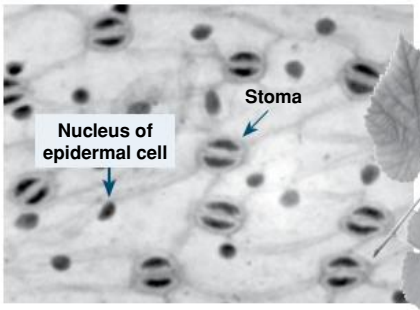
Respiring plant cells use oxygen (O_2) and produce carbon dioxide (CO_2). These gases move in and out of the plant and through the air spaces by diffusion. Angiosperms have many air spaces between the cells of the stems, leaves, and roots. These air spaces are continuous and gases are able to move freely through them and into the plant's cells via the **stomata** (sing. stoma).

When the plant is photosynthesising, the situation is more complex. Overall there is a net use of CO_2 and a net production of oxygen. CO_2 uptake (in photosynthesis) maintains a gradient in CO_2 concentration between the inside of the leaf and the atmosphere. Oxygen is produced in excess of respiratory needs and diffuses out of the leaf. These **net** exchanges are indicated by the arrows on the diagram.

Dicot Leaf Structure



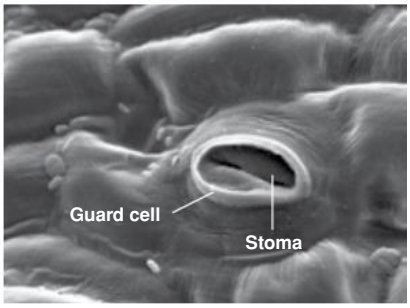
***Net gas exchanges** in a photosynthesising dicot leaf*



The surface of the leaf epidermis of a dicot illustrating the density and scattered arrangement of the pores or **stomata**. In dicots, stomata are usually present only on the lower leaf surface.



The leaves of dicots can be distinguished from those of monocots by their netted pattern of leaf veins. Monocots, in contrast, generally have leaves with parallel venation.



Guard cells on each side of a stoma (pl. stomata) regulate the entry and exit of gases and water vapour. Stomata permit gas exchange but are also the major routes for water loss.

RCN

1. Describe two adaptive features of leaves to reduce water loss:

   (a) _____

   (b) _____

2. Identify the region of a dicot leaf where most of the chloroplasts are found: _____

3. What is the purpose of the air spaces in the leaf tissue? _____

   _____

   _____

4. (a) How do gases enter and leave the leaf tissue? _____

   _____

   (b) How is this movement regulated? _____

   _____

   _____

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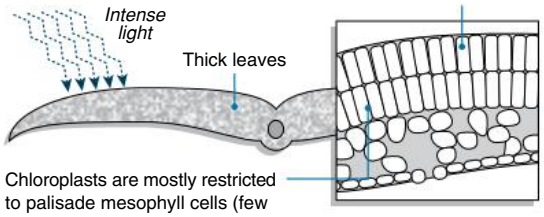
72 Adaptations for Photosynthesis

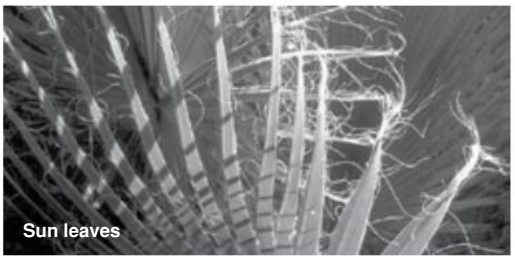
Key Idea: Plant adaptations maximise photosynthetic rate.

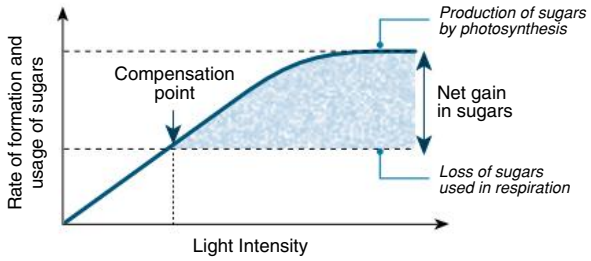
In order to photosynthesise, plants must obtain a regular supply of carbon dioxide (CO_2) so, the systems for gas exchange and photosynthesis are linked. Without a regular supply of CO_2, photosynthesis ceases. The leaf is adapted to maximise light capture and facilitate the entry of CO_2, while minimising water loss. The particular adaptations of the leaf reflect its growth environment, its resistance to water loss, and the importance of the leaf relative to other parts of the plant that may be photosynthetic, such as the stem.

Sun plant

A **sun leaf**, when exposed to high light intensities, can absorb much of the light available to the cells.



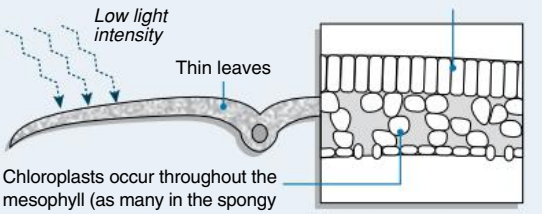




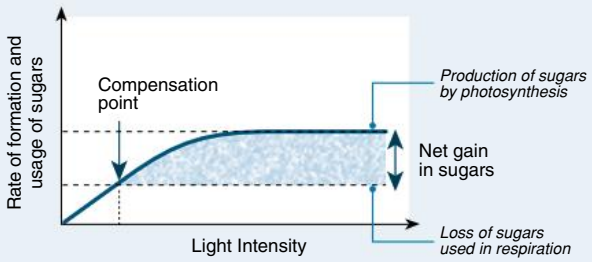
Plants adapted for full sunlight have higher levels of respiration and much higher **compensation points. Sun plants** include many weed species found on open ground. They expend much more energy on the construction and maintenance of thicker leaves than do shade plants. The benefit of this investment is that they can absorb the higher light intensities available and grow more quickly.

Shade plant

A **shade leaf** can absorb the light available at lower light intensities. If exposed to high light, most would pass through.







Shade plants typically grow in forested areas, partly shaded by the canopy of larger trees. They have lower rates of respiration than sun plants, mainly because they build thinner leaves. The fewer number of cells need less energy for their production and maintenance. As a result, shade plants reach their compensation point at a low light intensity; much sooner than sun plants do.

1. (a) From the diagrams above, determine what is meant by the **compensation point** in terms of sugar production:

_____

_____

(b) State which type of plant (sun or shade adapted) has the highest level of respiration: _____

(c) How does the plant compensate for the higher level of respiration? _____

_____

2. Discuss the adaptations of leaves in **sun** and **shade plants**: _____

_____

_____

_____

_____

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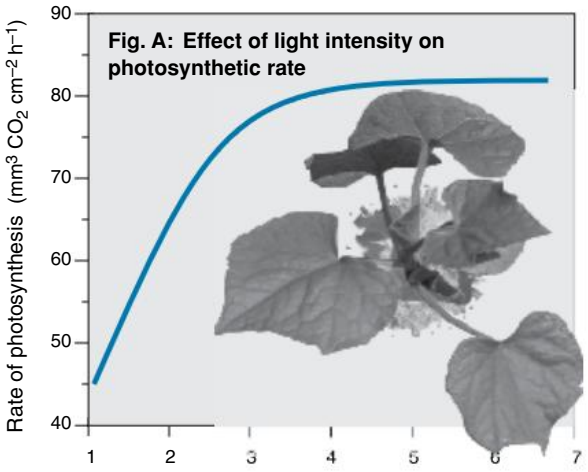
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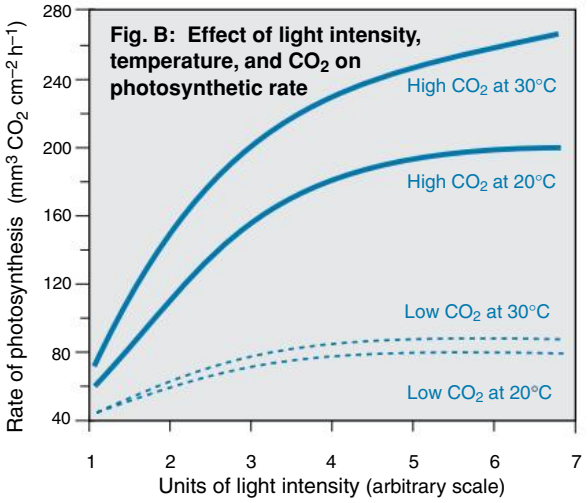
73 Factors Affecting Photosynthesis

Key Idea: Environmental factors, such as light availability and carbon dioxide level, affect photosynthetic rate.

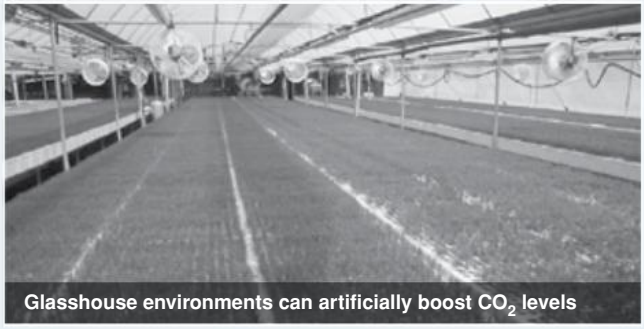
The rate at which plants can photosynthesise is dependent on environmental factors, particularly light and carbon dioxide (CO_2), but also temperature. In the plant's natural environment, fluctuations in these factors (and others) influence photosynthetic rate, so that the rate varies daily and seasonlly. The effect of each factor can be tested experimentally by altering one while holding the others constant. Usually, either light or CO_2 level is limiting. Humans can overcome the limitations of low light or CO_2 by growing plants in a controlled environment.

Factors Affecting Photosynthetic Rate





The rate of photosynthesis is affected strongly by abiotic factors in the environment, particularly light intensity, temperature, and carbon dioxide levels. The two graphs (left) illustrate the effect of these variables on the rate of photosynthesis in cucumber plants. Figure A shows the effect of increasing light intensity at constant temperature and CO_2 level. Figure B illustrates how this response is influenced by CO_2 concentration and temperature. 30°C is at the upper range of tolerance for many plants.



Glasshouse environments can artificially boost CO_2 levels



High wind increases water loss from stomata

Plants acquire CO_2 from the atmosphere through their stomata. They also lose water through their stomata when they are open, so conditions that cause them to close their stomata to reduce water loss also reduce CO_2 uptake and lower the photosynthetic rate. Such conditions include increased wind speed and water stress. Glasshouses are used to manipulate the physical environment to maximise photosynthetic rates.

1. Based on the figures above, summarise and explain the effect of each of the following factors on photosynthetic rate:

   (a) CO_2 concentration: _____

   _____

   (b) Light intensity: _____

   _____

   (c) Temperature: _____

   _____

2. Why does photosynthetic rate decline when the CO_2 level is reduced? _____

   _____

   _____

3. Why might hot, windy conditions reduce photosynthetic rates? _____

   _____

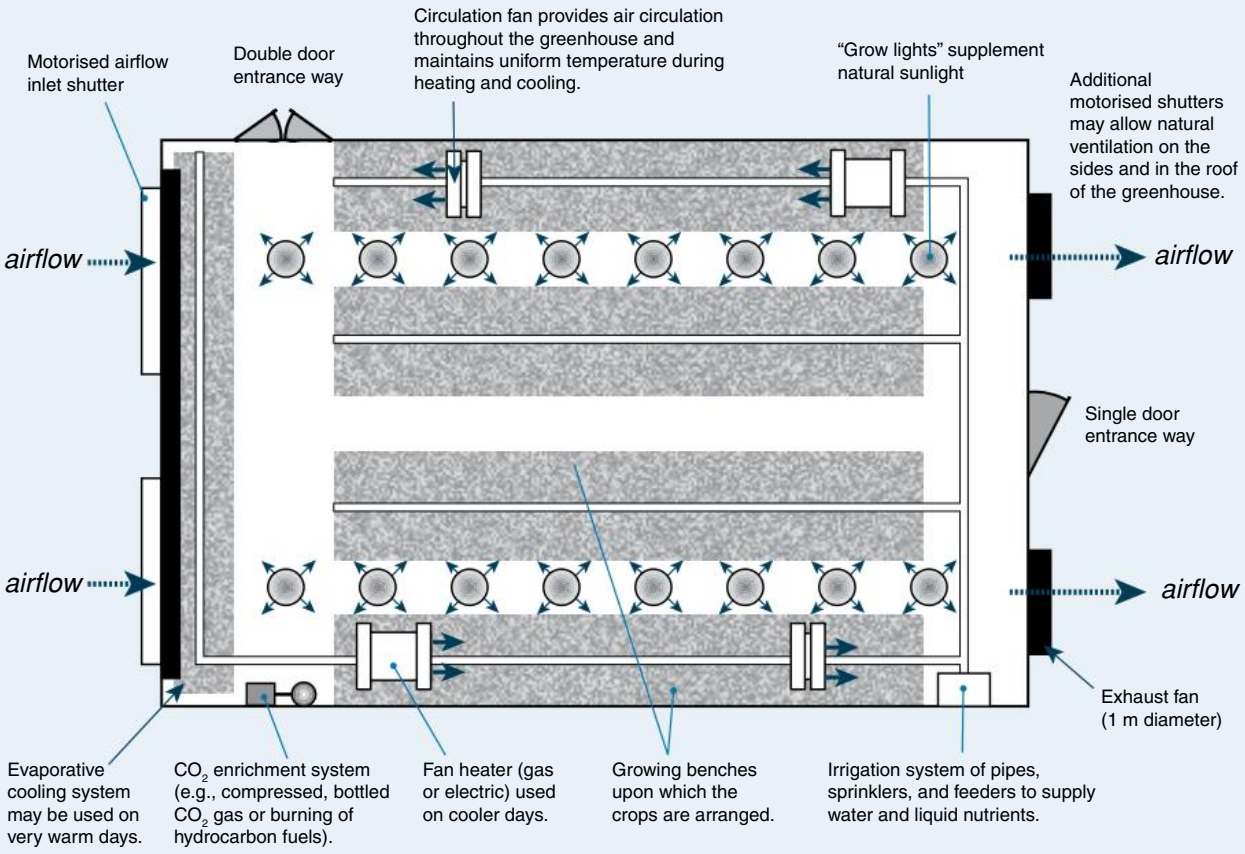
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74 Growing Plants in a Controlled Environment

Key Idea: The growth of plants in greenhouses can be increased by manipulating abiotic factors.

Manipulating abiotic (physical) factors can maximise crop yields for economic benefit. For example, covering the soil with black plastic reduces weed growth and increases soil temperature and so boosts production. A more complete control of the abiotic conditions is achieved by growing crops in a controlled-environment system such as a greenhouse. Temperature, carbon dioxide concentration, and light intensity may be optimised to maximise the rate of photosynthesis and therefore growth. Greenhouses also allow specific abiotic factors to be manipulated to trigger a change in the growing behaviour of some crops (e.g. flowering). Carbon dioxide enrichment dramatically increases the growth of greenhouse crops providing that other important abiotic factors (such as mineral nutrients) are not limiting.

Plan View of a Typical Commercial Greenhouse



Size of greenhouse: 12 m x 7.5 m



The growing environment can be controlled or modified to varying degrees. Black plastic sheeting can be laid over the soil to control weeds and absorb extra solar heat. Tunnel enclosures (such as those above) may be used to reduce light intensity and airflow, prevent frost damage, and reduce damage by pests.



Large, commercial greenhouses have elaborate computer-controlled watering systems linked to sensors that measure soil moisture, air temperature, and humidity. Coupled with a timer, they deliver optimal water conditions for plant growth by operating electric solenoid valves attached to the irrigation system.



Air flow through a greenhouse is essential to providing a homogeneous air temperature. Air flow also ensures an even distribution of carbon dioxide gas throughout the enclosure. A general airflow from one end of the enclosure to the other is maintained by a large number of fans all blowing in the same direction.

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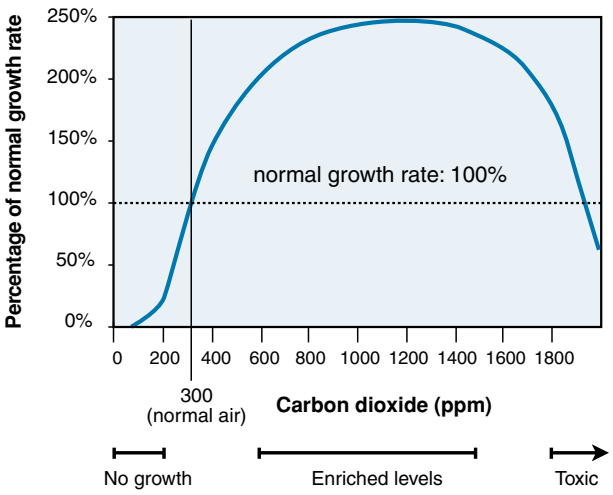
LINK 75 KNOW

Carbon Dioxide Enrichment

Carbon dioxide (CO_2) is a raw material used in photosynthesis. If the supply of carbon dioxide is cut off or reduced, plant growth and development are curtailed. The amount of CO_2 in air is normally 0.03% (250-330 ppm). Most plants will stop growing when the CO_2 level falls below 150 ppm. Even at 220 ppm, a slow-down in plant growth is noticeable (see graph below).

Controlled CO_2 atmospheres, which boost the CO_2 concentration to more than 1000 ppm, significantly increase the rate of formation of dry plant matter and total yield (e.g. of flowers or fruit). Extra carbon dioxide can be generated (at a cost) by burning hydrocarbon fuels, using compressed, bottled CO_2 or dry ice, or by fermentation or decomposition of organic matter.

The effect of CO_2 concentration on plant growth



Growing Crops in Alternative Media

Soil-less cultures provide very controlled conditions for crop production, meeting the plant's growing requirements in an artificially lit, soiless, environment. Artificial soil media may consist of sand or mica flakes. These media are attractive because they can be made to start off in a sterile state (no pests or diseases), but they are totally devoid of nutrients, which must be added. Plants may also be grown in a supporting medium of water, a technique known as **hydroponics**. Hydroponic crops provide a clean, easily harvested product all year round, and require very little growing medium relative to the final yield.



A technician at the US South Pole station, in Antarctica, monitors the hydroponic system growing lettuces and tomatoes. Here, they have to provide thermal insulation as well as nutrients.

Sources: Roger Thayer, Eco Enterprises; Hydroponic Soc. of America; Home Harvest at www.homeharvest.com

1. (a) List the abiotic factors that are controlled in a greenhouse environment: _____

   _____

   (b) In a general way, explain how control of these factors enhances plant growth: _____

   _____

   _____

2. Explain why **CO_2 enrichment** has the capacity to radically increase crop production: _____

   _____

3. (a) Outline the basic principles involved in the cultivation of crops using hydroponics: _____

   _____

   _____

   (b) Describe one advantage of this method: _____

   _____

4. State the two primary considerations influencing the **economic viability** of controlled environments: _____

   _____

5. (a) Describe in what way a greenhouse environment represents an **artificial ecosystem**: _____

   _____

   (b) Explain how the viability of such a system is maintained: _____

   _____

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75 Investigating Plant Growth

Key Idea: Systematic recording and analysis of results can help identify trends and draw conclusions about a biological response in an experiment.

Using the information below, analyse results and draw conclusions about the effect of a nitrogen fertiliser on the growth of radish plants.



Radishes

The Aim

To investigate the effect of a nitrogen fertiliser on the growth of plants.

Background

Inorganic fertilisers revolutionised crop farming when they were introduced during the late 19th and early 20th century. Crop yields soared and today it is estimated around 50% of crop yield is attributable to the use of fertiliser. Nitrogen is a very important element for plant growth and several types of purely nitrogen fertiliser are manufactured to supply it, e.g. urea.

Experimental Method

This experiment was designed to test the effect of nitrogen fertiliser on plant growth. Radish seeds were planted in separate identical pots (5 cm x 5 cm wide x 10 cm deep) and grown together in normal room conditions. The radishes were watered every day at 10 am and 3 pm with 1.25 L per treatment. Water soluble fertiliser was mixed and added with the first watering on the 1st, 11th and 21st days. The fertiliser concentrations used were: 0.00, 0.06, 0.12, 0.18, 0.24, and 0.30 g L^{-1} with each treatment receiving a different concentration. The plants were grown for 30 days before being removed, washed, and the root (radish) weighed. Results were tabulated below:

To investigate the effect of nitrogen on plant growth, a group of students set up an experiment using different concentrations of nitrogen fertiliser. Radish seeds were planted into a standard soil mixture and divided into six groups each, with five sample plants (30 plants in total).

Tables should have an accurate, descriptive title. Number tables consecutively through the report.

Heading and subheadings identify each set of data and show units of measurement.

Table 1: Mass (g) of radish plant roots under six different fertiliser concentrations (data given to 1dp).

Independent variable in the left column.

Fertiliser concentration (g L^{-1})	Mass of radish root (g)†						
	Sample (*n*)					Total mass	Mean mass
	1	2	3	4	5		
0	80.1	83.2	82.0	79.1	84.1	408.5	81.7
0.06	109.2	110.3	108.2	107.9	110.7		
0.12	117.9	118.9	118.3	119.1	117.2		
0.18	128.3	127.3	127.7	126.8	DNG*		
0.24	23.6	140.3	139.6	137.9	141.1		
0.30	122.3	121.1	122.6	121.3	123.1		

* DNG: Did not germinate

Control values (if present) should be placed at the beginning of the table.

Values should be shown only to the level of significance allowable by your measuring technique.

Organise the columns so that each category of like numbers or attributes is listed vertically.

Each row should show a different experimental treatment, organism, sampling site etc.

† Based on data from M S Jilani, *et al* Journal Agricultural Research

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LINK 76 DATA

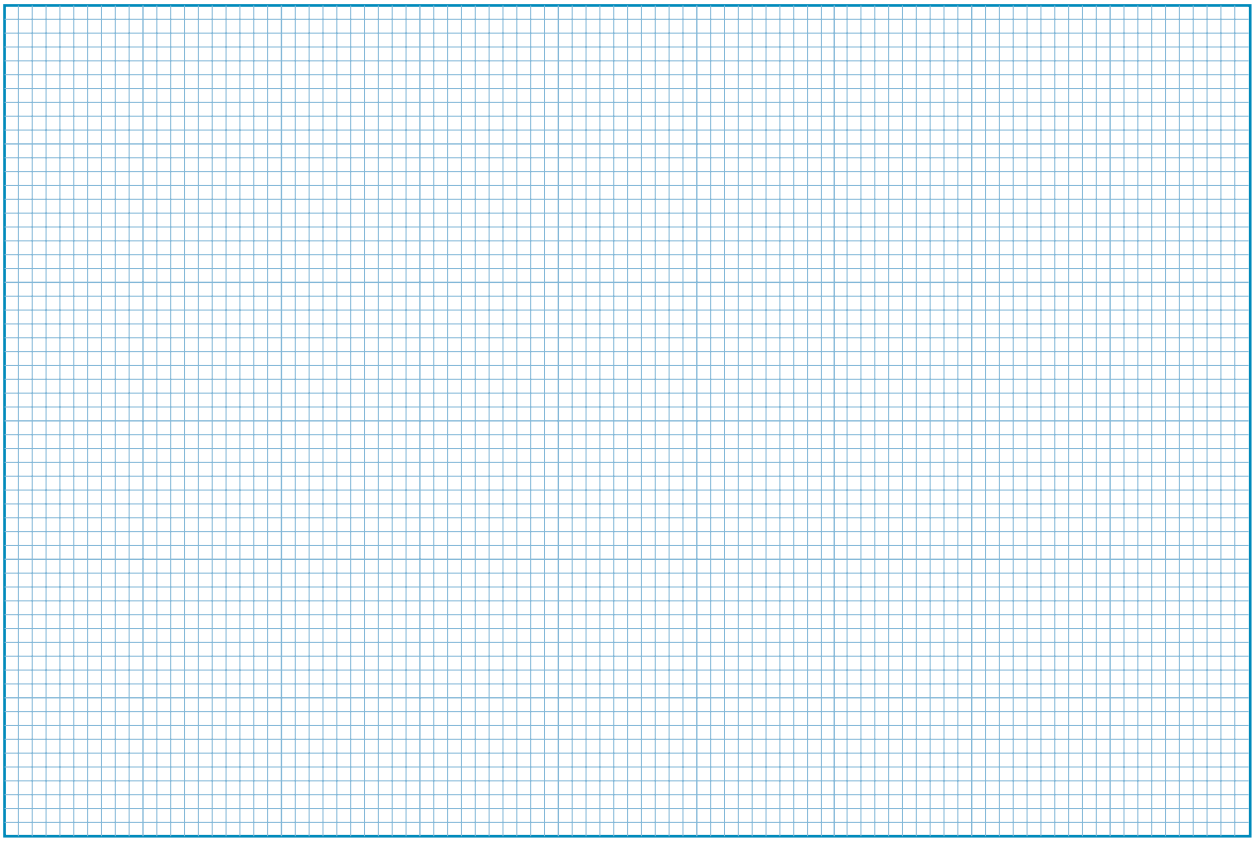
1. Identify the independent variable for the experiment and its range: _____

2. What is the sample size for each concentration of fertiliser? _____

3. One of the radishes recorded in Table 1 did not grow as expected and produced an extreme value. Record the **outlying value** here and decide whether or not you should include it in future calculations:

4. Complete the table on the previous page by calculating the **total mass** and **mean mass** of the radish roots:

5. Use the grid below to draw a **line graph** of the experimental results. Use your calculated means and remember to include a title and correctly labelled axes.



6. The students recorded the wet mass of the root (the root still containing water) in their table. What mass should they have actually recorded to get a better representation of the effect of the fertiliser on root mass?

7. Why would measuring just root mass not be a totally accurate way of measuring the effect of fertiliser on radish growth?

8. Describe some other measurements the students could have taken to make their experiment more complete:

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Calculating Simple Statistics for a Data Set

Statistic	Definition and use	Method of calculation
Mean	• The average of all data entries. • Measure of central tendency for normally distributed data.	• Add up all the data entries. • Divide by the total number of data entries.
Median	• The middle value when data entries are placed in rank order. • A good measure of central tendency for skewed distributions.	• Arrange the data in increasing rank order. • Identify the middle value. • For an even number of entries, find the mid point of the two middle values.
Mode	• The most common data value. • Suitable for bimodal distributions and qualitative data.	• Identify the category with the highest number of data entries using a tally chart or a bar graph.
Range	• The difference between the smallest and largest data values. • Provides a crude indication of data spread.	• Identify the smallest and largest values and find the difference between them.

Data can be simply summarised using **descriptive statistics**. Descriptive statistics, such as mean, median, and mode, can highlight trends or patterns in the data. The mean can be used to compare different groups. You can use more complex statistics to determine if the means of different groups are significantly different.

When NOT to calculate a mean:

In certain situations, calculation of a simple arithmetic mean is inappropriate.

Remember:

- *DO NOT* calculate a mean from values that are already means (averages) themselves.
- *DO NOT* calculate a mean of ratios (e.g. percentages) for several groups of different sizes; go back to the raw values and recalculate.
- *DO NOT* calculate a mean when the measurement scale is not linear, e.g. pH units are not measured on a linear scale.

The students decided to further their experiment by recording the number of leaves on each radish plant:

Table 2: Number of leaves on radish plant under six different fertiliser concentrations.

Fertiliser concentration (g L^{-1})	Number of leaves							
	Sample (*n*)					Mean	Median	Mode
	1	2	3	4	5			
0	9	9	10	8	7			
0.06	15	16	15	16	16			
0.12	16	17	17	17	16			
0.18	18	18	19	18	DNG*			
0.24	6	19	19	18	18			
0.30	18	17	18	19	19			

* DNG: Did not germinate

9. Complete Table 2 by calculating the mean, median and mode for each concentration of fertiliser:

10. Which concentration of fertiliser appeared to produce the best growth results? _____

11. Describe some sources of error for the experiment: _____

_____

12. Write a brief conclusion for the experiment. Include a reference to the aim and results: _____

_____

_____

_____

13. The students decided to replicate the experiment (carry it out again). How might this improve the experiment's results?

_____

_____

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76 Plant Mineral Nutrition

Key Idea: Plants require nutrients for metabolism and growth.

Plants normally obtain minerals from the soil, either from the soil water, adsorbed on to clay particles, or via release from humus and soil weathering. Macronutrients (e.g. nitrogen, sulfur, phosphorus) are required in large amounts for building basic macromolecules. Trace elements (e.g. manganese, copper, and zinc) are required in small amounts. Many are components of, or activators for, enzymes. After absorption, mineral ions may diffuse, or be actively transported, to the xylem for transport to other regions of the plant.

Plant Macronutrients

CARBON (as CO_2):
A component of all organic compounds.

NITROGEN (as NO_3^- or NH_4^+):

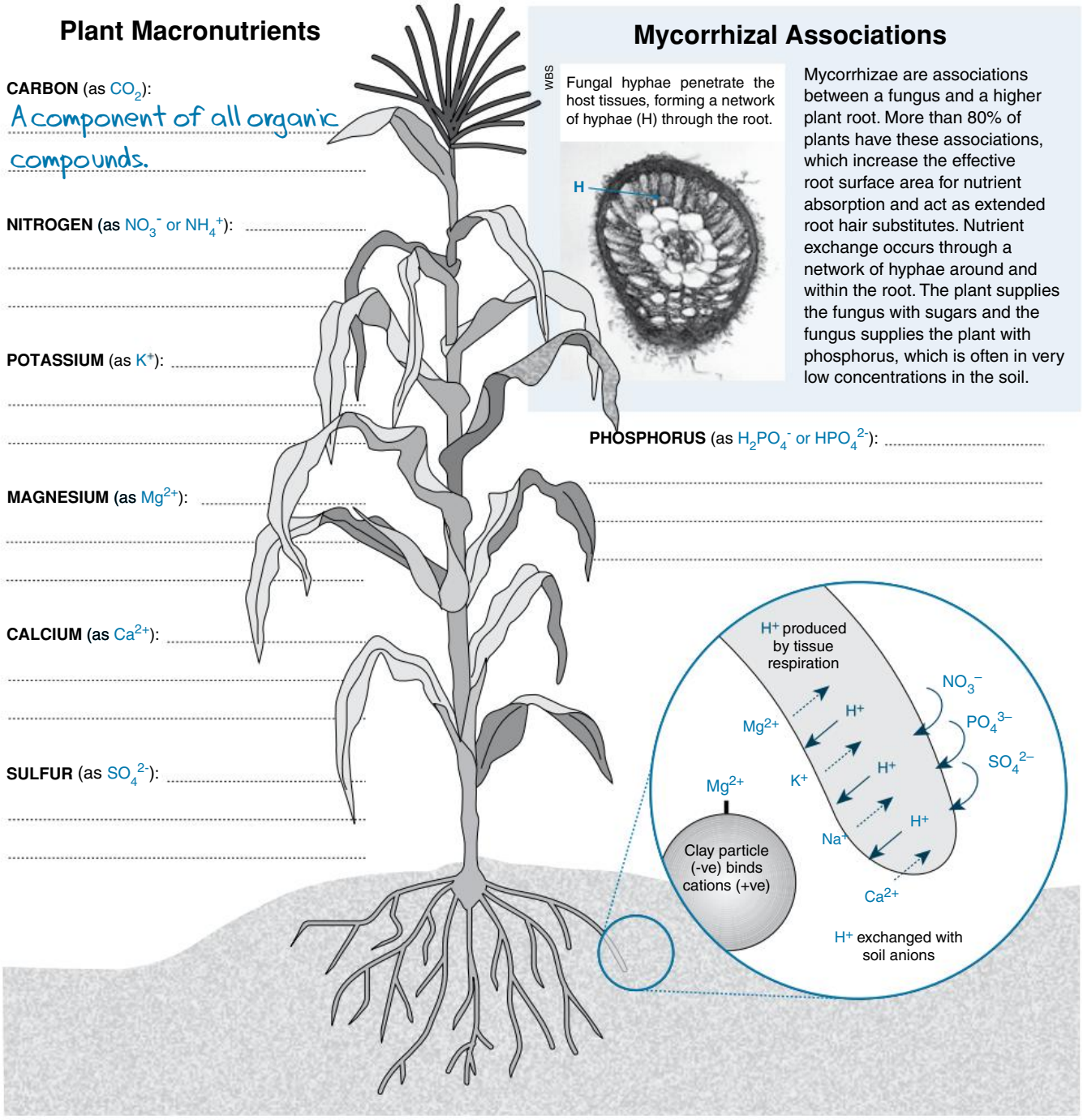
POTASSIUM (as K^+):

MAGNESIUM (as Mg^{2+}):

CALCIUM (as Ca^{2+}):

SULFUR (as SO_4^{2-}):

PHOSPHORUS (as $H_2PO_4^-$ or HPO_4^{2-}):



Mycorrhizal Associations

WBS

Fungal hyphae penetrate the host tissues, forming a network of hyphae (H) through the root.

Mycorrhizae are associations between a fungus and a higher plant root. More than 80% of plants have these associations, which increase the effective root surface area for nutrient absorption and act as extended root hair substitutes. Nutrient exchange occurs through a network of hyphae around and within the root. The plant supplies the fungus with sugars and the fungus supplies the plant with phosphorus, which is often in very low concentrations in the soil.

1. On the diagram above state the role the each macronutrients. Use an external reference source for help if necessary.
2. Identify the ways in which minerals are available to plants: _____
3. (a) Describe the role of mycorrhizal associations in plant nutrition: _____

   (b) Why might plants without mycorrhizal associations show poor growth? _____

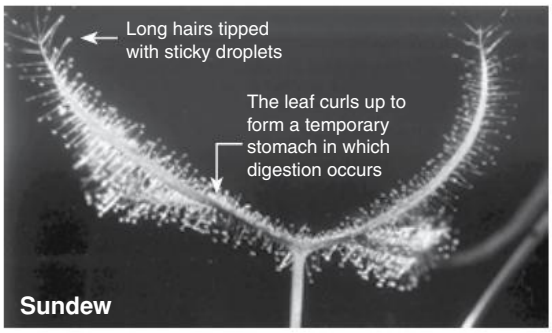
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77 Insectivorous Plants

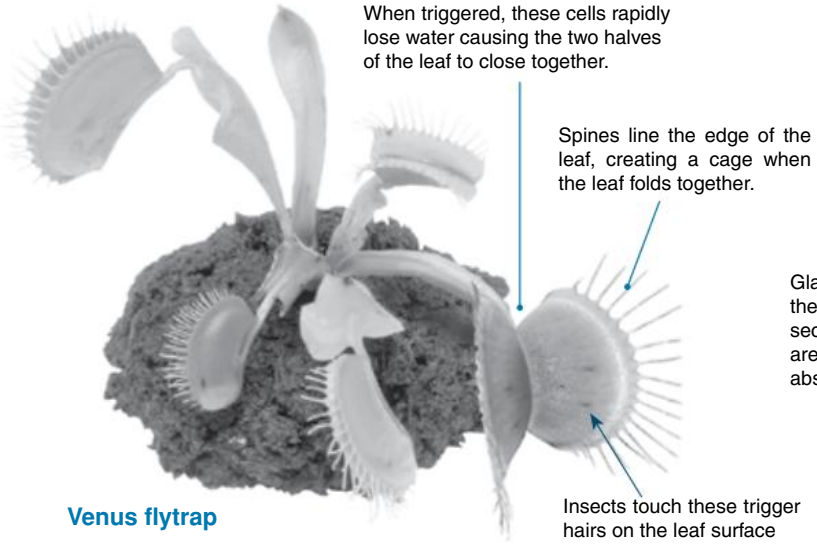
Key Idea: Insectivorous plants are photosynthetic but obtain nutrients, particularly nitrogen, from digesting animal tissues.

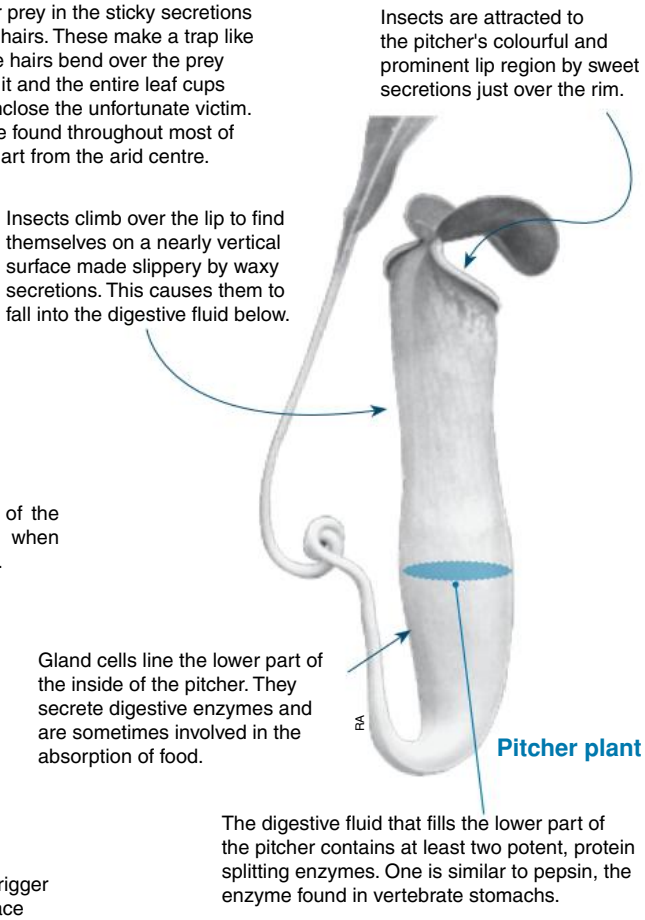
Plants that live in acid bogs or in nutrient-poor soils often obtain extra nutrients (particularly nitrogen) by capturing and digesting small invertebrates. These plants are called **insectivorous** (or sometimes carnivorous). They photosynthesise to make their own sugars, but obtain some of their nitrogen and minerals from animal tissues. The traps are leaf modifications and usually contain special glands that secrete digestive enzymes. Insectivorous plants are often small. This reflects the marginal growing environments in which they are found.

RCN



Sundew (left): Sundews (*Drosera*) capture their prey in the sticky secretions on their leaf hairs. These make a trap like flypaper. The hairs bend over the prey and restrain it and the entire leaf cups around to enclose the unfortunate victim. Sundews are found throughout most of Australia, apart from the arid centre.





Venus fly trap: The Venus fly trap consists of two, lobed modified leaves that can rapidly close together to trap prey (usually small insects). The trigger for closing is a touch on the sensory hairs of the leaves.

Pitcher plant: This plant is a passive trap. Prey fall into the water collected at the base of the pitcher and then drown. The digestive enzymes produced by the plant slowly digest the prey's tissues. Pitcher plants grow in the tropical rainforests of Cape York peninsula.

1. (a) What does an insectivorous plant gain from digesting insects? _____

   (b) How this is an advantage to the plant in its habitat? _____

2. (a) Describe one cost (disadvantage) to the plant of producing insect-trapping modified leaves: _____

   (b) Why are insectivorous plants not usually found growing in nutrient rich soils where ordinary plants are present?

3. For one of the named plants above, describe the modifications to the leaf structure that enable capture of insects:

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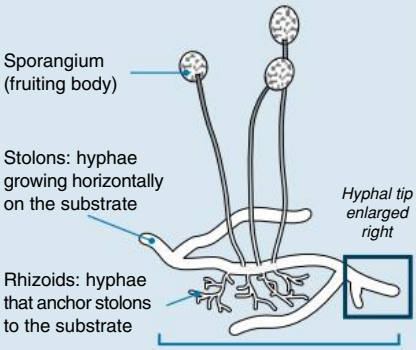
78 Saprotrophic Nutrition

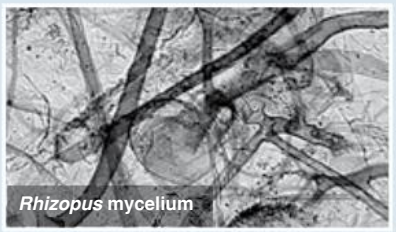
Key Idea: Saprotrophs obtain their nutrients by the extracellular digestion of dead organic matter.

All fungi are heterotrophs, they obtain their energy and nutrients by consuming other organisms. Many fungi are **saprotrophic** (also called saprophytic) and obtain their nutrients by the external digestion of dead organic matter. Saprotrophic fungi, together with bacteria, are the major decomposers of the biosphere. They contribute to decay and therefore to nutrient recycling. Like all fungi, the body is composed of filaments called **hyphae**, which together form a large mass called a **mycelium** (the feeding body of the fungus). The familiar mushroom-like structures that we see are the reproductive bodies arising from the main mycelium. Nutrition in a typical saprotroph, *Rhizopus*, is outlined below.

Bread Mould *(Rhizopus)*

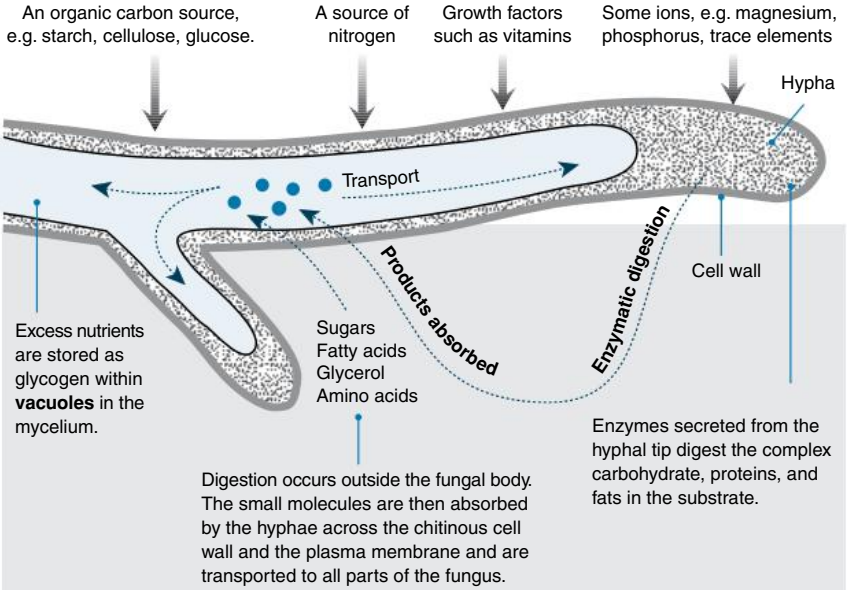
Saprotrophs grow best in dark, moist environments, but are found wherever organic material is available. *Rhizopus* is a common fungus, found on damp, stale bread, and rotting fruit. Unlike many fungi, *Rhizopus* has hyphae that are undivided by septa.





Saprotrophic Nutrition in Bread Mould (*Rhizopus*)

Nutrients required by most saprotrophs



The environmental requirements of fungi are met by the substrate on which they are growing:

- Temperature between 5° and 25°C
- Water (the fungal body is about 90% water)
- Oxygen (very few fungi are anaerobic)
- Neutral to slightly acid pH (pH 5.6-7) .

1. (a) Describe the structure of the feeding body of a saprotrophic fungus: _____

   _____

   (b) Why is a moist environment essential for fungal growth? _____

2. Identify four nutrients required by a saprotrophic fungus:

   (a) _____ (c) _____

   (b) _____ (d) _____

3. Where do these nutrients come from? _____

   _____

4. Describe how a saprotrophic fungus obtains its nutrients: _____

   _____

   _____

5. Compare and contrast digestion and absorption in a saprotrophic fungus and a holozoic animal: _____

   _____

   _____

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79 Obtaining Food

Key Idea: The adaptations of an animal for obtaining food reflect both its mode of feeding and diet.

All animals are **heterotrophs**, they feed on other things. They display a wide range of methods for obtaining the food they need. Animals may feed on solid or fluid food and may suck, bite, lap, or swallow it whole. The adaptations of mouthparts reflects the diet and the way in which they obtain their food. Some animals are predators and hunt other animals. Others are herbivorous and graze or browse continually. Omnivores feed off both animal and plant material.

Bulk Feeding

Many animals feed on large food masses which are ingested whole or in pieces. Carnivorous mammals and fish eat large pieces of food, and have teeth specialised for cutting flesh (below).


Tiger

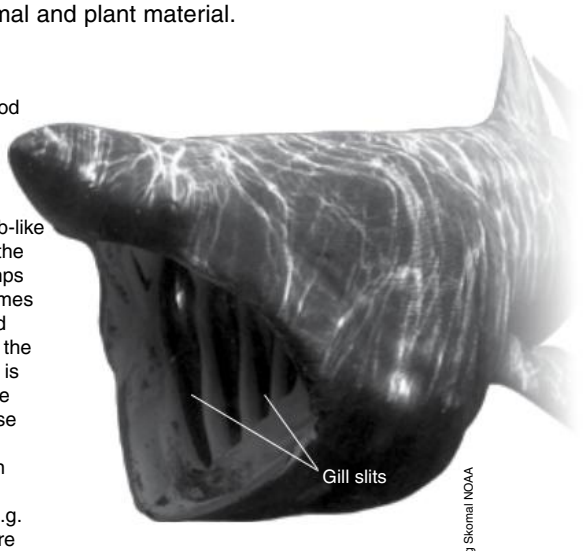

Caterpillar head

Tom Murphy VII CC 2.5

Grazing or cropping herbivores (e.g. many insects and mammalian herbivores), cut or tear vegetation and have mouthparts or teeth to chew the plant matter into pieces.

Filter Feeding

Filter feeders remove food that is suspended in the water using specialised filtering structures. Humpback and other baleen whales use comb-like plates suspended from the upper jaw to sieve shrimps and fish from large volumes of water. Food is trapped against the plates when the mouth closes and water is forced out. Some fish are also filter feeders and use sieve-like modifications of the gill rakers to strain plankton from the water. Some aquatic insects, e.g. some caddisfly larvae are also filter feeders.



Greg Skomal NOAA

The basking shark is a passive filter feeder, swimming with its mouth open and trapping plankton against the sieve-like lining of its gills.

Fluid Feeding

Many insects (e.g. moths, aphids), and some fish and mammals feed on fluids such as blood, plant sap, or nectar. Fluid feeders have mouthparts and guts that enable them to obtain and process a liquid diet. Insect fluid feeders have piercing or tubular mouthparts to obtain fluids directly. Mammalian and fish fluid feeders have small sharp teeth designed to pierce or even remove the skin of prey and lap the blood.


Vampire bats

dlveofficer CC 2.0

Deposit Feeding

Deposit feeders feed by sifting the substrate to find food. Many invertebrates, but relatively few insects, are deposit feeders. Insects that feed while burrowing through detritus or dung are deposit feeders as are some **benthic** fish. For example, mullet, catfish, and **carp** suck up mud and ingest the plant and animal matter in it.


Catfish

USGov

1. Describe one structural adaptation for obtaining food in each of the following:

   (a) A blood sucking mammal: _____

   (b) A filter feeding shark: _____

   (c) A mammalian predatory carnivore: _____

   (d) A leaf chewing caterpillar: _____

   (e) A deposit feeding fish: _____

2. Use lines to match each of the following modes of feeding with its correct description and example:

(a) Filter feeding	Obtaining nutrients by ingesting prey and its surrounding fluid	Mosquito
(b) Deposit feeding	Obtaining nutrients by eating whole organisms	Stoat
(c) Suction feeding	Obtaining nutrients from particles suspended in water	Dung beetle
(d) Bulk feeding	Obtaining nutrients by ingesting only the fluids of another organism	Zooplanktivorous fish
(e) Fluid feeding	Obtaining nutrients by sifting through or ingesting sediment or detritus	Baleen whale

3. Common carp is an introduced species and is responsible for the deterioration of water quality in many lakes and rivers. Based on their method of feeding, suggest why carp have such a negative effect on the environment:

_____

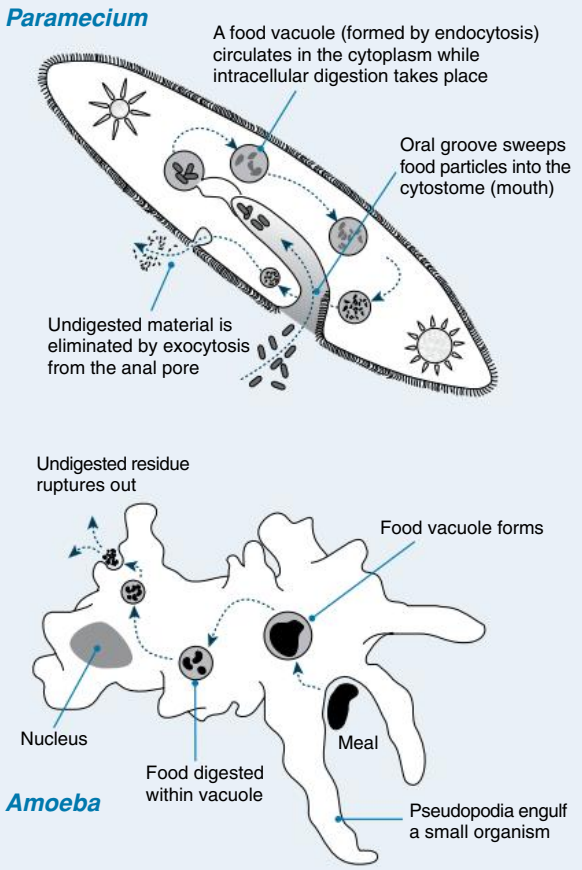
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80 Food Vacuoles and Simple Guts

Key Idea: Intracellular digestion occurs within food vacuoles. Extracellular digestion occurs outside the cell by enzymes.

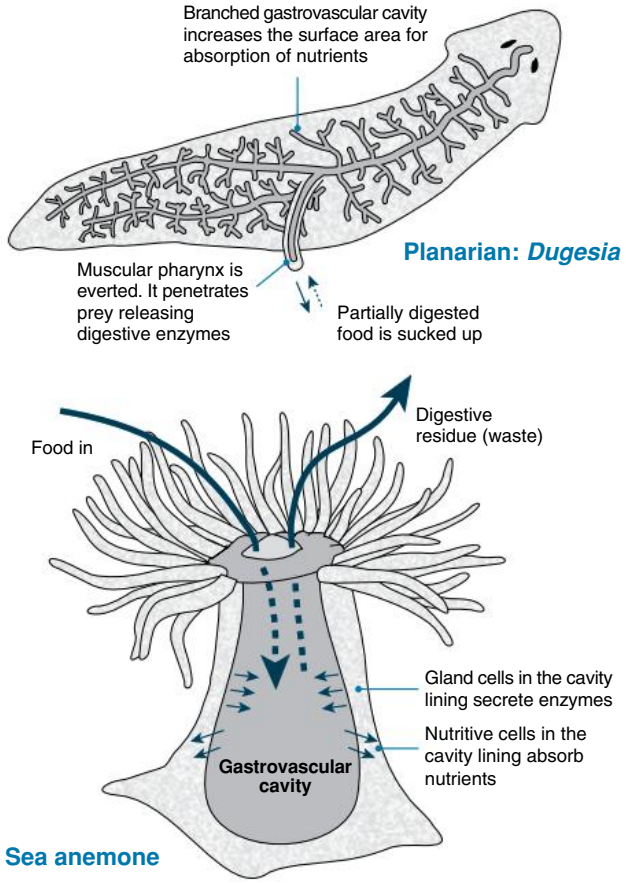
The simplest form of digestion occurs inside cells (intracellularly) within food vacuoles. This process is slow and digestion is exclusively intracellular only in protozoa and sponges. In animals with simple, sac-like guts, digestion begins extracellularly (with secretion of enzymes) and is completed intracellularly.



Intracellular Digestion In Food Vacuoles

EXAMPLES: *Protozoans (above), sponges*

The simplest digestive compartments are food vacuoles: organelles where a single cell can digest its food without the digestive enzymes mixing with the cell's own cytoplasm. Sponges and protozoans (e.g. *Paramecium* and *Amoeba*) digest food in this way. *Paramecium* sweeps food into a food groove, from where vacuoles form. *Amoeba* engulfs food using cytoplasmic extensions called pseudopodia. Digestion is intracellular, occurring within the cell itself.



Digestion In A Gastrovascular Cavity

EXAMPLES: *Cnidarians, flatworms (above)*

Some of the simplest animals have a digestive sac or gastrovascular cavity with a single opening through which food enters and digested waste passes out. In organisms with this system, digestion is both extra- and intracellular. Digestion begins (using secreted enzymes) either in the cavity (in cnidarians) or outside it (flatworms). In both these groups, the digestion process is completed intracellularly within the vacuoles in cells.

1. Describe two ways in which simple sac-like gastrovascular cavities differ from tubelike guts:

   (a) _____

   (b) _____

2. (a) Distinguish between intracellular and extracellular digestion: _____

   _____

   (b) Why is intracellular digestion unsuitable as the only means of digestion for most animals? _____

   _____

   _____

3. What is the main difference between extracellular digestion in sea anemones and *Dugesia*? _____

   _____

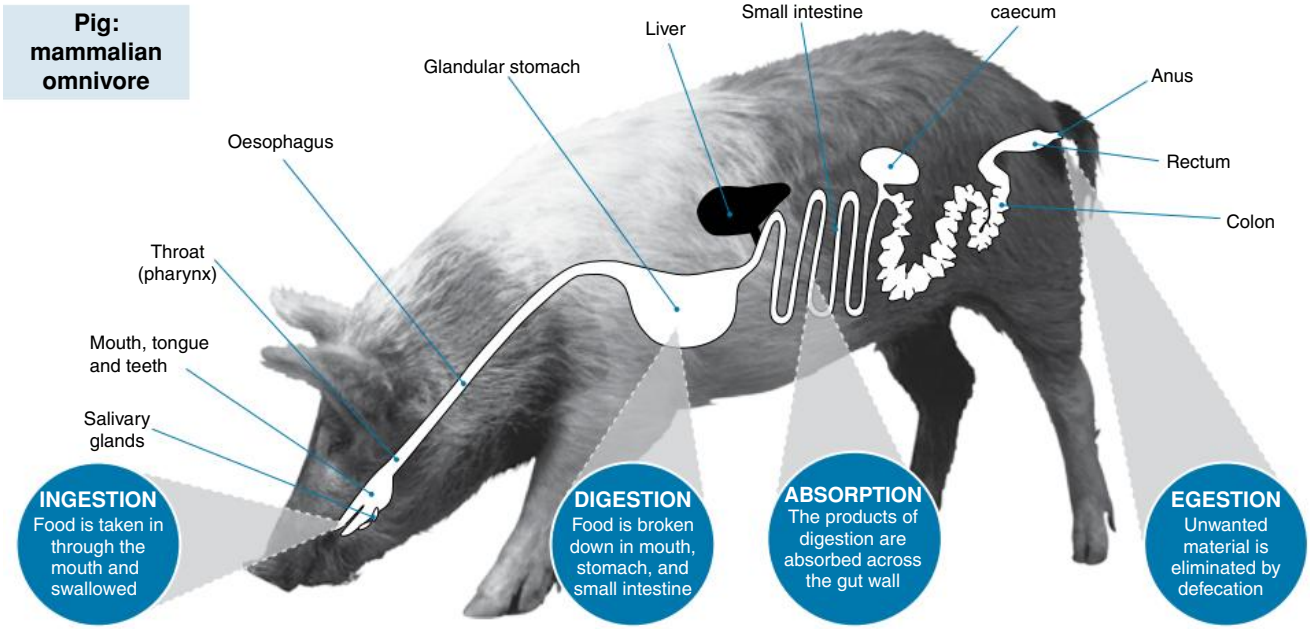
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81 Diversity in Tube Guts

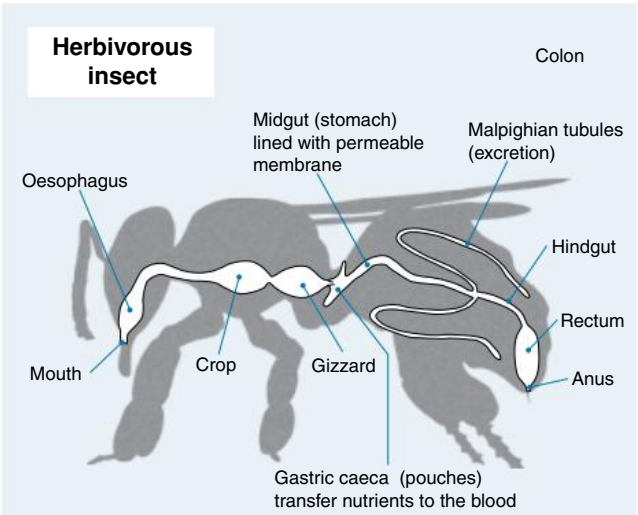
Key Idea: The tube guts of animals have a similar basic plan, but have specific adaptations related to taxon as well as diet.

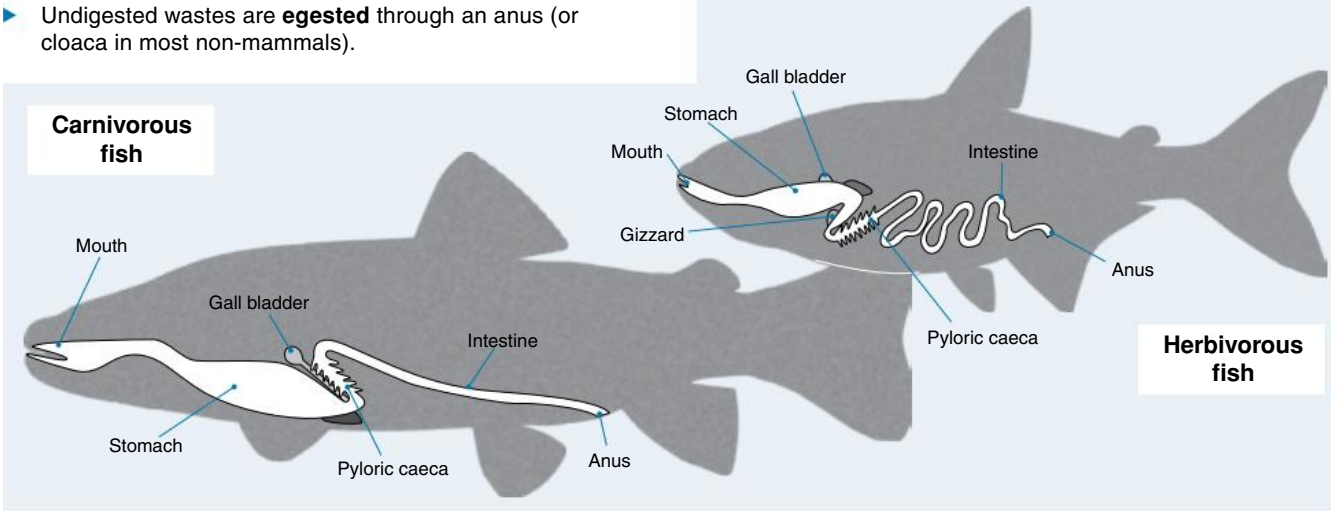
Most animals have digestive tubes running between two openings, a mouth and an anus. One-way movement of food allows the gut to become regionally specialised for processing food. Tube guts are quite uniform in general structure, with regions for storing, digesting, absorbing, and eliminating the food. Specific adaptations are related to diet and mode of feeding, as well as the taxonomic group to which the animal belongs. The processes in a tube gut are described below.



Processing Food

- The gut is essentially a hollow, open-ended, muscular tube, and the food within it is essentially outside the body, having contact only with the cells lining the tract.
- Usually, food **ingested** at the mouth and pharynx passes through an oesophagus to the stomach (or equivalent).
- Food is moved through the gut by muscular contractions.
- During **digestion**, food is first physically broken down by chewing and mixed by the muscular activity of the stomach. It is then broken down in stages by enzymes contained within digestive secretions. This is called chemical digestion.
- The products of chemical digestion are then **absorbed** across the gut wall. Absorbed molecules can then be assimilated (taken up be the cells). The liver is a large organ associated with the gut but not part of it. Like the pancreas, it contributes digestive secretions but has other non-digestive functions as well.
- Undigested wastes are **egested** through an anus (or cloaca in most non-mammals).



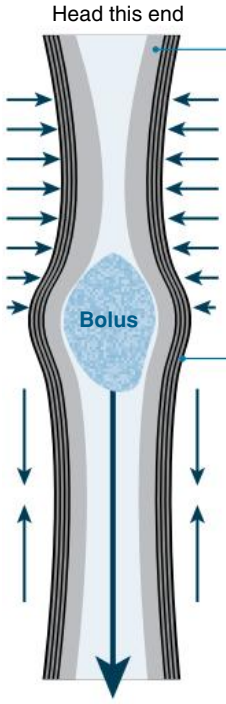


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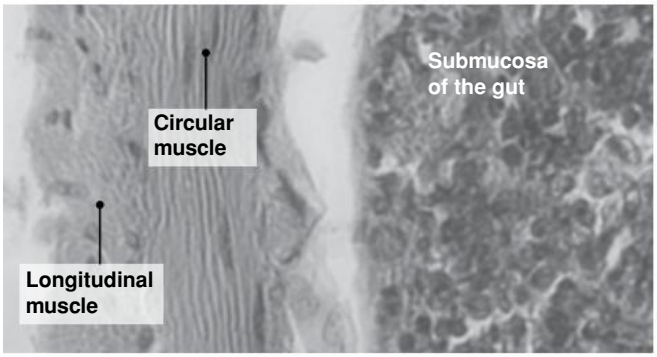
Peristalsis

Ingested food is chewed and mixed with saliva to form a small mass called a bolus. Wave-like muscular contractions called **peristalsis** moves the food, first as a bolus and then as semi-fluid chyme, through the digestive tract as described below.



Longitudinal muscles contract ahead of the bolus, causing the tube to shorten and widen to receive the food mass.

The bolus enters the stomach, where the digestive activity there reduces it to a slurry called chyme. The chyme enters the small intestine for further digestion.

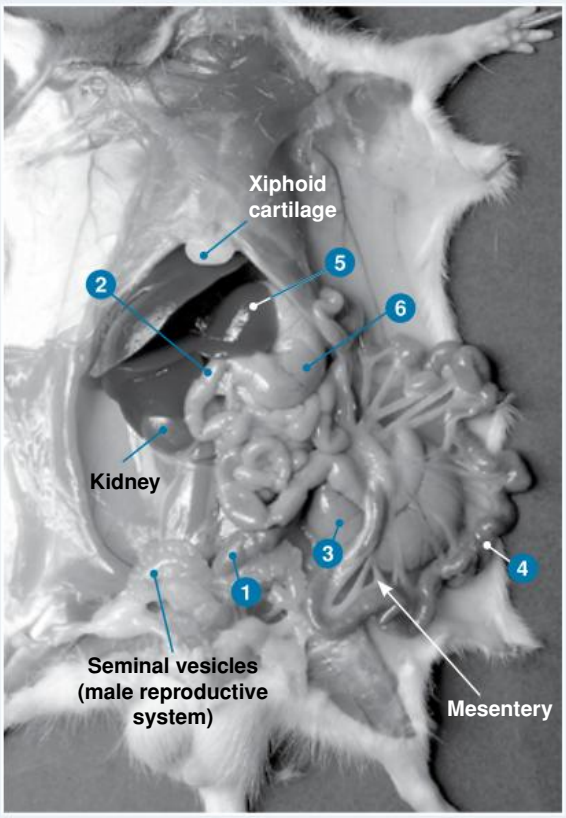


EII

Cross Section Through the Small Intestine

A cross section through the small intestine shows the outer longitudinal and inner circular muscles involved in peristalsis. In this cross sectional view, the longitudinal muscles appear circular because they are viewed end on, while the circular muscle appears in longitudinal section.

Recognising digestive organs in a dissection



In your studies you may be required to complete a dissection. The photograph above shows a dissection of the body cavity of a rat to show the gut. The numbers indicate structures to be labelled.

1 _____

2 _____

3 _____

4 _____

5 _____

6 _____

1. Some structures have a similar function in different animals. What is the general function of the following gut structures?

   (a) Gizzard: _____

   (b) Stomach or crop: _____

   (c) Intestine (midgut in insects): _____

2. (a) In the dissection of the rat (above), label each of the structures indicated in the spaces provided. Use the following word list to help you: *stomach, colon, liver, rectum, duodenum, ileum*.

   (b) Of the various guts pictured previously, which one does the rat gut most closely resemble? _____

   (c) Explain your answer: _____

3. How does peristalsis move food through the gut? _____

_____

_____

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82 The Teeth of Fish

Key Idea: The teeth and jaws of fish are adapted to their diet.

Fish are **homodonts**, meaning that, within the mouth, their teeth are identical. As a group though, fish show an extremely varied array of teeth types depending on their diet (e.g. flesh, coral, fuids). The teeth are not always found only in the jaw. Fish may have teeth or teeth-like structures on the roof of the mouth, the tongue, and the gill arches. In most cases the teeth are curved backwards to help grip prey.

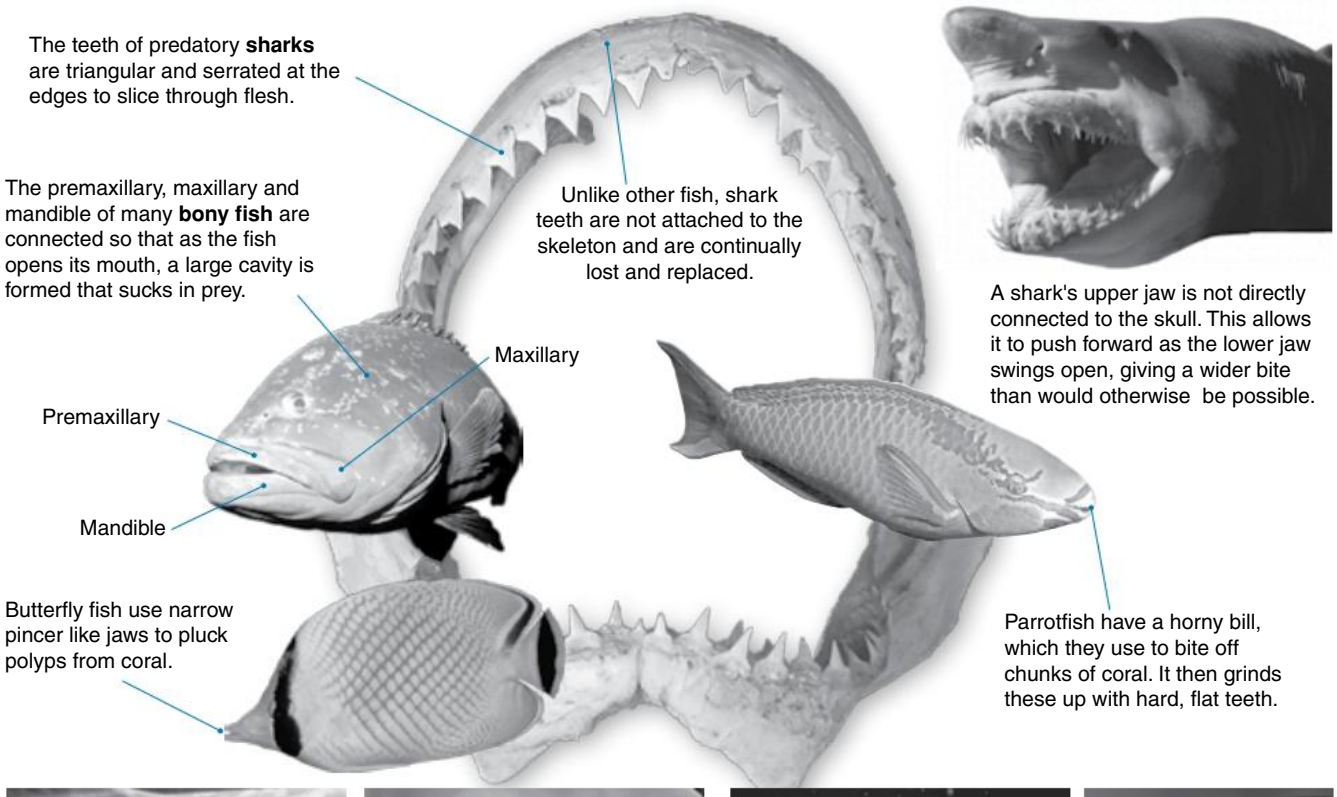
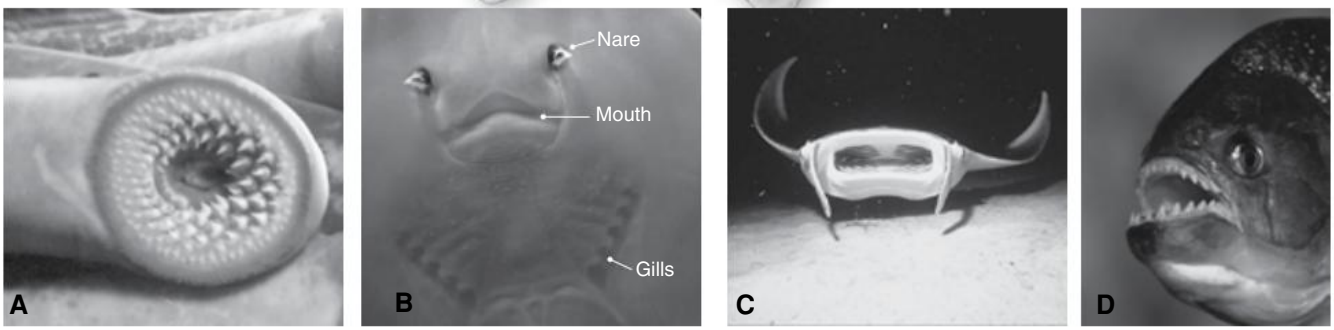


Photo: Drow Male



(A) **Lampreys** lack jaws and latch onto a host using an **oral disc**. They then bore through the skin to suck the host's fluids. (B) **Sting rays** feed on shellfish and use flat plates of grinding teeth to crack and crush shells. Spiracles on the dorsal surface allow water to the gills so gas exchange continues while feeding.

(C) Filter feeders often lack teeth and use sieve plates in the mouth to sieve plankton and small fish from the water. (D) Predatory fish have teeth that grip and slice. Few are able to chew and bite off chunks of flesh that are swallowed whole.

1. Fish are homodonts. Explain how their teeth differ from those of mammals: _____

2. Identify the fish using the following types of teeth and jaws and describe its diet:
   a) Narrow pincer like jaws: _____
   b) Sieve plates: _____
   c) Serrated, triangular teeth: _____
   d) Horny bill and flat grinding teeth: _____
   e) No jaws, teeth-like structure on the tongue: _____

3. Why do sharks need to continually replace their teeth? _____

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83 Comparing Mammalian Teeth

Key Idea: Mammals are heterodonts and the diversity of their dentition reflects their diet and mode of feeding.

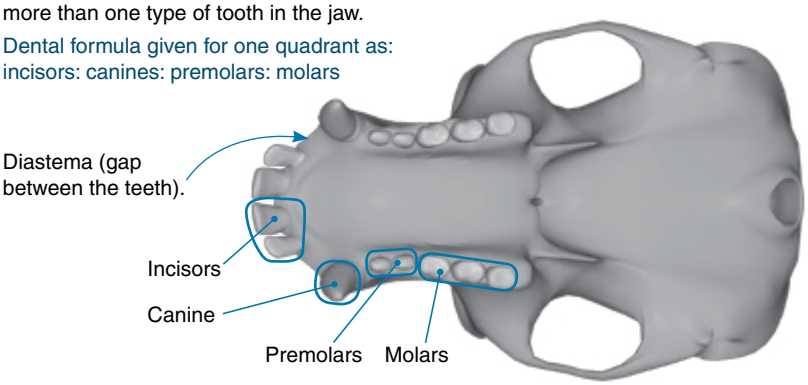
Mammals as a group have a diverse range of diets and this is reflected in their teeth, skull and jaw, and gut.



The chimpanzee skull (right) shows generalist dentition. Chimpanzees are omnivorous and their dentition enables them to process a variety of foods.

Mammals are heterodonts, meaning they have more than one type of tooth in the jaw.

Dental formula given for one quadrant as: incisors: canines: premolars: molars



Dental formulae









The oral cavity is divided into quadrants and the number of teeth in each quadrant given by a dental formula (above right). In humans, the formula is: $\frac{2\,1\,2\,3}{2\,1\,2\,3}$

indicating the number of teeth in the top and bottom jaw (one side of the mouth). Other mammals have different formulae:

Goat	Pig	Dog	Horse
$\frac{0\,0\,3\,3}{3\,1\,3\,3}$	$\frac{3\,1\,3\,3}{3\,1\,3\,3}$	$\frac{3\,1\,4\,2}{3\,1\,4\,3}$	$\frac{3\,1\,4\,3}{3\,1\,4\,3}$

The teeth of mammalian **carnivores** are specialised for gripping prey and slicing and shearing flesh and bone. The canine teeth are adapted to holding prey. The incisors are pointed and the molars modified into carnassials, adapted for shearing.

Herbivorous mammals, especially grazers such as horses, cattle, and sheep, have relatively large incisors for clipping grasses. The canine teeth can be missing and the molars are large, flat, and adapted for chewing and grinding plant material.

The teeth of **omnivorous** mammals are generalised and adapted to biting, tearing, and chewing a variety of food.



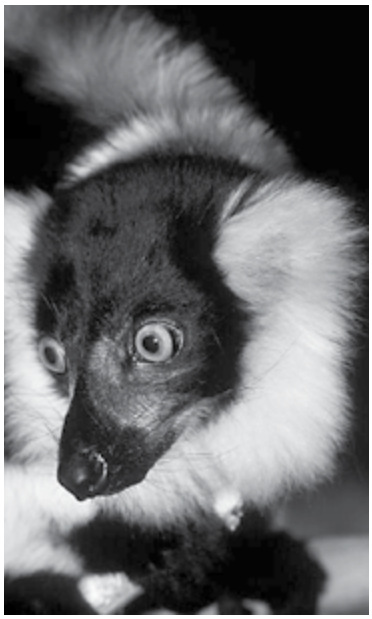
Animal: dolphin
Diet: fish



Animal: lion
Diet: meat



Animal: big horn sheep
Diet: rough vegetation and grasses



Animal: black and white ruffed lemur
Diet: leaves, fruit, flowers, nectar



Animal: zebra
Diet: grasses



Animal: pig
Diet: omnivorous

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1. (a) Match each skull below to its animal (photos opposite, lower panel).
   (b) State the diet. (c) Describe one adaptation to diet that is evident from the skull.

Skull 1:

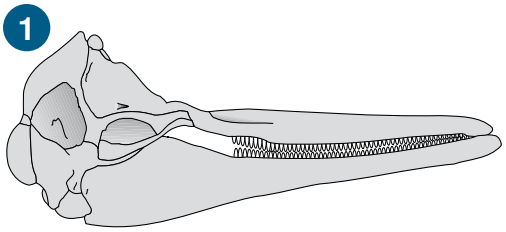
(a) Animal: _____

(b) Diet: _____

(c) Adaptation of teeth to diet: _____

_____

_____



Skull 2:

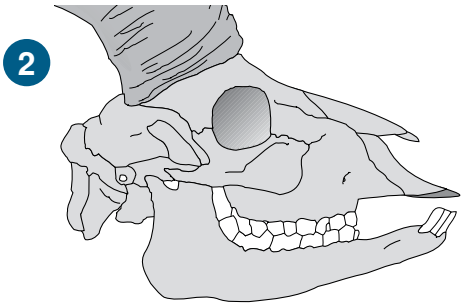
(a) Animal: _____

(b) Diet: _____

(c) Adaptation of teeth to diet: _____

_____

_____



Skull 3:

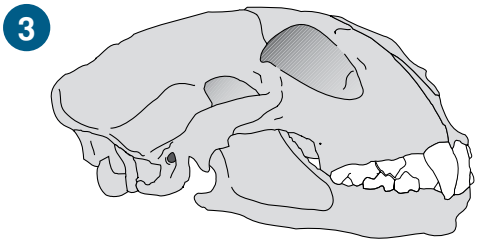
(a) Animal: _____

(b) Diet: _____

(c) Adaptation of teeth to diet: _____

_____

_____



Skull 4:

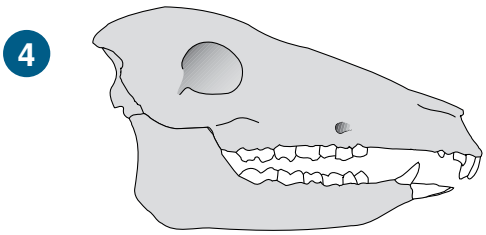
(a) Animal: _____

(b) Diet: _____

(c) Adaptation of teeth to diet: _____

_____

_____



Skull 5:

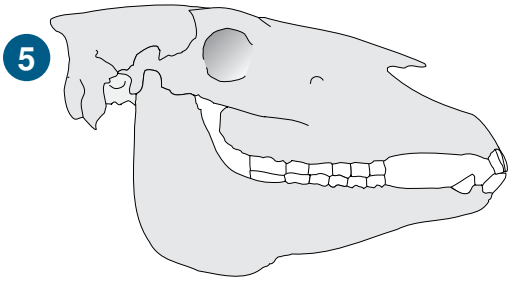
(a) Animal: _____

(b) Diet: _____

(c) Adaptation of teeth to diet: _____

_____

_____



Skull 6:

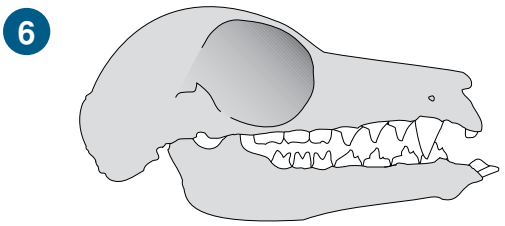
(a) Animal: _____

(b) Diet: _____

(c) Adaptation of teeth to diet: _____

_____

_____



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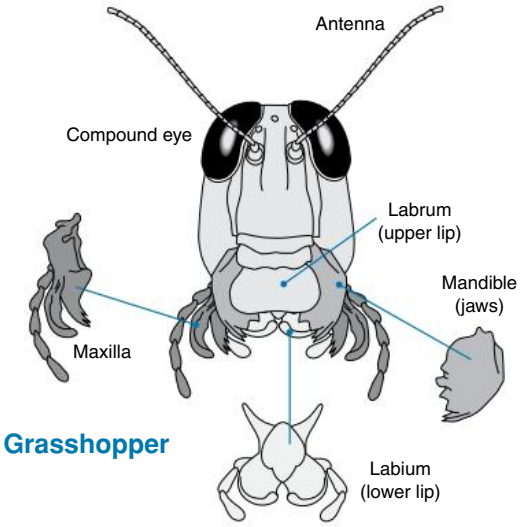
84 Insect Mouthparts

Key Idea: Insect mouthparts consist of the labrum and three sets of modified, paired appendages that are adapted for chewing, lapping, or piercing and sucking food.

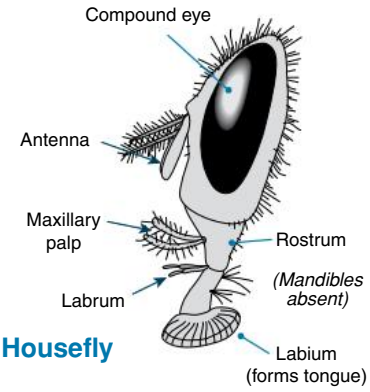
Insect mouthparts consist of the labrum and three sets of modified, paired appendages (the mandibles, maxillae, and labium). They are variously adapted to capture, manipulate, or chew food. In some cases, this has involved loss or fusion of some of the paired appendages. In insects with chewing mouthparts, the **labrum** serves as an upper lip and helps pull food into the mouth. The **mandibles** form the first pair of mouthparts and move from side to side, rather than up and down. They are used as jaws to chew, cut, and tear food, and may also be used to carry things, fight (see right), or to mould wax. The **maxillae** form the second pair of mouthparts and are used for food sensing and handling. The **labium** is a single structure formed from a fused pair of mouthparts. It acts as a lower lip to close the mouth. Both the maxillae and the labium may have finger-like extensions called **palps**.



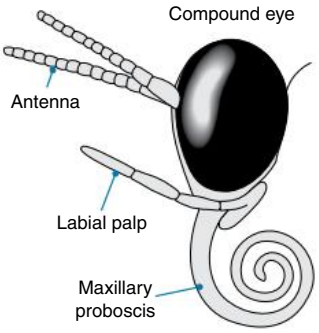
The ferocious-looking mandibles on this stag beetle are not for feeding, but are used for ritualised combat with other stag beetles.



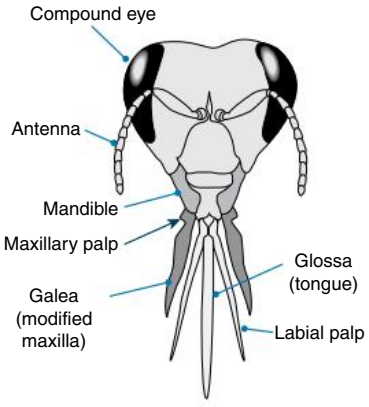
Grasshopper



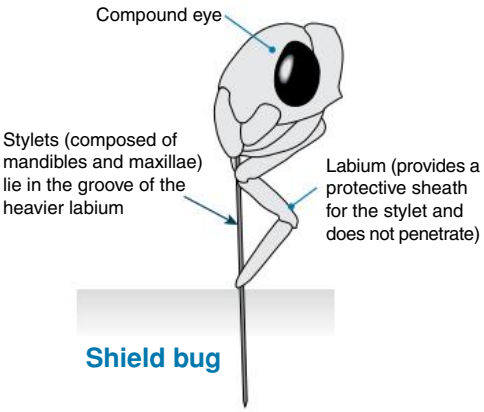
Housefly



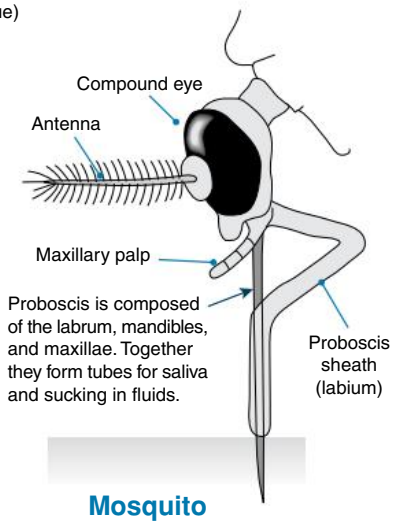
Butterfly



Honey bee (worker)



Shield bug



Mosquito

1. Describe the components of an insect's mouthparts: _____

_____

2. Describe the four main modes of feeding carried out by the various insect groups: _____

_____

3. Match the following list of insects with their correct mode of feeding: *locust, bee, biting fly, moth, mosquito, beetle, cicada, housefly, flea, dragonfly, aphid, maggot.* There may be more than one example for each feeding mode.

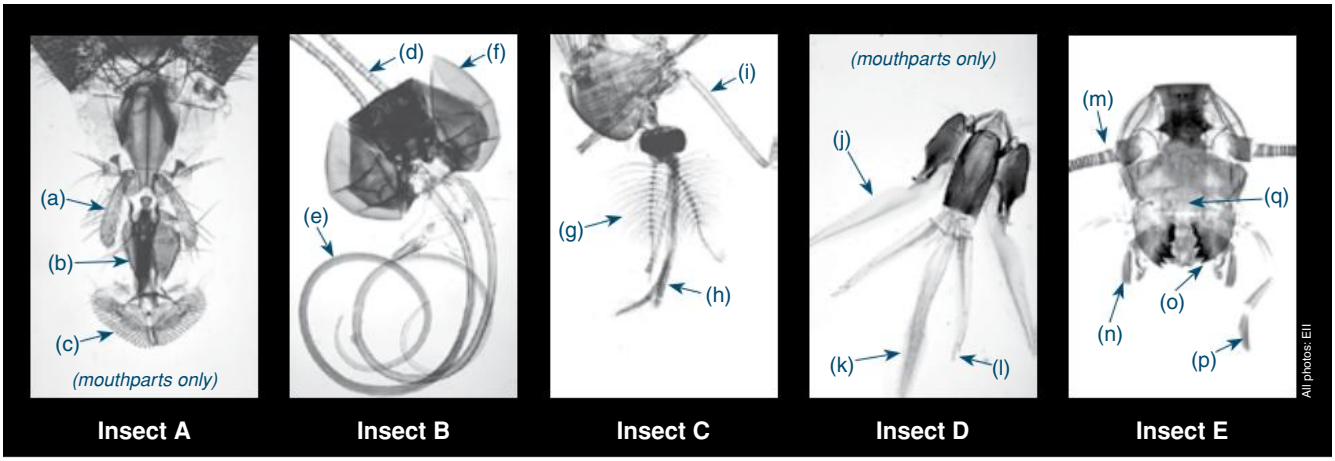
(a) Chewing: _____ (e) Sucking: _____

(b) Sponging: _____ (f) Piercing/sponging: _____

(c) Chewing/lapping: _____ (g) Piercing/sucking: _____

(d) Seizing/chewing: _____ (h) Sucking with mouth hooks: _____

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4. For each of the photographs of insects above (**A - E**), identify the **type of insect** and the structures that are labelled (a)-(q). Note that some of the labelled structures are not mouthparts:

Identity of **insect A**: _____

(a) _____ (c) _____

(b) _____

Identity of **insect B**: _____

(d) _____ (f) _____

(e) _____

Identity of **insect C**: _____

(g) _____ (i) _____

(h) _____

Identity of **insect D**: _____

(j) _____ (l) _____

(k) _____

Identity of **insect E**: _____

(m) _____ (p) _____

(n) _____ (q) _____

(o) _____

5. The diagrams on the right illustrate the arrangement of the mouthparts for various insects. Use highlighter pens to create a colour key and colour in each type of mouthpart.

6. Many insects undergo metamorphosis at certain stages in their life cycle. Butterflies start their active life as caterpillars, after which they pass through a pupal stage, to finally emerge as butterflies. Comment on the diets and changes to the mouthparts of caterpillars and their adult forms (butterflies):

(a) Caterpillar diet: _____

Mouthparts: _____

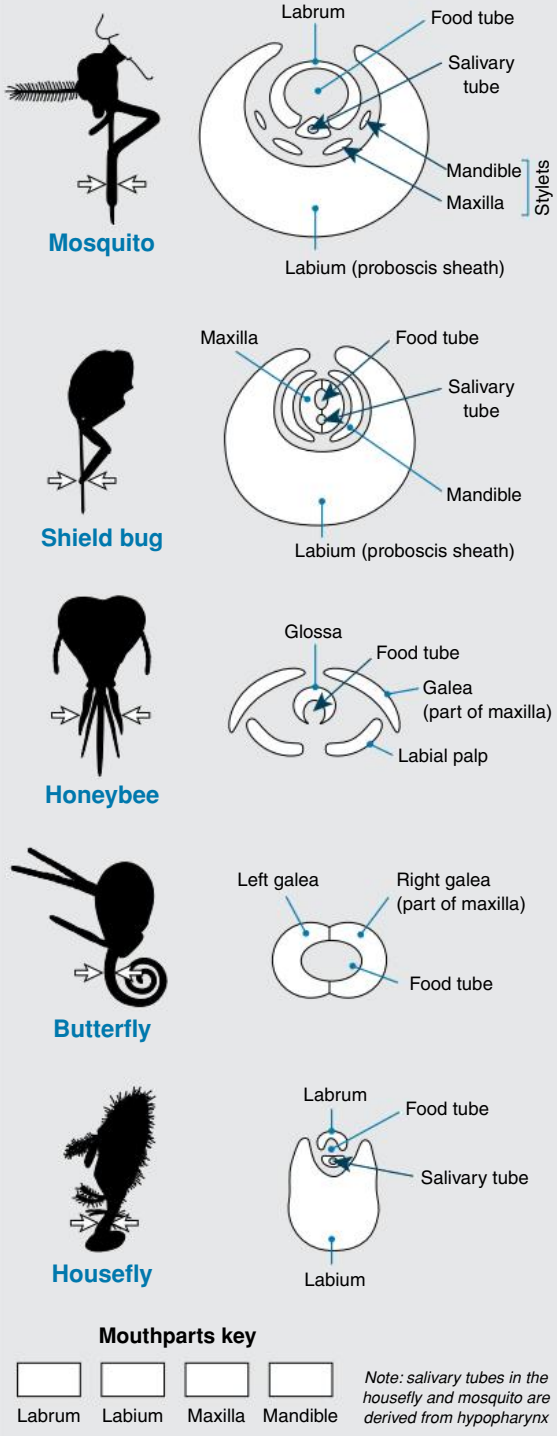
_____

(b) Butterfly diet: _____

Mouthparts: _____

_____

Cross-Section Through Insect Mouthparts



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85 Mammalian Guts

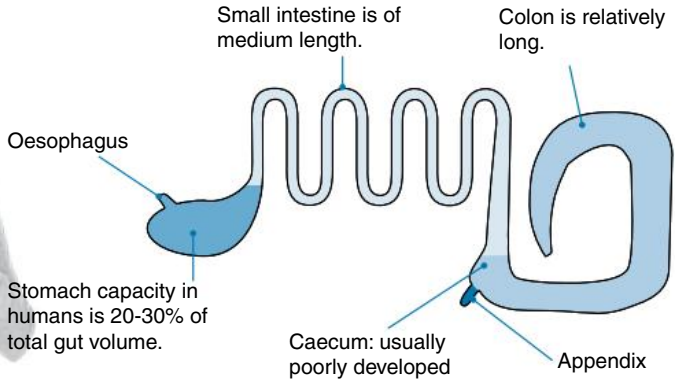
Key Idea: Mammalian gut structure reflects diet. Herbivores tend to have longer guts with larger chambers than carnivores.

The specialisations of the digestive system (gut) in a mammal reflects its particular diet. Among animals, bulky, high fibre diets are harder to digest than diets with very little plant material. Herbivores therefore tend to have longer guts with larger chambers than carnivores. Grazing mammals depend on symbiotic microbes to digest plant cellulose for them. This microbial activity may take place in the stomach (as in grazing ruminants such as cattle), or in the colon and caecum (as in rabbits). The marsupials show equivalent gut adaptations to placentals across all dietary types, with fore- and hind-gut fermenters as well as species that specialise in nectar and fluid feeding.

Omnivore

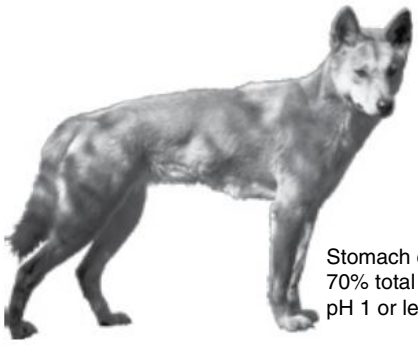
The regional specialisations of omnivore guts vary according to the balance of animal and plant material eaten. In all mammals (and all vertebrates) digestion in the stomach always involves secretion of hydrochloric acid and the protein-digesting enzyme pepsin. Possums and humans are examples of omnivores.

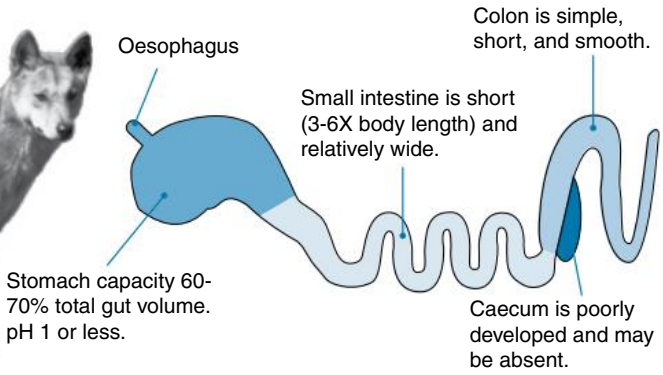




Carnivore

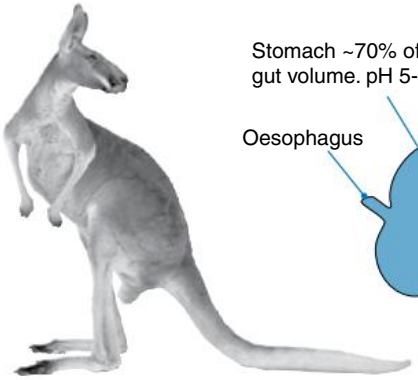
The guts of carnivores e.g. cats and dogs, are adapted for processing animal flesh. They are often large in order to hold large, infrequent meals. Guts and internal organs of killed or scavenged animals are eaten as well as the muscle and provide valuable nutrients. Regions for microbial fermentation are poorly developed or absent.

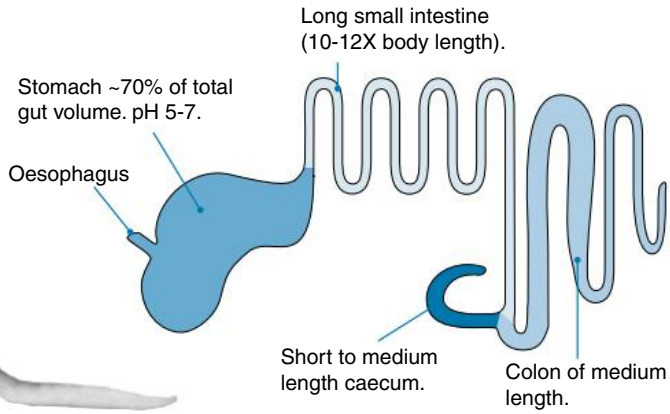




Herbivore: foregut digestion

Kangaroos have a ruminant-like gut, and the stomach is a fermentation chamber where bacteria and protozoan ciliates break down plant cellulose. Volatile fatty acids released by the microbes provide energy, and digestion of the microbes themselves provides the kangaroo with protein. The foregut of a kangaroo is smaller and more tubular than a ruminant, which reduces its weight and increases the rate of food passage.

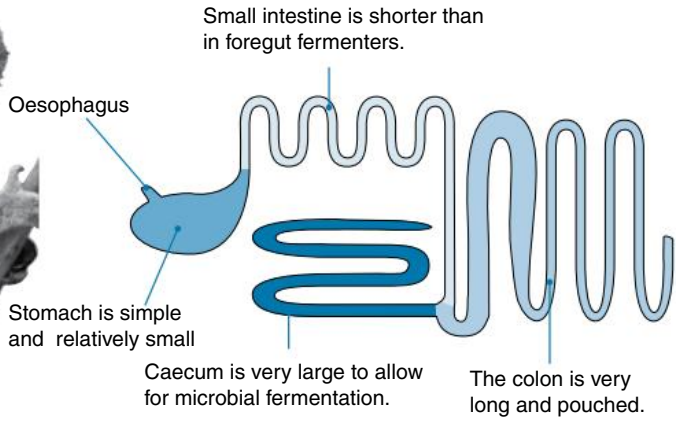




Herbivore: hindgut digestion

The gut of a koala is specialised to process large volumes of eucalypt leaves. The caecum is greatly expanded into a chamber for microbial fermentation of cellulose. It also retains smaller particles for up to 80 hours, allowing lower-grade, large particles to pass through the gut rapidly. This reduces gut residence time and enables the koala to meet its protein needs by eating more.



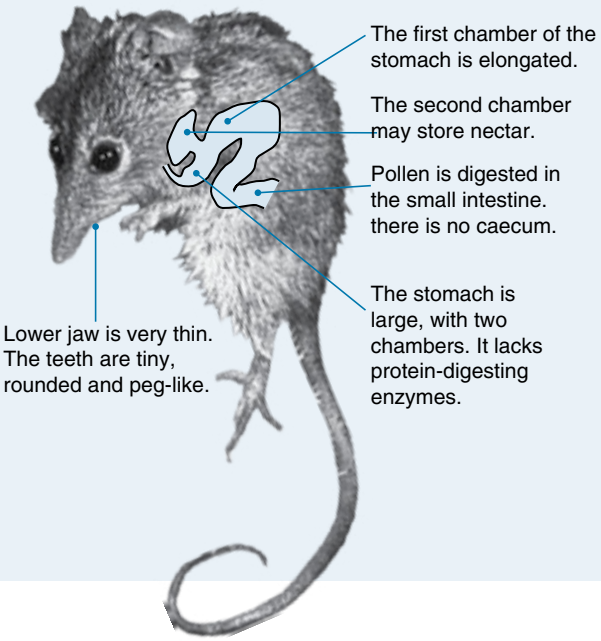


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Nectar Feeding: The Honey Possum

Nectar and pollen form all or most of the diet of six genera of bats (including the Australian blossom bats, *Macroglossus*), and the tiny, highly specialised Australian honey possum *Tarsipes rostratus*, which feeds on the nectar and pollen of banksias. Nectar is a sugary solution of sucrose, glucose, and fructose. Protein is provided by plant pollen. Nectar feeding mammals are important pollinators of paperbarks, bottlebrushes, banksias, and cultivated bananas.

Honey possums are adapted to exploit the nectar and pollen of banksia flowers. Some adaptations of the gut are described on the image (right). An important adaptation of the honey possum is its long, slender, and protrusible tongue, which has a brush-like end. Finger-like projections of the tongue slope to the throat, helping to move nectar and pollen into the mouth.



1. Contrast the gut structure of a carnivore and a herbivore with respect to each of the following:

   (a) Size of stomach (relative to body size): _____

   _____

   (b) Relative length of small intestine: _____

   _____

   (c) Development of hind gut (caecum and colon): _____

   _____

2. (a) What is the role of microbial fermentation in the nutrition of a kangaroo or other foregut fermenter?

   _____

   _____

   (b) What type of herbivorous diet would be less reliant on microbial fermentation? _____

   _____

3. Give two reasons why kangaroos thrive on poor forage in arid regions unsuitable for cattle:

   (a) _____

   (b) _____

4. Contrast the pH of the stomach contents in carnivores and herbivores, and explain the differences:

   _____

   _____

   _____

5. Koalas often have difficulty obtaining sufficient nitrogen, and their ability to survive is dependent on the quality of the forage available, specifically the availability of younger leaves (as opposed to old leaves). Explain this observation:

   _____

   _____

6. Describe two adaptations of the honey possum to its diet, explaining the significance of each:

   (a) _____

   (b) _____

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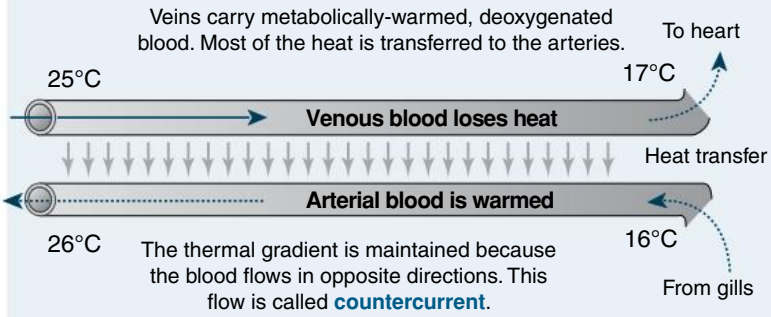
86 Adaptations for Digestion in Fish

Key Idea: Some large predatory fish are able to regulate the temperature of their core organs in order to increase the rate of digestion and maintain an active lifestyle.

Fish are generally **ectothermic**, meaning that their body temperature is dependent on external sources of energy, not metabolism.

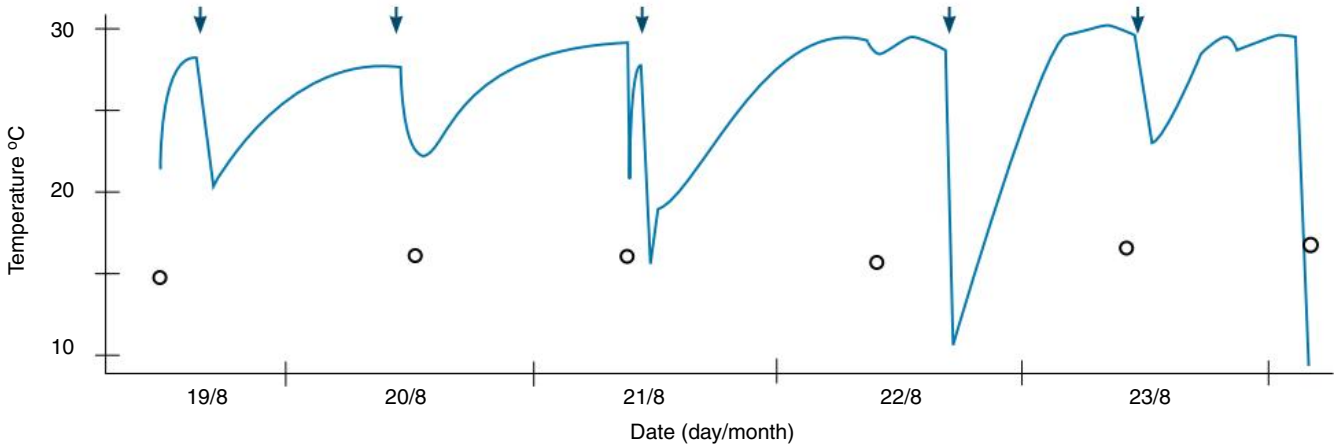
- For most fish, the temperature of the body and the environment are the same. However, some large predatory fish, such as tuna and large sharks, can maintain at least some of the body at temperatures above those of the seawater.
- Increasing body temperature enables them to maintain high levels of activity and process greater quantities of food more rapidly.
- They maintain these higher temperatures, e.g. in the swimming muscle and around the gut, using a **countercurrent network** of blood capillaries.

Countercurrent heat exchange



Blood returning to the heart in veins passes through a network of capillaries running the length of the fish beside the vertebral column. Heat generated by the swimming muscles is transferred from the venous blood returning to the heart to the cold arterial blood passing to the core. In this way, higher core temperatures are maintained and heat loss to the environment is minimised.

Stomach temperature of bluefin tuna (*Thunnus thynnus*)



Tuna stomach temperature ——

Surface water temperature o

Feeding times ↓

The graph above shows the stomach temperature of a bluefin tuna over several days. The tuna was fed with semi-frozen food which caused a sudden drop in its stomach temperature. However, the temperature rapidly increased as the food was digested. It was determined that some of the temperature increase came from the hydrolysis (break down) of the food itself, while the rest came from an increase in metabolic activity.

1. Study the graph above. What is the evidence for endothermy in bluefin tuna? _____

2. What is the advantage of keeping internal organs warm? _____

3. How are countercurrent exchange systems used to raise the temperature of internal organs? _____

KNOW LINK 92 LINK 102

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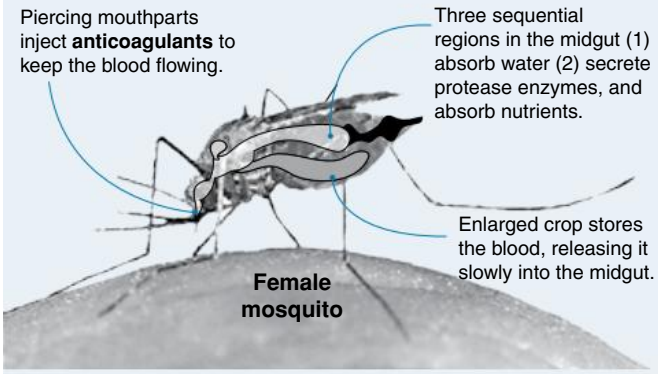
87 Adaptations for Digestion in Insects

Key Idea: The adaptations seen in the digestive systems of different insects reflect their very different diets.

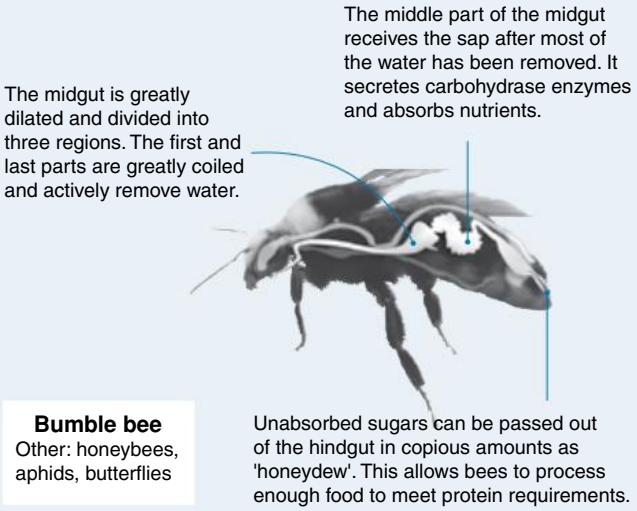
As in all animals, the diets of insects are highly variable. Some foods, such as egg and honey, are concentrated nutriment. Some diets are nutritious but contain a lot of water (e.g. blood), while others are bulky and hard to digest (e.g. vegetation). The structure of the gut in different insect groups reflects their adaptations to particular diets.

Feeding on Fluid

Insects that feed on fluids must be able to store large volumes during feeding and remove the water from the fluid to concentrate it before it is digested.



Blood: A high protein fluid

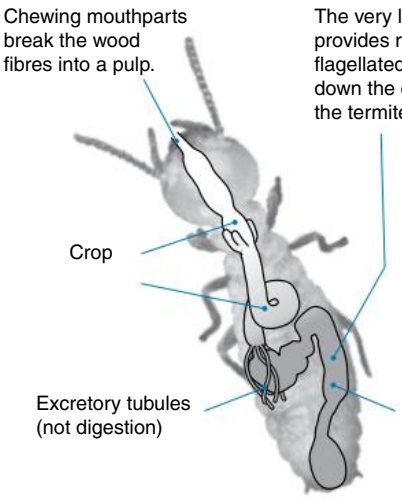


Bumble bee
Other: honeybees, aphids, butterflies

Plant sap: A high volume, low protein fluid

Feeding on Wood

Insects that eat wood rely on microbial populations to break the chemical bonds between the glucose molecules and provide them with molecules they can use.



It's complicated! A symbiont within a symbiont

Termites	Protozoa	Bacteria
Chew and ingest woody material	Engulf wood fibres using phagocytosis	Break down cellulose using cellulase enzymes
Absorb sugars released from protozoan symbionts	Use some sugars and release some to the termite symbiont	Use some sugars and release some to the protozoan symbiont



The flagellated protozoans in the termite gut are very mobile. They are more easily kept as gut residents than free bacteria, which would be lost.

1. Describe one common adaptation of the guts of fluid feeders and its role: _____

_____

_____

2. Summarise features of digestion in termites under the following headings:

(a) Termite's chewing mouthparts: _____

(b) Role of bacteria in the gut: _____

(c) Role of protozoa in the gut: _____

_____

(d) Phagocytosis: _____

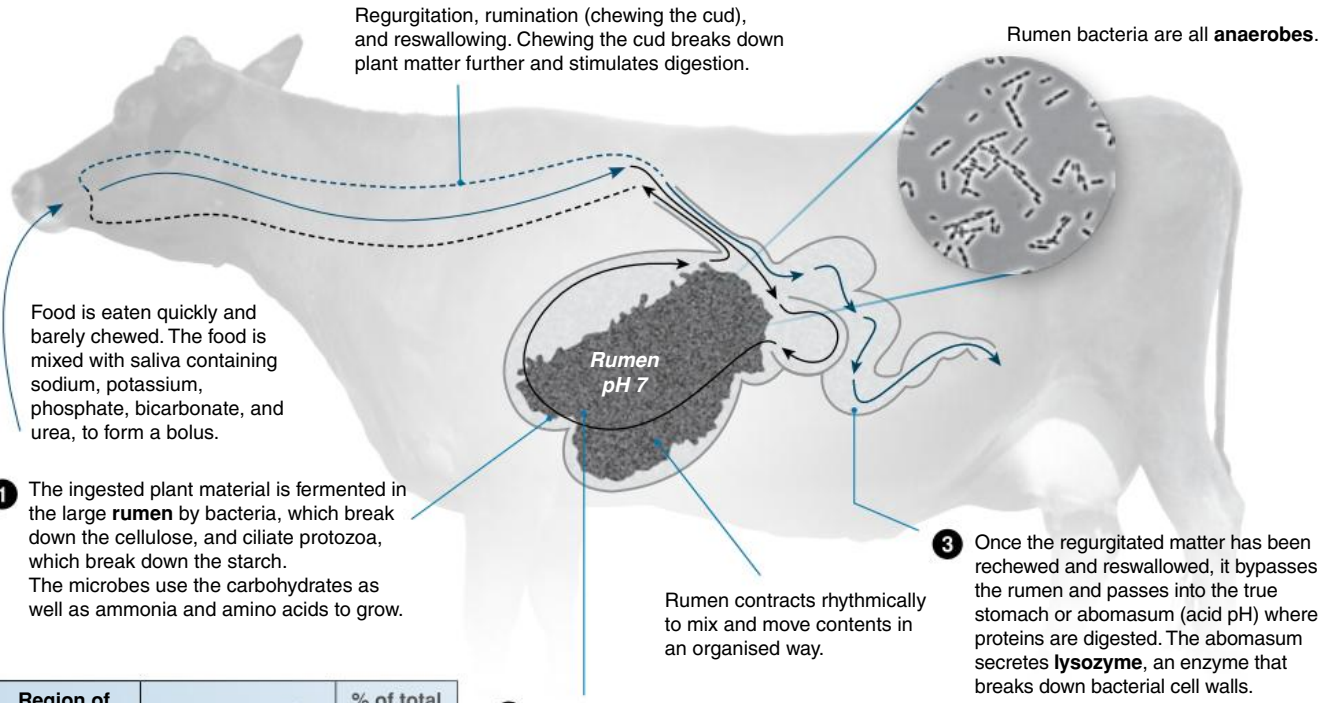
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LINK 91 LINK 88 KNOW

88 Cellulose Digestion in a Ruminant

Key Idea: Ruminants rely on bacteria in the rumen of the stomach to break down cellulose.

Mammals lack the enzymes needed to break the bonds joining the glucose molecules in cellulose. Herbivorous mammals are able to digest cellulose by making use of mutualistic microorganisms in their gut. Ruminants, such as cattle, goats, and sheep, rely on microbes in the rumen to break down the cellulose, regurgitating, rechewing, and reswallowing the partially digested material so that digestion can continue.



Region of stomach	Functional role	% of total volume
Rumen	Microbial fermentation of cellulose to produce VFAs	~84%
Reticulum		
Omasum	Removal of water	12%
Abomasum	Gastric digestion	4%

The rumen and reticulum act as a single chamber and occupy more than 80% of the total volume of the stomach.

2 Fermentation releases **volatile fatty acids** (VFAs), as well as methane, hydrogen sulfide, and carbon dioxide. The VFAs are **absorbed directly from the rumen** and provide up to 70% of the cattle's daily energy needs. The gases are belched out and the remaining matter is regurgitated and rechewed.

The VFAs are transported to the liver and converted to glucose.

Did you know? Bacteria in the rumen also make protein from inorganic nitrogen. Microbes pass into the abomasum and are digested, providing the cattle with up to 100 g of protein a day.

1. Use bullet points to briefly describe the various adaptations of ruminants for digesting cellulose. Identify each of the adaptations you describe as structural, behavioural, or physiological:

2. Explain the purpose of chewing the cud:

3. From what you know of the products of fermentation, suggest why cattle produce vast quantities of alkaline saliva:

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89 Cellulose Digestion in a Hindgut Fermenter

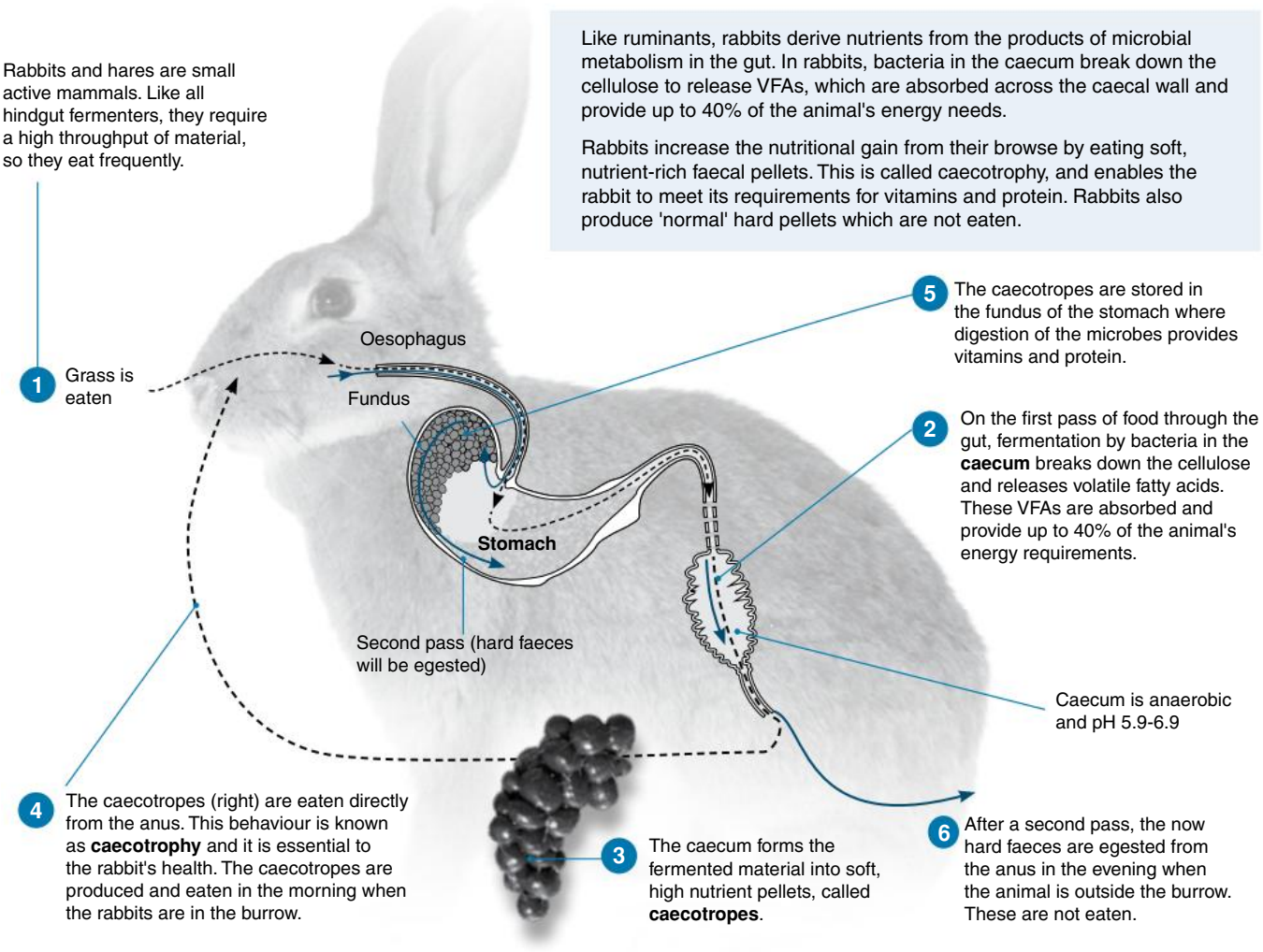
Key Idea: In hindgut fermenters, microbial breakdown of cellulose occurs in the large intestine.

Hindgut fermenters, such as horses and rodents, house their cellulose-digesting microorganisms in the hindgut, rather than the foregut like ruminants. Rabbits have a further strategy, called caecotrophy, which enhances their nutritional gain from the food ingested. In **caecotrophy**, some faeces are reingested to be processed for a second time.

Like ruminants, rabbits derive nutrients from the products of microbial metabolism in the gut. In rabbits, bacteria in the caecum break down the cellulose to release VFAs, which are absorbed across the caecal wall and provide up to 40% of the animal's energy needs.

Rabbits increase the nutritional gain from their browse by eating soft, nutrient-rich faecal pellets. This is called caecotrophy, and enables the rabbit to meet its requirements for vitamins and protein. Rabbits also produce 'normal' hard pellets which are not eaten.

Rabbits and hares are small active mammals. Like all hindgut fermenters, they require a high throughput of material, so they eat frequently.



1 Describe the nature of the mutualistic relationship between hind-gut fermenters and their gut microbes:

2. Explain the adaptive value of a daily rhythm for hard and soft faeces production in rabbits:

3. Use bullet points to briefly describe the various adaptations of rabbits for digesting cellulose:

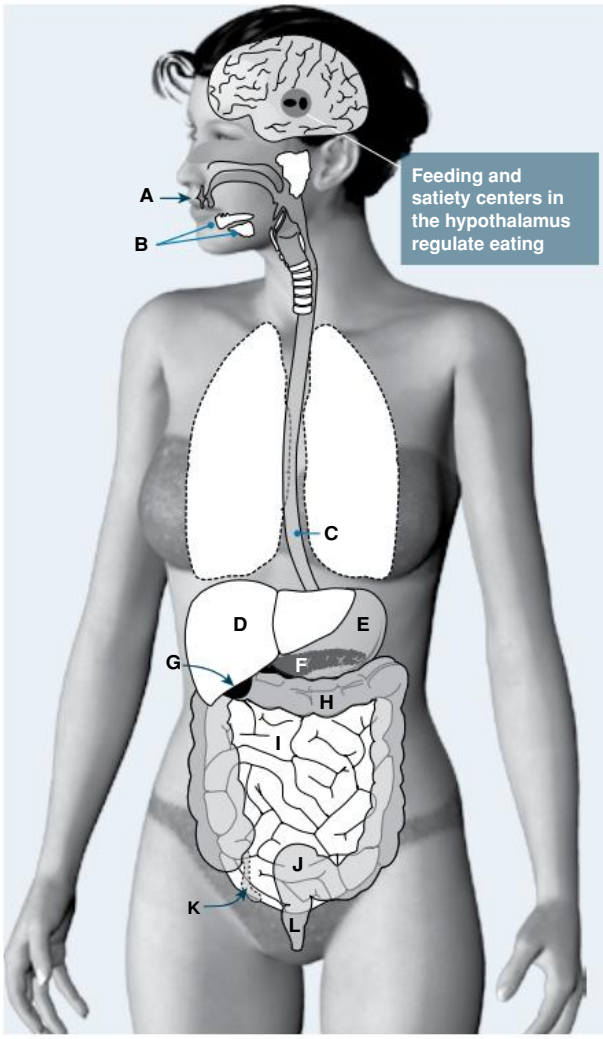
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90 The Human Digestive Tract

Key Idea: The digestive tract is specialised to maximise the digestion of food, absorption of nutrients, and elimination of undigested material.

The human digestive tract is a tube gut and is regionally specialised to maximise the efficiency of physical and chemical breakdown (digestion) of food, absorption, and elimination. The gut is essentially a hollow, open-ended, muscular tube, and the food within it is essentially outside the body, having contact only with the cells lining the tract. Food is moved through the gut tube by waves of muscular contraction (peristalasis), and is broken down by enzymes. The products of this breakdown are then absorbed across the gut wall. Several organs associated with the gut produce secretions, to aid the digestive process.



Structures of the Human Gut

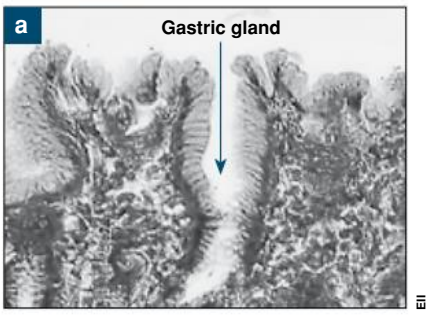
Word list: *Liver, small intestine, gall bladder, stomach, salivary glands, colon (large intestine), oesophagus, pancreas, mouth and teeth, anus, rectum, appendix.*

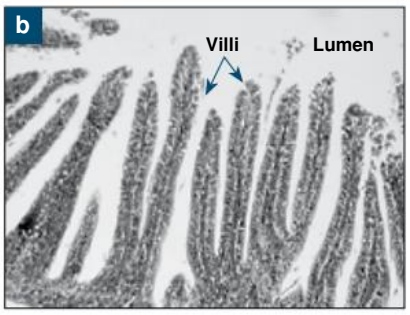
A	G
B	H
C	I
D	J
E	K
F	L

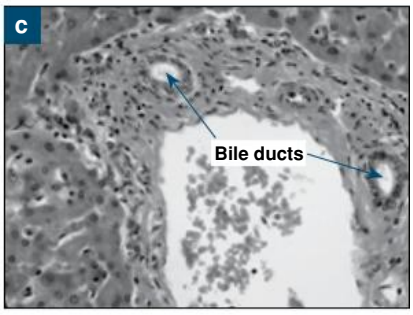
The Functions of Gut Structures

In the boxes provided, write the letter (A-L) that represents the part of the gut responsible for each of the functions summarised below:

- ☐ (a) Main region for enzymatic digestion & nutrient absorption
- ☐ (b) Consolidation of the faeces before elimination
- ☐ (c) Main function (humans) is water and mineral absorption
- ☐ (d) Secretes acid and pepsin, stores and mixes food
- ☐ (e) A gland which produces an alkaline, enzyme-rich fluid
- ☐ (f) Produces bile and has many homeostatic functions
- ☐ (g) Produces saliva which contains the enzyme amylase







1. In the spaces provided on the diagram above, identify the parts labeled **A-L** (choose from the word list provided). Match each of the **functions** described (a)-(g) with the letter representing the corresponding structure on the diagram.
2. On the same diagram, mark with lines and labels: anal sphincter (**AS**), pyloric sphincter (**PS**), cardiac sphincter (**CS**).
3. Identify the region of the gut illustrated by the photographs (a)-(c) above. For each one, explain the identifying features:

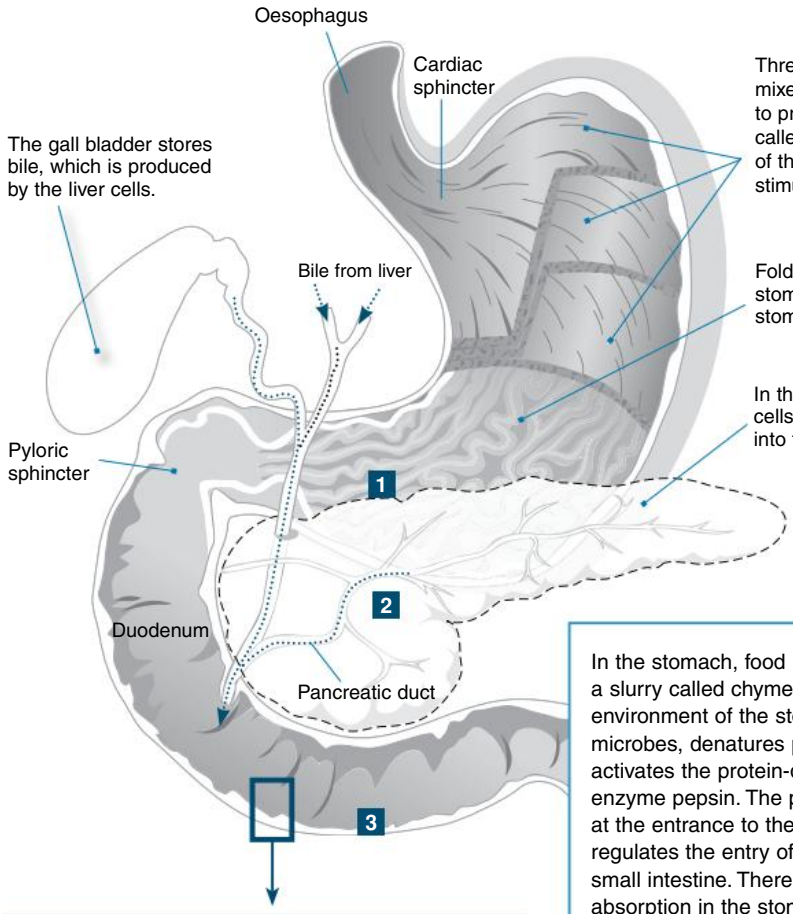
   (a) _____

   (b) _____

   (c) _____

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The Stomach, Duodenum, and Pancreas



Three layered muscular wall mixes the stomach contents to produce a soupy mixture called chyme. Stretching of the stomach wall is a stimulus for gastric secretion.

Folds (rugae) in the stomach wall allow the stomach to expand to 1L.

In the pancreas, the acinar cells secrete an alkaline fluid into the pancreatic duct.

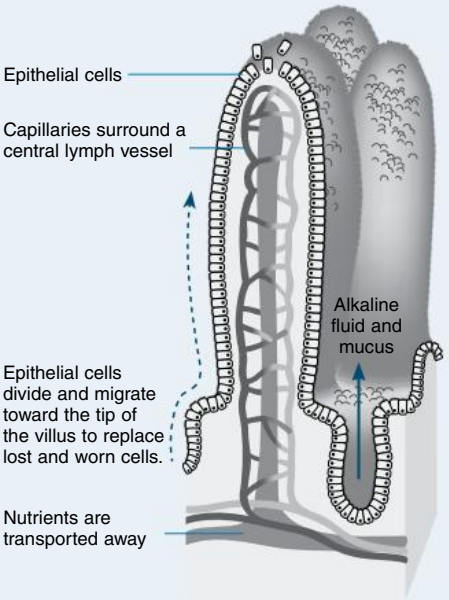
In the stomach, food is mixed to a slurry called chyme. The acid environment of the stomach destroys microbes, denatures proteins, and activates the protein-digesting enzyme pepsin. The pyloric sphincter, at the entrance to the duodenum, regulates the entry of chyme into the small intestine. There is very little absorption in the stomach, but very small molecules (glucose, aspirin, alcohol) are absorbed directly across the stomach wall into the gastric blood vessels surrounding the stomach.

Enzymes and their actions

1 Gastric juice	
Acts in stomach (optimal pH)	
Pepsin (1.5-2.0)	
Protein → peptides	
2 Pancreatic juice	
Acts in duodenum (optimal pH)	
1. Pancreatic amylase (6.7-7.0) 2. Trypsin (7.8-8.7) 3. Chymotrypsin (7.8) 4. Pancreatic lipase (8.0)	
1. Starch → maltose 2. Protein → peptides 3. Protein → peptides 4. Fats → fatty acids & glycerol	
3 Intestinal juice	
Acts in small intestine (optimal pH)	
1. Maltase (6.0-6.5) 2. Peptidases (~ 8.0)	
1. Maltose → glucose 2. Polypeptides → amino acids	

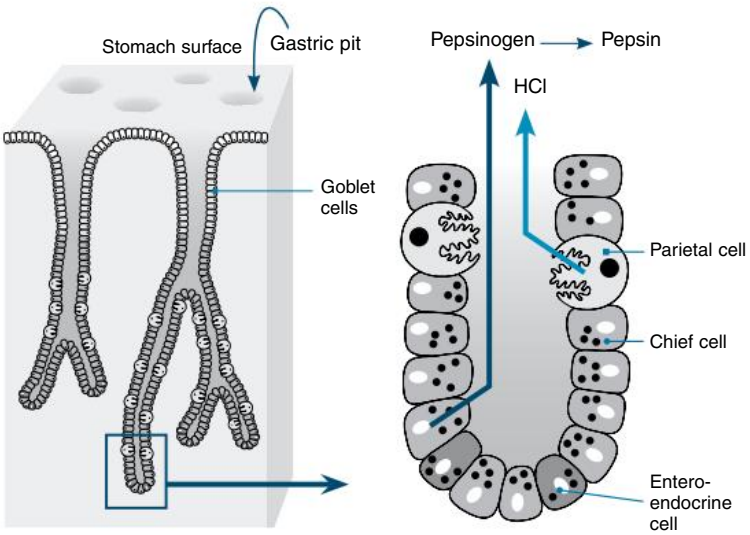
Detail of a Villus (Small Intestine)

The **intestinal villi** project into the gut lumen and provide an immense surface area for nutrient absorption. The villi are lined with **epithelial cells** and each has a brush border of many **microvilli** which further increase the surface area.



Enzymes bound to the surfaces of the epithelial cells break down peptides and carbohydrate molecules. The breakdown products are then absorbed into the underlying blood and lymph vessels. Tubular exocrine glands and goblet cells secrete alkaline fluid and mucus into the lumen.

Detail of a Gastric Gland (Stomach Wall)

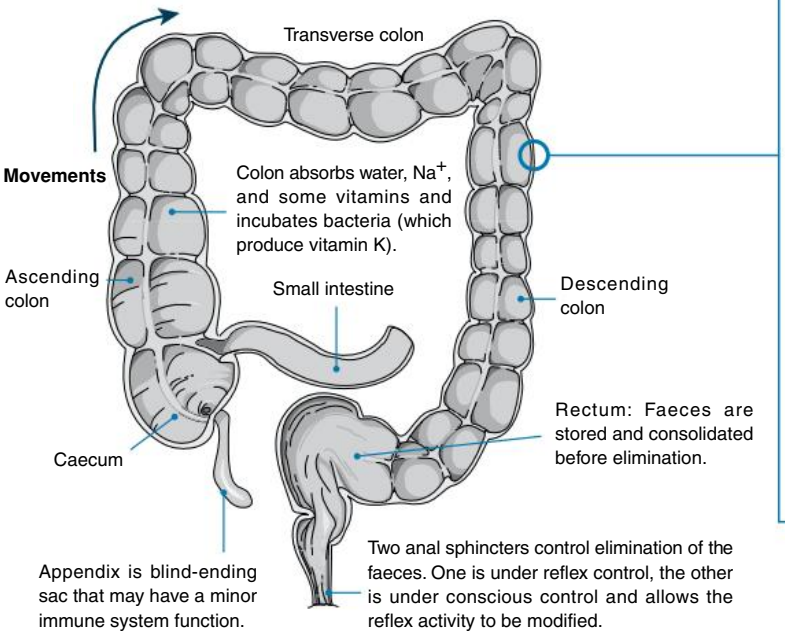


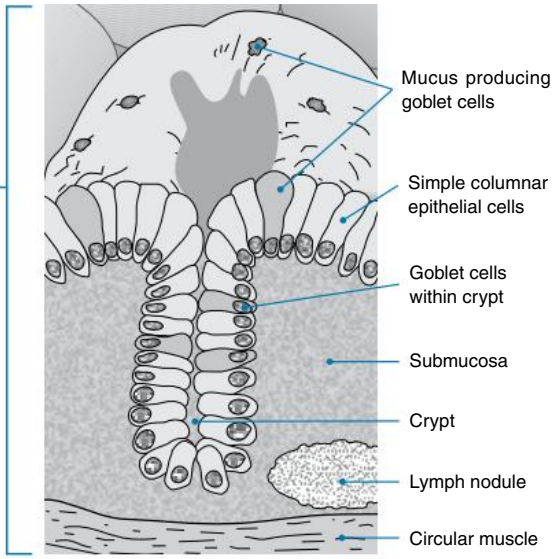
Gastric secretions are produced by **gastric glands**, which pit the lining of the stomach. Chief cells in the gland secrete pepsinogen, a precursor of the enzyme pepsin. Parietal cells produce hydrochloric acid, which activates the pepsinogen. Goblet cells at the neck of the gastric gland secrete mucus to protect the stomach mucosa from the acid. Enteroendocrine cells in the gastric gland secrete the hormone gastrin which acts on the stomach to increase gastric secretion.

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The Large Intestine

After most of the nutrients have been absorbed in the small intestine, the remaining fluid contents pass into the large intestine (appendix, caecum, and colon). The fluid includes undigested or undigestible food, bacteria, dead cells, mucus, bile, ions, and water. The large intestine's main role is to reabsorb water and electrolytes.





The wall of the large intestine is lined with simple columnar epithelium. The epithelium is contains tubular glands called crypts containing mucus-secreting goblet cells. The mucus lubricates the colon wall and aids formation of the faeces.

4. Summarise the structural and functional specialisations in each of the following regions of the gut:

   (a) Stomach: _____

   _____

   (b) Small intestine: _____

   _____

   (c) Large intestine: _____

   _____

5. Identify two sites for enzyme secretion in the gut, give an example of an enzyme produced there, and state its role:

   (a) Site: _____ Enzyme: _____

   Enzyme's role: _____

   (b) Site: _____ Enzyme: _____

   Enzyme's role: _____

6. (a) Suggest why the pH of the gut secretions varies at different regions in the gut: _____

   _____

   (b) Why are protein-digesting enzymes (e.g. pepsin) secreted in an inactive form and then activated after release:

   _____

7. (a) How is food moved through the digestive tract? _____

   _____

   (b) How is this movement of food through the gut regulated? _____

   _____

8. (a) Predict the consequence of food moving too rapidly through the gut: _____

   (b) Predict the consequence of food moving too slowly through the gut: _____

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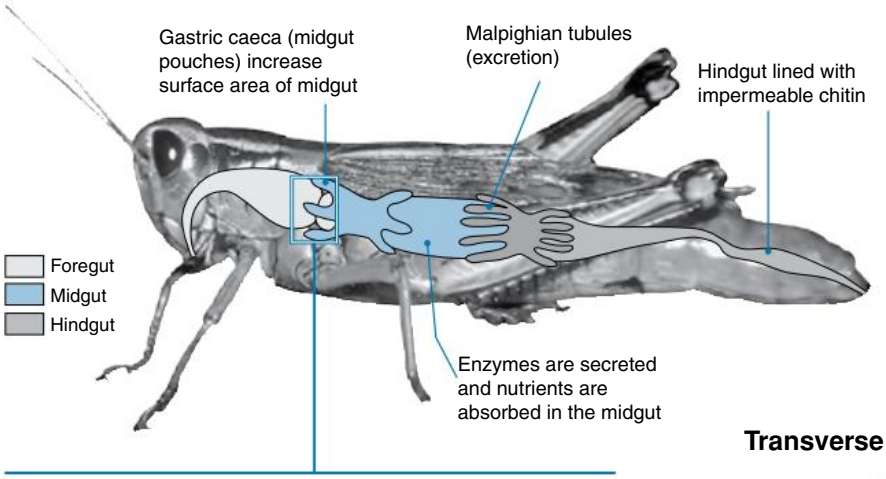
91 Adaptations for Absorption in Insects

Key Idea: In insect guts, nutrient absorption can only occur in the midgut. Gastric caeca increase the midgut's surface area.

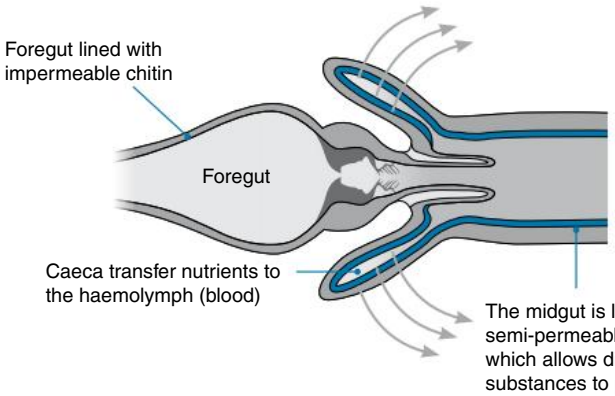
The components of food must be absorbed across the gut wall before they can be assimilated (taken up by the body's cells). Adaptations that increase the surface area of the gut increase rates of nutrient absorption so that more food can be processed more quickly. Many insects have gut pouches called **caeca** that do this.

Insect Gastric Caeca

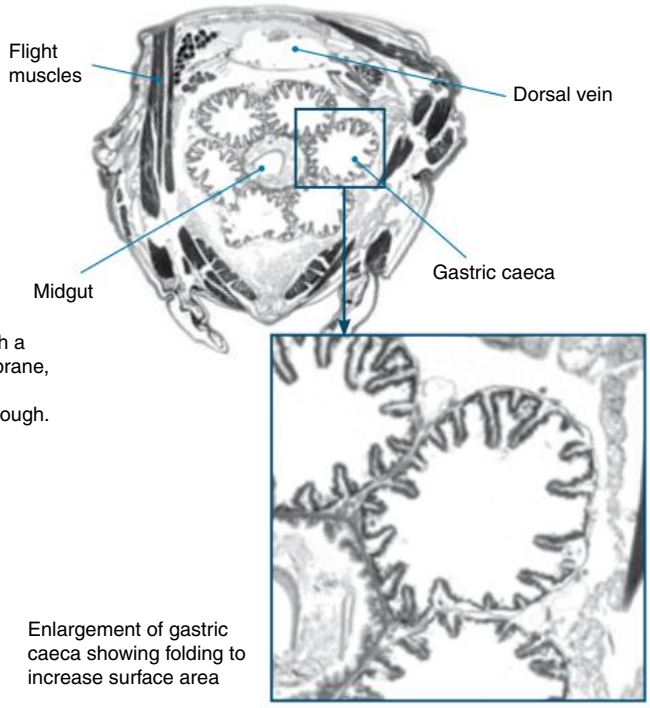
Examples: Grasshoppers, cockroaches



- Gut pouches and folds increase the gut surface area, providing a larger area across which nutrients can be absorbed.
- Increased gut surface area increases the efficiency with which food can be processed. This can be especially important when an animal needs to process a lot of food quickly, e.g. to take advantage of seasonal abundance of food or to support a high growth rate.
- Nutrients are absorbed by diffusion or active transport and transported away in the blood or haemolymph.



Transverse section through locust thorax



Enlargement of gastric caeca showing folding to increase surface area

In grasshoppers and their relatives, the **gastric caeca** are midgut pouches just behind the gizzard. The caeca improve absorption by transferring nutrients into the haemolymph ('blood'). The membrane lining the midgut is continually lost, surrounding the faecal pellets when they are passed out. The membrane is replaced by the underlying epithelial cells (much like our skin).

1. In which part of the insect gut does enzyme secretion occur? _____
2. In which part of the insect gut does absorption occur? _____
3. What structure in insects increases the surface area for absorption? _____
4. What prevents nutrient absorption in other parts of the gut? _____

_____

5. What is the adaptive value (the advantage) of increasing the surface area available for nutrient absorption?

_____

_____

_____

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LINK 87 LINK 81 KNOW

92 Adaptations for Absorption in Fish

Key Idea: Cartilaginous fish increase nutrient absorption by increasing the time food spends in the gut. Bony fish have pyloric caeca to increase the surface area for absorption.

The guts of fish are relatively short compared with most mammalian guts and there is less regional specialisation. However, many fish have adaptations to increase the surface area of the gut for absorption and retaining food until it has been fully digested.

Intestinal spiral valve

Examples: cartilaginous fish, e.g. sharks, rays

The streamlined shape of sharks (and most other fish) makes it difficult to fit a long intestine into the body. Cartilaginous fish, such as sharks, as well as primitive bony fish, solve this problem by having a short intestine with a spiralling fold in the inner wall. This **spiral valve** increases the length of time digested material remains in the intestine by effectively increasing the intestine's length. This enables the fish to process large infrequent meals. The spiral valve also prevents large masses of indigestible material passing into the intestines.

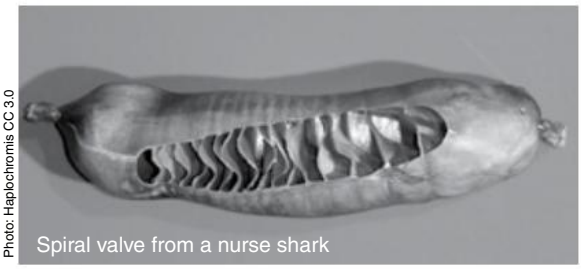
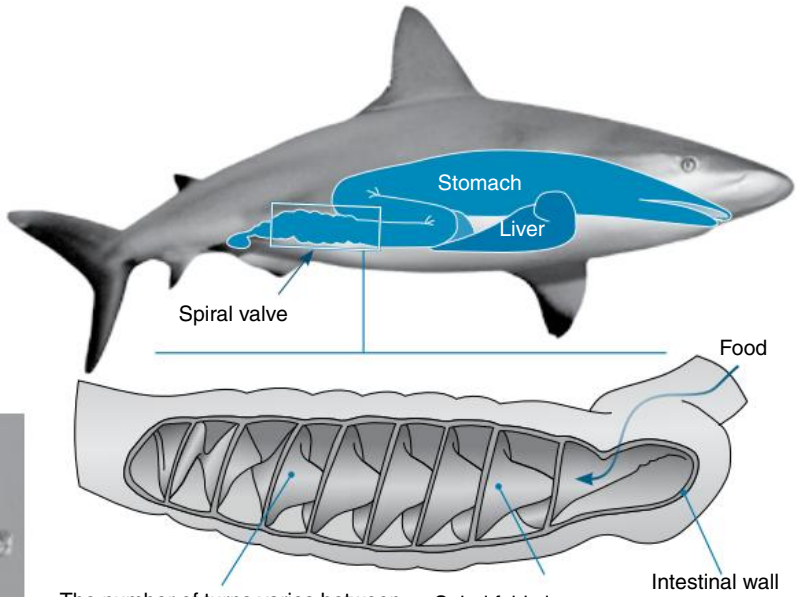


Photo: Haplochromis CC 3.0

Spiral valve from a nurse shark



The number of turns varies between 5 and 50 depending on diet and activity level of the species.

Spiral folds increase surface area for nutrient absorption

Pyloric caeca

Example: most bony fish

In most bony fish, the elongated intestines are folded back on themselves in coils. At the junction of the stomach and intestine are tube-like outgrowths called pyloric caeca which increase gut surface area and appear to have a function in enzyme secretion and nutrient absorption.

Most bony fish have several hundred pyloric caeca and they are more developed in carnivores, especially those with short guts.

Gut of bony fish showing the pyloric caeca, which open into the first part of the intestine

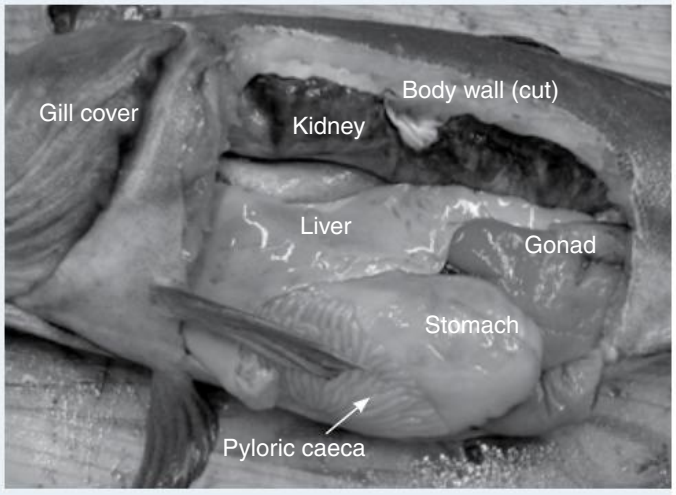


Photo: H Dahlmo CC3.0

1. Describe the adaptations of cartilaginous and bony fish to increase the surface area of the intestine: _____

2. Name one factor that might determine the extent to which surface area is increased. Explain your reasoning: _____

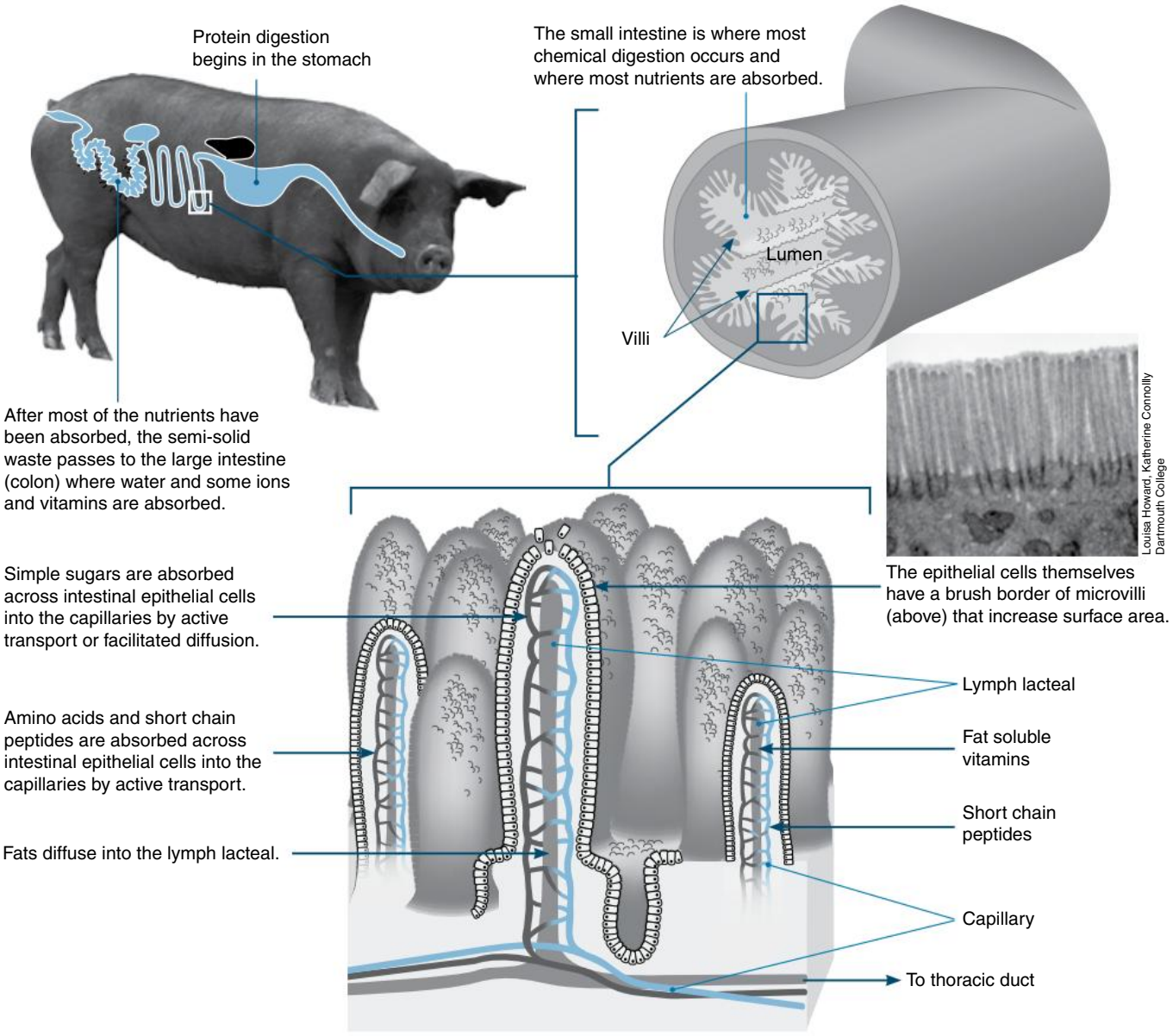
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93 Adaptations for Absorption in Mammals

Key Idea: The small intestine of mammals is folded into finger-like structures called villi, which increase the surface area of the intestine for nutrient absorption.

The simple molecules that result from digestion are absorbed across the intestinal wall. The intestine is notable for two features. Firstly, the intestinal wall is folded into microscopic finger-like structures called villi. Secondly, each of the epithelial cells lining the intestine has a border of microvilli. These features increase the surface area for absorption of nutrients into the blood



1. Describe how absorption of nutrients is maximised in the gut of a mammal: _____

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94 Parasitism

Key Idea: Parasites obtain their nutrition from a host, with detrimental effects to the host.

Parasitism is the most common type of symbiosis (a term that means "living together") and a specialised way to obtain nutrients. Parasites always harm their host, but do not usually kill it. The parasite benefits by obtaining nutrition, but there are often other advantages, such as protection. Animal parasites are highly specialised carnivores, feeding off the body fluids or skin of host species. **Parasitoids** are animals adapted to spend only part of their life cycle as a parasite, killing and often consuming the host before leaving for a free-living (non-parasitic) adult stage.

The **emerald cockroach wasp**: a small parasitoid with a strategy to subdue its host species.

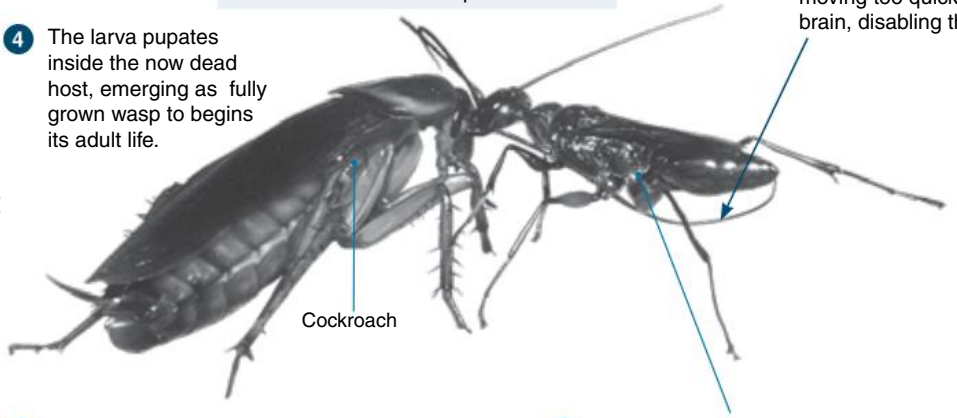


Photo: Radiogaga

1. The wasp stings and paralyses the front legs of the cockroach to stop it moving too quickly, then stings the brain, disabling the escape reflex.
2. The wasp leads the cockroach to its burrow by tugging on the cockroach's antennae.
3. Once Inside the burrow, the wasp lays an egg on the cockroach's abdomen. The larva hatches and lives inside the roach, eating its organs in an order that ensures the host remains alive long enough for the larva to complete development.
4. The larva pupates inside the now dead host, emerging as fully grown wasp to begins its adult life.

The bed bug (*Cimex*) is an **ectoparasite**, meaning it lives and feeds on the outside of its host. Bed bugs are fluid feeders, feeding mostly at night on human blood, piercing the skin with a long sucking beak.





Vampire bat (*Desmodus rotundus*)

Vampire bats are sometimes called the only mammalian parasite. They have many features of parasites: they are specialised for feeding on blood and do not kill their host. However, they do not live on the host, but return to a roost when they have finished feeding.



Male anglerfish

Animals are not always parasites of other species. Male deep sea anglerfish seek out the much larger females and attach to them by biting and holding on to their skin. They then regress as they merge with the female, becoming little more than a sperm-producing appendage.



NOAA

Sea lampreys attached to host fish

Lampreys are jawless fishes that feed by attaching to the flanks of a fish with their rubbery sucker mouthparts. They scrape away the skin with their teeth and then suck the body fluids from the host. Lampreys can swim, but do not need to while attached to the host.

1. (a) How does a parasitoid differ from a true parasite? _____

_____

(b) Using the emerald cockroach wasp as an example, explain the close relationship a parasitoid has with its host:

_____

_____

2. Suggest why many insect parasites are also vectors of disease: _____

_____

3. Give reasons for and against the classification of vampire bats as parasites: _____

_____

_____

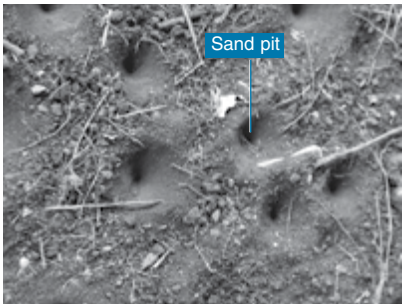
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95 Adaptations of Predators

Key Idea: Predators have adaptations to capture and consume prey.

A **predator** is any animal that hunts, captures, and consumes prey. In most cases, the predator and prey are different species, but some species are cannibalistic (consume the same species). Predators have adaptations for locating prey (e.g. vibration sense, vision, hearing), capturing and subduing it (e.g. traps or lures, speed, camouflage, claws), and then consuming and digesting the flesh or fluids (e.g. teeth, low stomach pH).





Traps and lures allow predators to wait in ambush for their prey. **Antlion larvae** build pits in sand as insect traps. The larva waits at the bottom of the pit (photo, top), buried in the soil with only the jaws projecting above the surface, often open wide (above). The loose sand of the pit sides makes it difficult for insects to escape once they have fallen in, and they are quickly captured.

Anglerfish also use lures to attract prey. The lure is a fleshy growth extending over the fish's head. A reflex closes the jaw on the prey as soon as the lure is touched.



Echolocation ('sonar') enables bats to hunt their insect prey while flying at night. Sonar allows the flying bat to locate the exact position of its prey even when both prey and predator are in flight. Some bats (above) also hunt on the ground amongst the leaf litter, but only use sonar for location of prey in the air.





Concealment and ambush are common strategies amongst insect predators. Mantids are well camouflaged against the vegetation in their environment. Unsuspecting prey are ambushed and captured with a rapid movement of the highly specialised, elongated forelegs.

Speed, agility, and cooperation enable dolphins to hunt together to exploit large schools of fish. The dolphin group will encircle a large school of fish, driving them together into a dense mass or bait ball. The dolphins then take turns to charge through the school to feed. Dolphins use echolocation to navigate and to locate prey.

1. (a) Describe the role of camouflage in the predatory strategy of ambush predators such as mantids:

(b) Describe some other adaptations commonly associated with prey capture in ambush predators:

2. Describe the adaptations of antlion larvae for prey capture and identify them as structural, behavioural, or physiological:

3. Describe the adaptations of dolphins for prey capture and identify them as structural, behavioural, or physiological:

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96 KEY TERMS: Did You Get It?

1. Describe the difference between an autotroph and an heterotroph: _____

2. (a) Write a word equation for photosynthesis: _____

   (b) In which organelle does photosynthesis take place: _____

   (c) Name the two reactions of photosynthesis and state exactly where they take place: _____

3. In which region of a tube gut do each of the following four processes occur?

   (a) Ingestion: _____ (c) Absorption: _____

   (b) Digestion: _____ (d) Egestion: _____

4. (a) What structures from the intestine of a mammal are shown in the photograph (right)?

   _____

   (b) What is their function? _____



5. Match the words below with their definitions:

absorption	
bulk feeding	
dentition	
deposit feeding	
digestion	
egestion	
filter feeding	
ingestion	
intestinal villi	
large intestine	
small intestine	

A A feeding method in which large parts of an organism are eaten at once.

B The process of obtaining food via trapping it in a system of filters, such as those formed by projections on the gill arches.

C Finger-like projections lining the surface of the intestine that increase the surface area for absorption.

D The feeding method in which soil is eaten to obtain the food particles within.

E The kind, number, and arrangement of the teeth in the tooth rows.

F The first part of the intestine comprising the duodenum, jejunum and ileum. It is the main site for digestion and absorption of nutrients.

G The second part of the intestine comprising the appendix, caecum and colon.

H The chemical breakdown of food.

I The process of eliminating undigested food from the gut.

J The process by which the products of digestion move across a gut lining into the blood or lymph.

K The taking in of fluid or food into the body (by drinking or eating).

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QLD As required
VCE Unit 1 (2)
WA ATAR Unit 2
SA Theme O

Gas Exchange

Key terms

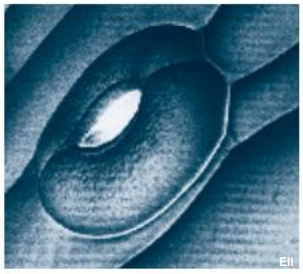
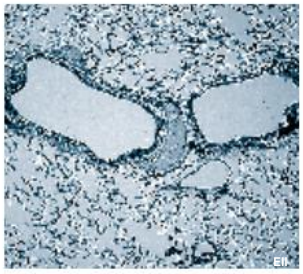
alveoli
breathing
bronchi
bronchioles
carbon dioxide
cellular respiration
chlorocruorin
countercurrent flow
expiration (exhalation)
extraction rate
gas exchange
gills
guard cells
haemerythrin
haemocyanin
haemoglobin
inspiration (inhalation)
lenticels
lungs
mesophyll
mesophyte
oxygen
respiration
respiratory gas
respiratory pigment
spiracles
stomata
tracheae
ventilation
xerophyte

Principles of gas exchange

Learning aims and skills

Activity number

- ☐ 1 Distinguish between cellular respiration and gas exchange and explain why organisms must exchange respiratory gases with their environment. Summarise cellular respiration, indicating the raw materials used and waste products. — 97
- ☐ 2 Describe the essential features of gas exchange surfaces and their significance in terms of gas exchange rates. Explain the significance of the surface area: volume ratio in organisms to the exchange of gases with the environment. — 97
- ☐ 3 Describe how gases are exchanged across gas exchange surfaces. Explain the constraints the environment places on animal gas exchange systems. — 98 100

Gas exchange in plants

Learning aims and skills

Activity number

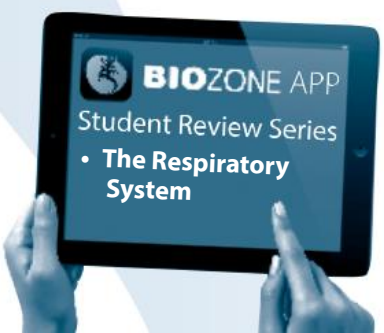
- ☐ 4 Identify the gases that plants exchange with their environment. Identify the particular gas exchange problems of plants in different environments. — 98 99
- ☐ 5 Describe movement of gases into and out of the mesophyll. Describe the location, structure, and role of stomata and lenticels in gas exchange. Describe how water loss is an inevitable consequence of gas exchange in plants. — 98 99
- ☐ 6 Describe and explain adaptations of plants to gas exchange in air or water, e.g. xerophytes and mesophytes, or terrestrial and aquatic plants. — 231-233

Diversity in animal gas exchange systems

Learning aims and skills

Activity number

- ☐ 7 Describe structural and functional diversity in animal gas exchange systems, relating specific features to function and suitability in the environment.
  - (a) INSECTS: Describe the structure and function of tracheae (tracheal tubes) in insects, including the role of the spiracles. — 100 101
  - (b) FISH: Describe the structure and function of gills in bony fish. Explain how countercurrent exchange achieves high oxygen extraction rates. — 100 102
  - (c) AIR BREATHING VERTEBRATES: Describe the structure and function of lungs in a representative vertebrate, e.g mammal. — 100 103
- ☐ 8 Describe how the gas exchange surface is ventilated in various animal groups, e.g insects, fish, mammals. — 101 102 104
- ☐ 9 Explain the role of respiratory pigments in gas transport in most animal taxa. Explain the absence of respiratory pigments in most insects. — 106
- ☐ 10 Discuss the transport of oxygen and carbon dioxide in the blood in mammals, including the movement of gases between the alveoli and the blood and between the blood and the tissues. — 105



97 Introduction to Gas Exchange

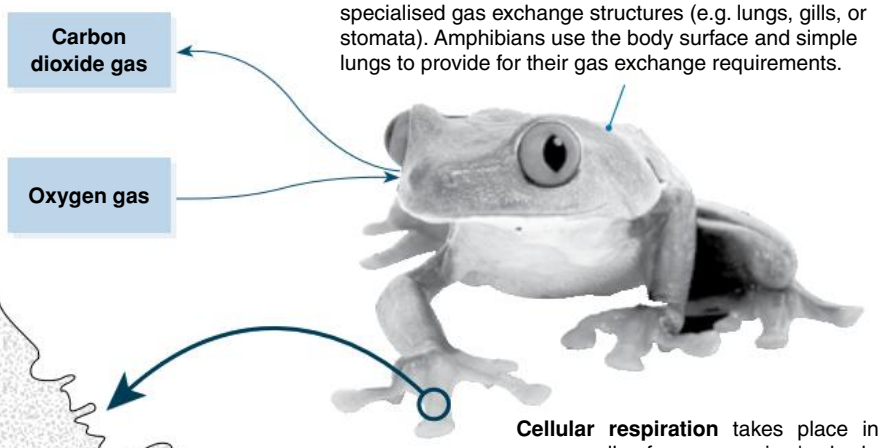
Key Idea: Gas exchange is the process by which oxygen and carbon dioxide are exchanged between the cells of an organism and the environment.

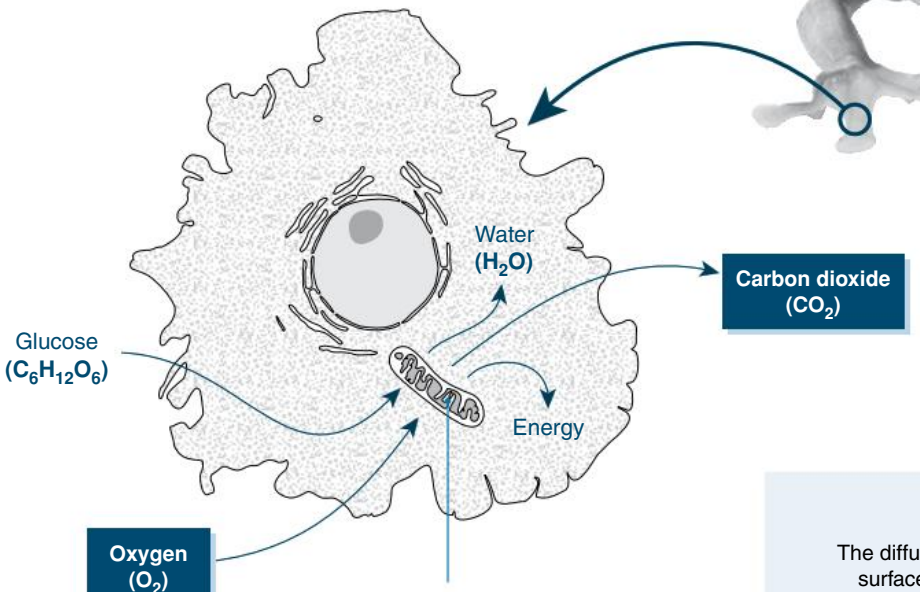
Energy is released in cells by the breakdown of sugars and other substances in cellular respiration. As a consequence of this process, gases (carbon dioxide and oxygen) need to be exchanged by diffusion. Gas exchange occurs between respiring cells and the blood, and between the lungs and the external environment. Diffusion gradients are maintained by transport of gases away from the gas exchange surface. Gas exchange membranes must be in close proximity to the blood for this to occur effectively.

The Need for Gas Exchange

Gas exchange is the process by which respiratory gases (oxygen and carbon dioxide) enter and leave the body by **diffusion** across **gas exchange surfaces**. To achieve effective gas exchange rates, gas exchange surfaces are thin and have a high surface area. They must also be moist so that the gases can dissolve before diffusing across. The concentration gradients for diffusion are maintained by cellular respiration in the cells of the body.

Gas exchange surfaces provide a means for gases to enter and leave the body. Some organisms use the body surface as the sole gas exchange surface, but many have specialised gas exchange structures (e.g. lungs, gills, or stomata). Amphibians use the body surface and simple lungs to provide for their gas exchange requirements.





Cellular respiration takes place in every cell of an organism's body. Cellular respiration creates a constant demand for oxygen (O_2) and a need to eliminate carbon dioxide gas (CO_2).

Living cells require energy for the activities of life. **Mitochondria** are the main site where glucose is broken down to release energy. In the process, oxygen is used to make water and carbon dioxide is released as a waste product.

Fick's Law

The diffusion rate across gas exchange surfaces is described by Fick's law:

$$\frac{\text{Surface area of membrane} \times \text{Difference in concentration across the membrane}}{\text{Thickness of the membrane}}$$

1. Distinguish between cellular respiration and gas exchange: _____

2. (a) What gases are involved in cellular respiration? _____

   (b) By which transport process do these gases move? _____

3. What is the main function of a gas exchange surface? _____

4. Describe the three properties that all gas exchange surfaces have in common and state the significance of each:

   (a) _____

   (b) _____

   (c) _____

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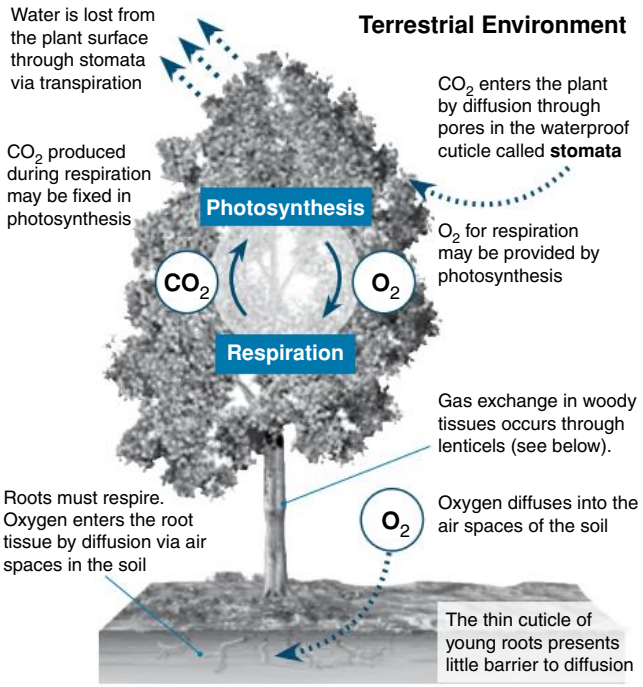
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98 Environment and Gas Exchange

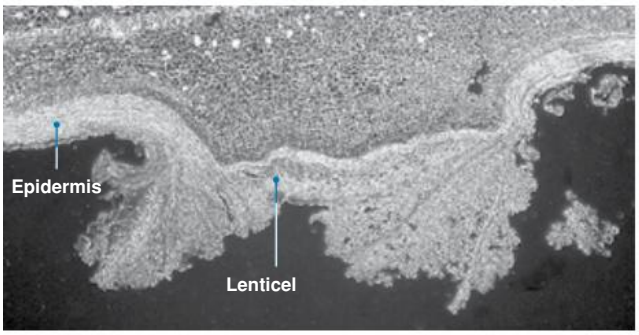
Key Idea: Gas exchange in plants occurs through stomata.

Respiring tissues require oxygen, and the photosynthetic tissues of plants also require carbon dioxide in order to produce the sugars for growth and maintenance. The main gas exchange organs in plants are the leaves, and sometimes the stems. In most plants, gases cannot diffuse directly across the leaf surface because of its waxy cuticle, so gases enter and leave the leaf via **stomata** (pores) in the leaf surface. The plant has to balance its need for CO_2 (stomata open) against its need to reduce water loss (stomata closed).

Terrestrial Environment



Most gas exchange in plants occurs through the leaves, but some also occurs through the stems and roots. Leaves are very thin with a high surface area and this assists gas exchange by diffusion.

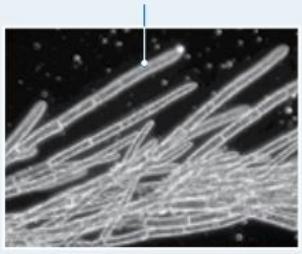


In woody plants, the wood prevents gas exchange. A lenticel is a small area in the bark where the loosely arranged cells allow entry and exit of gases into the stem tissue underneath.

Aquatic Environment

Water loss in an aquatic environment is not a problem for plants, but CO_2 availability is often limited because most of the dissolved CO_2 is present as bicarbonate ions, which are not directly available to plants. Maximising uptake of gaseous CO_2 by reducing barriers to diffusion is therefore important.

Absorption of CO_2 by direct diffusion



Algae lack stomata but achieve adequate gas exchange through simple diffusion into the cells.

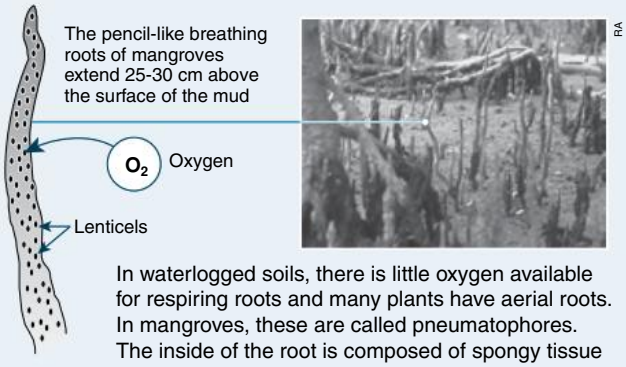
Gas exchange through stomata on the upper surface



Floating leaves, such as the water lilies above, generally lack stomata on their lower surface.

Most plants have stomata to provide for gas exchange. CO_2 uptake is aided in submerged plants because they have little or no cuticle to form a barrier to diffusion of gases. The few submerged aquatics that lack stomata altogether rely only on diffusion through the epidermis. Most aquatic plants also have air spaces in their spongy tissues (which also assist buoyancy).

Transitional Environment



In waterlogged soils, there is little oxygen available for respiring roots and many plants have aerial roots. In mangroves, these are called pneumatophores. The inside of the root is composed of spongy tissue filled with air from lenticels in the bark.

1. By which process does oxygen enter the plant tissues? _____
2. What is the role of lenticels in plant gas exchange? _____

_____

3. Identify two properties of leaves that assist gas exchange: _____
4. With respect to gas exchange and water balance, describe the most important considerations for:

   (a) Terrestrial plants: _____

   (b) Aquatic plants: _____

5. Describe an adaptation for gas exchange in the following plants:

   (a) A submerged aquatic angiosperm: _____

   (b) A mangrove in a salty mudflat: _____

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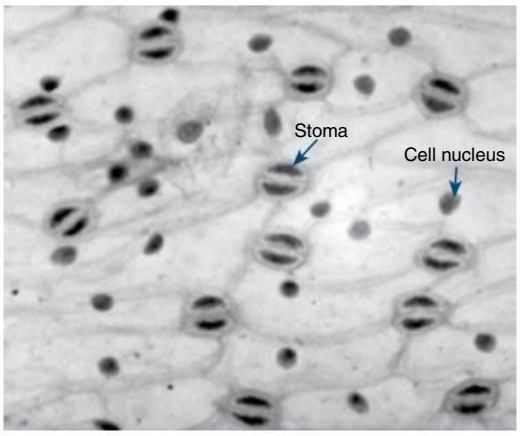
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99 Gas Exchange in Plants

Key Idea: Gas exchange through stomata is associated with water losses. Plants have adaptations to limit this loss.

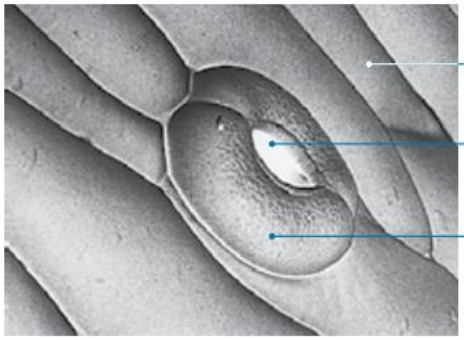
The leaf epidermis of most land plants is covered with tiny pores, called **stomata**. Each stoma has a special **guard cell** on each side which regulate the stomata's size to control the passage of gases and water vapour. Stomata allow gas exchange between the air and the photosynthetic cells inside the leaf, but they are also the major routes for water loss through transpiration. About 90% of water loss occurs via stomata. About 10% occurs directly through the waxy cuticle, but this figure can be higher if the cuticle is thin (as in ferns), or lower in plants with thick, waxy leaves.

Structure and Function of Stomata



RCN

Stomatal arrangement (above): A surface view of the leaf epidermis, illustrating the density and arrangement of stomata. Note the nuclei of the epidermal cells.



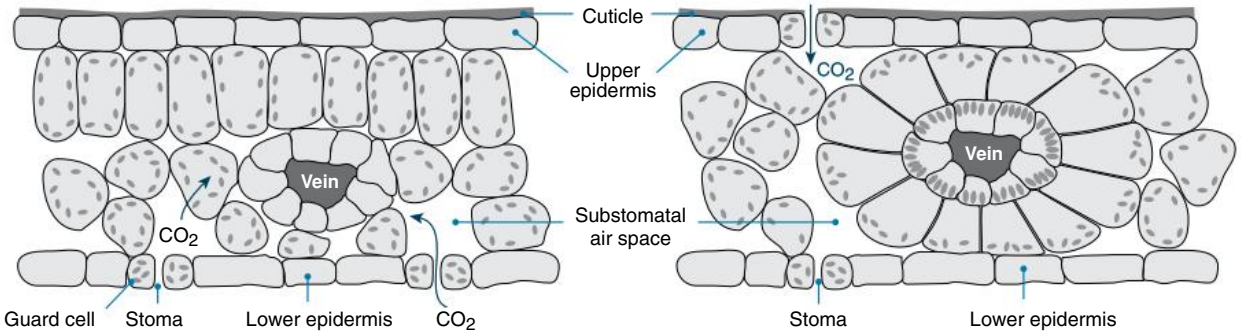
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Epidermal cell

Stoma: a pore in the leaf epidermis through which gases enter and leave.

Guard cell: A pair of guard cells surround each stoma. These are bean shaped in dicots and dumbbell shaped in monocots.

Stomatal structure: The image above show a scanning electron micrograph (SEM) of a single stoma from the leaf epidermis of a dicot. Guard cells on either side of the stoma (pore) regulate the pore's size, closing or opening it to control the entry of carbon dioxide gas and loss of water vapour. The absolute number of stomata varies greatly between different plant species. Plants adapted to dry conditions have mechanisms to limit water loss and may have fewer stomata or a large number of stomata that are sunken in pits.

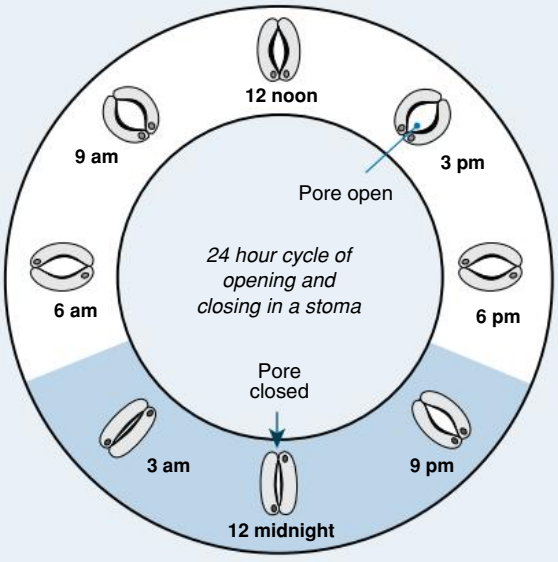


Stomata in a dicot leaf

In the flattened leaves typical of most dicots, the stomata are usually present only on the lower surface. Stomatal density is typically higher than for monocots (75 to 450 per mm^2).

Stomata in a monocot leaf

Typically, monocot leaves are bayonet shaped, with stomata on both upper and lower leaf surfaces. Stomatal density (lower surface) is typically lower than for dicots (40 to 175 per mm^2).



The Opening and Closing of Stomata

The opening and closing of stomata depends on environmental factors, the most important being light, carbon dioxide concentration in the leaf tissue, and water supply. Stomata show a daily (diurnal) cycle of opening and closing. They tend to open during daylight in response to light, and close at night (left).

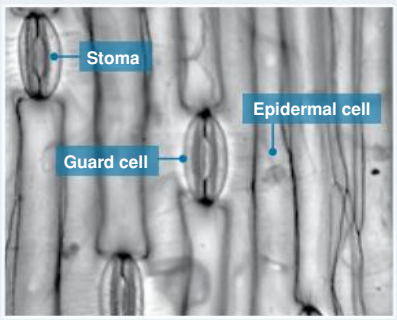
The table below summarises the effect of various environmental factors on stomatal opening. Daylight and low carbon dioxide levels promote stomatal opening. Conditions that induce water stress, e.g. low soil water, cause a loss of turgor from the guard cells and the stomata close, regardless of light or CO_2 level.

Stomata	Guard cells	Daylight	CO_2	Soil water
Open	Turgid	Light	Low	High
Closed	Flaccid	Dark	High	Low

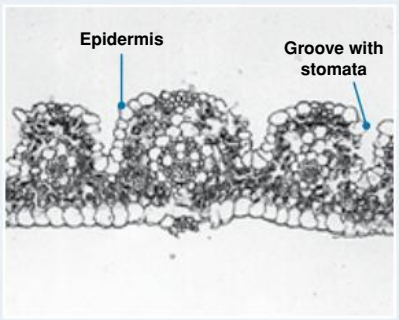
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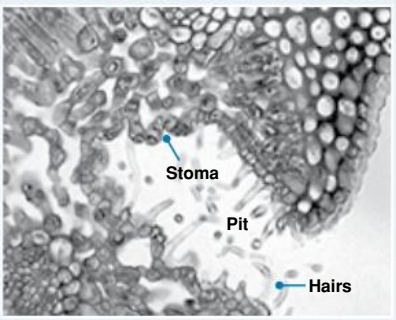
Adaptations for Gas Exchange in Plants



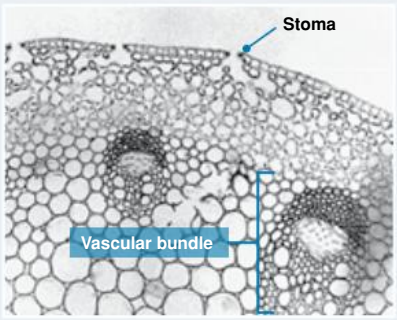
Surface view of stomata on a monocot leaf (grass). The parallel arrangement of stomata is a typical feature of monocot leaves. Grass leaves show properties of xerophytes, with several water conserving features (see right).



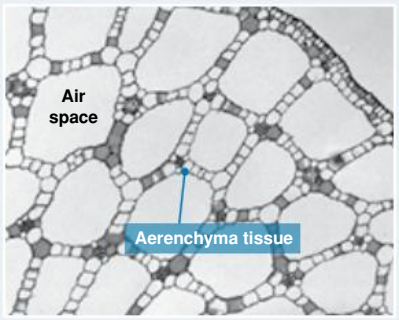
Cross section through a grass leaf showing the stomata housed in grooves. When the leaf begins to dehydrate, it may fold up, closing the grooves and thus preventing or reducing water loss through the stomata.



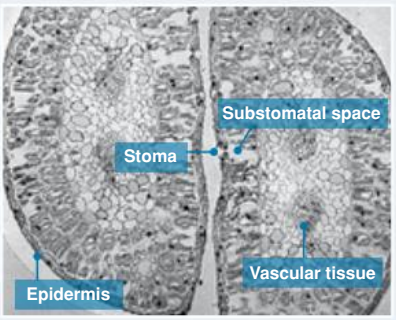
Oleander (above) is a xerophyte with many water conserving features. The stomata occur at the bottom of pits on the underside of the leaf. The pits restrict water loss to a greater extent than they reduce CO_2 uptake.



The stems of some plants (e.g. the buttercup above) are photosynthetic, and gas exchange must occur between the stem tissues and the environment. The epidermis has stomata and there are large air spaces in the cortex.



Hydrophytes, such as *Potamogeton*, above, have stems with massive air spaces. The air within the stem provides oxygen by diffusion to the roots and causes the plant to float. Tissue with air spaces is called **aerenchyma**.



This transverse view of the twin leaves of a two-needle pine shows the sunken stomata and sub-stomatal spaces. This adaptation for arid conditions reduces water loss by creating high humidity around the stoma.

EII

Photos WBS unless indicated otherwise

1. Name the pores in the leaf that facilitate gas exchange in plants: _____

2. (a) What is the adaptive value of stomata opening during daytime and closing at night? _____

_____

_____

(b) What time(s) during a 24 hour period are stomata open the widest? _____

(c) Explain your answer: _____

_____

(d) What time during daylight hours are the stomata open the least amount? _____

(e) Why would this be the case? _____

_____

3. Describe two adaptations in plants for reducing water loss while maintaining gas exchange:

(a) _____

_____

(b) _____

_____

4. Describe an adaptation of photosynthetic stems for maintaining gas exchange: _____

_____

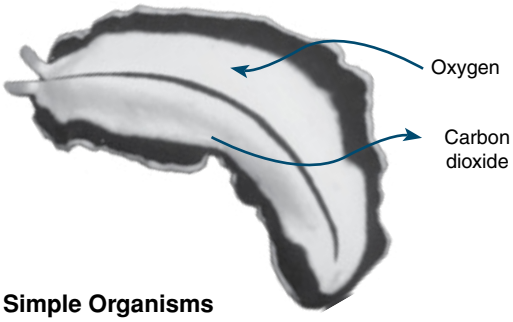
5. Name two purposes for the air spaces in *Potamogeton*: _____

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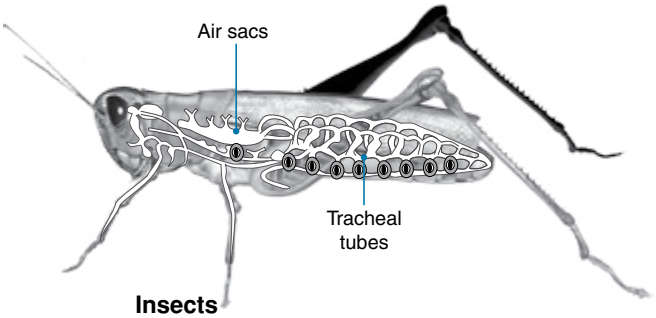
100 Gas Exchange in Animals

Key Idea: Animal gas exchange systems are suited to the animal's environment, body form, and metabolic needs.

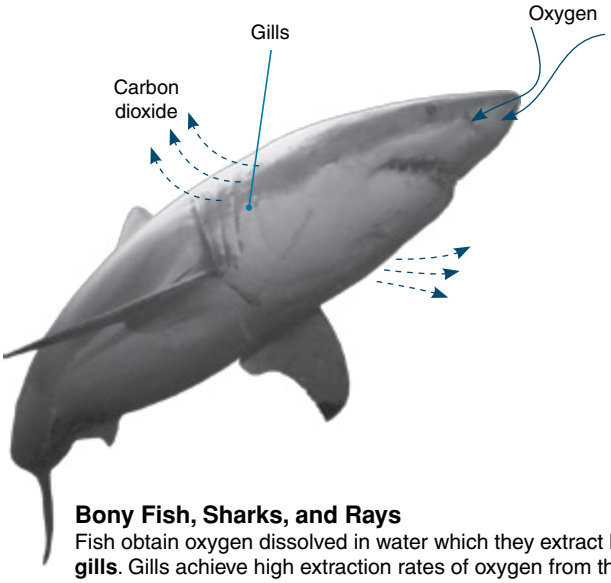
The way an animal exchanges gases with its environment is influenced by the animal's body form and by the environment in which the animal lives. Small, aquatic organisms, such as sponges and flatworms, require no specialised respiratory structures, but larger animals need more complex exchange systems to support their metabolic activities. The complexity of these is related to the efficiency of gas exchange required. This is determined by the oxygen demands of the organism.



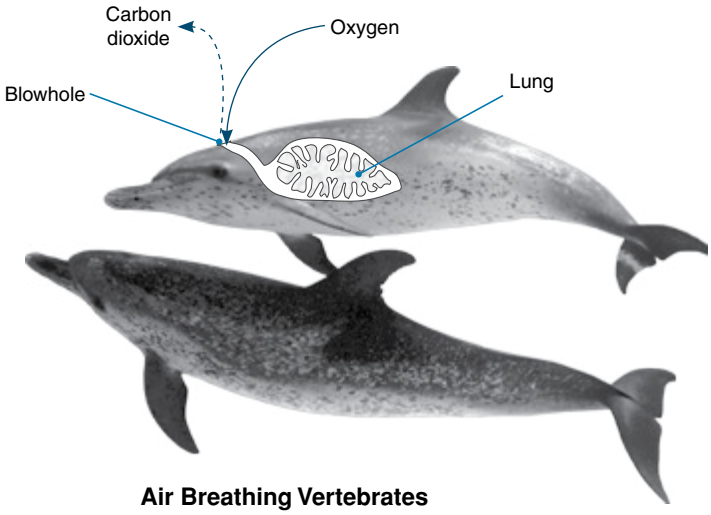
Simple Organisms
Flat organisms can use the body surface as the gas exchange surface.



Insects
Insects transport gases via a system of branching tubes called **tracheae** (or tracheal tubes). The tracheae deliver oxygen directly to the tissues. Larger insects can increase the air moving in and out of these tubes by contracting and expanding the abdomen.



Bony Fish, Sharks, and Rays
Fish obtain oxygen dissolved in water which they extract by using **gills**. Gills achieve high extraction rates of oxygen from the water which is important because there is less oxygen in water than air. The gills can be exposed directly to the environment without the gas exchange membrane drying out.



Air Breathing Vertebrates
The gas exchange surface in mammals and other air breathing vertebrates is located in internal **lungs**. Their internal location within the body keeps the lungs moist and prevents them from drying out. Lungs have a large surface area to maximise gas exchange.

1. Describe two reasons for the development of gas exchange structures and systems in animals:

   (a) _____

   (b) _____

2. Describe two ways in which air breathers manage to keep their gas exchange surfaces moist:

   (a) _____

   (b) _____

3. Explain why gills would not work in a terrestrial environment: _____

   _____

   _____

4. Explain why mammals must ventilate their lungs (breathe in and out): _____

   _____

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101 Gas Exchange in Insects

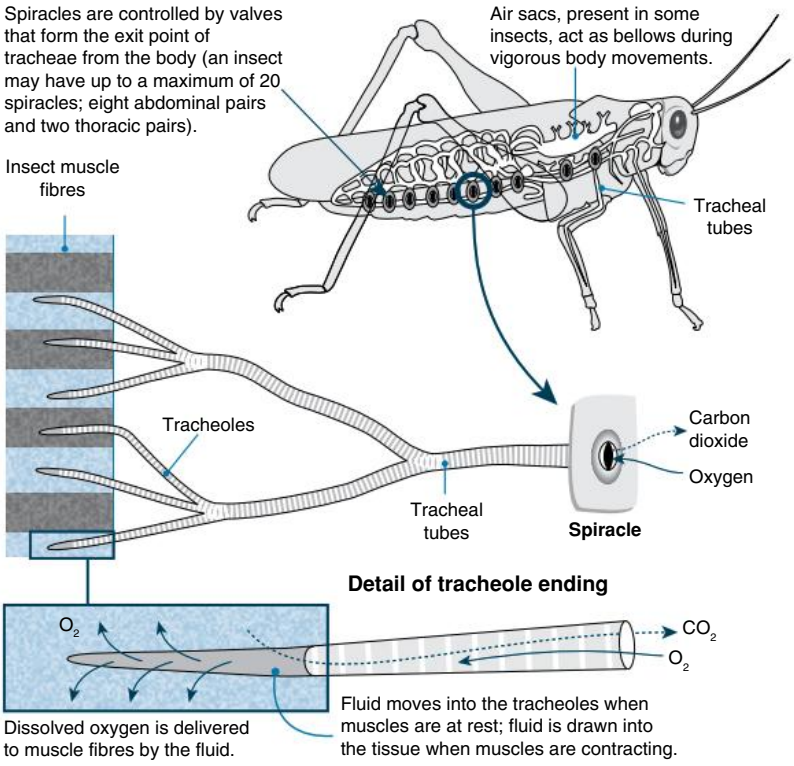
Key Idea: Insects transport air throughout their bodies via a system of tracheal tubes. Spiracles allow air to enter and leave the body.

Terrestrial air breathers lose water from their gas exchange surfaces to the environment. Most terrestrial insects have a large surface area to volume ratio and so are at risk of drying out. They minimise water losses with a waxy outer layer to their exoskeleton and a system of **tracheal tubes** for gas exchange that loses very little water to the environment. Tracheal systems, which open to the air via paired openings (**spiracles**) in the body wall, are the most common gas exchange organs of insects. Filtering devices stop the system clogging and valves control the degree to which the spiracles are open. In small insects, diffusion is the only mechanism needed to exchange gases, because it occurs so rapidly through the air-filled tubules. Larger, active insects, such as locusts, have air sacs, which can be compressed and expanded to assist in moving air through the tubules.

Insect Tracheal Tubes

Insects, and some spiders, transport gases via a system of branching tubes called tracheae or tracheal tubes. Respiratory gases move by diffusion across the moist lining directly to and from the tissues. The end of each tube contains a small amount of fluid in which the respiratory gases are dissolved. The fluid is drawn into the muscle tissues during their contraction, and is released back into the tracheole when the muscle rests. Insects ventilate their tracheal system by making rhythmic body movements to help move the air in and out of the tracheae.





1. How are oxygen and carbon dioxide exchanged between the air and tissues at the end of insect tracheoles?

2. Valves in the spiracles can regulate the amount of air entering the tracheal system. Suggest a reason for this adaptation:

3. How is ventilation achieved in a terrestrial insect? _____

4. Even though most insects are small, they have evolved an efficient and highly developed gas exchange system that is independent of diffusion across the body surface. Why do you think this is the case?

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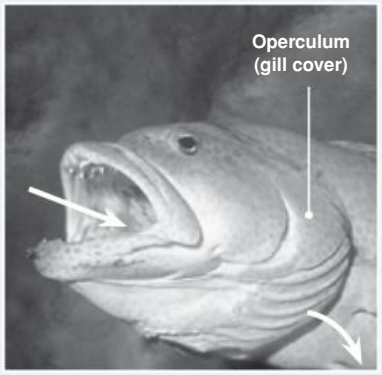
102 Gas Exchange in Fish

Key Idea: The gills of fish exchange gases between the blood and the environment. Gills are thin filamentous, vascular structures located just behind the head.

Fish obtain the oxygen they need from the water using gills, which are membranous structures supported by cartilaginous or bony struts. Gill surfaces are very large and as water flows over the gill surface, respiratory gases are exchanged between the blood and the water. The percentage of dissolved oxygen in a volume of water is much less than in the same volume of air. Air is 21% oxygen, whereas in water, dissolved oxygen is about 1% by volume. Active organisms with gills must therefore be able to extract oxygen efficiently from the water. In fish, high oxygen extraction rates are achieved using countercurrent mechanisms and by pumping water across the gill surface or swimming continuously with the mouth open.

Fish Gills

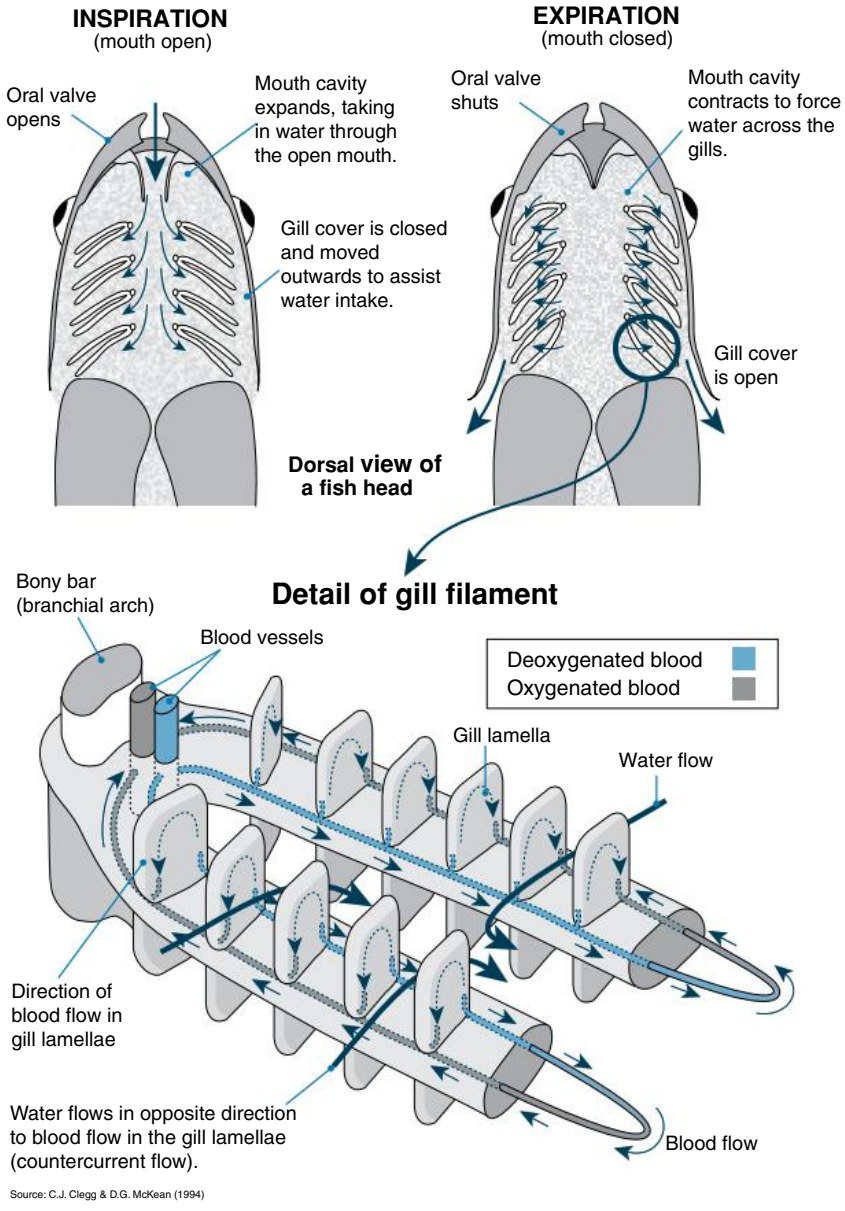
The gills of fish have a great many folds, which are supported and kept apart from each other by the water. This gives them a high surface area for gas exchange. The outer surface of the gill is in contact with the water, and blood flows in vessels inside the gill. Gas exchange occurs by diffusion between the water and blood across the gill membrane and capillaries. The operculum (gill cover) permits exit of water and acts as a pump, drawing water past the gill filaments. The gills of fish are very efficient and achieve an 80% extraction rate of oxygen from water; over three times the rate of human lungs from air.





Cartilaginous fish have five or six pairs of gills. Water enters via the mouth and spiracle and exits through gill slits (there is no operculum).

Breathing in bony fish



Source: C.J. Clegg & D.G. McKean (1994)

1. Describe three features of a fish gas exchange system (gills and related structures) that facilitate gas exchange:

   (a) _____

   (b) _____

   (c) _____

2. Why do fish need to ventilate their gills? _____

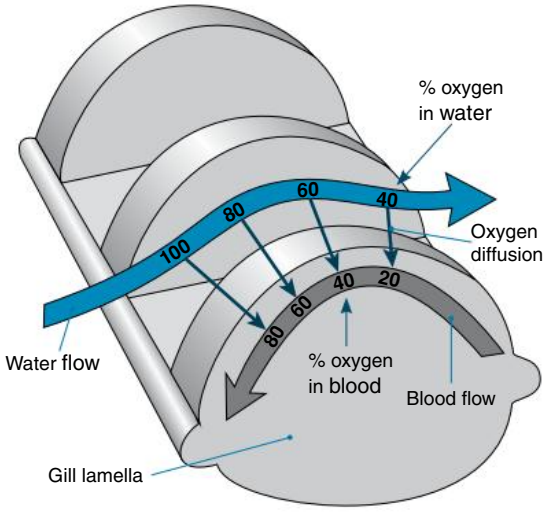
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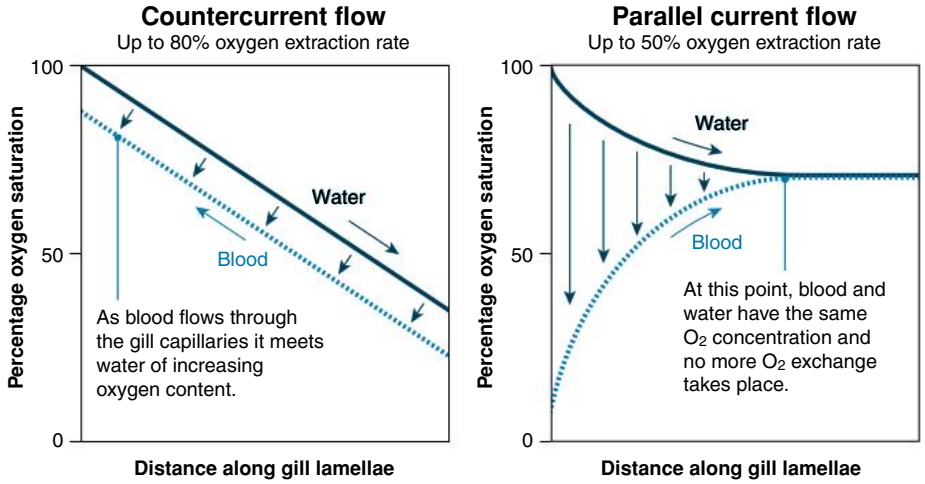
Countercurrent Flow

- The structure of fish gills and their physical arrangement in relation to the blood flow maximises gas exchange rates. A constant stream of oxygen-rich water flows over the gill filaments in the **opposite** direction to the blood flowing through the gill filaments.
- This is called **countercurrent flow** (below left) and it is an adaptation for maximising the amount of O_2 removed from the water. Blood flowing through the gill capillaries encounters water of increasing oxygen content.



The concentration gradient (for oxygen uptake) across the gill is maintained across the entire distance of the gill lamella and oxygen continues to diffuse into the blood (CO_2 diffuses out at the same time).

A parallel current flow would not achieve the same oxygen extraction rates because the concentrations across the gill would quickly equalise (far right).



3. Describe how bony fish achieve adequate ventilation of the gills through:

   (a) Pumping (mouth and operculum): _____

   _____

   (b) Continuous swimming (mouth open): _____

   _____

4. Describe countercurrent flow: _____

   _____

   _____

5. (a) How does the countercurrent system in a fish gill increase the efficiency of oxygen extraction from the water?

   _____

   _____

   _____

   (b) Explain why parallel flow would not achieve the same rates of oxygen extraction: _____

   _____

   _____

6. In terms of the amount of oxygen available in the water, explain why fish are very sensitive to increases in water temperature or suspended organic material in the water:

   _____

   _____

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103 The Human Gas Exchange System

Key Idea: Lungs are internal sac-like organs connected to the outside by a system of airways. The smallest airways end in thin-walled alveoli, where gas exchange occurs.

The gas exchange (or respiratory) system includes all the structures associated with exchanging respiratory gases with the environment. In humans, this system consists of paired lungs connected to the outside air by way of a system of tubular passageways: the trachea, bronchi, and bronchioles. The details of exchanges across the gas exchange membrane are described on the next page.

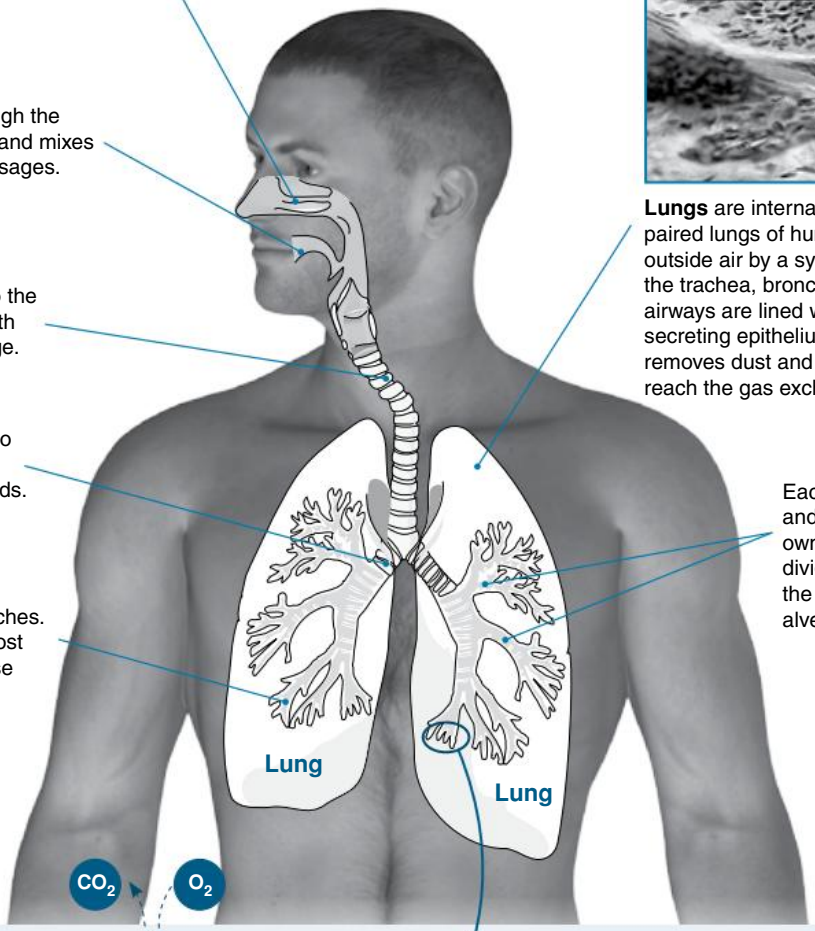
Nasal passages warm and moisten the air entering through the nostrils. Each nostril has a border of hairs to trap particles and filter them out of the system.

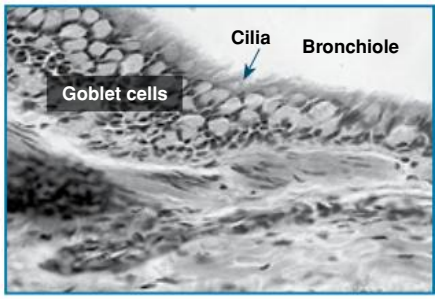
Air entering the body through the mouth enters the pharynx and mixes with air from the nasal passages.

The trachea transfers air to the lungs. It is strengthened with C-shaped bands of cartilage.

The trachea divides into two bronchi. These are also supported by cartilage bands.

Bronchioles branch from the bronchi and divide into progressively smaller branches. The cartilage is gradually lost as the bronchioles decrease in diameter.

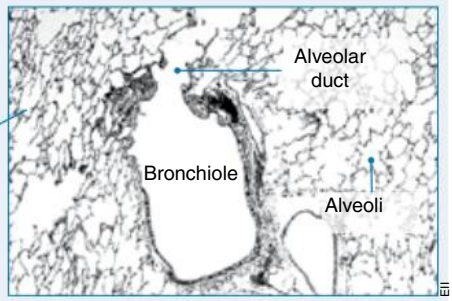




Lungs are internal sac-like organs. The paired lungs of humans are connected to the outside air by a system of tubular airways: the trachea, bronchi, and bronchioles. The airways are lined with ciliated, mucus-secreting epithelium (above), which traps and removes dust and pathogens before they reach the gas exchange surfaces.

Each lung has several lobes and each lobe receives its own bronchus. The bronchi divide many times, ending in the respiratory bronchioles, the alveolar ducts, and many alveoli.

The **alveoli** are the site of gas exchange. They provide a large surface area (70 m^2) for the exchange of respiratory gases by diffusion between the air in the lungs and the blood in the capillaries. The alveoli deflate after each breath out. A phospholipid **surfactant** helps to prevent collapse of the alveoli by decreasing surface tension.



The walls of the smallest respiratory bronchioles lack cartilage but have a large amount of smooth muscle. They subdivide into the **alveolar ducts** which lead to the alveoli (above and left). Note the thin alveolar walls.

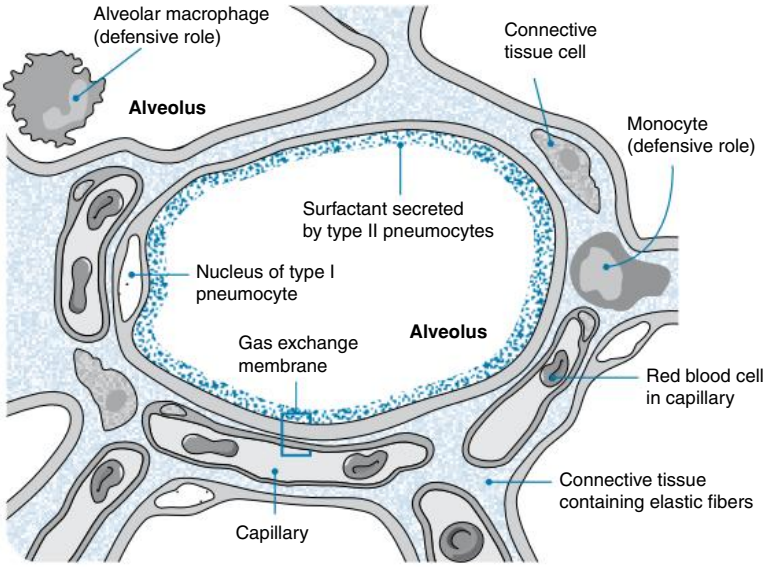
The lung **capillaries** surround the alveoli very closely, allowing for rapid diffusion of gases between the alveoli and capillary. Oxygen is transported in the blood bound to haemoglobin in the red blood cells. Carbon dioxide is carried in the blood as bicarbonate. The transport of gases to and from the gas exchange surface maintains the concentration gradient for diffusion of gases.

Oxygen enters blood from air in alveoli
Carbon dioxide leaves blood and is breathed out.

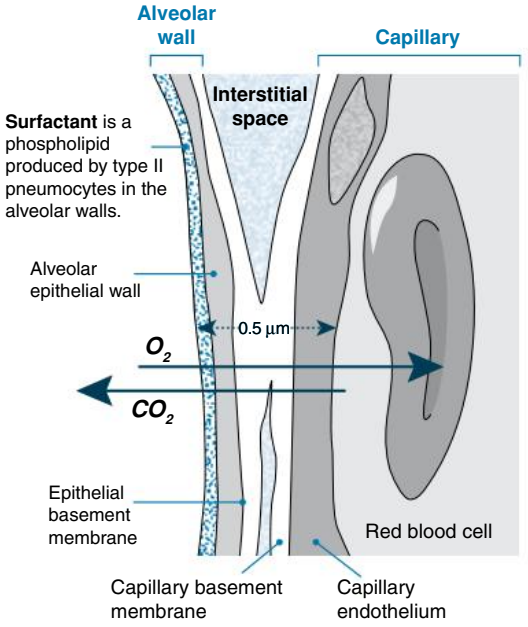
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Cross Section Through an Alveolus



The Gas Exchange Membrane



The diagram above illustrates the physical arrangement of the alveoli to the capillaries through which the blood moves. Phagocytes (monocytes and macrophages) are also present to protect the lung tissue. Elastic connective tissue gives the alveoli their ability to expand and recoil.

The **alveolar-capillary membrane** (gas exchange membrane) is the layered junction between the alveolar epithelial cells, the endothelial cells of the capillary, and their associated basement membranes (thin, collagenous layers under the epithelia). Gases move freely across this membrane.

1. (a) How does the basic structure of the human gas exchange system provide such a large area for gas exchange?

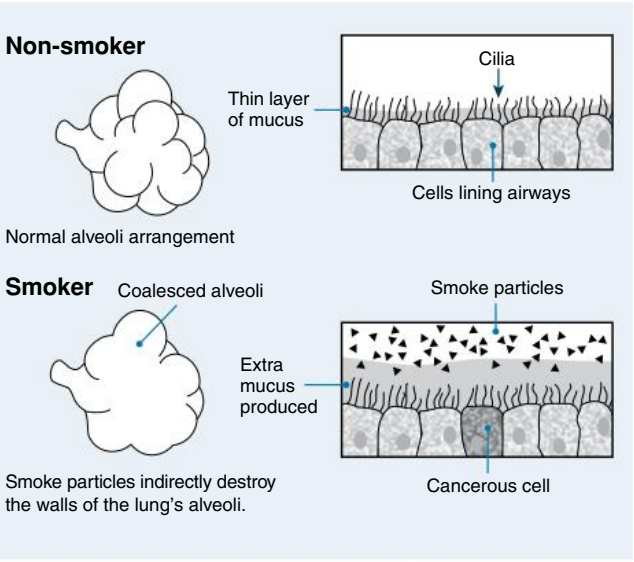
   (b) In what region of the lung does the actual exchange of gases take place? _____

2. Describe the structure and purpose of the alveolar-capillary (gas exchange) membrane: _____

3. (a) What is the role of the surfactant in the alveoli? _____

   (b) Premature babies often lack sufficient surfactant. Explain why this is fatal if not treated: _____

4. Tobacco smoking is a major risk factor in the occurrence of emphysema, chronic bronchitis, and cancers of the respiratory tract. Smoking causes the lung tissue to lose its elasticity and tar from the tobacco smoke clogs the airways and damages the alveoli (right). Use the diagram to help you to explain why smoking reduces the gas exchange capacity of the lung tissue:



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104 Breathing in Humans

Key Idea: Breathing provides a continual supply of air to the lungs to maintain the concentration gradients for gas exchange. Different muscles are used in inspiration and expiration to force air in and out of the lungs.

Breathing (ventilation) provides a continual supply of oxygen-rich air to the lungs and expels air high in carbon dioxide. Together with the cardiovascular system, which transports respiratory gases between the alveolar and the cells of the body, breathing maintains concentration gradients for gas exchange. Breathing is achieved by the action of muscles.

1. Explain the purpose of breathing: _____

2. In general terms, how is breathing achieved?

3. (a) Describe the sequence of events involved in quiet breathing:

   (b) What is the essential difference between this and the situation during forced breathing:

4. During inspiration, which muscles are:

   (a) Contracting: _____

   (b) Relaxed: _____

5. During forced expiration, which muscles are:

   (a) Contracting: _____

   (b) Relaxed: _____

6. Explain the role of antagonistic muscles in breathing:

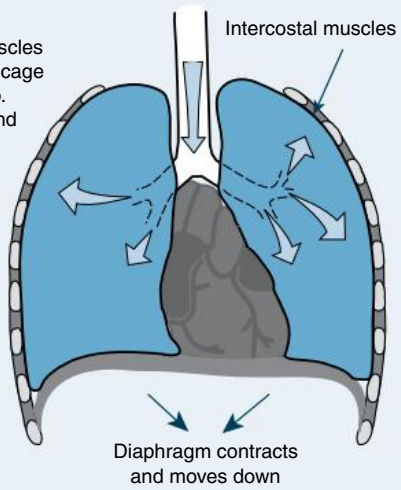
Breathing and Muscle Action

Muscles can only do work by contracting, so they can only perform movement in one direction. To achieve motion in two directions, muscles work as antagonistic pairs. Antagonistic pairs of muscles have opposing actions and create movement when one contracts and the other relaxes. Breathing in humans involves two sets of antagonistic muscles. The external and internal intercostal muscles of the ribcage, and the diaphragm and abdominal muscles.

Inspiration (Inhalation or Breathing In)

During quiet breathing, inspiration is achieved by increasing the thoracic volume (therefore decreasing the pressure inside the lungs). Air then flows into the lungs in response to the decreased pressure inside the lung. Inspiration is always an active process involving muscle contraction.

1. External intercostal muscles contract causing the ribcage to expand and move up. Diaphragm contracts and moves down.
2. Thoracic volume increases, lungs expand, and the pressure inside the lungs decreases.
3. Air flows into the lungs in response to the pressure gradient.

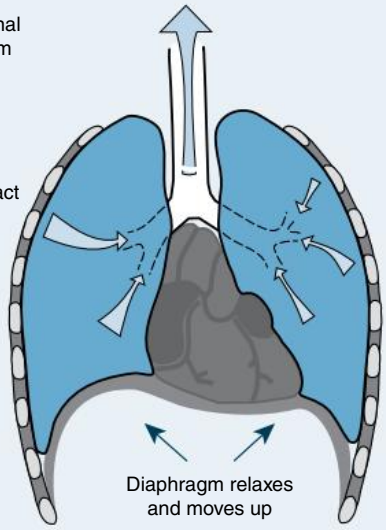


Expiration (Exhalation or Breathing Out)

In quiet breathing, expiration is a passive process, achieved when the external intercostals and diaphragm relax and thoracic volume decreases. Air flows passively out of the lungs to equalise with the air pressure. In active breathing, muscle contraction is involved in bringing about both inspiration and expiration.

1. In **quiet breathing**, external intercostals and diaphragm relax. The elasticity of the lung tissue causes recoil.

   In **forced breathing**, the internal intercostals and abdominal muscles contract to compress the thoracic cavity and increase the force of the expiration.
2. Thoracic volume decreases and the pressure inside the lungs increases.
3. Air flows passively out of the lungs in response to the pressure gradient.



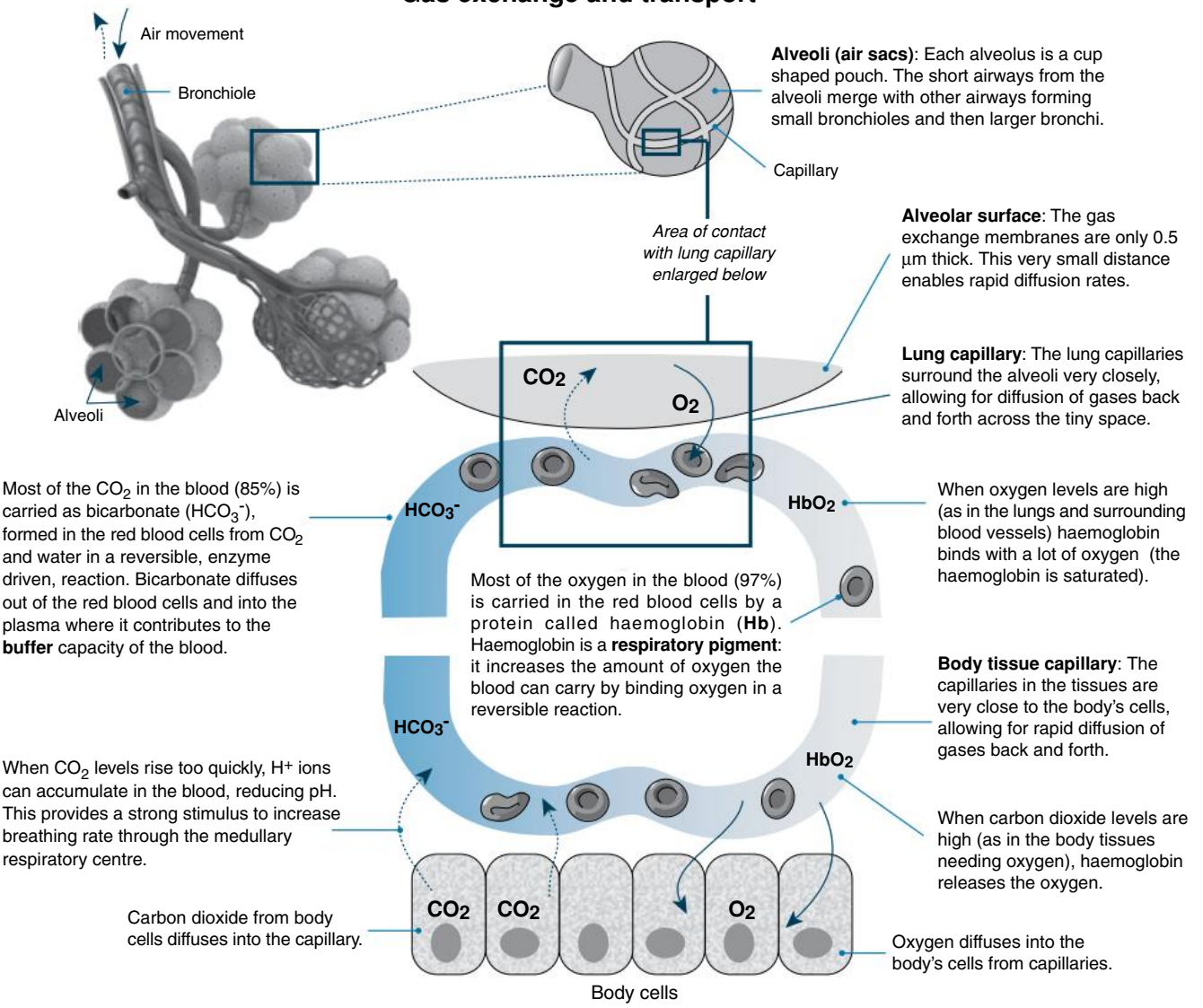
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105 Gas Transport in Mammals

Key Idea: In mammals, oxygen is bound to haemoglobin in red blood cells and transported by the circulatory system. Carbon dioxide is transported in plasma, mainly as bicarbonate.

The transport of respiratory gases around the body is the role of the blood and its respiratory pigments. Oxygen is transported throughout the body chemically bound to the respiratory pigment **haemoglobin** inside the red blood cells. Haemoglobin binds oxygen strongly when oxygen levels are high (as in the lung capillaries) but releases it when oxygen levels are low (as in the capillaries of the tissues). In this way, haemoglobin picks up oxygen and delivers it efficiently to where it is required.

Gas exchange and transport



1. (a) Identify two regions in the body where oxygen levels are very high: _____

   (b) Identify two regions where carbon dioxide levels are very high: _____

2. Explain the role of haemoglobin in gas transport, particularly the significance of the reversible binding reaction:

   _____

   _____

3. Carbon monoxide (CO) is a colourless and odourless gas found in car exhaust fumes and tobacco smoke. It binds to haemoglobin 200x more strongly than oxygen and is released very slowly. Given this information, explain why:

   (a) Carbon monoxide is so toxic: _____

   _____

   (b) The blood of smokers has reduced oxygen carrying ability: _____

   _____

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106 Respiratory Pigments

Key Idea: Respiratory pigments bind oxygen and increase the efficiency of its transport through the body.

The amount of oxygen that can be carried in solution in the blood is small. The efficiency of gas transport in animals is enhanced by the presence of respiratory pigments. All respiratory pigments consist of proteins complexed with iron or copper. They combine reversibly with oxygen and greatly increase the capacity of blood to transport oxygen and deliver it to the tissues. For example, the amount of oxygen dissolved in the plasma in mammals is only about 2 ml O_2 per litre. However the amount carried bound to haemoglobin is 100 times this. Haemoglobin is the most widely distributed respiratory pigment but there is some variability in structure and oxygen carrying capacity between different taxa.

Respiratory Pigments

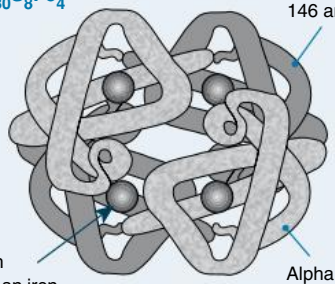
Respiratory pigments are coloured proteins capable of combining reversibly with oxygen, hence increasing the amount of oxygen that can be carried by the blood. Pigments typical of representative taxa are listed below. Note that the polychaetes are very variable in terms of the pigment possessed.

Taxon	Oxygen capacity (ml O_2 per 100 ml blood)	Pigment
Oligochaetes	1 - 10	Haemoglobin
Polychaetes	1 - 10	Haemoglobin, chlorocruorin, or haemerythrin
Crustaceans	1 - 6	Haemocyanin
Molluscs	1 - 6	Haemocyanin
Fishes	2 - 4	Haemoglobin
Reptiles	7 - 12	Haemoglobin
Birds	20 - 25	Haemoglobin
Mammals	15 - 30	Haemoglobin

Mammalian Haemoglobin

Haemoglobin is a globular protein consisting of 574 amino acids arranged in four polypeptide sub-units: two identical ***beta chains*** and two identical ***alpha chains***. The four sub-units are held together as a functional unit by bonds. Each sub-unit has an iron-containing haem group at its centre and binds one molecule of oxygen.

Chemical formula:
$C_{3032}H_{4816}O_{872}N_{780}S_8Fe_4$

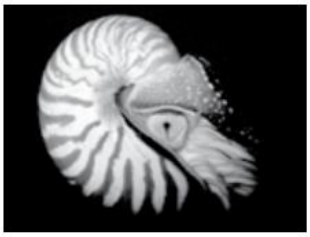



Aquatic polychaete fanworms, e.g. *Sabella,* possess **chlorocruorin**.


BOB
Oligochaete annelids, such as earthworms, have **haemoglobin**.

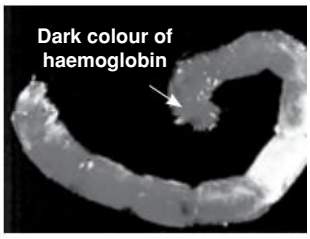

Aquatic crustaceans, e.g. crabs, possess **haemocyanin** pigment.


Vertebrates such as this fish have **haemoglobin** pigment.


Cephalopod molluscs such as *Nautilus* contain **haemocyanin**.


Birds, being vertebrates contain the pigment **haemoglobin**.


RCN
Many large active polychaetes, e.g. *Nereis*, contain **haemoglobin**.



Stephen Moore
Chironomus is one of only two insect genera to contain a pigment.

1. (a) How do respiratory pigments increase the carrying capacity of the blood? _____

_____

(b) Which feature of a respiratory pigment determines its oxygen carrying capacity? _____

_____

2. How is oxygen carrying capacity of haemoglobin related to metabolic activity across different animal taxa? _____

_____

_____

3. Why are larger molecular weight respiratory pigments carried dissolved in the plasma rather than within cells?

_____

KNOW
LINK 26
LINK 105
LINK 116

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107 KEY TERMS: Mix and Match

Test your vocabulary by matching each term to its definition, as identified by its preceding letter code.

alveoli .....

breathing .....

bronchi .....

bronchioles .....

carbon dioxide .....

cellular respiration .....

chlorocruorin .....

countercurrent flow .....

expiration .....

extraction rate .....

gas exchange .....

gills .....

haemerythrin .....

haemocyanin .....

haemoglobin .....

inspiration .....

lenticels .....

lungs .....

mesophyll .....

oxygen .....

respiratory gas .....

respiratory pigment .....

spiracles .....

stomata .....

surfactant .....

tracheae .....

A A respiratory pigment found in aquatic polychaete worms.

B A substance carried in blood that is able to bind oxygen for transport to cells. Examples include haemoglobin and haemocyanin.

C The rate at which oxygen is removed from the medium by the gas exchange organs.

D Large air tubes that branch from the trachea to enter the lungs.

E Small air tubes that divide from the bronchi and become progressively smaller.

F The exterior opening of the tracheae in arthropods.

G Series of tube like structures that allow gas to be conducted into the body in insects.

H Copper based respiratory pigment found in the blood of many crustaceans and molluscs. It appears blue when exposed to air.

I A term describing the flow of fluids and/or air in opposite directions so that diffusion gradients are maintained between the two media and exchanges between them are maximised.

J The chloroplast-containing tissue making up the bulk of the leaf in most plants.

K A large iron-containing protein that transports oxygen in the blood of vertebrates.

L Microscopic structures in the lungs of most vertebrates that form the terminus of the bronchioles. The site of gas exchange.

M The act of breathing in or filling the lungs with air.

N A gas produced as a waste product of metabolism.

O The catabolic process in which the chemical energy in complex organic molecules is coupled to ATP production.

P The exchange of oxygen and carbon dioxide across the respiratory membrane.

Q Gas required for aerobic respiration. Levels average 21% in the atmosphere.

R Internal gas exchange structures found in air breathing vertebrates.

S The act of breathing out or removing air from the lungs.

T Localised regions of loosely arranged tissue in the bark of woody plants through which gases can enter and leave the tissues underneath.

U Any gas that takes part in the respiratory process (usually just oxygen or carbon dioxide).

V Red iron-containing respiratory pigment found in the blood of some annelids.

W The respiratory organs of most aquatic animals (although not aquatic mammals).

X The act of inhaling air into and exhaling air from the lungs.

Y Phospholipid substance responsible for reducing surface tension in the lung tissue.

Z Pores in the epidermis of a leaf through which gases enter and leave the leaf tissue.

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QLD As required
VCE Unit 1 (2)
WA ATAR Unit 2
SA Theme O

Internal Transport

Key terms

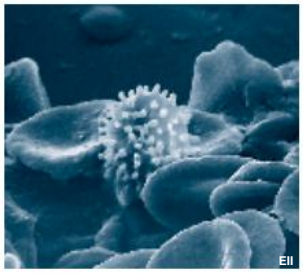
artery (pl. arteries)
atrium (pl. atria)
blood
capillary (pl. capillaries)
cardiac cycle
circulatory fluid
closed circulatory system
cohesion-tension
double circulatory system
haemolymph
heart
lymph
open circulatory system
phloem
root
single circulatory system
sink
source
stem
tissue fluid
translocation
transpiration
transpiration rate
vein
ventricle
xylem

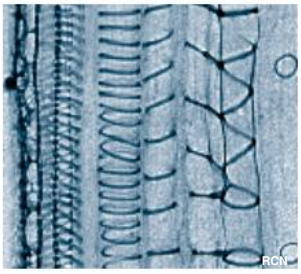
Internal transport in plants

Learning aims and skills

		Activity number
☐	1 Describe the general structure of the plant body, including reference to the relationship between the support and transport tissues.	108
☐	2 Describe the structure of stem tissue in relation to its function. Describe the composition, arrangement, and role of phloem and xylem tissue.	109 111
☐	3 Describe the structure of a dicot root in relation to its function. Discuss the role of root hairs and relate the root hair structure to its functional role.	109 110
☐	4 Explain the role of osmosis and active transport in uptake of minerals.	110
☐	5 Explain transpiration in plants. Describe how water is moved up the plant, including reference to the cohesion-tension hypothesis. Describe the effect of environmental factors, e.g. temperature and wind, on transpiration rate.	112 113
☐	6 Explain translocation in plants, including reference to the pressure-flow hypothesis. Identify sources and sinks in the transport of sucrose.	114



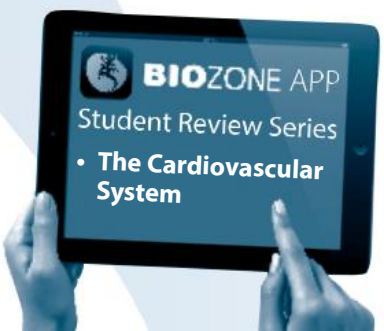




Internal transport in animals

Learning aims and skills

		Activity number
☐	7 Describe the components and functions of a transport system in animals. Explain how the type of circulatory system and the efficiency of transport are related to metabolic needs and environment.	115
☐	8 Explain the role of the circulatory fluid (e.g. blood or haemolymph) in the transport systems of vertebrates and invertebrates respectively.	116
☐	9 Describe the structure and function of circulatory systems in animals, including:	
	(a) Open circulatory systems (arthropods, e.g. insects, and most molluscs).	117
	(b) Closed circulatory systems (vertebrates and some invertebrates).	118 119
☐	10 Describe and explain diversity in the structure and function of blood vessels in vertebrates, including arteries, capillaries, and veins.	120 121 122 123
☐	11 Compare and contrast the structure and function of vertebrate hearts, including those with three chambers in series (fish) and those with four chambers separating systemic and pulmonary circuits (mammals, birds).	115 125
☐	12 Describe the structure and function of the mammalian heart, including its operation as a double pump. Recognise pulmonary and systemic circuits and the main vessels entering and leaving the heart.	125
☐	13 Describe and explain the cardiac cycle, relating the series of actions of the heart to the electrical activity as indicated on an electrocardiograph (ECG).	126



108 Transport in Plants

Key Idea: The plant body comprises three main organs: roots, leaves, and stems. The xylem and phloem form the vascular tissue that links all parts of the plant.

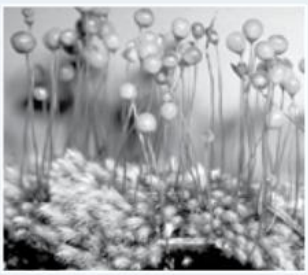
The support and transport systems in plants are closely linked; many of the same tissues are involved in both systems. Primitive plants (e.g. mosses and liverworts) are small and low growing, and have no need for support and transport systems. If a plant is to grow to any size, it must have ways to hold itself up against gravity and to move materials around its body. The body of a flowering plant has three parts (or organs): **roots** anchor the plant and absorb nutrients from the soil, **leaves** produce sugars by photosynthesis, and **stems** link the roots to the leaves and provide support for the leaves and reproductive structures. Vascular tissues (xylem and phloem) link all plant parts so that water, minerals, and manufactured food can be transported between different regions. All plants rely on fluid pressure within their cells (turgor) to give some support to their structure.



Food produced in the leaves must be transported around the plant.

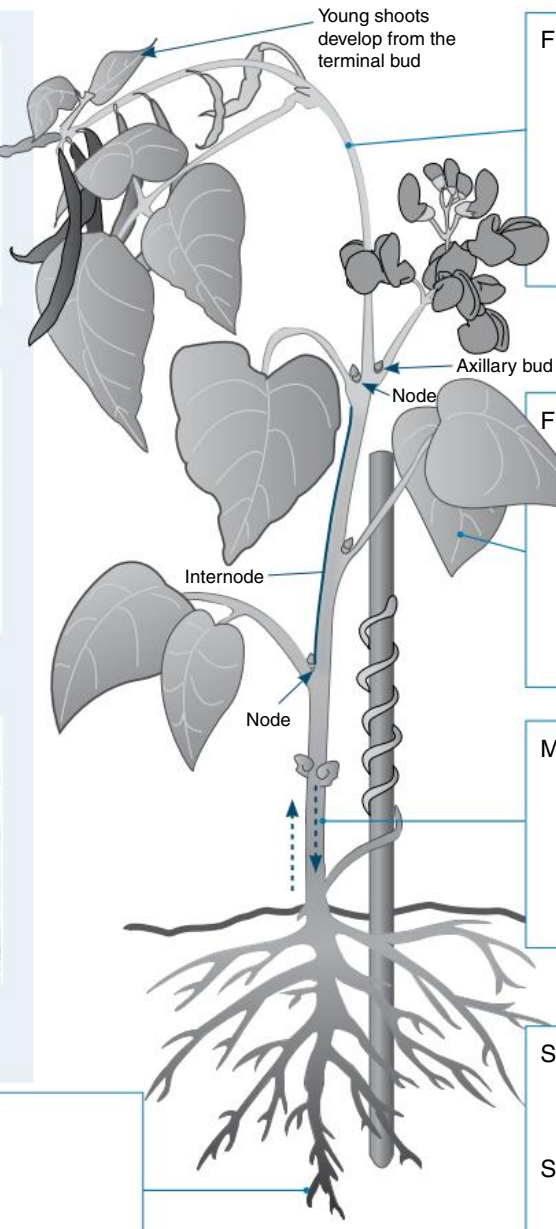


The great heights reached by some trees presents problems for support and transport of materials.



Mosses lack true vascular tissue. This limits their size and the kind of environments they are able to live in.

BOB



Functions of the stems:

Functions of the leaves:

Materials transported around the plant:

Specific functions of xylem:

Specific functions of phloem:

Functions of the roots:

1. In the boxes provided in the diagram above:
   (a) List the main functions of the leaves, roots and stems (remember that the leaves themselves have leaf veins).
   (b) List the materials that are transported around the plant body.
   (c) Describe the functions of the transport tissues: xylem and phloem.
2. What is the solvent for all materials transported around the plant? _____
3. State what processes are involved in the transport of sap in the following tissues:
   (a) The xylem: _____
   (b) The phloem: _____

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LINK 114 LINK 112 LINK 111 WEB 108 KNOW

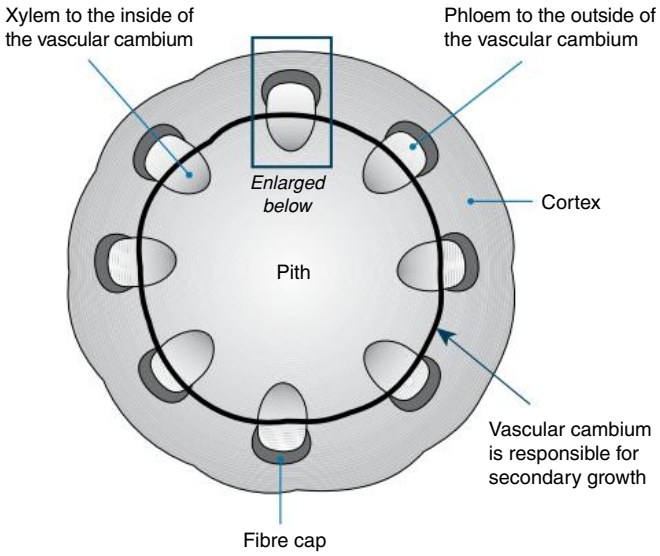
109 Stems and Roots

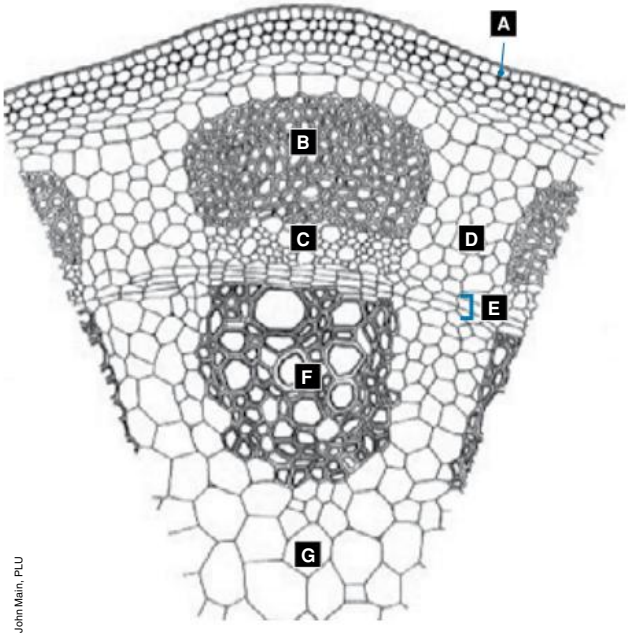
Key Idea: In dicots, the vascular tissue in the stem is distributed around the periphery of the stem. In the roots, the vascular tissue is found near the centre of the root.

Stems are the primary organs for supporting the plant. Roots anchor the plant in the ground, absorb water and minerals from the soil, and transport these materials around the plant. Roots may also store excess food. The vascular tissues of stems and roots are organised in bundles containing the xylem and phloem and strengthening fibres. The entire plant body, including the roots and stems is covered in an epidermis but, unlike most of the plant, the root epidermis has only a thin cuticle that presents no barrier to water entry. Young roots are also covered with root hairs. Compared with stems, roots are relatively simple and uniform in structure, and their features are associated with aeration of the tissue and transport of water and minerals form the soil.

Dicot Stem Structure

In dicots, the vascular bundles are arranged in an orderly fashion around the stem. Each vascular bundle contains **xylem** (to the inside) and **phloem** (to the outside). Between the phloem and the xylem is the **vascular cambium**; a layer of cells that divide to produce the thickening of the stem. The middle of the stem, called the **pith**, is filled with thin-walled parenchyma cells. The vascular bundles in dicots are arranged in an orderly way around the periphery of the stem (below).



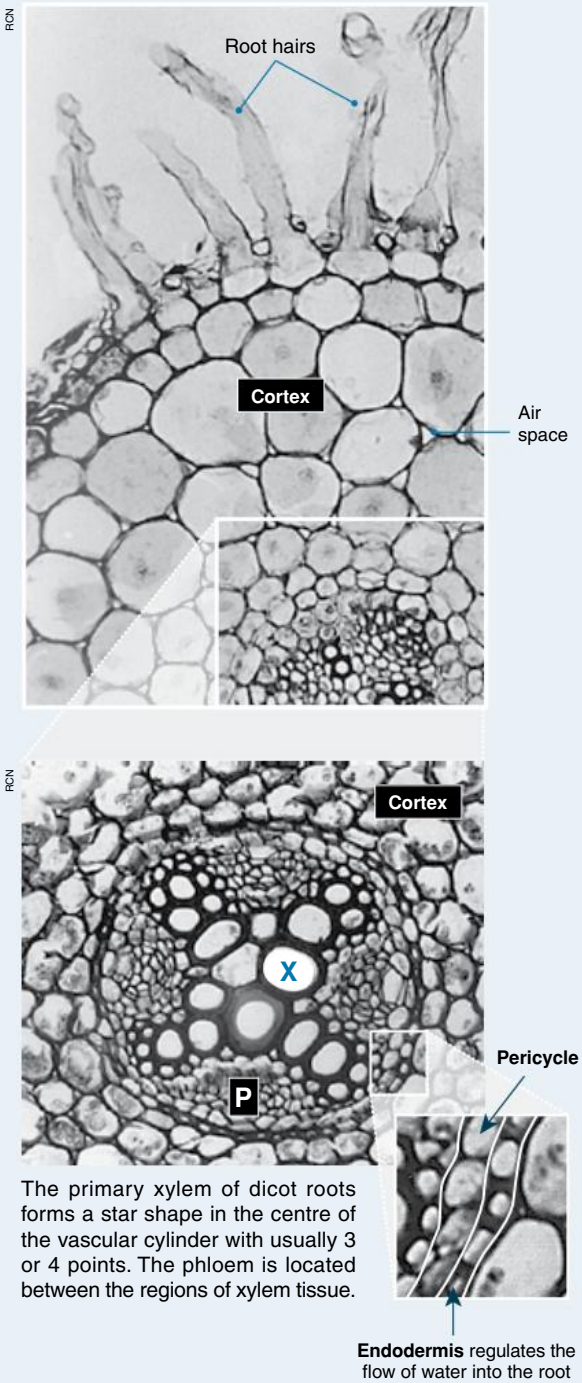


John Main, PLU

Cross section through a typical dicot stem

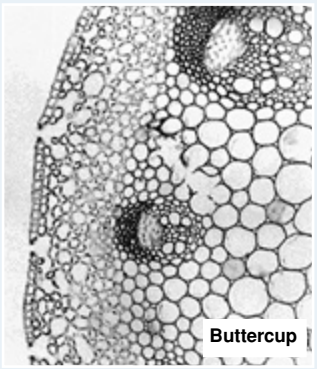
Dicot Root Structure

The primary tissues of a dicot root are simple in structure. The large cortex is made up of parenchyma (packing) cells, which store starch and other substances. The air spaces between the cells are essential for aeration of the root tissue, which is non-photosynthetic. The vascular tissue, xylem (**X**) and phloem (**P**) forms a central cylinder through the root and is surrounded by the **pericycle**, a ring of cells from which lateral roots arise.

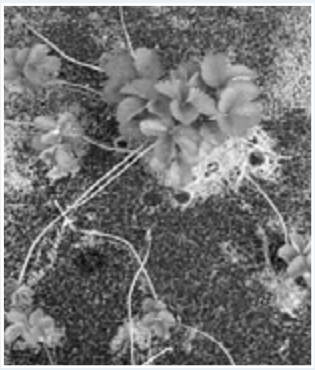


The primary xylem of dicot roots forms a star shape in the centre of the vascular cylinder with usually 3 or 4 points. The phloem is located between the regions of xylem tissue.

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In plants with photosynthetic stems, CO_2 enters the stem through stomata in the epidermis. The air spaces in the cortex are more typical of leaf mesophyll than stem cortex.



Strawberry plants send out runners. These are above-ground, trailing stems that form roots at their nodes. The plant uses this mechanism to spread vegetatively over a wide area.



Root hairs are located just behind the region of cell elongation in the root tip. The root tip is covered by a slimy root cap. This protects the dividing cells of the tip and lubricates root movement.



The roots and their associated root hairs provide a very large surface area for the uptake of water and ions, as shown in this photograph of the roots of a hydroponically grown plant.

1. Use the information provided to identify the structures **A**-**G** in the photograph of the dicot stem on the previous page:

   (a) A: _____ (e) E: _____

   (b) B: _____ (f) F: _____

   (c) C: _____ (g) G: _____

   (d) D: _____

2. Describe a distinguishing feature of stem structure in dicots: _____

3. What is the role of the vascular cambium? _____

4. Describe three functions of roots: _____

5. Describe two distinguishing features of internal anatomy of a primary dicot root:

   (a) _____

   (b) _____

6. What is the role of the parenchyma cells of the root cortex? _____

7. What is the purpose of the root hairs? _____

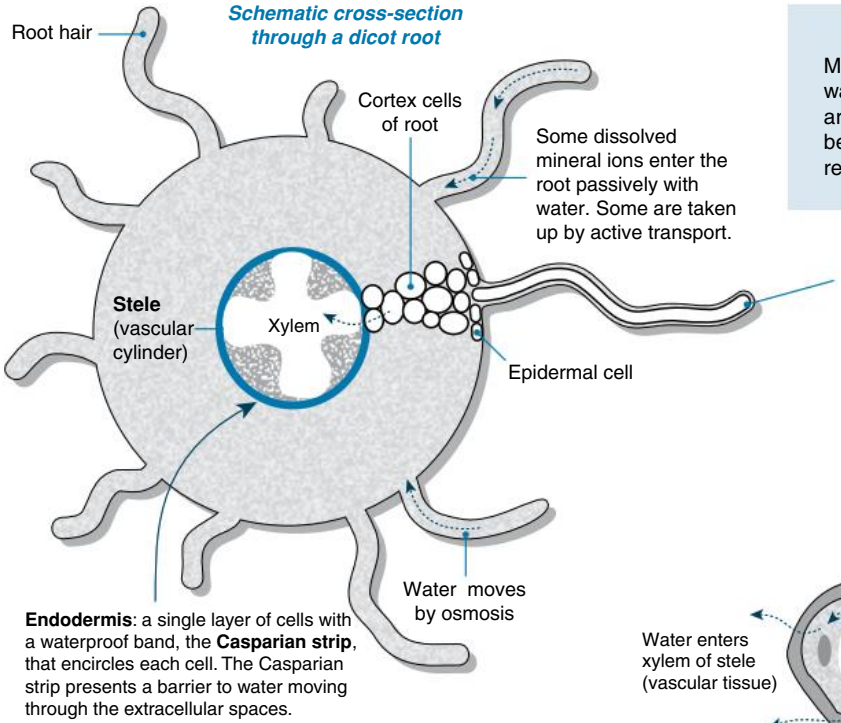
8. Why is the root tip covered by a cap of cells? _____

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110 Uptake at the Root

Key Idea: Water uptake by the root is a passive process. Mineral uptake can be passive or active.

Plants need to take up water and minerals constantly. They must compensate for the continuous loss of water from the leaves and provide the materials the plant needs to make food. The uptake of water and minerals is mostly restricted to the younger, most recently formed cells of the roots and the root hairs. Some water moves through the plant tissues via the plasmodesmata (microscopic channels between cells), but most passes through the free spaces outside the plasma membranes. Water uptake occurs by osmosis, whereas mineral ions enter the root by diffusion and active transport.



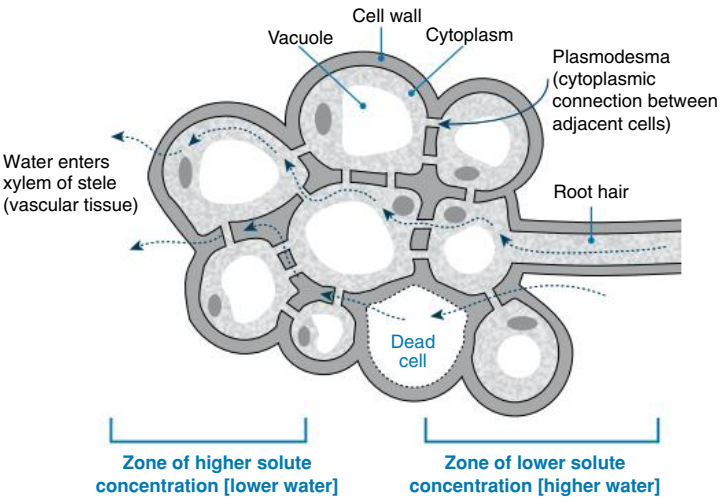
Endodermis: a single layer of cells with a waterproof band, the **Casparian strip**, that encircles each cell. The Casparian strip presents a barrier to water moving through the extracellular spaces.

Mineral Uptake

Many minerals are absorbed passively along with the water they are dissolved in. However, some minerals are in such low concentration in the soil that they must be taken up actively by the root. This active transport requires energy and is an energy cost to the plant.

Root hairs greatly increase the surface area for absorption of water and nutrients. The root hairs are extensions of the root epidermal cells, extending out to make intimate contact with the film of water on the soil particles. Unlike older roots, the root hairs have no waterproof suberin layer and a very thin cuticle, so they present little barrier to water entry.

Enlargement of Root Cells



Water Uptake

The uptake of water through the roots occurs by osmosis; the diffusion of water from a lower solute concentration to a higher solute concentration. Three different pathways of water transport exist in flowering plants. Most water travels through the spaces within the cellulose cell walls, the water-filled spaces of dead cells, and the hollow tubes of xylem vessels. A smaller amount moves through the living cytoplasm of cells. A very small amount travels through the plant vacuoles.

1. (a) What two mechanisms do plants use to absorb nutrients? _____

   (b) Describe the two principal pathways by which water moves through a plant: _____

2. Plants take up water constantly to compensate for losses due to transpiration. Describe a benefit of a large water uptake: _____

3. (a) What effect do you think the **Casparian strip** has on the route water takes into the stele? _____

   (b) Why might this feature be an advantage in terms of selective mineral uptake? _____

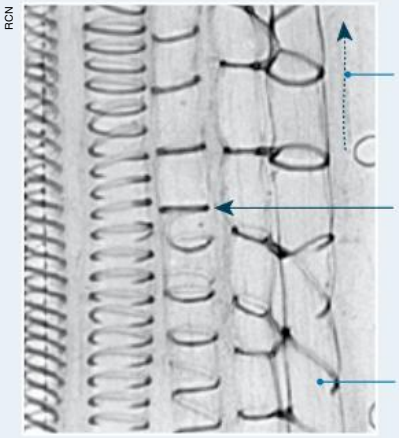
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111 Xylem and Phloem

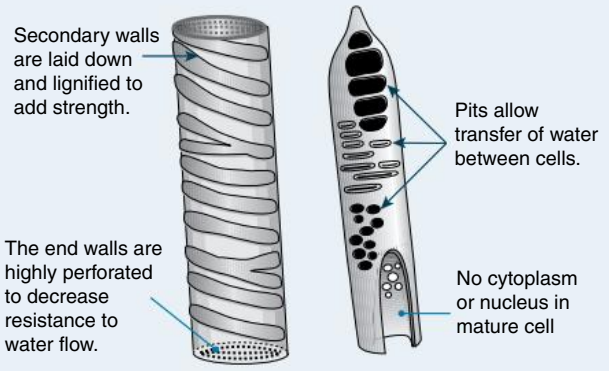
Key Idea: In vascular plants, xylem transports water and minerals and phloem transports dissolved sugar.

Xylem and phloem are the main supporting tissue in plants. Both are complex tissues composed of a number of cell types. **Xylem** tissue is largely composed of large vessels, which have thickened and strengthened walls and conduct water. It also contains packing cells (parenchyma) and fibres, which support the tissue. Mature xylem is dead. **Phloem** tissue is composed of packing cells and supporting fibre cells, and two special cell types: **sieve tubes** and **companion cells**. Phloem transports dissolved sugars and is alive when mature.

Xylem Tissue



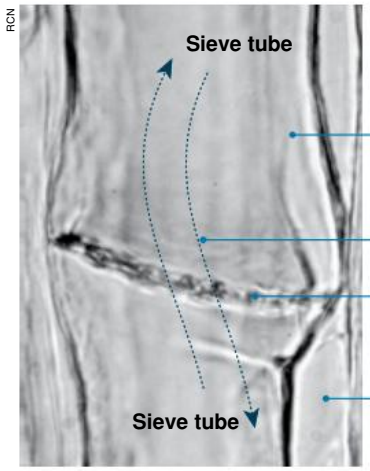
Conducting cells of xylem

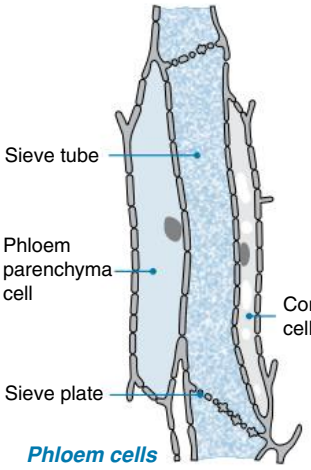


Vessel element: angiosperms only

Tracheid: angiosperms and gymnosperms

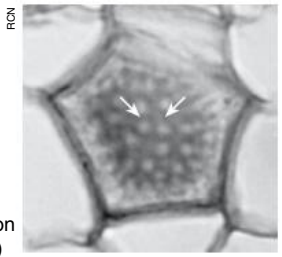
Phloem Tissue





Phloem cells

Cross-section through sieve tube end plate



Sieve tube end plate: Small holes (arrows) perforate the sieve tube cells allowing the sugar solution to pass through.

1. How is xylem strengthened in a mature plant? _____

2. Describe a difference between the xylem tissue of gymnosperms and angiosperms: _____

3. What is the purpose of the holes in the **sieve plate** at the ends of each sieve tube cell? _____

4. (a) Name the cell type in the phloem that actually conducts the sugar solution: _____

   (b) What is the purpose of the companion cell in phloem tissue? _____

5. Describe the structural and functional differences between xylem and phloem: _____

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LINK 114 LINK 112 LINK 64 LINK 60 WEB 111 KNOW

112 Transpiration

Key Idea: Water moves through the xylem primarily as a result of evaporation from the leaves and the cohesive and adhesive properties of water molecules.

Plants lose water all the time. Approximately 99% of the water a plant absorbs from the soil is lost by evaporation from the leaves and stem. This loss, mostly through stomata, is called **transpiration** and the flow of water through the plant is called the **transpiration stream**. Plants rely on a gradient in solute concentration that increases from the roots to the air to move water through their cells. Water flows passively from soil to air along this gradient of increasing solute concentration. The gradient is the driving force for the movement of water up a plant. Transpiration has benefits to the plant because evaporative water loss cools the plant and the transpiration stream helps the plant to take up minerals. Factors contributing to water movement are described below.

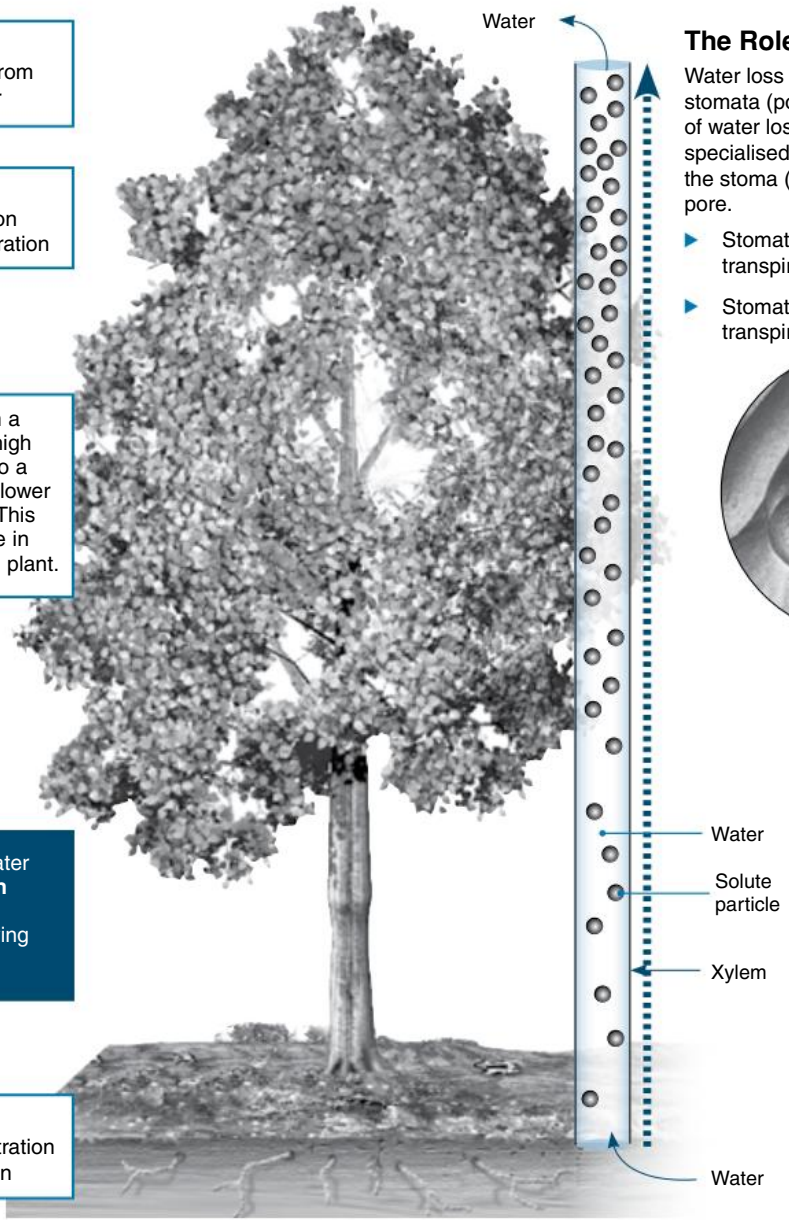
Air
Evaporative loss of water from the leaves as water vapour

Leaves
Highest solute concentration
Lowest free water concentration

Water flows passively from a low solute concentration (high free water concentration) to a high solute concentration (lower free water concentration). This gradient is the driving force in the transport of water up a plant.

The continuous flow of water is called the **transpiration stream**. It is primarily responsible for water moving up the plant.

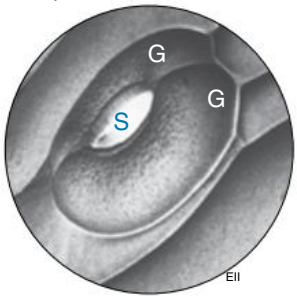
Soil
Highest free water concentration
Lowest solute concentration



The Role of Stomata

Water loss occurs mainly through stomata (pores in the leaf). The rate of water loss can be regulated by specialised guard cells (G) each side of the stoma (S), which open or close the pore.

- Stomata open: gas exchange and transpiration rate increase.
- Stomata closed: gas exchange and transpiration rates decrease.



1. (a) What is transpiration? _____

_____

(b) Describe one benefit of the transpiration stream for a plant: _____

_____

_____

_____

2. How does the plant regulate the amount of water lost from the leaves? _____

_____

KNOW WEB 112 LINK 49 LINK 111 LINK 113

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Processes involved in Moving Water Through the Xylem

1 Transpiration Pull

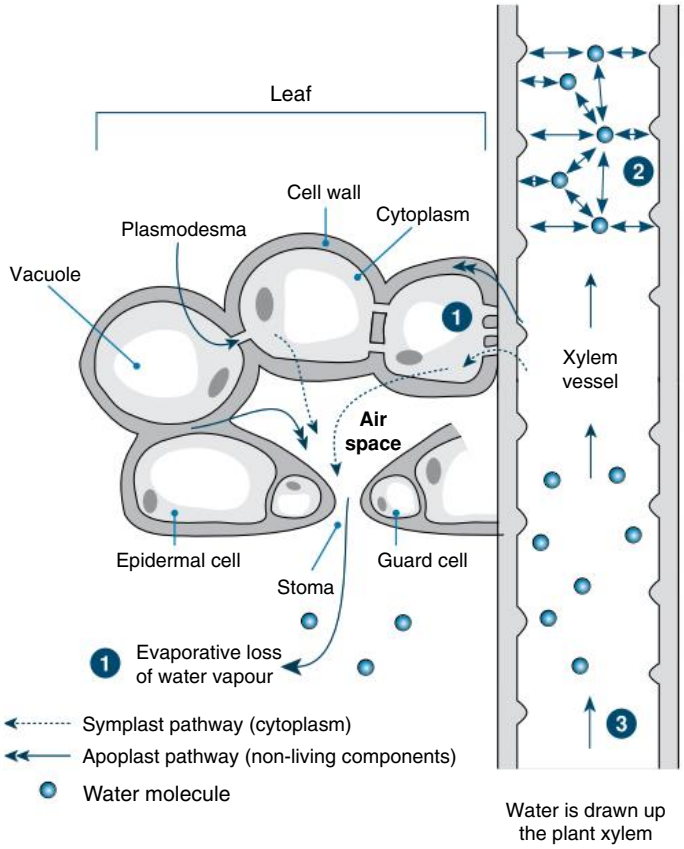
Water is lost from the air spaces by evaporation through stomata and is replaced by water from the mesophyll cells. The constant loss of water to the air (and production of sugars) creates a solute concentration in the leaves that is higher than elsewhere in the plant. Water is pulled through the plant along a **gradient of increasing solute concentration**.

2 Cohesion-Tension

The transpiration pull is assisted by the special **cohesive** properties of water. Water molecules cling together as they are pulled through the plant. They also **adhere** to the walls of the xylem (**adhesion**). This creates one **unbroken column of water** through the plant. The upward pull on the cohesive sap creates a tension (a negative pressure). This helps water uptake and movement up the plant.

3 Root Pressure

Water entering the stele from the soil creates a **root pressure**; a weak 'push' effect for the water's upward movement through the plant. Root pressure can force water droplets from some small plants under certain conditions (**guttation**), but generally it plays a minor part in the ascent of water.



Water is drawn up the plant xylem

3. (a) What would happen if too much water was lost from the leaves? _____

_____

(b) When might this happen? _____

4. Describe the three processes that assist the transport of water from the roots of the plant upward:

(a) _____

_____

_____

_____

(b) _____

_____

_____

(c) _____

_____

_____

5. The maximum height water can move up the xylem by cohesion-tension alone is about 10 m. How then does water move up the height of a 40 m tall tree?

_____

_____

_____

_____

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113 Investigating Plant Transpiration

Key Idea: The relationship between the rate of transpiration and the environment can be investigated using a potometer. This activity describes a typical experiment to investigate the effect of different environmental conditions on transpiration rate using a potometer. You will present and analyse the results provided.

The Potometer

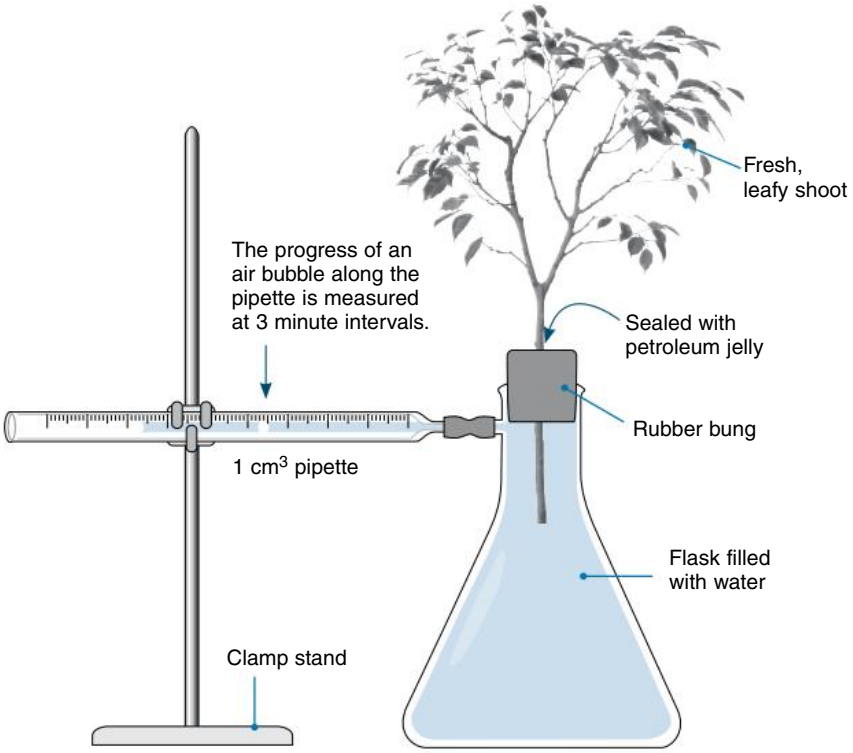
A potometer is a simple instrument for investigating transpiration rate (water loss per unit time). The equipment is simple to use and easy to obtain. A basic potometer, such as the one shown right, can easily be moved around so that transpiration rate can be measured under different environmental conditions.

Some physical conditions investigated are:

- Humidity or vapour pressure (high or low)
- Temperature (high or low)
- Air movement (still or windy)
- Light level (high or low)
- Water supply

It is also possible to compare the transpiration rates of plants with different adaptations e.g. comparing transpiration rates in plants with rolled leaves vs rates in plants with broad leaves. If possible, experiments like these should be conducted simultaneously using replicate equipment. If conducted sequentially, care should be taken to keep the environmental conditions the same for all plants used.





The Aim

To investigate the effect of environmental conditions on the transpiration rate of plants.

Background

Plants lose water all the time by evaporation from the leaves and stem. This loss, mostly through pores in the leaf surfaces, is called **transpiration**. Despite the adaptations plants have to help prevent water loss (e.g. waxy leaf cuticle), 99% of the water a plant absorbs from the soil is lost by evaporation. Environmental conditions can affect transpiration rate by increasing or decreasing the gradient for diffusion of water molecules between the plant and its external environment.

The Apparatus

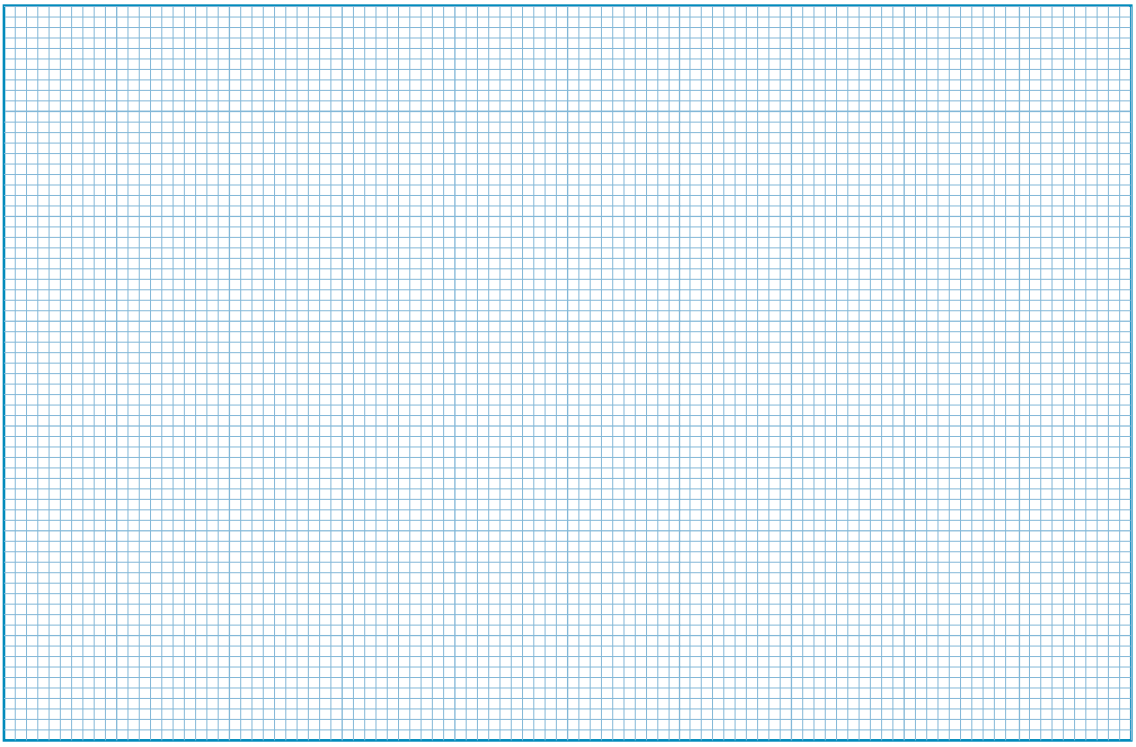
This experiment investigated the influence of environmental conditions on plant transpiration rate. The experiment examined four conditions: room conditions (ambient), wind, bright light, and high humidity. After setting up the potometer, the apparatus was equilibrated for 10 minutes, and then the position of the air bubble in the pipette was recorded. This is the time 0 reading. The plant was then exposed to one of the environmental conditions. Students recorded the location of the air bubble every three minutes over a 30 minute period. The potometer readings for each environmental condition are presented in Table 1 (next page).

A class was divided into four groups to study how four different environmental conditions (ambient, wind, bright light, and high humidity) affected transpiration rate. A **potometer** was used to measure transpiration rate (water loss per unit time). A basic potometer, such as the one shown left, can easily be moved around so that transpiration rate can be measured under different environmental conditions.

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Table 1. Potometer readings (in mL water loss)

Time (min) / Treatment	0	3	6	9	12	15	18	21	24	27	30
Ambient	0	0.002	0.005	0.008	0.012	0.017	0.022	0.028	0.032	0.036	0.042
Wind	0	0.025	0.054	0.088	0.112	0.142	0.175	0.208	0.246	0.283	0.325
High humidity	0	0.002	0.004	0.006	0.008	0.011	0.014	0.018	0.019	0.021	0.024
Bright light	0	0.021	0.042	0.070	0.091	0.112	0.141	0.158	0.183	0.218	0.239



1. (a) Plot the potometer data from Table 1 on the grid provided:

   (b) Identify the independent variable: _____

2. (a) Identify the control: _____

   (b) Explain the purpose of including an experimental control in an experiment: _____

   _____

   _____

   (c) Which factors increased water loss? _____

   (d) How does each environmental factor influence water loss? _____

   _____

   _____

   (e) Explain why the plant lost less water in humid conditions: _____

   _____

   _____

   _____

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114 Translocation

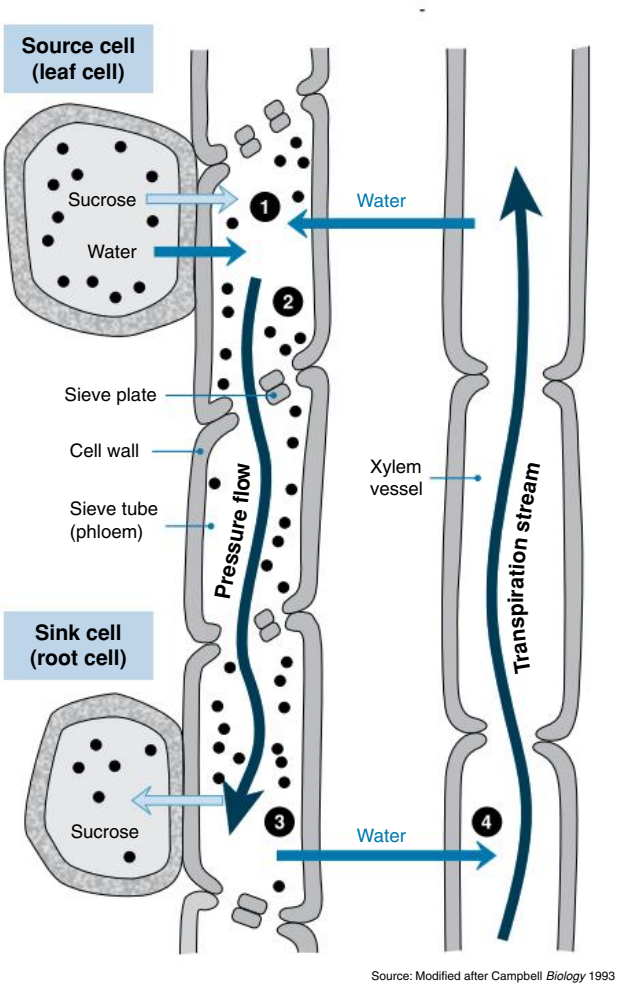
Key Idea: Phloem transports the organic products of photosynthesis (sugars) through the plant by translocation.

In angiosperms, the sugar moves through the sieve-tube members, which are arranged end-to-end and perforated with sieve plates. Apart from water, phloem sap comprises mainly sucrose (up to 30%). It may also contain minerals, hormones, and amino acids, in transit around the plant. Movement of sap in the phloem is from a **source** (a plant organ where sugar is made or mobilised) to a **sink** (a plant organ where sugar is stored or used). Loading sucrose into the phloem at a source involves energy expenditure; it is slowed or stopped by high temperatures or respiratory inhibitors. In some plants, unloading the sucrose at the sinks also requires energy, although in others, diffusion alone is sufficient to move sucrose from the phloem into the cells of the sink organ.

Phloem Transport

Phloem sap moves from source to sink at rates as great as 100 m h^{-1}, which is too fast to be accounted for by cytoplasmic streaming. The most acceptable model for phloem movement is the **pressure-flow** (bulk flow) hypothesis. Phloem sap moves by bulk flow, which creates a pressure (hence the term "pressure-flow"). The key elements in this model are outlined below and right. Note that, for simplicity, the cells that lie between the source (and sink) cells and the phloem sieve-tube have been omitted.

1. Loading sugar into the phloem increases the solute concentration inside the sieve-tube cells. This causes the sieve-tubes to take up water by osmosis.
2. The water uptake creates a hydrostatic pressure that forces the sap to move along the tube, just as pressure pushes water through a hose.
3. The pressure gradient in the sieve tube is reinforced by the active unloading of sugar and consequent loss of water by osmosis at the sink (e.g. root cell).
4. Xylem recycles the water from sink to source.



Source: Modified after Campbell *Biology* 1993



DH

Measuring Phloem Flow

Experiments investigating flow of phloem often use aphids. Aphids feed on phloem sap (left) and act as natural **phloem probes**. When the mouthparts (stylet) of an aphid penetrate a sieve-tube cell, the pressure in the sieve-tube force-feeds the aphid. While the aphid feeds, it can be severed from its stylet, which remains in place in the phloem. The stylet serves as a tiny tap that exudes sap. Using different aphids, the rate of flow of this sap can be measured at different locations on the plant.

1. (a) From what you know about osmosis, explain why water follows the sugar as it moves through the phloem: _____

_____

_____

(b) What is meant by '**source to sink**' flow in phloem transport? _____

_____

2. Why does a plant need to move food around, particularly from the leaves to other regions? _____

_____

_____

3. (a) Why is it necessary for phloem to be alive to be functional? _____

_____

(b) What evidence there is that phloem is live tissue? _____

_____

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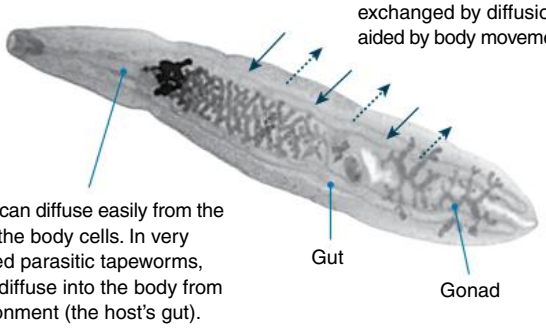
115 Transport and Exchange in Animals

Key Idea: Internal transport systems in animals move materials between exchange surfaces by mass transport.

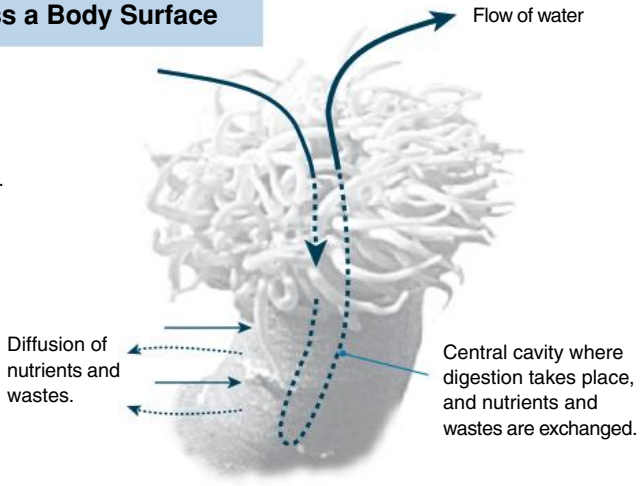
Living cells require a constant supply of nutrients and oxygen, and continuous removal of wastes. Simple, small organisms achieve this through diffusion. Larger, more complex organisms require specialised systems to facilitate exchanges as their surface area to volume ratio decreases. **Mass transport** (also known as mass flow or bulk flow) describes the movement of materials at equal rates or as a single mass. Mass transport accounts for the long distance transport of fluids in living organisms. It includes the movement of blood in the circulatory systems of animals.

Exchanges Across a Body Surface

In some small multicellular organisms, where body depth is not great, diffusion is sufficient to allow adequate exchanges with the environment.

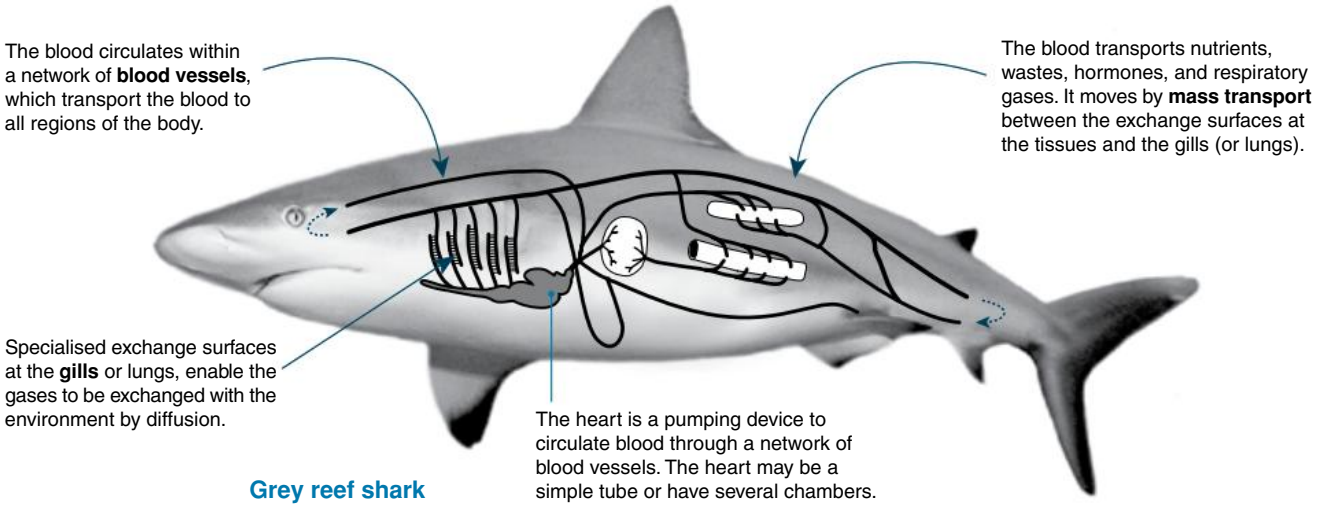


Platyhelminthes (liver fluke)



Cnidarians (sea anomone)

Systems for Exchange and Transport



Grey reef shark

1. Why do animals above a certain size or level of complexity require specialised systems for transport and exchange?

2. (a) How do materials move within the circulatory system of a vertebrate?

   (b) Contrast this with how materials are transported in a flatworm or single celled eukaryote:

   (c) Identify two exchange sites in a vertebrate:

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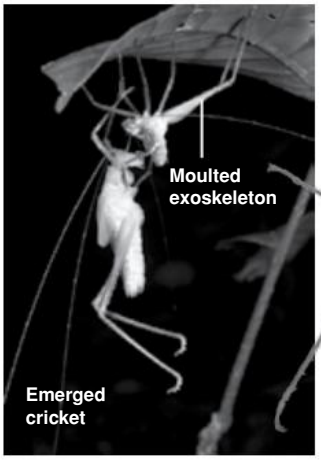
LINK 52 LINK 32 KNOW

116 Circulatory Fluids

Key Idea: Circulatory fluid transports nutrients, wastes, hormones, and often respiratory gases around the body.

The internal transport system of most animals includes a circulating fluid. In animals with closed systems, the fluid in the blood vessels is distinct from the tissue fluid outside the vessels and is called **blood**. Blood can have many different appearances, depending on the animal group, but it usually consists of cells and cell fragments suspended in a watery fluid. It serves many functions, including transporting dissolved gases, nutrients, wastes, and hormones. In animals with open systems, there is no difference between the fluid in the vessels and that in the sinuses (haemocoel) so the circulating fluid is called **haemolymph**. In insects, the haemolymph carries nutrients but not respiratory gases.

Insect Haemolymph



Fluid pressure is used to facilitate moulting in insects. Overwintering insects even have antifreezes, such as glycerol, in the plasma so they don't freeze during winter.



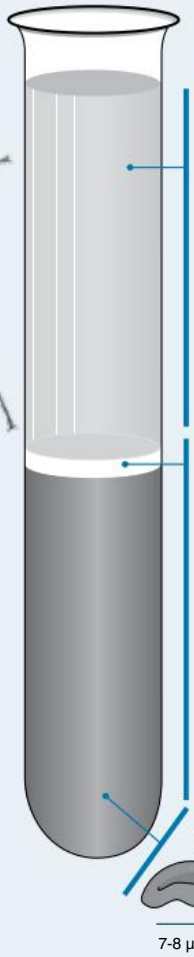
Haemolymph may make up between 11% and 40% of the total body mass of an insect

Haemolymph is a blood-like substance found in all invertebrates with open circulatory systems. The haemolymph fills the **haemocoel** and surrounds all cells.

About 90% of **insect haemolymph** is plasma, a watery fluid, which is usually clear. Compared to vertebrate blood, it contains relatively high concentrations of amino acids, proteins, sugars, and inorganic ions.

The remaining 10% of haemolymph volume is made up of various cell types (**haemocytes**). These are involved in clotting and internal defence. Unlike vertebrate blood, insect haemolymph lacks red blood cells and (with a few exceptions) lacks respiratory pigment, because oxygen is delivered directly to tissues by the tracheal system.

Mammalian Blood



NON-CELLULAR COMPONENTS

The non-cellular part of the blood is the plasma, a watery matrix making up 50-60% of blood volume.

Most of the blood is water. It transports dissolved substances, provides cells with water, distributes heat, and maintains blood volume. The plasma also contains ions (e.g. Ca^{2+}) and proteins.

CELLULAR COMPONENTS

The formed elements of blood float in the plasma and make up 40-50% of the total blood volume

White blood cells and platelets

2-3% of the total blood volume. White blood cells are involved in internal defence. Platelets are involved in blood clotting.

Lymphocytes: 24% of the white cell count. Lymphocytes are responsible for immunity.

Granulocytes: White blood cells with a role in phagocytosis, inflammation, and allergic responses.

Platelets: Small, membrane-bound cell fragments with a role in blood clotting.

Red blood cells (RBCs)

38-48% of total blood volume. RBCs transport oxygen (carried bound to haemoglobin) and a small amount of carbon dioxide.

1. Describe two common functions of mammalian blood and insect haemolymph:

   (a) _____

   (b) _____

2. Describe one function of mammalian blood not performed by insect haemolymph: _____

   _____

3. Describe one function of insect haemolymph not performed by mammalian blood: _____

   _____

4. Describe one feature distinguishing red and white blood cells in mammalian blood: _____

   _____

5. Contrast the proportions of cellular and non-cellular components in blood and haemolymph: _____

   _____

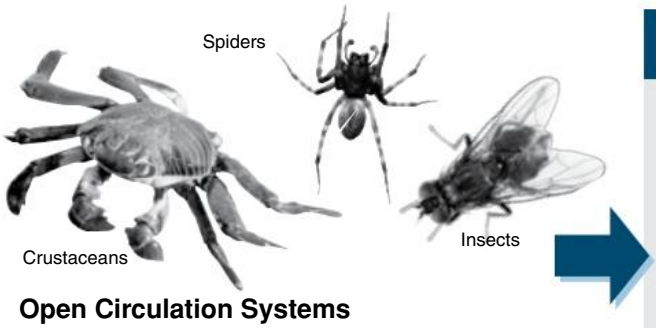
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117 Open Circulatory Systems

Key Idea: In open circulatory systems, the haemolymph circulates in the body cavity, not enclosed in vessels.

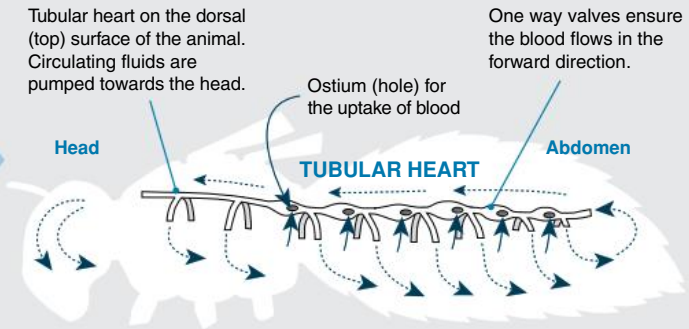
The circulatory systems of animals may be open or closed. **Open circulatory systems**, in which the body fluid circulates freely in the body cavity, are typical of most invertebrates. Insects, unlike most other arthropods, do not use the circulatory system to transport oxygen, which is delivered directly to the tissues via a system of tracheal tubes. In addition to its usual transport functions, the circulatory system may also be important in hydraulic movements of the whole body (e.g. many molluscs) or its parts (e.g. butterflies expand the wings after moulting).



Open Circulation Systems

Arthropods and molluscs (except cephalopods) have open circulatory systems in which the blood is pumped by a tubular, or sac-like, heart through short vessels into large spaces in the body cavity. The blood bathes the cells before reentering the heart through holes (**ostia**). Muscle action may assist the circulation of the blood.

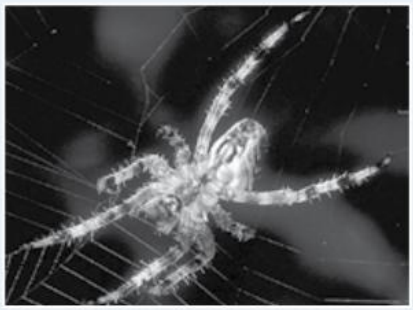
Open Circulatory System



Body fluids flow freely within the body cavity



The circulatory system of crabs is best described as incompletely closed. The thoracic heart has three pairs of ostia and a number of arteries, which leave the heart and branch extensively to supply various organs before draining into discrete channel-like sinuses.



In spiders, arteries from the dorsal heart empty the haemolymph into tissue spaces and then into a large ventral sinus that bathes the book lungs where gas exchange takes place. Venous channels conduct the haemolymph back to the heart.



The haemolymph occupies up to 40% of the body mass of an insect and is usually under low pressure due its lack of confinement in vessels. The circulation of the haemolymph is aided by body movements such as the ventilating movements of the abdomen.

1. How does an open circulatory system move fluid (haemolymph) about the body? _____

2. Describe one disadvantage of an open circulatory system: _____

3. Compare insects and decapod crustaceans (e.g. crabs) in the degree to which the circulatory system is closed:

4. (a) Why is the crab's circulatory system usually described as an open system? _____

   (b) In what way is this description not entirely accurate? _____

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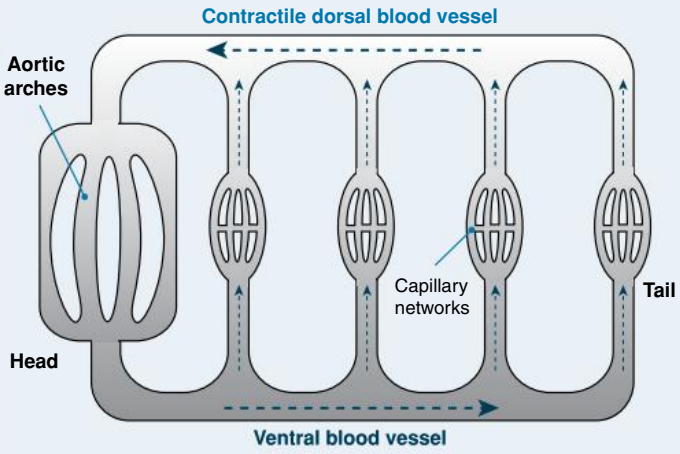
118 Closed Circulatory Systems

Key Idea: In closed circulatory systems, the blood is contained within blood vessels.

In closed circulatory systems, the blood is contained within vessels and pumped around the body by a heart. Oxygen is transported by the blood and diffuses through capillary walls into the body cells. In large, active animals closed systems efficiently distribute oxygen and nutrients to the body's cells. Closed systems allow the animal to control the distribution of blood flow to different organs and parts of the body by contracting or dilating blood vessels. Vertebrate systems have a pulmonary circuit taking up oxygen and a systemic circuit delivering oxygenated blood to the body.

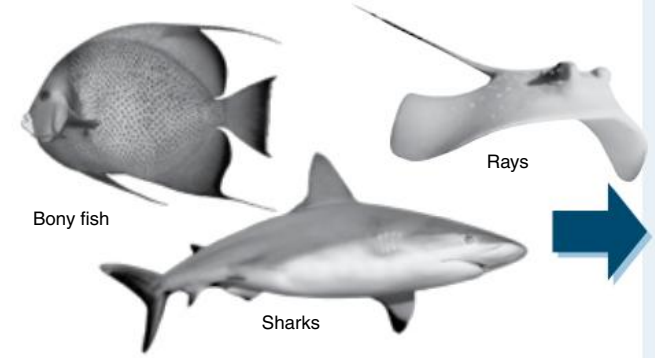
INVERTEBRATE CLOSED SYSTEMS

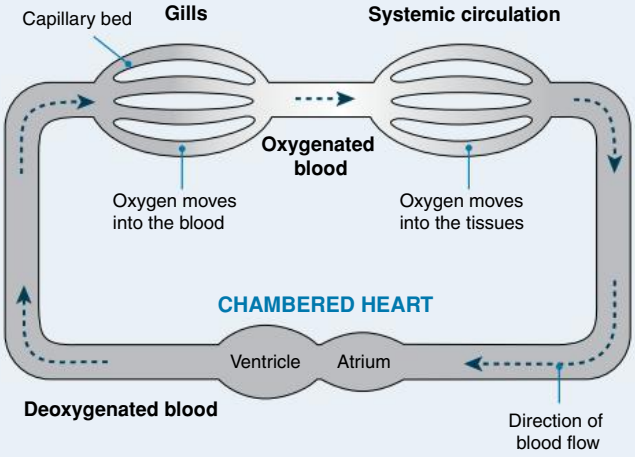




The closed systems of many annelids (e.g. earthworms) circulate blood through a series of vessels before returning it to the heart. In annelids, the dorsal and ventral blood vessels are connected by lateral vessels in every segment (right). The dorsal vessel receives blood from the lateral vessels and carries it towards the head. The ventral vessel carries blood posteriorly and distributes it to the segmental vessels. The dorsal vessel is contractile and is the main method of propelling the blood, but there are also several contractile aortic arches ('hearts') which act as accessory organs for blood propulsion.

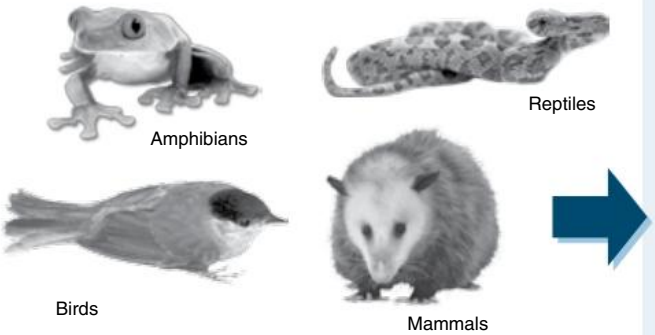
VERTEBRATE CLOSED SYSTEMS

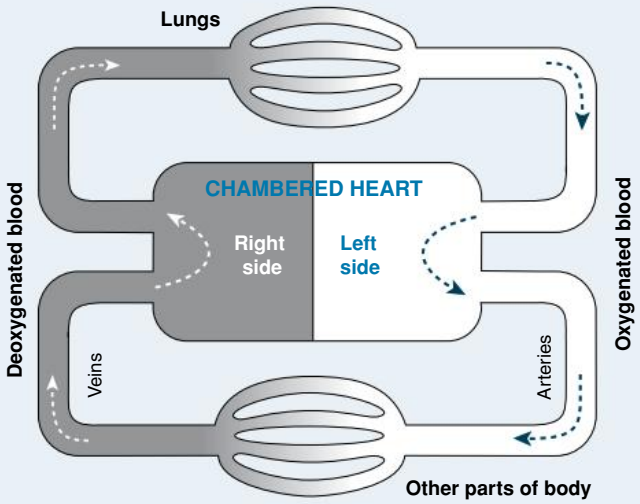




Closed, single circuit systems

In closed circulation systems, the blood is contained within vessels and is returned to the heart after every circulation of the body. Exchanges between the blood and the fluids bathing the cells occurs by diffusion across capillaries. In single circuit systems, typical of fish, the blood goes directly from the gills to the body. The blood loses pressure at the gills and flows at low pressure around the body.





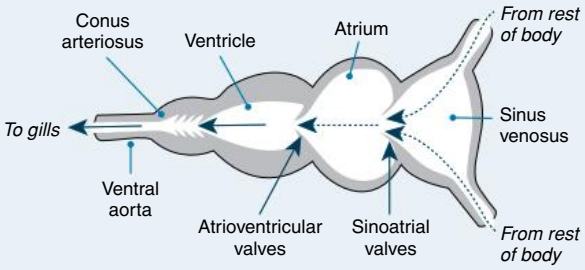
Closed, double circuit systems

Double circulation systems occur in all vertebrates other than fish. The blood is pumped through a pulmonary circuit to the lungs, where it is oxygenated. The blood returns to the heart, which pumps the oxygenated blood, through a systemic circuit, to the body. In amphibians and most reptiles, the heart is not completely divided and there is some mixing of oxygenated and deoxygenated blood. In birds and mammals, the heart is fully divided and there is no mixing.

KNOW
LINK 102
LINK 119
LINK 123

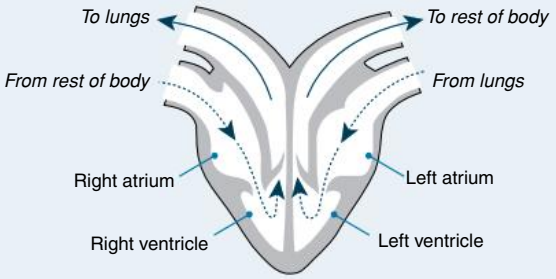
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Fish Heart



The fish heart is linear, with a sequence of chambers in series. There are two main chambers (atrium and ventricle) as well as an entry (the sinus venous) and somtimes a smaller exit chamber (the conus). Blood from the body first enters the heart through the sinus venosus, then passes into the atrium and the ventricle. A series of one-way valves between the chambers prevents reverse blood flow. Blood leaving the heart travels to the gills.

Mammalian Heart



In birds and mammals, the heart is fully partitioned into two halves, resulting in four chambers. Blood circulates through two circuits, with no mixing of the two. Oxygenated blood from the lungs is kept separated from the deoxygenated blood returning from the rest of the body.

1. What is the main difference between closed and open systems of circulation? _____

2. (a) Where does the blood flow to immediately after it has passed through the gills in a fish? _____

   (b) Relate this to the pressure at which the blood flows in the systemic circulation: _____

3. (a) Where does the blood flow to immediately after it has passed through the lungs in a mammal? _____

   (b) Relate this to the pressure at which the blood flows in the systemic circulation: _____

4. Explain the higher functional efficiency of a double circuit system, relative to a single circuit system: _____

5. Hearts range from being simple contractile structures to complex chambered organs. Describe basic heart structure in:

   (a) Fish: _____

   (b) Mammals: _____

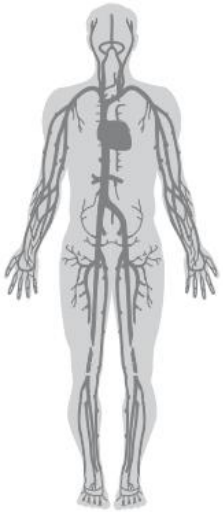
6. How does a closed circulatory system give an animal finer control over the distribution of blood to tissues and organs?

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119 Mammalian Transport

Key Idea: The mammalian circulatory system is double circuit system made up of a pulmonary circuit and a systemic circuit.

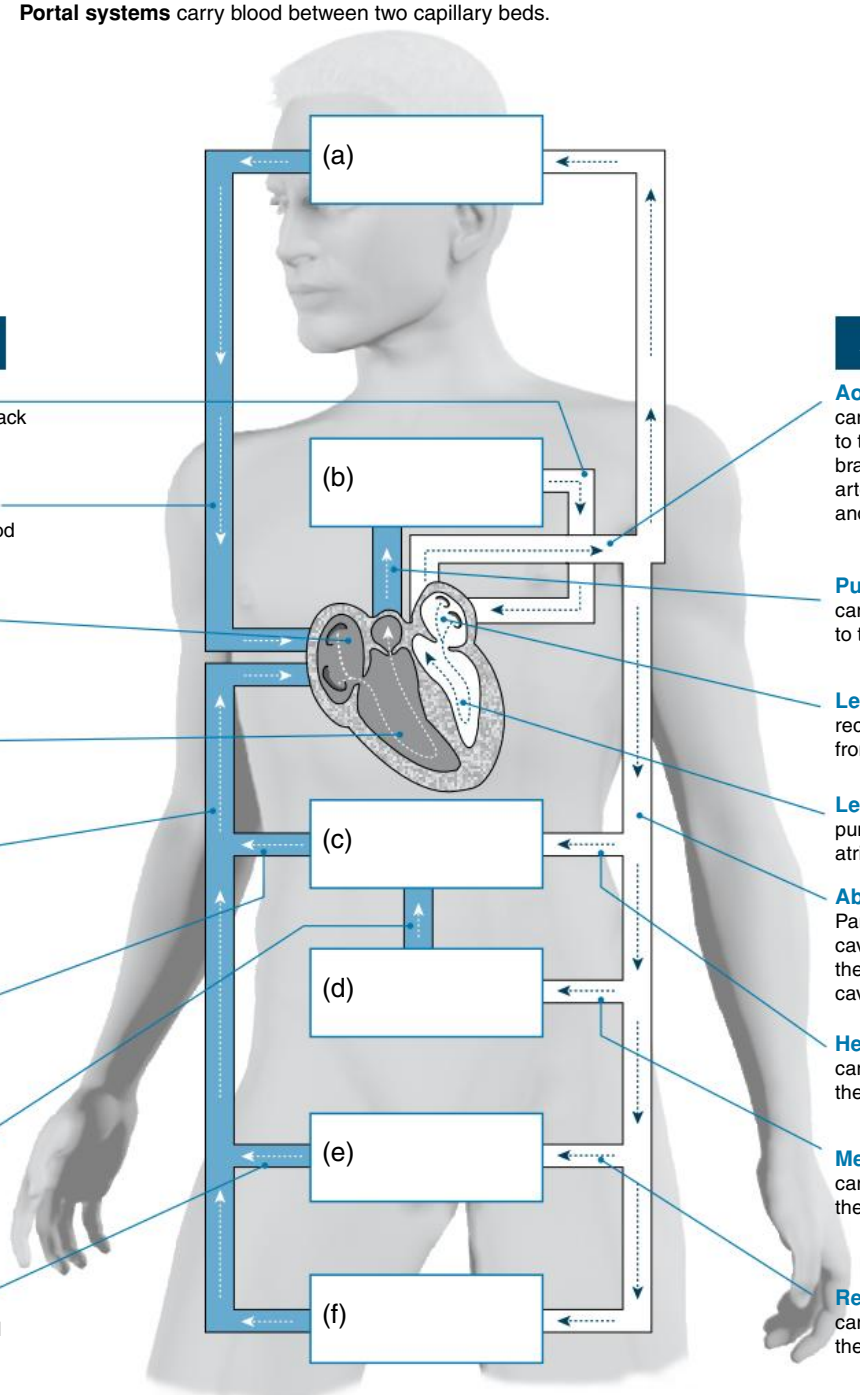
The blood vessels of the circulatory system form a network of tubes that carry blood away from the heart, transport it to the tissues of the body, and then return it to the heart. The figure below shows a number of the basic circulatory routes. Mammals have a double circulatory system: a **pulmonary system**, which carries blood between the heart and lungs, and a **systemic system**, which carries blood between the heart and the rest of the body. The systemic circulation has many subdivisions. Two important subdivisions are the coronary (cardiac) circulation, which supplies the heart muscle, and the hepatic portal circulation, which runs from the gut to the liver.



Schematic Overview of the Human Circulatory System

Deoxygenated blood (coloured blue below) travels to the right side of the heart via the vena cavae. The heart pumps the deoxygenated blood to the lungs where it releases carbon dioxide and receives oxygen. The oxygenated blood (coloured white below) travels via the pulmonary vein back to the heart from where it is pumped to all parts of the body. The **venous system** (figure, left) returns blood from the capillaries to the heart. The **arterial system** (figure right) carries blood from the heart to the capillaries. **Portal systems** carry blood between two capillary beds.





VENOUS SYSTEM

Pulmonary vein: carries oxygenated blood back to the heart.

Superior vena cava: receives deoxygenated blood from the head and body.

Right atrium: receives deoxygenated blood via the superior and inferior vena cavae.

Right ventricle: pumps deoxygenated blood to the lungs.

Inferior vena cava: receives deoxygenated blood from the lower body and organs.

Hepatic vein: carries deoxygenated blood from the liver.

Hepatic portal vein: carries deoxygenated, nutrient rich blood from the gut for processing.

Renal vein: carries deoxygenated blood from the kidneys.

ARTERIAL SYSTEM

Aorta: carries oxygenated blood to the body. Anteriorly, it branches to form the carotid arteries supplying the head and neck.

Pulmonary artery: carries deoxygenated blood to the lungs.

Left atrium: receives oxygenated blood from the lungs.

Left ventricle: pumps blood from the left atrium to the aorta.

Abdominal aorta: Parallel to the inferior vena cava, branching to supply the organs of the abdominal cavity.

Hepatic artery: carries oxygenated blood to the liver.

Mesenteric artery: carries oxygenated blood to the gut.

Renal artery: carries oxygenated blood to the kidneys.

1. Complete the diagram above by labelling the boxes with the correct organs: *lungs, liver, head, intestines, genitals/lower body, kidneys.*

2. Circle the two blood vessels involved in the pulmonary circuit.

KNOW LINK 123 LINK 125

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120 Arteries

Key Idea: Arteries are blood vessels that carry blood away from the heart to the capillaries within the tissues.

In vertebrates, **arteries** are the blood vessels that carry blood away from the heart to the capillaries within the tissues. The large arteries that leave the heart divide into medium-sized (distributing) arteries. Within the tissues and organs, these distributing arteries branch to form **arterioles**, which deliver blood to capillaries. Arterioles lack the thick layers of arteries and consist only of an endothelial layer wrapped by a few smooth muscle fibres at intervals along their length. Blood flow to the tissues is altered by contraction (**vasoconstriction**) or relaxation (**vasodilation**) of the blood vessel walls. Vasoconstriction increases blood pressure whereas vasodilation has the opposite effect.

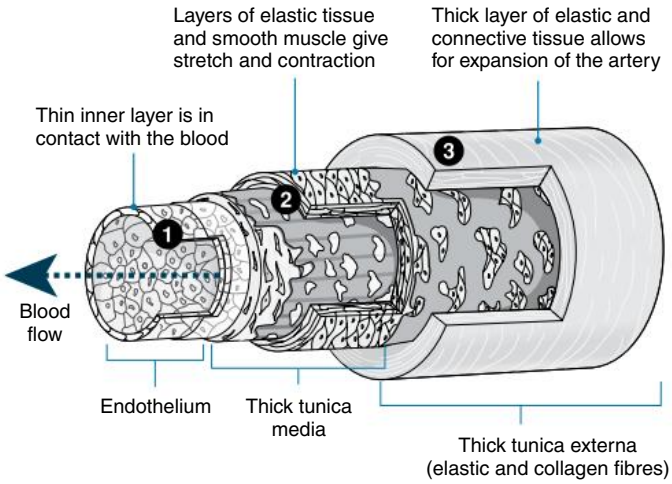
Arteries

Arteries have an elastic, stretchy structure that gives them the ability to withstand the high pressure of blood being pumped from the heart. At the same time, they help to maintain pressure by having some contractile ability themselves (a feature of the central muscle layer). Arteries nearer the heart have more elastic tissue, giving greater resistance to the higher blood pressures of the blood leaving the left ventricle. Arteries further from the heart have more muscle to help them maintain blood pressure. Between heartbeats, the arteries undergo elastic recoil and contract. This tends to smooth out the flow of blood through the vessel.

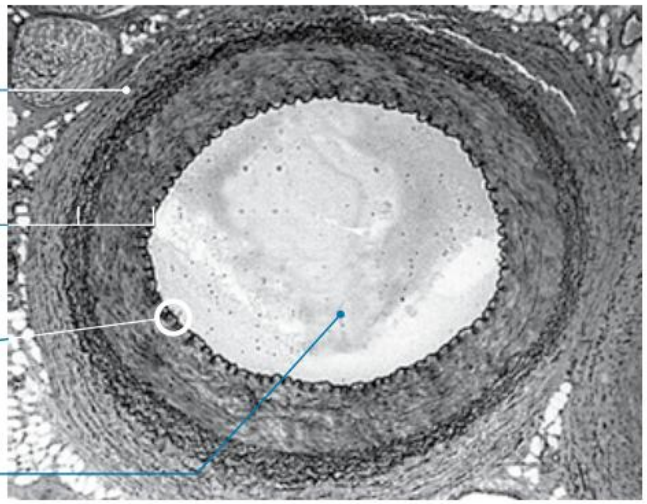
Arteries comprise three main regions (right):

1. A thin inner layer of epithelial cells called the endothelium lines the artery.
2. A central layer (the **tunica media**) of elastic tissue and smooth muscle that can both stretch and contract.
3. An outer connective tissue layer (the **tunica externa**) has a lot of elastic tissue.

Artery Structure



Cross Section through a Large Artery



1. Using the diagram to help you, label the photograph (a)-(d) of the cross section through an artery (above).
2. (a) Why do the walls of arteries need to be thick with a lot of elastic tissue? _____

   _____

   (b) Why do arterioles lack this elastic tissue layer? _____

   _____
3. What is the purpose of the smooth muscle in the artery walls? _____

   _____
4. (a) What is the effect of vasodilation on the diameter of an arteriole? _____

   (b) What is the effect of vasodilation on blood pressure? _____

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121 Veins

Key Idea: Veins are blood vessels that carry blood from the tissues back to the heart.

Veins are the blood vessels that return blood to the heart from the tissues. The smallest veins (**venules**) return blood from the capillary beds to the larger veins. Veins and their branches contain about 59% of the blood in the body. The structural differences between veins and arteries are mainly associated with differences in the relative thickness of the vessel layers and the diameter of the lumen. These, in turn, are related to the vessel's functional role.

Veins

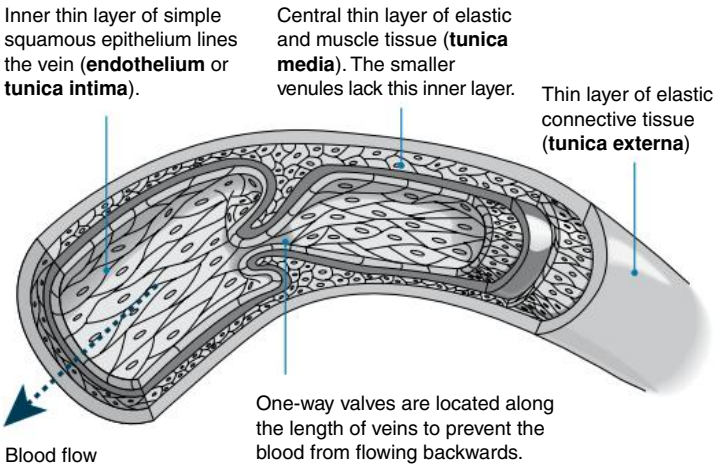
When several capillaries unite, they form small veins called **venules**. The venules collect the blood from capillaries and drain it into **veins**. Veins are made up of essentially the same three layers as arteries but they have less elastic and muscle tissue and a larger **lumen**. The venules closest to the capillaries consist of an **endothelium** and a tunica externa of connective tissue. As the venules approach the veins, they also contain the tunica media characteristic of veins (right). Although veins are less elastic than arteries, they can still expand enough to adapt to changes in the pressure and volume of the blood passing through them. Blood flowing in the veins has lost a lot of pressure because it has passed through the narrow capillary vessels. The low pressure in veins means that many veins, especially those in the limbs, need to have valves to prevent backflow of the blood as it returns to the heart.

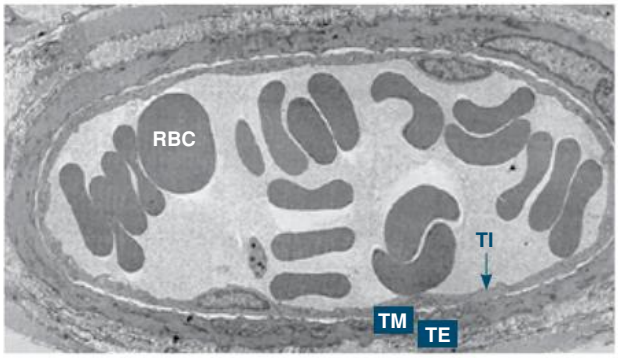


Dan Butler

If a vein is cut, as is shown in this severed finger wound, the blood oozes out slowly in an even flow, and usually clots quickly as it leaves. In contrast, arterial blood spurts rapidly and requires pressure to staunch the flow.

Vein Structure





EII

Above: TEM of a vein showing red blood cells (RBC) in the lumen, and the tunica intima (TI), tunica media (TM), and tunica externa (TE).

1. Contrast the structure of veins and arteries for each of the following properties:

   (a) Thickness of muscle and elastic tissue: _____

   _____

   (b) Size of the lumen (inside of the vessel): _____

   _____

2. With respect to their functional roles, explain the differences you have described above: _____

   _____

   _____

3. What is the role of the valves in assisting the veins to return blood back to the heart? _____

   _____

4. Why does blood ooze from a venous wound, rather than spurting as it does from an arterial wound?

   _____

   _____

   _____

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122 Capillaries

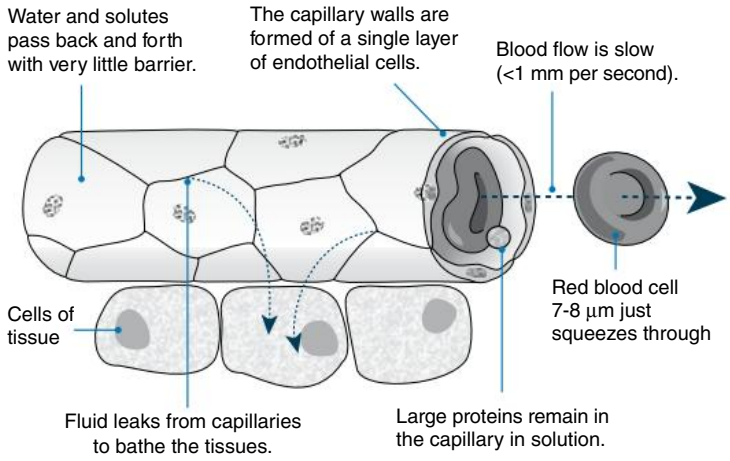
Key Idea: Capillaries allow the exchange of material between the blood and the tissues.

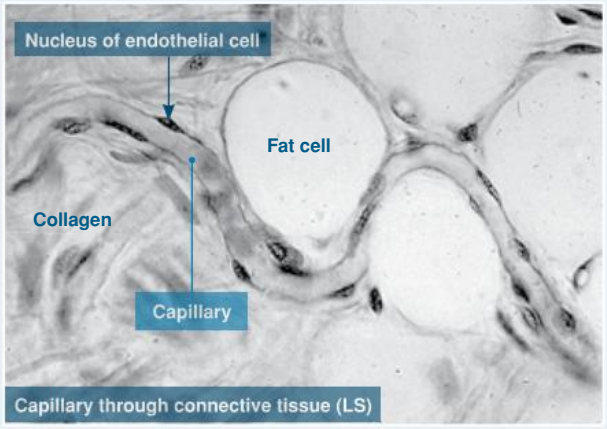
In vertebrates, **capillaries** are very small vessels that connect arterial and venous circulation and allow efficient exchange of nutrients and wastes between the blood and tissues. Capillaries form networks or beds and are abundant where metabolic rates are high. Fluid that leaks out of the capillaries has an essential role in bathing the tissues.

Exchanges in Capillaries

Blood passes from the arterioles into the capillaries. Capillaries are small blood vessels with a diameter of just 4-10 µm. The only tissue present is an **endothelium** of squamous epithelial cells. Capillaries are so numerous that no cell is more than 25 µm from any capillary. It is in the capillaries that the exchange of materials between the body cells and the blood takes place.

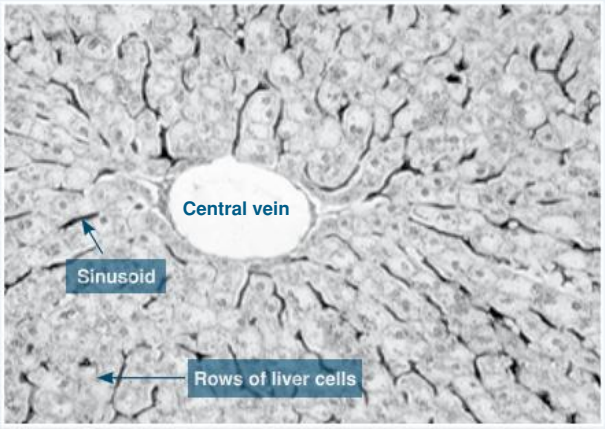
Blood pressure causes fluid to leak from capillaries through small gaps where the endothelial cells join. This fluid bathes the tissues, supplying nutrients and oxygen, and removing wastes (right).The density of capillaries in a tissue is an indication of that tissue's metabolic activity. For example, cardiac muscle relies heavily on oxidative metabolism. It has a high demand for blood flow and is well supplied with capillaries. Smooth muscle is far less active than cardiac muscle, relies more on anaerobic metabolism, and does not require such an extensive blood supply.





Dept of Biological Sciences, University of Delaware

Capillaries are found near almost every cell in the body. In many places, the capillaries form extensive branching networks. In most tissues, blood normally flows through only a small portion of a capillary network when the metabolic demands of the tissue are low. When the tissue becomes active, the entire capillary network fills with blood.



EII

Microscopic blood vessels in some dense organs, such as the liver (above), are called **sinusoids**. They are wider than capillaries and follow a more convoluted path through the tissue. Instead of the usual endothelial lining, they are lined with phagocytic cells. Like capillaries, sinusoids transport blood from arterioles to venules.

1. Describe the structure of a capillary, contrasting it with the structure of a vein and an artery:

2. Sinusoids provide a functional replacement for capillaries in some organs:

   (a) How do sinusoids differ structurally from capillaries? _____

   (b) In what way are capillaries and sinusoids similar? _____

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123 Capillary Networks

Key Idea: Capillaries form branching networks where exchanges between the blood and tissues take place.

The flow of blood through a capillary bed is called microcirculation. In most parts of the body, there are two types of vessels in a capillary bed: the true capillaries, where exchanges take place, and a vessel called a vascular shunt, which connects the arteriole and venule at either end of the bed. The shunt diverts blood past the true capillaries when the metabolic demands of the tissue are low. When tissue activity increases, the entire network fills with blood.

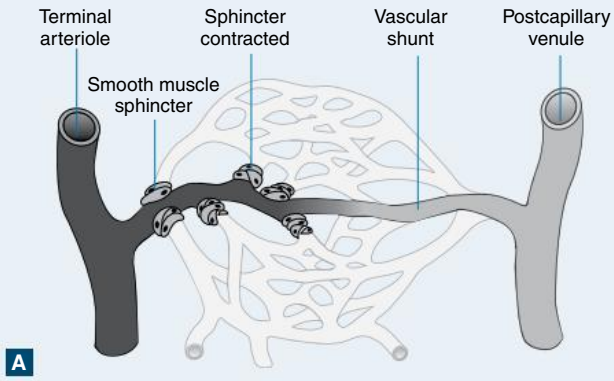
1. Describe the structure of a capillary network:

2. Explain the role of the smooth muscle sphincters and the vascular shunt in a capillary network:

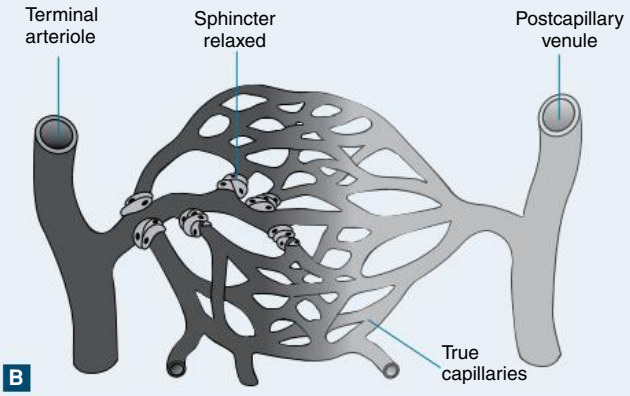
3. (a) Describe a situation where the capillary bed would be in the condition labelled **A**:

   (b) Describe a situation where the capillary bed would be in the condition labelled **B**:

4. How does a portal venous system differ from other capillary systems?



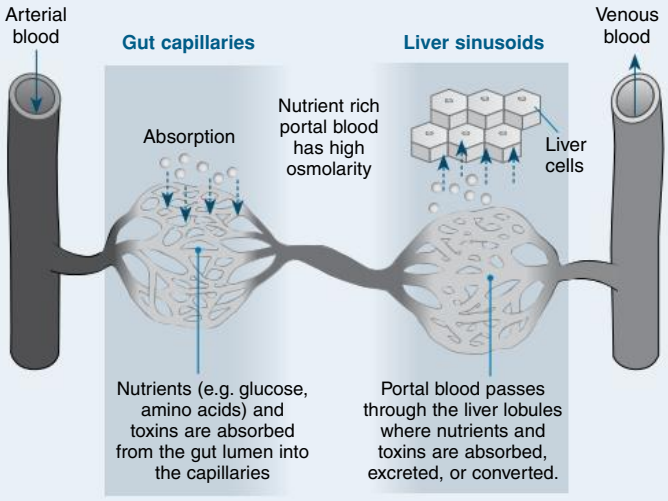
When the sphincters contract (close), blood is diverted via the vascular shunt to the postcapillary venule, bypassing the exchange capillaries.



When the sphincters are relaxed (open), blood flows through the entire capillary bed allowing exchanges with the cells of the surrounding tissue.

Connecting Capillary Beds

The role of portal venous systems



A portal venous system occurs when a capillary bed drains into another capillary bed through veins, without first going through the heart. Portal systems are relatively uncommon. Most capillary beds drain into veins which then drain into the heart, not into another capillary bed. The diagram above depicts the hepatic portal system, which includes both capillary beds and the blood vessels connecting them.

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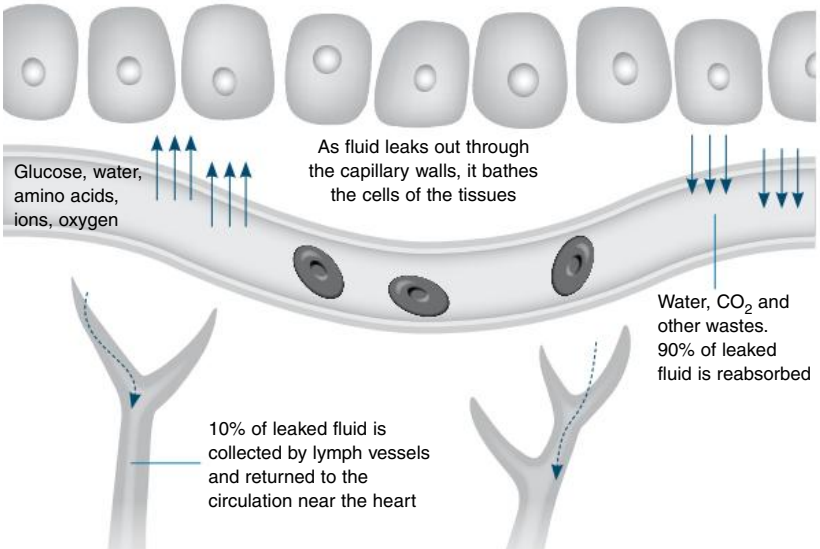
124 The Formation of Tissue Fluid

Key Idea: Tissue fluid is formed by leakage from capillaries. It provides oxygen and nutrients to tissues and removes wastes.

The network of capillaries supplying the body's tissues ensures that no substance has to diffuse far to enter or leave a cell. Substances reach the cells through the tissue fluid and can move into and out of the capillaries by diffusion, by cytosis, and through gaps where the membranes are not joined by tight junctions. Some specialised capillaries are relatively more leaky and occur where absorption or filtration is important (e.g. in the intestine or the kidney). Because capillaries are leaky, fluid flows across their plasma membranes. Whether fluid moves into or out of a capillary depends on the balance between the blood pressure and the concentration of solutes at each end of a capillary bed.

At the arteriolar end of a capillary bed, hydrostatic (blood) pressure (HP) forces fluid out of the capillaries and into the tissue fluid.

At the venous end of a capillary bed, hydrostatic pressure drops and most (90%) of the leaked fluid moves back into the capillaries.

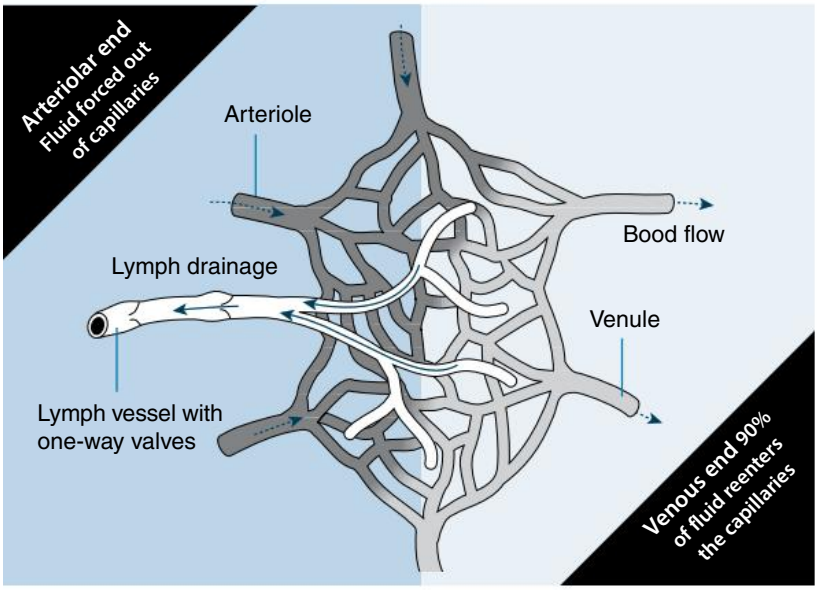


Arteriolar end of a capillary bed
Hydrostatic pressure and solute concentration is higher at the arteriolar end

Venous end of a capillary bed
Hydrostatic pressure is lower at the venous end. Solute concentration is slightly higher in the capillary too because of retained proteins.

RESULT: Net outward pressure
Water and solutes leave the capillary

RESULT: Net inward pressure
Water and solutes re-enter the capillary



As described above, not all the fluid reenters the capillaries at the venous end of the capillary bed. This extra fluid is collected by the lymphatic vessels, a network of vessels alongside the blood vessels. Once the fluid enters the lymphatic vessels it is called lymph. The lymphatic vessels drain into the subclavian vein near the heart. Lymph is similar to tissue fluid but has more lymphocytes.

1. What is the purpose of the tissue fluid?

2. Describe the features of capillaries that allow exchanges between the blood and other tissues:

3. Explain how hydrostatic (blood) pressure and solute concentration operate to cause fluid movement at:

   (a) The arteriolar end of a capillary bed:

   (b) The venous end of a capillary bed:

4. Describe the two ways in which tissue fluid is returned to the general circulation:

   (a)

   (b)

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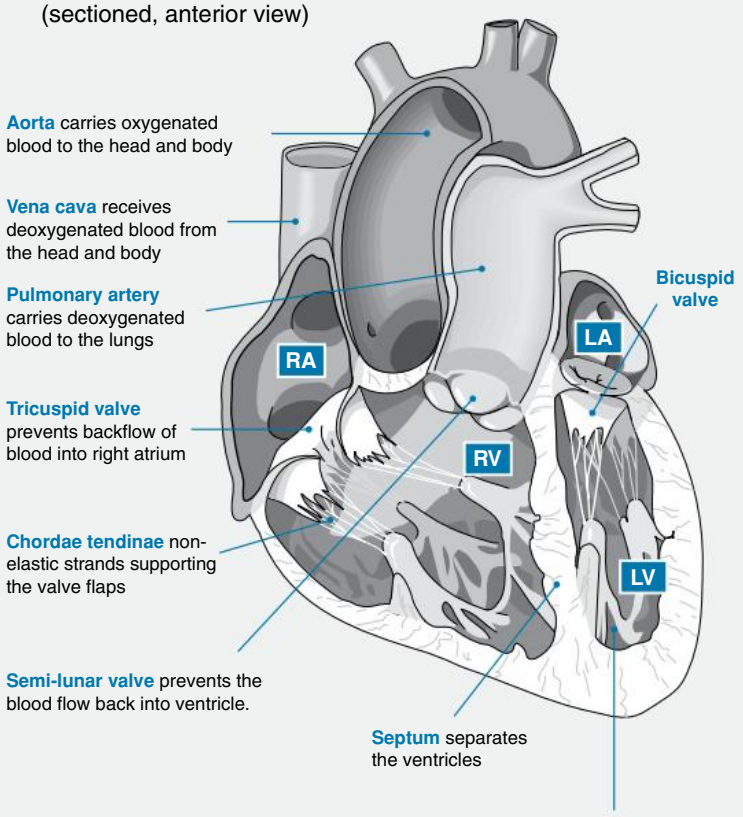
125 The Human Heart

Key Idea: Humans have a four chambered heart divided into left and right halves. It acts as a double pump.

The heart is the centre of the human cardiovascular system. It is a hollow, muscular organ made up of four chambers (two **atria** and two **ventricles**) that alternately fill and empty of blood, acting as a double pump. The left side (systemic circuit) pumps blood to the body tissues and the right side (pulmonary circuit) pumps blood to the lungs. The heart lies between the lungs, to the left of the midline, and is surrounded by a double layered pericardium of connective tissue, which prevents over distension of the heart and anchors it within the central compartment of the thoracic cavity.

Human Heart Structure

(sectioned, anterior view)

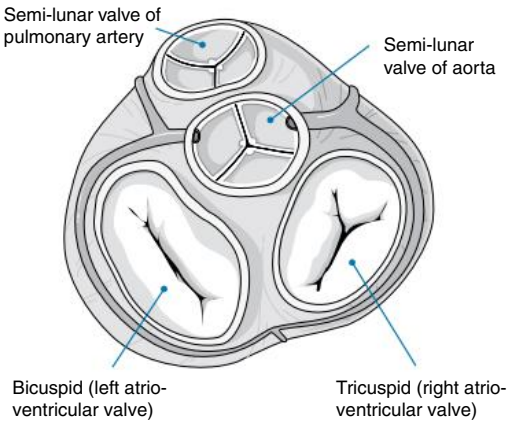


The heart is not a symmetrical organ. Although the quantity of blood pumped by each side is the same, the walls of the left ventricle are thicker and more muscular than those of the right ventricle. The difference affects the shape of the ventricular cavities, so the right ventricle is twisted over the left.

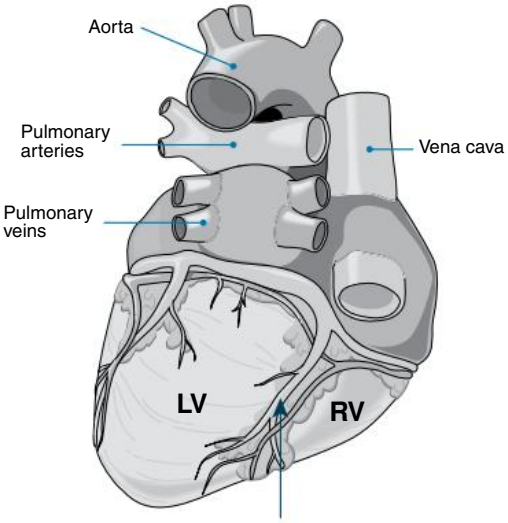
Key to abbreviations

RA	Right atrium: receives deoxygenated blood via the anterior and posterior vena cava
RV	Right ventricle: pumps deoxygenated blood to the lungs via the pulmonary artery
LA	Left atrium: receives blood returning to the heart from the lungs via the pulmonary veins
LV	Left ventricle: pumps oxygenated blood to the head and body via the aorta

Top view of a heart in section, showing valves

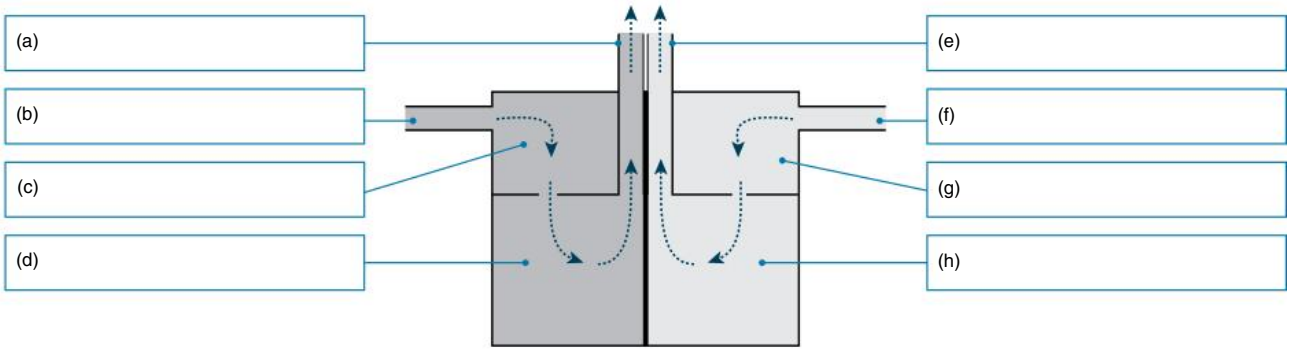


Posterior view of heart



Coronary arteries: The high oxygen demands of the heart muscle are met by a dense capillary network. Coronary arteries arise from the aorta and spread over the surface of the heart supplying the cardiac muscle with oxygenated blood. Deoxygenated blood is collected by cardiac veins and returned to the right atrium via a large coronary sinus.

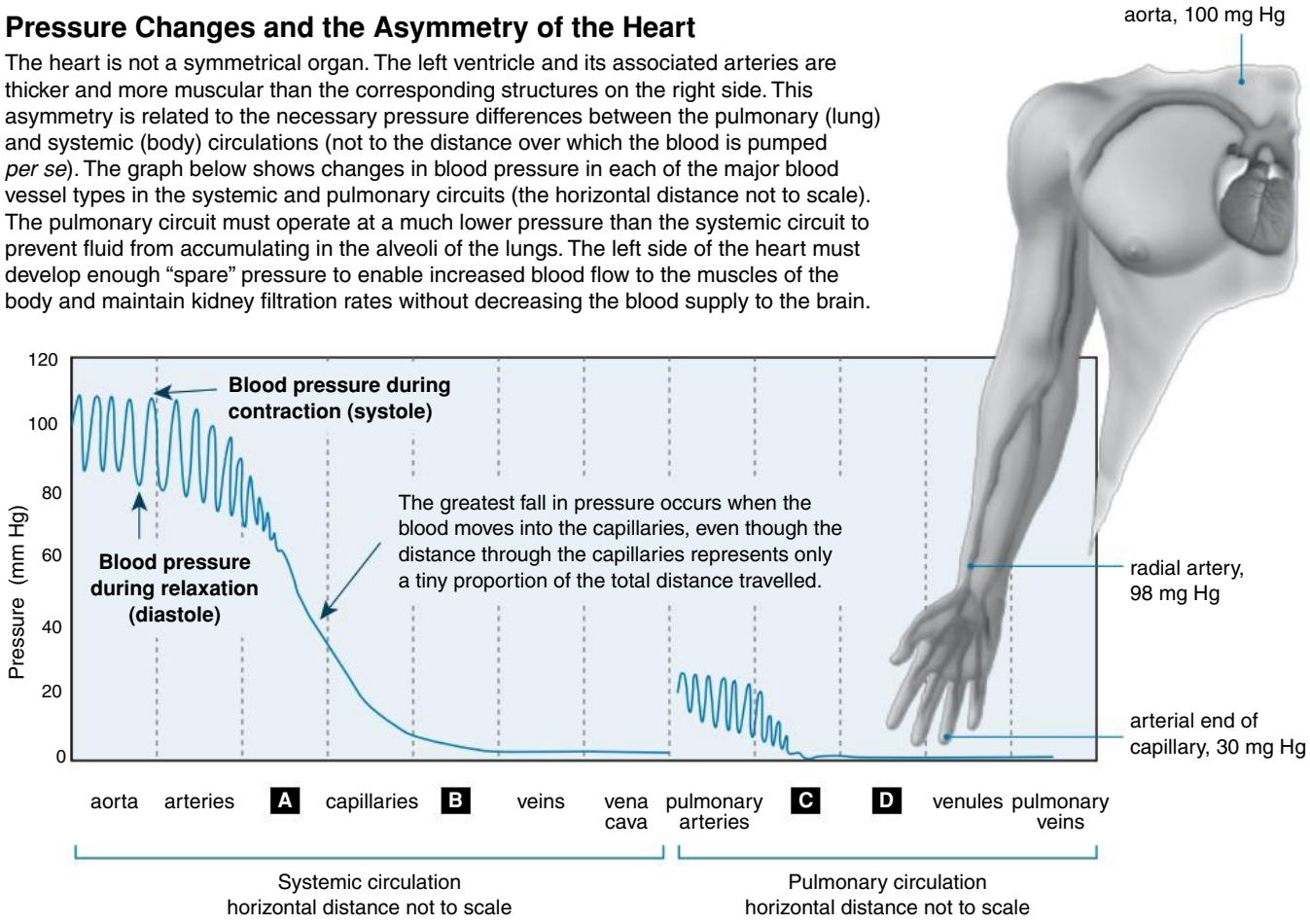
1. In the schematic diagram of the heart, below, label the four chambers and the main vessels entering and leaving them. The arrows indicate the direction of blood flow. Use large coloured circles to mark the position of each of the four valves.



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Pressure Changes and the Asymmetry of the Heart

The heart is not a symmetrical organ. The left ventricle and its associated arteries are thicker and more muscular than the corresponding structures on the right side. This asymmetry is related to the necessary pressure differences between the pulmonary (lung) and systemic (body) circulations (not to the distance over which the blood is pumped *per se*). The graph below shows changes in blood pressure in each of the major blood vessel types in the systemic and pulmonary circuits (the horizontal distance not to scale). The pulmonary circuit must operate at a much lower pressure than the systemic circuit to prevent fluid from accumulating in the alveoli of the lungs. The left side of the heart must develop enough "spare" pressure to enable increased blood flow to the muscles of the body and maintain kidney filtration rates without decreasing the blood supply to the brain.



2. What is the purpose of the valves in the heart? _____

_____

3. The heart is full of blood, yet it requires its own blood supply. Suggest two reasons why this is the case:

   (a) _____

   (b) _____

4. Predict the effect on the heart if blood flow through a coronary artery is restricted or blocked: _____

_____

_____

5. Identify the vessels corresponding to the letters **A-D** on the graph above:

   A: _____ B: _____ C: _____ D: _____

6. (a) Why must the pulmonary circuit operate at a lower pressure than the systemic system? _____

_____

_____

   (b) Relate this to differences in the thickness of the wall of the left and right ventricles of the heart: _____

_____

_____

7. What are you recording when you take a pulse? _____

_____

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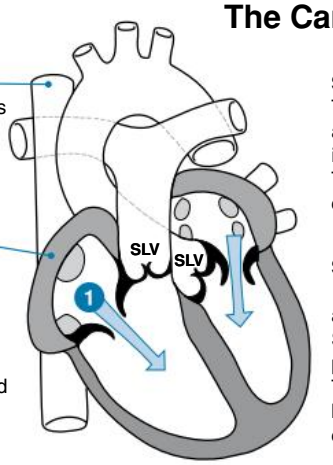
126 The Cardiac Cycle

Key Idea: The cardiac cycle refers to the orderly sequence of events of a heartbeat. The electrical activity of the heart corresponds to its contraction and relaxation during the cycle. The heart pumps with alternate contractions (**systole**) and relaxations (**diastole**) in response to electrical impulses generated by the cardiac muscle itself. Heartbeat occurs in a cycle involving three stages (below). Pressure changes in the heart's chambers generated by the contraction and relaxation are responsible for blood movement and cause the heart valves to open and close, preventing the backflow of blood.

The Cardiac Cycle

The **pulse** results from the rhythmic expansion of the arteries as the blood spurts from the left ventricle. Pulse rate therefore corresponds to heart rate.

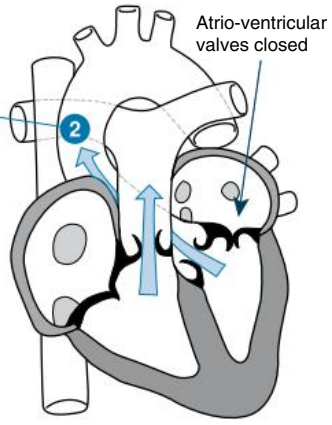
Stage 1: **Atrial contraction and ventricular filling**
The ventricles relax and blood flows into them from the atria. Note that 70% of the blood from the atria flows passively into the ventricles. It is during the last third of ventricular filling that the atria contract.



Heart during ventricular filling

Stage 2: **Ventricular contraction**
The atria relax, the ventricles contract, and blood is pumped from the ventricles into the aorta and the pulmonary artery. The start of ventricular contraction coincides with the first heart sound.

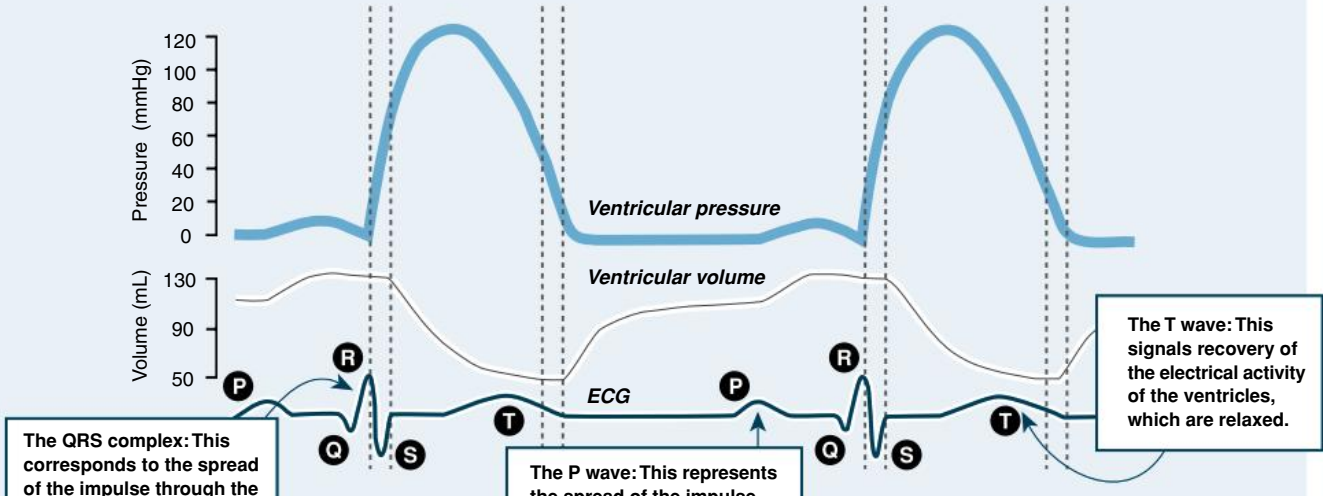
Stage 3: **Complete cardiac diastole**
(not shown) There is a short period of atrial and ventricular relaxation. Semilunar valves (**SLV**) close to prevent backflow into the ventricles. The cycle begins again. For a heart beating at 75 beats per minute, one cardiac cycle lasts about 0.8 seconds.



Heart during ventricular contraction

Cardiac Cycle Events in the Left Ventricle

The heartbeat occurs in response to electrical impulses generated spontaneously by the heart muscle itself. These can be recorded as a trace called an electrocardiogram or ECG. The ECG pattern is the result of impulses produced at each phase of the cycle. Each part is identified with a letter. An ECG is used to monitor heart activity and to detect disorders. Volume and pressure changes accompany the electrical trace.



A summary trace showing the changes in pressure, volume and electrical activity recorded in the left ventricle during two complete cardiac cycles

1. Identify each of the following phases of an ECG by its international letter code:

   (a) Excitation of the ventricles and ventricular systole: _____

   (b) Electrical recovery of the ventricles and ventricular diastole: _____

   (c) Excitation of the atria and atrial systole: _____

2. Suggest the physiological reason for the period of electrical recovery experienced each cycle (the T wave):

   _____

3. Using the letters indicated, mark the points on trace above corresponding to each of the following:

   (a) E: Ejection of blood from the ventricle

   (b) AVC: Closing of the atrioventricular valve

   (c) FV: Filling of the ventricle

   (d) AVO: Opening of the atrioventricular valve

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127 KEY TERMS: Did You Get It?

1. (a) What type of blood vessel transports blood away from the heart? _____

   (b) What type of blood vessel transports blood to the heart? _____

   (c) What type of blood vessel enables exchanges between the blood and tissues? _____

2. (a) What is the circulatory fluid in vertebrates called? _____

   (b) Which cell type in this fluid transports oxygen? _____

   (c) Which cell type in this fluid fights disease? _____

   (d) Which component of this fluid is involved in clotting? _____

3. (a) What is the general pattern of the mammalian circulatory system? _____

   (b) What is the general pattern of a fish circulatory system? _____

   (c) What is the general pattern of an insect circulatory system? _____

4. (a) What is the name given to the contraction phase of the cardiac cycle? _____

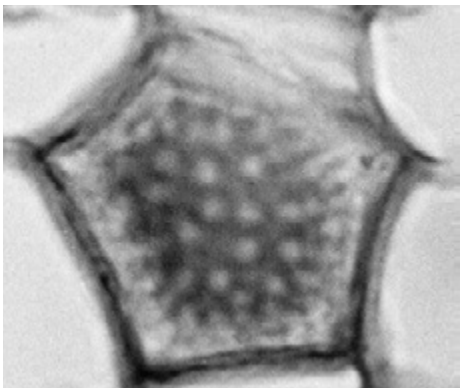
   (b) What is the name given to the relaxation phase of the cardiac cycle? _____

5. (a) What is the name given to the loss of water vapour from plant leaves and stems? _____

   (b) What plant tissue is involved in this process? _____

   (c) Is this tissue alive or dead? _____

   (d) Does this process require energy? _____

6. 

   (a) What does the image (left) show: _____

   _____

   (b) In what tissue would you find it? _____

   (c) Is this tissue alive or dead? _____

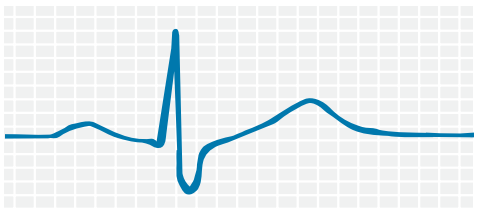
   (d) What transport process is it associated with?

   _____

   (e) What is being moved in this process? _____

7. Match the following words with their definitions:

atrium	**A** A chamber of the mammalian heart that receives blood from the body or lungs.
cohesion-tension	**B** A chamber of the mammalian heart that pumps blood into arteries.
haemolymph	**C** Device used for investigating the rate of transpiration.
heart	**D** The circulatory fluid of invertebrates with an open circulatory system.
potometer	**E** Partial explanation for the movement of water up the plant in the transpiration stream.
ventricle	**F** Muscular chambered organ of the vertebrate circulatory system.

8. 

   (a) What does the image (left) show:

   (b) Circle the QRS complex.

   (c) Circle the region corresponding to highest ventricular pressure.

   (d) Ventricular volume at this time is increasing/decreasing (delete one)

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QLD As required
VCE Unit 1 (2)
WA ATAR Unit 2
SA Theme O

Excretion and Fluid Balance

Key terms

absorption
ammonia
bladder
collecting duct
convoluted tubule
excretion
flame cells
gills
glomerulus
ion balance
kidney
loop of Henle
Malpighian tubules
nephridia
nephron
nitrogenous waste
osmoregulation
protonephridia
renal dialysis
secretion
ultrafiltration
urea
ureter
urethra
uric acid
urine

Diversity in excretory systems

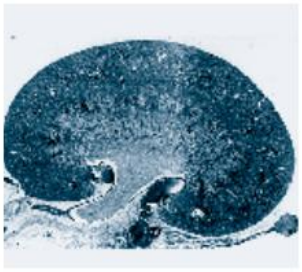
Learning aims and skills

Activity number

- ☐ 1 Identify the substances excreted by plants and their origin. Explain how plants can accumulate wastes in some tissues without damage. Use examples (e.g. salt excretion in mangroves) to show how plants dispose of wastes. — 128
- ☐ 2 Identify the form of the nitrogenous waste excreted by different animal taxa and relate this to life history and environment. — 129
- ☐ 3 Describe diversity in the structure and function of systems for excretion and osmoregulation in representative invertebrate taxa. Examples include: — 131

  (a) Protonephridia (flatworms) or nephridia (annelids).
  (b) Malpighian tubules (insects).
- ☐ 4 Describe diversity in the structure and function of systems for excretion and osmoregulation in representative vertebrate taxa. Examples include: — 130 133

  (a) Gills (fish).
  (b) Salt glands (marine birds and reptiles).
  (c) Kidneys and associated structures (all vertebrates).







Balancing fluid and ions

Learning aims and skills

Activity number

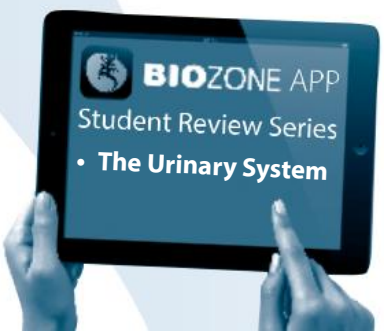
- ☐ 5 Distinguish between excretion and osmoregulation and explain the link between these processes. — 210 211
- ☐ 6 Describe the problems associated with maintaining water and salt (ion) balance in marine and fresh water. — 133 211
- ☐ 7 Describe diversity in mechanisms and strategies for salt and water balance in different environments and in representative taxa. — 210-213

Excretion in humans

Learning aims and skills

Activity number

- ☐ 8 Describe the origin of waste products in humans. — 132
- ☐ 9 Describe the structure of the urinary system including kidneys, ureters, bladder, and urethra. Describe the structure and function of the mammalian kidney including the nephron and its associated capillary network. — 134
- ☐ 10 Summarise urine formation, including the role of ultrafiltration in the glomerulus, secretion of unwanted ions and toxins, and reabsorption of ions in the tubules. State the role of the loop of Henle in establishing and maintaining a salt gradient in the kidney that is essential to the withdrawal of water in the collecting duct. — 134



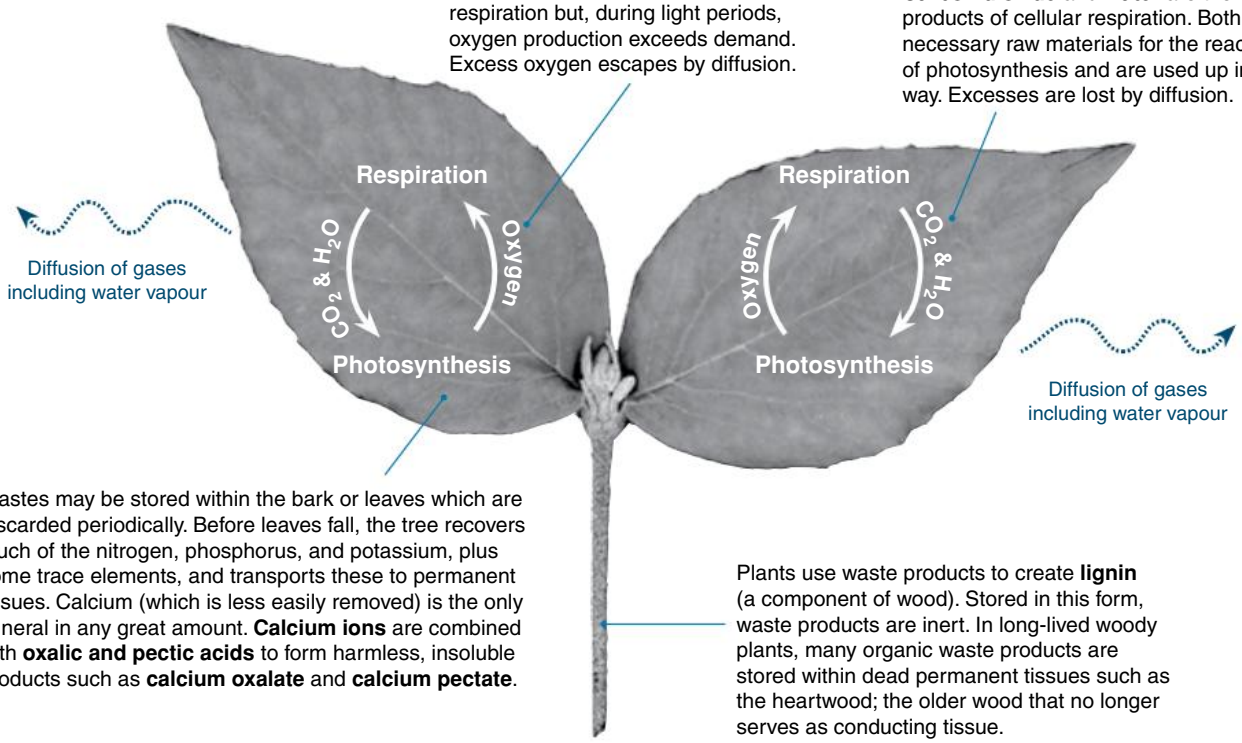
128 Excretion in Plants

Key Idea: The main metabolic wastes in plants are oxygen, carbon dioxide, and water. These are the raw materials for other reactions. Plants produce little nitrogenous waste.

All organisms must dispose of metabolic wastes. There are important differences between plant and animal metabolism that make excretion (removal) in plants of less significance than excretion in animals. Firstly, plants are producers and synthesise all their organic requirements. They manufacture, from raw material (e.g. NH_4^+), only the protein they require to meet immediate needs. There is rarely excess protein and therefore little excretion of nitrogenous waste. Three of the waste products of plant metabolism (oxygen, carbon dioxide, and water) are the raw materials for other reactions, so excesses are used up. Secondly, plants have low metabolic rates compared with animals of the same size, so metabolic wastes accumulate slowly. Thirdly, plant structure is based around carbohydrate rather than protein, and structural proteins are less important in plants than they are in animals.

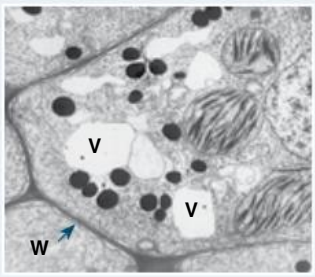
The only major gaseous excretory product in plants is **oxygen**, which is a by-product of photosynthesis. It is used in cellular respiration but, during light periods, oxygen production exceeds demand. Excess oxygen escapes by diffusion.

Carbon dioxide and **water** are the end products of cellular respiration. Both are necessary raw materials for the reactions of photosynthesis and are used up in this way. Excesses are lost by diffusion.

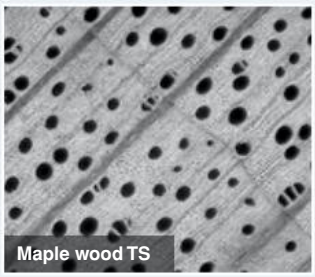


Wastes may be stored within the bark or leaves which are discarded periodically. Before leaves fall, the tree recovers much of the nitrogen, phosphorus, and potassium, plus some trace elements, and transports these to permanent tissues. Calcium (which is less easily removed) is the only mineral in any great amount. **Calcium ions** are combined with **oxalic and pectic acids** to form harmless, insoluble products such as **calcium oxalate** and **calcium pectate**.

Plants use waste products to create **lignin** (a component of wood). Stored in this form, waste products are inert. In long-lived woody plants, many organic waste products are stored within dead permanent tissues such as the heartwood; the older wood that no longer serves as conducting tissue.



BF
Non-woody plants store wastes in the vacuoles (V) and walls (W) of their cells until they die back.



EII
Compounds stored in wood, e.g. **oils**, **gums**, **resins**, and **tannins**, make the wood coloured and aromatic.


The colour of autumn leaves is partly due to the breakdown of chlorophyll. It normally masks other pigments.


In some plants, e.g. eucalypts, toxins deposited in the cell walls make the old leaves tough and unpalatable.

1. (a) Name the three primary waste products of plants: _____

   (b) Where do these come from? _____

   (c) How are these excreted from the plant? _____

2. Describe two purposes for the wastes that are stored in plant tissues:

   (a) _____

   (b) _____

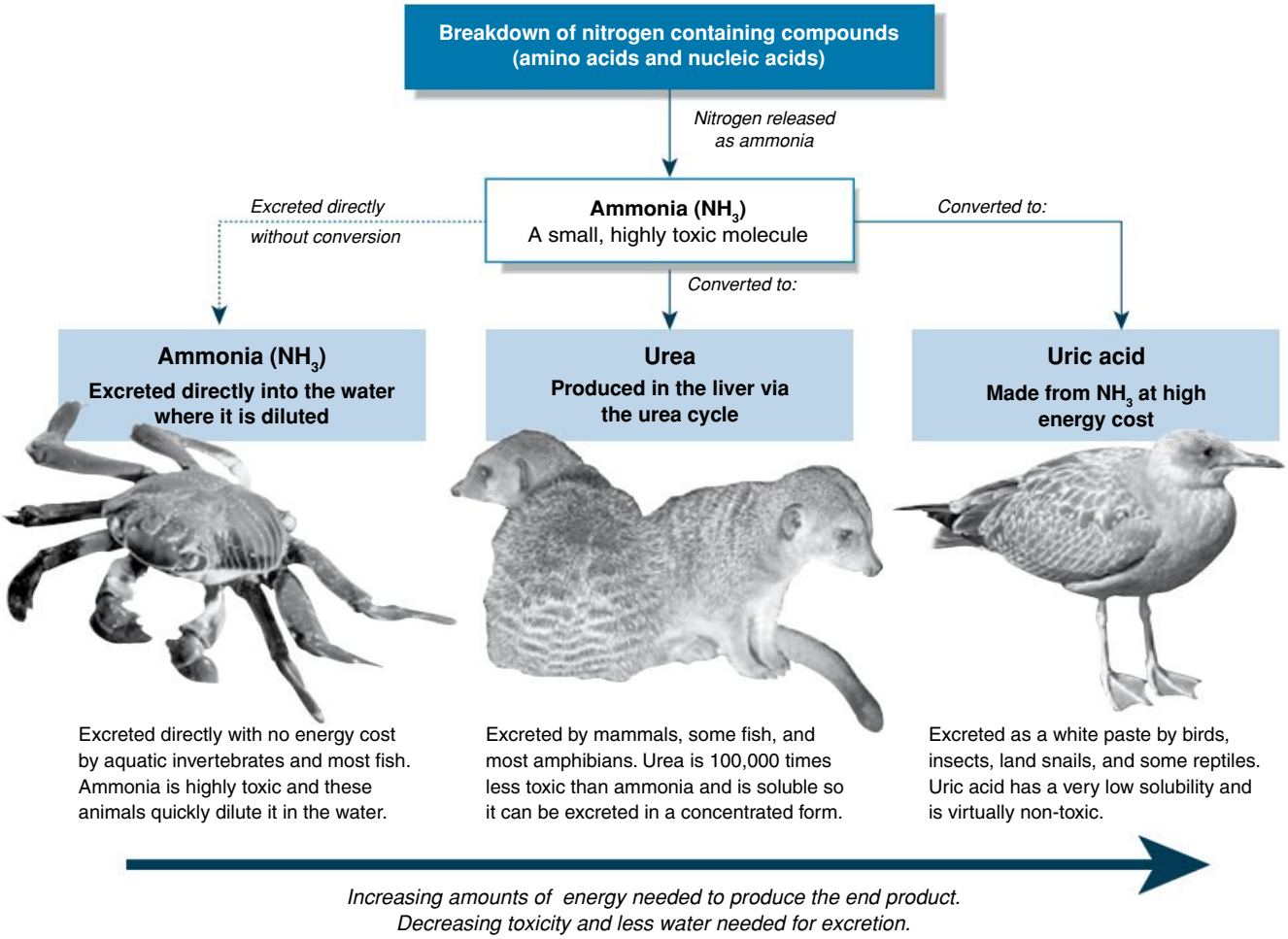
3. Name three regions where wastes in plants can be stored: _____

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129 Nitrogenous Wastes in Animals

Key Idea: Nitrogenous wastes are produced from the breakdown of nitrogen containing compounds. They must be excreted before they accumulate to toxic levels.

Wastes generated by cellular metabolism must be continually removed (**excreted**) so that they do not accumulate to toxic levels and cause damage. **Nitrogenous** (nitrogen containing) **wastes** are produced from the breakdown of amino acids and nucleic acids. The simplest breakdown product of nitrogen-containing compounds is **ammonia**, a highly toxic molecule that cannot be retained in the body for long. Other animals convert the ammonia to a less toxic form (either **urea** or **uric acid**) that can remain in the body for a short time before being excreted via special excretory organs. The form of the excretory product in terrestrial animals depends on the type of organism and its life history. Terrestrial animals that lay eggs produce uric acid rather than urea, because it is non-toxic and very insoluble. It remains as an inert solid mass in the egg until hatching.



1. What is the main source of nitrogen-containing wastes in animals? _____

2. (a) Describe one advantage of uric acid as an excretory product (relative to urea and ammonia): _____

   (b) Describe one disadvantage of ammonia as an excretory product: _____

3. Discuss the relationship between the type of excretory product and an animal's environment: _____

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130 Birds With Runny Noses



Key Idea: Marine animals ingest seawater with food. Excess salt is removed by excreting it. In seabirds, it is removed by salt glands in the nares.

"*Water, water, everywhere and not a drop to drink*".... The line from the 'Rime of the Ancient Mariner' clearly states the need to drink, but in an ocean, none can be found. However it may have been a lot easier for the albatross that accompanied the ship on its voyage. It, and other marine adapted animals can, literally, drink seawater.

There are around 35 g of dissolved salts (mostly sodium chloride with some potassium salts) in every litre of seawater. Human kidneys have an excretory efficiency such that it would take 1.5 L of water from the body to rid the body of the salt in 1 L of seawater. Consequently, drinking seawater causes humans to become more dehydrated than not drinking at all. In addition, in the period of time it takes for the kidneys to excrete that volume of water, the excess salt accumulates in the blood and creates potentially fatal ion imbalances.

The kidneys of birds and reptiles can produce urine with salt concentrations twice that of their blood, but they are less efficient than mammalian kidneys. Seabirds (and marine animals in general) have a special problem with salt loading because they eat food in an environment where the intake of seawater is inevitable. Seabirds and marine reptiles solve this problem by excreting the salt though a different mechanism; salt glands in the head. In birds, the salt glands excrete salt via the nares (nostrils) and the salty water can sometimes be seen dripping from the end of the beak; in turtles, the salt is excreted by glands near the eyes, so that turtles often appear to be weeping. The salt glands in birds likely evolved from the nasal glands of reptiles in the late Palaeozoic era. They work by active transport via a Na-K pump that moves salt from the blood into the collecting duct of the gland, where it can be excreted as a concentrated solution. The glands regulate salt balance, and allow marine vertebrates to drink seawater. The salt glands have an extraordinarily high capacity for excreting salt. One experiment found that a gull given 10% of its body weight in seawater (equivalent to a 70 kg human drinking 7 L of seawater) was able to excrete the salt in around 3 hours. Concentrations of up to 64 gL^{-1} of salt have been recorded in the salt gland secretions of petrels; nearly twice the concentration of seawater. Marine iguanas can produce nearly 70 gL^{-1}.



In contrast to marine birds and reptiles, marine mammals lack specialised glands to excrete salt, despite the fact that their incidental salt intake (with food) is high. All salt excretion is through the kidney and their kidneys are highly specialised to handle large volumes of electrolytes and protein. Evaporative losses are low for aquatic species so there is little need to drink, and the efficient kidneys, with their long loops of Henle, can concentrate the urine to twice the concentration of seawater and therefore easily deal with the incidental consumption of salt through the diet. The urine of a humpback whale may contain around 44 gL^{-1} salt; well above the concentration of seawater.

1. Explain why humans can not drink seawater to quench their thirst: _____

2. Describe and explain the role of the salt glands in marine birds and reptiles: _____

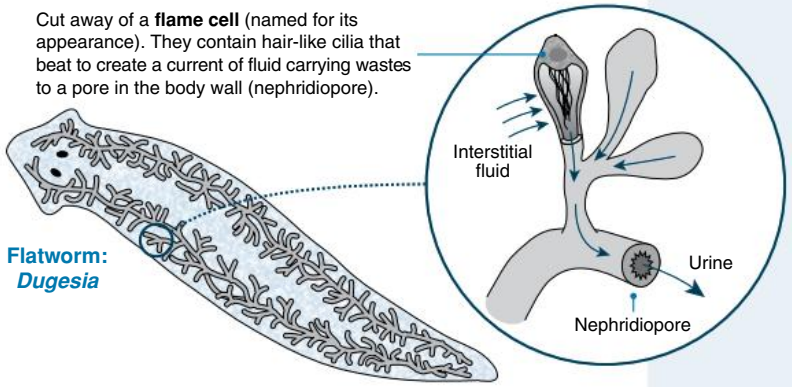
3. Discuss the efficiency of the salt glands in birds and reptiles and the kidneys in marine mammals:

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131 Invertebrate Excretory Systems

Key Idea: Invertebrate excretory systems include protonephridia and nephridia, which produce dilute urine by filtration, and Malpighian tubules, which produce a concentrated excretory paste of uric acid.

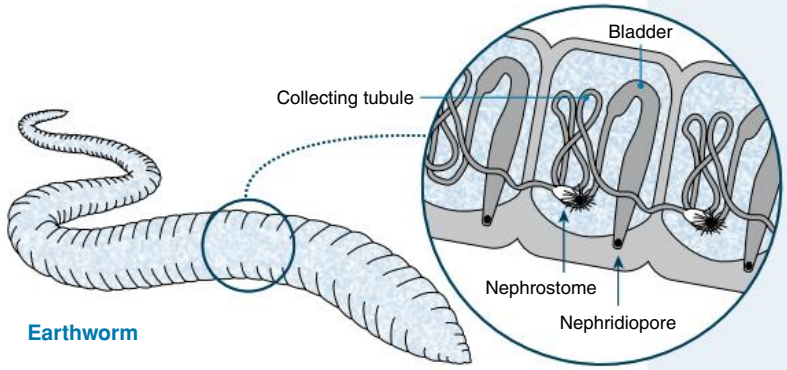
Excretory systems remove waste products from an organism's body. The simplest excretory organs, widely distributed in invertebrates, are simple tubes (protonephridia and nephridia) opening to the outside through a pore. The Malpighian tubules of insects are highly efficient, removing nitrogenous wastes and also functioning in osmoregulation.



Platyhelminthes (flatworms)

Excretory system: **protonephridia**

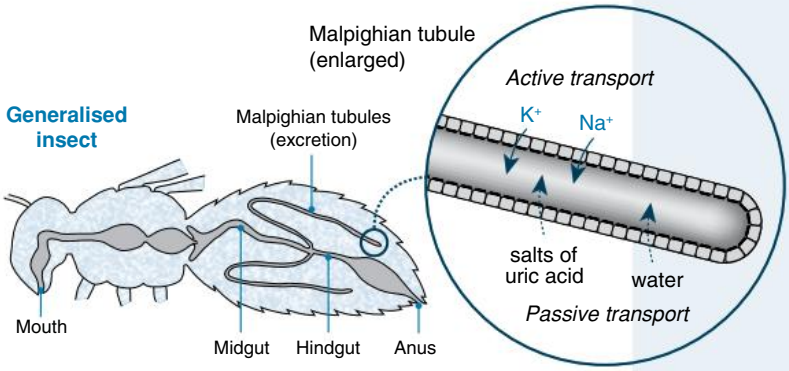
Protonephridia are very simple excretory structures. Each protonephridium consists of a network of dead-end tubules ending in a number of **flame cells**. Flatworms do not have a circulatory system or fluid-filled inner body spaces. They use their branching network of flame cells to regulate the composition of the fluid bathing the cells (interstitial fluid). Interstitial fluid enters the flame cell and is propelled along the tubule, away from the blind end, by beating cilia. The tubules merge into ducts that expel the urine (as **ammonia**) through **nephridiopores** to the outside. The excretory fluid is very dilute, helping to balance osmotic influx from the moist environment.



Annelids (segmented worms)

Excretory system: **nephridia**

In earthworms, each segment has a pair of excretory organs called **nephridia**, which drain the next segment in front. Fluid enters the nephrostome and passes through the collecting tubule. These tubules are surrounded by a capillary network of blood vessels (not shown here) which recover valuable salts from the developing urine. The collecting tubule empties into a storage bladder which expels the dilute urine (a mix of **ammonia** and **urea**) to the outside through the nephridiopore.



Insects

Excretory system: **Malpighian tubules**

Insects have two to several hundred **Malpighian tubules** projecting from the junction of the midgut and hindgut. They bathe in the clear fluid (haemolymph) of the insect's body cavity where they actively pump K^+ and Na^+ into the tubule. Water, uric acid salts, and several other substances follow by passive transport. Water and some ions are reabsorbed in the hindgut, while **uric acid** precipitates out as a paste and is passed out of the anus along with the faecal material. The ability to conserve water by excreting solid uric acid has enabled insects to colonise very arid environments.

1. For each of the following, name the organs for excreting nitrogenous waste and state the form of the waste product:

   (a) Flatworm: _____ Waste: _____

   (b) Insect: _____ Waste: _____

   (c) Earthworm: _____ Waste: _____

2. (a) Explain how insects concentrate their nitrogenous waste into a paste, outlining the physiological processes involved:

   _____

   _____

   (b) Identify a cost to the insect of this type of excretion: _____

   (c) Why does this type of excretion confer an advantage despite the cost? _____

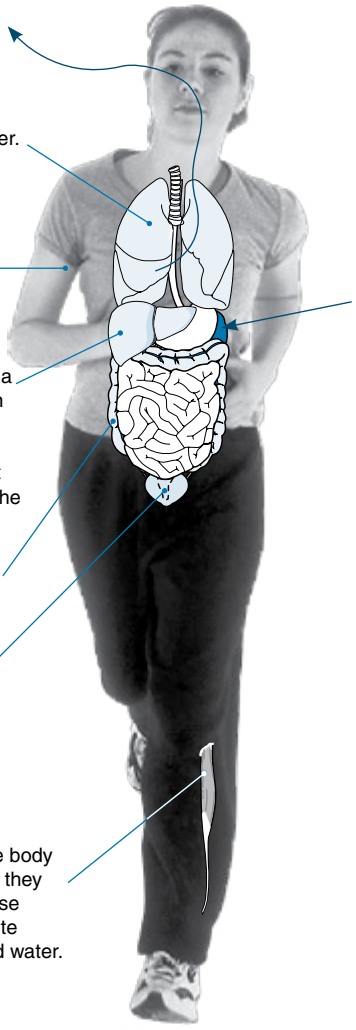
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132 Waste Products in Humans

Key Idea: Metabolism produces a number of waste products that must be excreted from the body.

A number of organs contribute to the excretion of metabolic wastes in humans and other mammals. The kidneys are the primary excretory organs but the lungs, skin, and gut are also involved. The liver is a particularly important organ in the initial treatment of waste products, particularly the breakdown of haemoglobin and the formation of urea from ammonia. Excretion is different from the process eliminating undigested and unabsorbed food material from the gut.



Lungs
Excretion of carbon dioxide (CO_2) with some loss of water.

Skin
Excretion of water, CO_2, hormones, salts and ions, and small amounts of urea as sweat.

Liver
Produces urea from ammonia in the urea cycle. Breakdown of haemoglobin in the liver produces the bile pigments e.g. bilirubin. These pass out with the faeces, but are not the result of digestion.

Gut
Excretion of bile pigments in the faeces. Also loses water, salts, and carbon dioxide.

Bladder
Storage of urine before it is expelled to the outside.

All cells
All the cells that make up the body carry out cellular respiration; they break down glucose to release energy and produce the waste products, carbon dioxide and water.

Excretion in Humans

In mammals, the kidneys are the main organs of excretion, although the liver, skin, and lungs are also important. As well as ridding the body of nitrogenous wastes, the kidneys also regulate pH and excrete many toxins that are taken in from the environment. Many toxic substances, such as alcohol, are rendered harmless by detoxification in the liver, but the kidneys can also eliminate some by actively secreting them into the urine.

Kidney
Filtration of the blood to remove urea. Unwanted ions, particularly hydrogen (H^+) and potassium (K^+), and some hormones are also excreted by the kidneys. Some poisons and drugs (e.g. penicillin) are also excreted by active secretion into the urine. Water is lost in excreting these substances and extra water may be excreted if necessary.

Substance	Origin*	Organ(s) of excretion
Carbon dioxide		
Water		
Bile pigments		
Urea		
Ions (K^+, HCO_3^-, H^+)		
Hormones		
Poisons		
Drugs		

*Origin refers to from where in the body each substance originates

1. Explain the need for excretion: _____

2. Complete the table above summarising the origin of excretory products and the main organ(s) of excretion for each.

3. What is the role of the liver in excretion, even though it is not primarily an excretory organ? _____

4. Why is ammonia converted to urea to be excreted, despite the high energy cost of doing so? _____

5. In people suffering renal failure, the kidneys cease to produce filtrate. Based on your knowledge of the central role of the kidneys in fluid and electrolyte balance, as well as nitrogen excretion, describe the typical symptoms of kidney failure:

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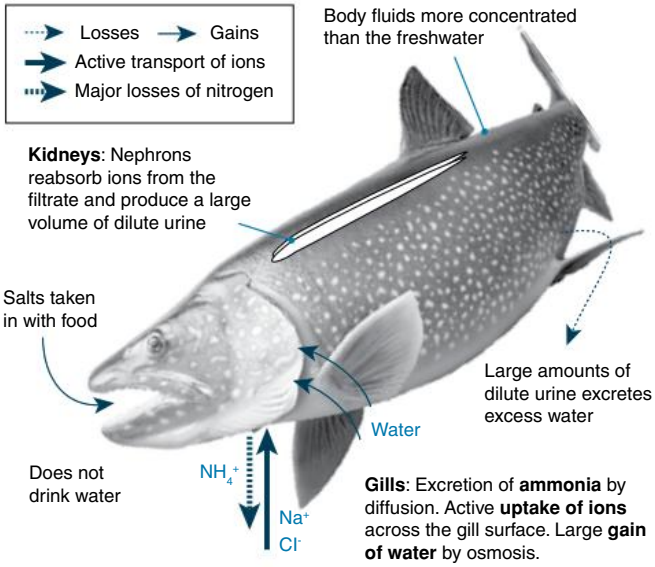
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133 Vertebrate Excretory Systems

Key Idea: Kidneys are the main excretory organs of terrestrial vertebrates. In fish, most excretion occurs via the gills.

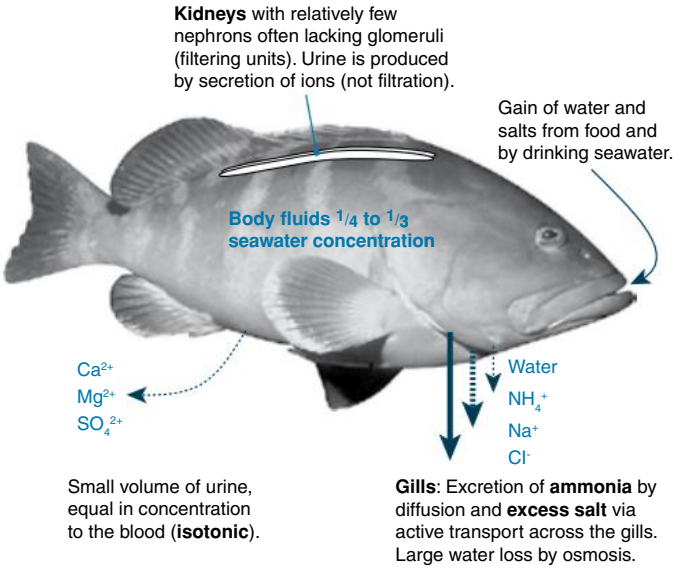
In vertebrates, the excretory units (**nephrons**) are collected into organs called **kidneys**. The kidneys of most vertebrates are similar in that they produce and excretory fluid called **urine** by filtering the body fluids and then modifying the filtrate by reabsorption and secretion of ions. The kidneys of a few bony fish differ from this general pattern and produce urine solely through the secretion of ions. The kidneys of all vertebrates produce urine, but only birds and mammals can produce a urine that is more concentrated than the body fluids. The kidneys of bony fish have few nephrons and can only create a urine that is the same concentration, or more dilute, than the blood. Nearly all their nitrogenous waste is excreted by the gills, which also have an important role in salt balance. Mammals and birds have very efficient kidneys that can produce a concentrated urine, excreting nitrogenous wastes whilst conserving water and ions.

Freshwater Bony Fish



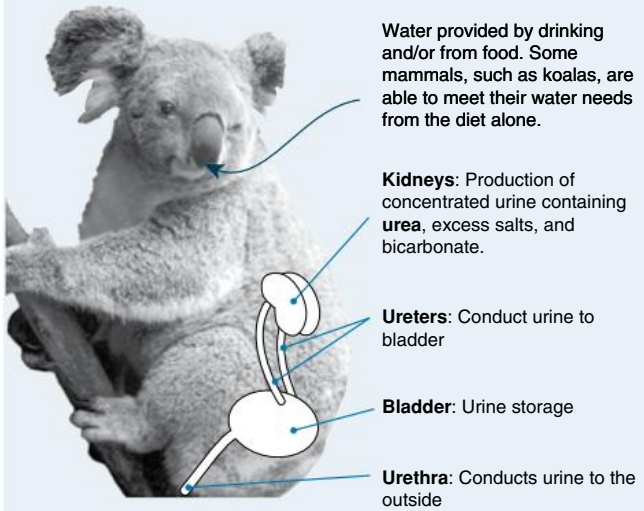
Fish in freshwater must excrete **excess water** gained through osmosis and they must excrete **nitrogenous waste**. Their kidneys excrete large amounts of dilute urine; valuable ions are lost because of the large urine volumes produced. The kidneys reabsorb salts from the filtrate through active transport mechanisms, and the gills take up ions from the water.

Marine Bony Fish

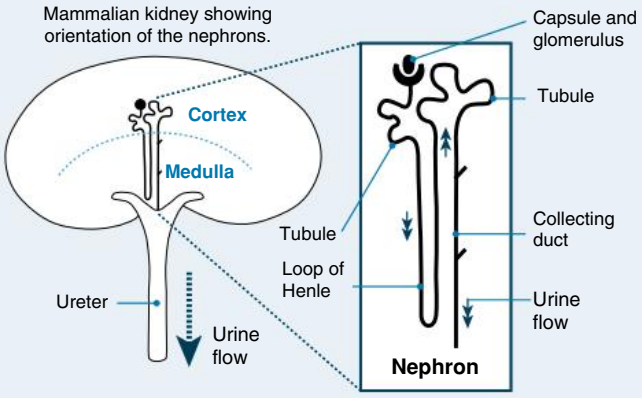


Fish in seawater must excrete **excess salt** gained through diet as well as **nitrogenous waste**. The urine is isotonic, and excess salts are actively excreted across the gill surface into the water (against a concentration gradient). Note that, unlike bony fish, sharks and rays tolerate high urea levels in their tissues and excrete excess salts via a salt gland in the rectum.

Terrestrial Mammal



Water loss is a major problem for most mammals. The degree to which urine can be concentrated (and water conserved) depends on the number of nephrons present and the length of the loop of Henle. The highest urine concentrations are found in desert-adapted mammals.



Mammalian **kidneys** each contain more than one million **nephrons**: the selective filter elements which regulate the composition of the blood and excrete wastes. In the nephron, the initial urine is formed by **filtration** in the glomerulus and Bowman's capsule. The filtrate is modified by **secretion** and **reabsorption** of ions and water. These processes create a salt gradient in the fluid around the nephron, which allows water to be withdrawn from the urine in the collecting duct.

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1. Describe the contrasting problems of excretion and osmoregulation for bony fish in fresh and salt water environments:

2. With reference to their ion and water regulation, explain why:

   (a) Marine bony fish must drink vast quantities of salt water:

   (b) Freshwater bony fish do not drink water at all:

3. What is the primary organ for nitrogen excretion in fish?

4. (a) What is the functional excretory unit of the mammalian kidney?

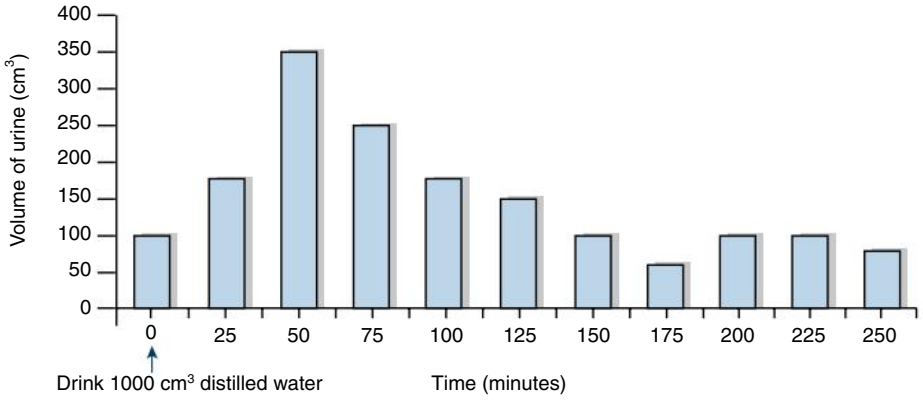
   (b) How are mammals able to produce a concentrated urine?

5. (a) How do desert-adapted mammals differ from most other mammals in terms of their water requirements?

   (b) What two factors determine the degree to which mammalian urine can be concentrated? Explain your answer:

6. How are the kidneys of fish functionally and structurally different from mammalian kidneys?

7. The graph below shows the volume of urine collected from a subject after drinking 1000 cm^3 of distilled water. The subject's urine was collected at 25 minute intervals over a number of hours.



   (a) Describe the changes in urine output during the experiment:

   (b) Explain the difference in the volume of urine collected at 25 minutes and 50 minutes:

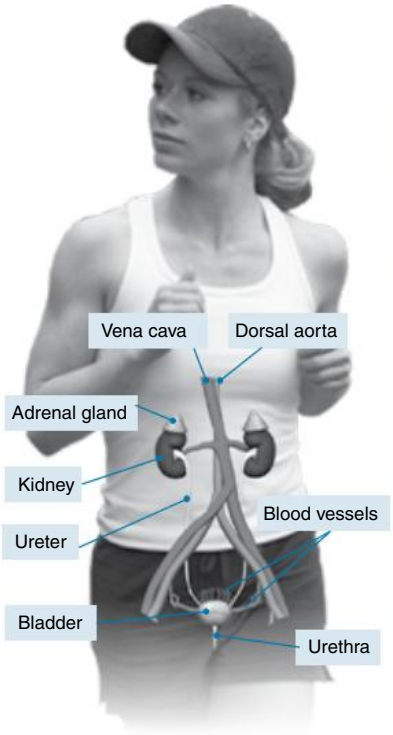
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134 The Human Urinary System

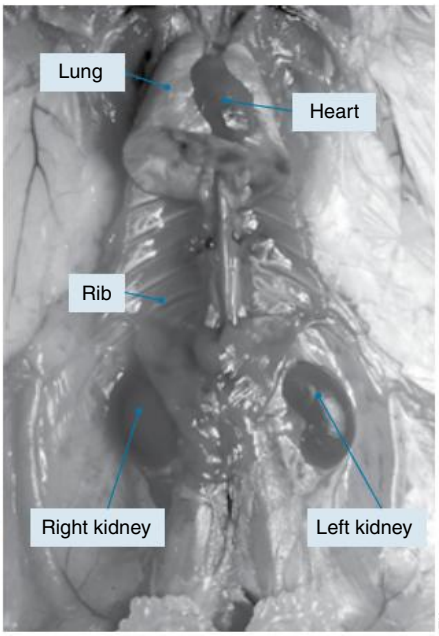
Key Idea: The kidneys excrete nitrogenous waste as urea in urine and also maintain water and solute balance.

The mammalian urinary system consists of the kidneys and bladder, and their associated blood vessels and ducts. The kidneys have a plentiful blood supply from the renal artery. The blood plasma is filtered by the kidneys to form urine. Urine is produced continuously, passing along the ureters to the bladder, where it is stored. Each day the kidneys filter about 180 L of plasma. Most of this is reabsorbed, leaving a daily urine output of about 1 L. By adjusting the composition of the fluid excreted, the kidneys help to maintain the body's internal chemical balance. Mammalian kidneys are very efficient, producing a urine that is concentrated to varying degrees depending on requirements.

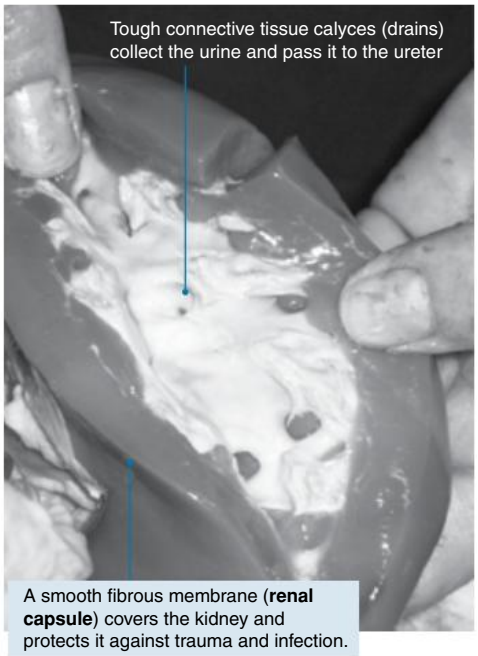
Urinary System



Kidneys *in-situ* (Rat)



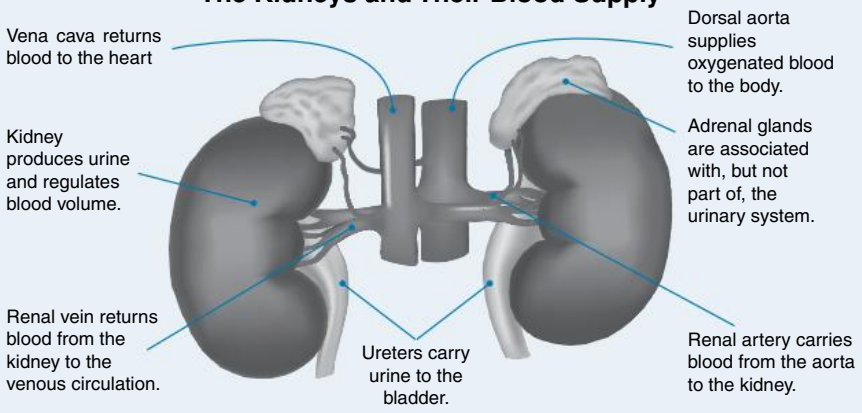
Sagittal Section of Kidney (Pig)



The kidneys of humans (above), rats (dissection, above centre), and many other mammals (e.g. pig above right) are distinctive, bean shaped organs that lie at the back of the abdominal cavity to either side of the spine. They are partly protected by the lower ribs (see kidneys *in-situ* above center).

Human kidneys are ~100-120 mm long and 25 mm thick. A cut through in a sagittal plane (see photo above right), reveals numerous tough connective tissue calyces. These collect the urine from the papillae where it is discharged and drain it into the ureter.

The Kidneys and Their Blood Supply



1. State the function of each of the following components of the urinary system:

   (a) Kidney: _____

   (b) Ureters: _____

   (c) Bladder: _____

   (d) Urethra: _____

   (e) Renal artery: _____

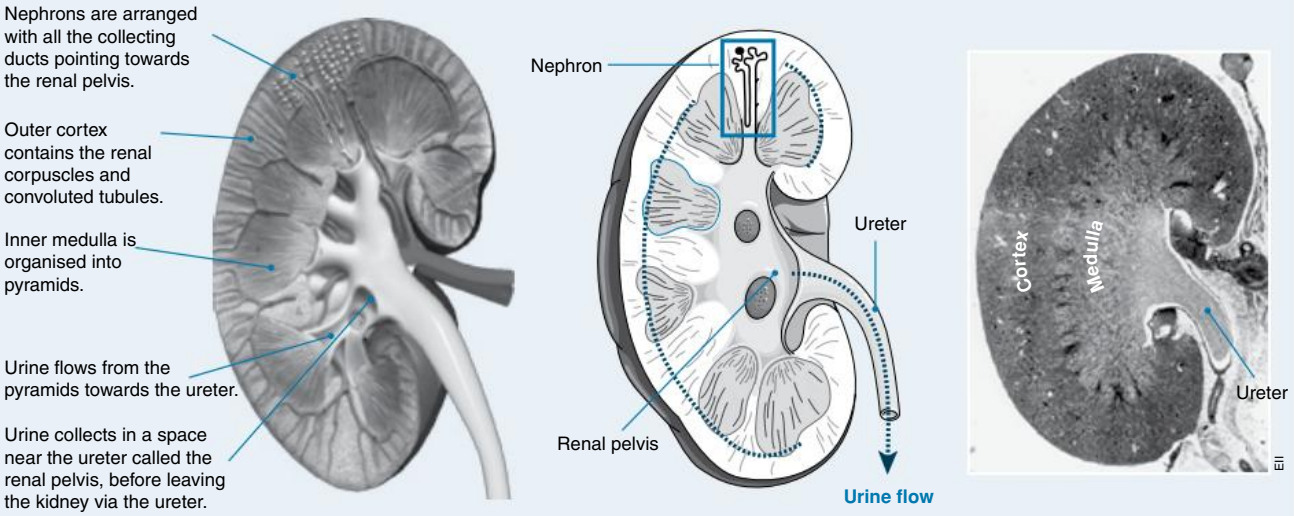
   (f) Renal vein: _____

   (g) Renal capsule: _____

2. Calculate the percentage of the plasma reabsorbed by the kidneys: _____

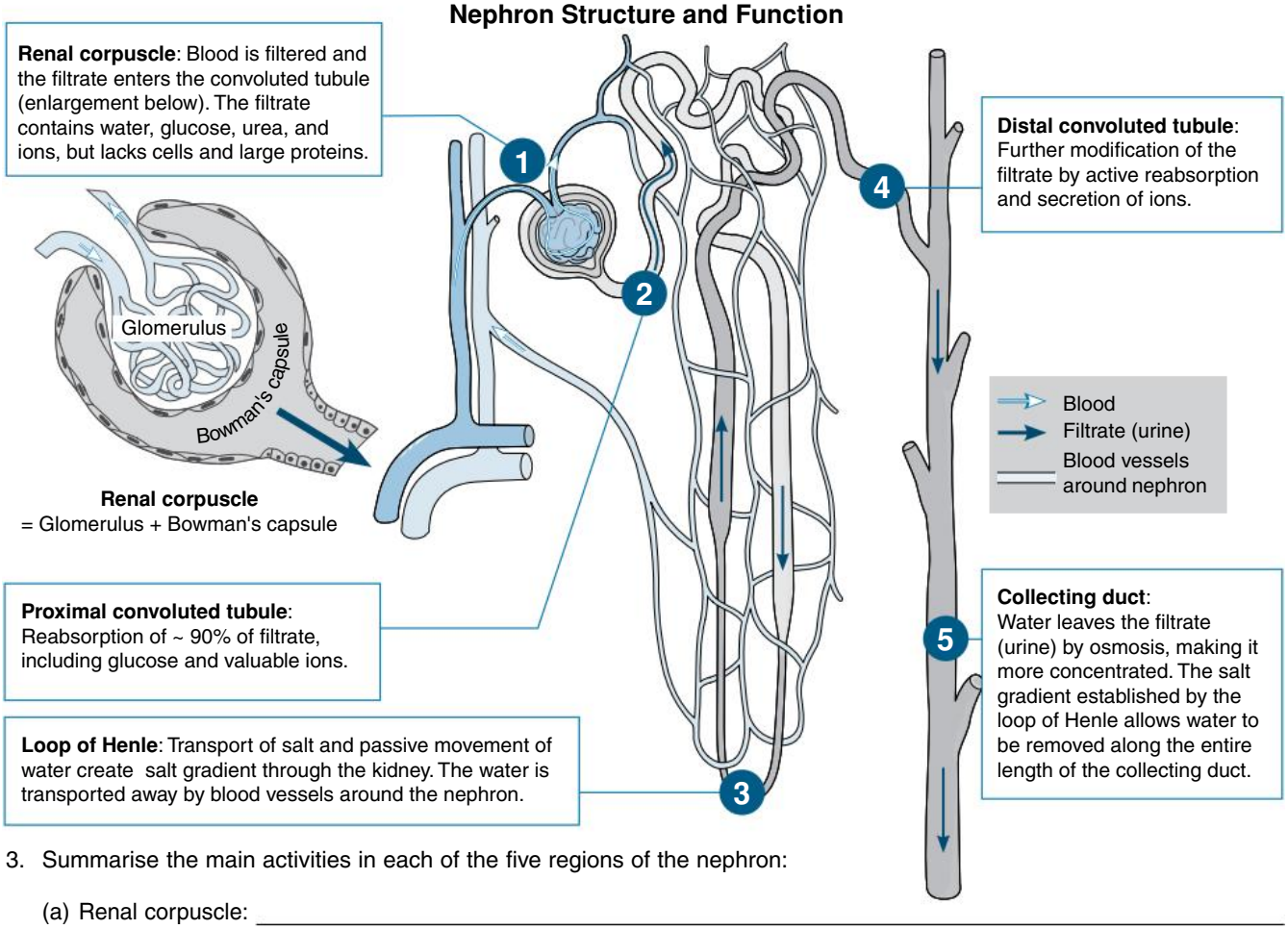
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Internal Structure of the Human Kidney



The inside of the kidney appears striped because the nephrons are all aligned so that urine is concentrated as it flows towards the ureter. The outer cortex and inner medulla can be seen in the low power LM of the kidney, far right.

Nephron Structure and Function



3. Summarise the main activities in each of the five regions of the nephron:

   (a) Renal corpuscle: _____

   (b) Proximal (near) convoluted tubule: _____

   (c) Loop of Henle: _____

   (d) Distal (far) convoluted tubule: _____

   (e) Collecting duct: _____

4. Why are the nephrons all aligned in the same way in the kidney: _____

_____

_____

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135 KEY TERMS: Word Find

Use the clues below to find the relevant key terms in the WORD FIND grid



G	Q	K	U	N	S	D	U	R	I	N	E	F	U	R	I	C	A	C	I	D	X	M	O	C
T	C	M	R	X	A	C	V	W	U	D	T	A	E	X	C	R	E	T	I	O	N	I	C	E
H	Z	O	V	F	P	O	P	B	B	D	W	U	L	R	U	R	E	A	G	R	U	O	Z	F
C	X	R	J	K	F	N	Q	H	R	A	T	G	C	G	L	T	Z	D	L	T	J	N	P	F
Y	U	B	N	H	V	V	I	G	Z	W	H	H	O	L	U	U	E	F	O	V	U	B	B	Z
J	P	E	P	S	O	O	S	Z	E	P	L	R	L	R	L	N	O	F	M	Q	X	A	S	U
J	Z	W	L	S	Q	L	E	F	F	M	M	B	L	Z	G	N	I	N	E	B	Q	L	H	O
S	G	W	E	C	E	U	C	A	L	Q	U	L	E	M	Q	Y	K	E	R	M	K	A	D	O
P	O	A	M	L	K	T	R	M	A	G	R	A	C	E	A	N	K	P	U	U	A	N	E	J
S	N	Y	Z	J	H	E	E	M	M	I	E	D	T	B	J	L	S	H	L	T	S	C	X	T
X	Q	J	B	G	E	D	T	O	E	L	T	D	I	L	D	D	P	R	U	Z	J	E	N	U
K	W	K	R	S	N	T	I	N	C	L	H	E	N	U	U	S	C	I	S	L	Q	M	E	Y
F	G	I	E	O	L	U	O	I	E	S	R	R	G	S	Y	V	H	D	G	M	W	G	P	S
M	J	D	X	M	E	B	N	A	L	V	A	E	D	F	P	D	M	I	Z	H	U	I	H	G
M	K	N	E	H	M	U	V	C	L	H	J	D	U	K	W	G	Y	A	Z	L	I	V	R	C
N	C	E	I	Z	B	L	Y	K	S	E	K	V	C	Y	J	L	Z	W	K	Y	F	A	O	K
L	J	Y	M	Q	B	E	U	O	I	O	E	Z	T	C	B	R	G	X	S	K	T	I	N	U

The removal of metabolic wastes from the body.

Bean shaped organ used to remove and concentrate metabolic wastes from the blood.

A knot of capillaries in the kidney bound within the Bowman's capsule.

Nitrogenous excretory product produced in the liver by mammals and most amphibians.

The process by which a substance is transported across the plasma membrane of a cell to the outside. A common function of gland cells.

Cells containing flagella that make up part of the excretory units of platyhelminthes (flatworms).

Loop of __ __ __ __ __

Tubules that make up part of the excretory organs of arthropods; they collect wastes from the body fluids and discharge them into the hind gut.

Duct leading from the urinary bladder of mammals to the exterior of the body.

Excretory unit in the kidney comprising Bowman's capsule, glomerulus, the loop of Henle, the convoluted tubules, and collecting duct.

Fluid containing metabolic wastes that collects in the urinary bladder.

Part of the renal tubule in the kidney in which water reabsorption takes place.

Organs for both gas exchange and excretion in fish.

White paste-like substance, with a low solubility, excreted by birds, reptiles, and most insects.

Organ of the urinary system that collects urine.

Ducts within the kidney nephron with the function of re-absorbing salt and water. Divided into the proximal and distal regions.

The process of maintaining the correct balance of ions within the body.

Nitrogenous molecule produced from the breakdown of amino acids. Highly toxic.

The excretory units in annelids.

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QLD As required
VCE Unit 1 (2)
WA ATAR Unit 2
SA Theme C, O

Reproduction and Development

Key terms

ageing (=senescence)
alternation of generations
asexual reproduction
birth (=parturition)
budding
copulation
contraception
diploid
double fertilisation
embryo
fertilisation
fission
fragmentation
gamete
gametophyte
gametogenesis
germination
haploid
infertility treatment
lactation
meiosis
menopause
menstrual cycle
mitosis
ovulation
ovum/ova (=egg/eggs)
placenta
pollen
pollen tube
pollination
pregnancy
puberty
seed
sexual reproduction
sperm
sporophyte
zygote

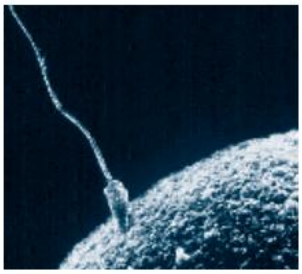


Reproduction in plants

Learning aims and skills

Activity number

☐	1	Describe the diversity of mechanisms for vegetative propagation in angiosperms and explain its adaptive value as a reproductive strategy.	136
☐	2	Describe alternation of generations as a distinctive feature of plants. Explain the significance of the haploid (gametophyte) and diploid (sporophyte) generations and their relative dominance in different phyla.	137-140
☐	3	Describe and explain diversity in the structure and function of reproductive structures in insect-pollinated and wind-pollinated angiosperms.	141 142
☐	4	Describe pollination and the events leading to fertilisation in an angiosperm, including the development of the pollen tube, and the double fertilisation.	143
☐	5	Describe the structure of a seed and relate the structure to its functional role. Describe seed germination and the conditions required for it.	144
☐	6	Describe and explain diversity in methods of seed dispersal in seed-producing plants.	145 146







Animal reproduction and development

Learning aims and skills

Activity number

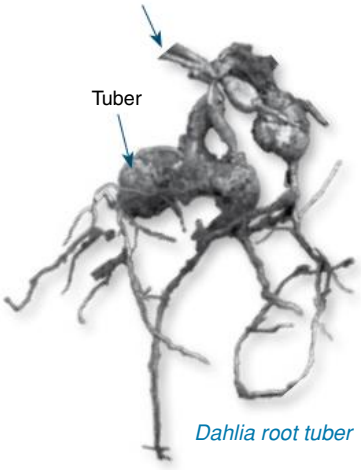
☐	7	Distinguish between asexual and sexual reproduction in animals. Describe types of asexual reproduction including budding and fission.	147 148
☐	8	Describe diversity in animal reproductive strategies, e.g. alternating sexual and asexual phases, internal vs external fertilisation, ovovivipary, oviparity, vivipary, and diapause. Distinguish copulation from fertilisation. Describe the characteristics, advantages, and disadvantages of each strategy.	148-152
☐	9	Compare and contrast the characteristics and role of the male and female gametes in mammals (e.g. humans).	153
☐	10	Describe the structure and function of adult male and female reproductive systems in humans. Describe gametogenesis in each sex.	154 155
☐	11	Explain the features of the menstrual cycle, relating the changes in the menstrual cycle to the changes in the hormones regulating the cycle.	156 157
☐	12	Describe the structure and role of the placenta.	158
☐	13	Describe fertilisation and the events in the development of the embryo between implantation and 5-8 weeks.	159
☐	14	Describe the role of hormones in the maintenance of pregnancy in humans. Describe how humans can manipulate the levels of reproductive hormones for the prevention of pregnancy (i.e. contraception) or to treat female infertility.	160 161
☐	15	Describe birth (parturition) and its control. Explain what is meant by lactation and explain its importance to mammalian nutrition.	162
☐	16	Describe milestones in the growth and development of humans, including infancy, childhood, and puberty.	163 164
☐	17	Explain the biological basis of ageing and describes its effects on the human body, including reference to menopause.	165

136 Plant Propagation

Key Idea: Vegetative propagation in plants produces new individuals without the production of seeds or spores.

Many flowering plants reproduce asexually by vegetative propagation, the process by which new individuals arise without the production of seeds or spores. Plants can spread quickly by vegetative means when conditions are favourable. By doing this they do not need to produce flowers, pollen or seeds (processes with large energy costs to the plant). Humans exploit the ability of plants to reproduce by vegetative means and many successful strains of crop plants are hardly ever grown from seed. Vegetative propagation enables successful varieties to be propagated indefinitely.

Natural Vegetative Structures in Plants



Dahlia root tuber

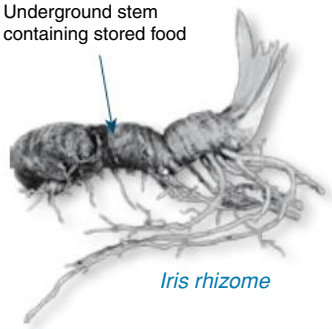
Root tubers, e.g. dahlias (above), lack terminal and lateral buds. Both stem and root tubers can give rise to new individuals.

Tubers are the swollen part of an underground stem or root, usually modified for storing food. The potato (below) is a **stem tuber**, as indicated by the presence of terminal and lateral buds.

Potato stem tuber



'Eye' (lateral bud)

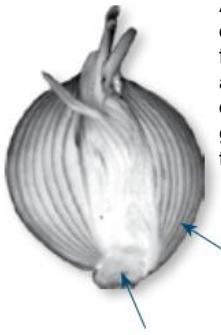


Iris rhizome

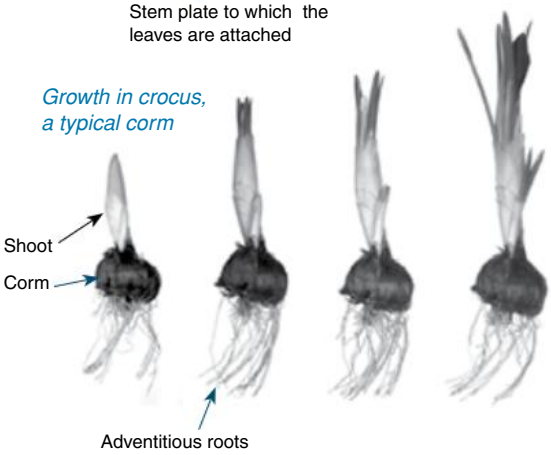
In **rhizomes**, as in corms, food is stored in the horizontal, underground stem. Rhizomes tend to be thick, fleshy or woody, and bear nodes with scale or foliage leaves and buds. Growth occurs at the buds on the ends of the rhizome or nearby nodes. Ginger, irises and lily-of-the-valley are rhizomes.

Bulbs

A bulb is really just a typical shoot compressed into a shortened form. Fleshy storage leaves are attached to a stem plate and form concentric circles around the growing tip. New roots form from the lower part of the stem.



Growth in crocus, a typical corm



In a **corm**, food is stored in stem tissue. Corms look like bulbs, but if you cut a corm in half you see a mass of homogenous tissue rather than concentric rings of fleshy leaves as in a bulb. Cyclamen, gladiolus, and crocus (above) are corms.



Garlic propagates via a bulb. Axillary buds (called cloves) form beside the existing bulb.



Strawberry plants send out runners. These are above-ground, trailing stems that form roots at their nodes.



Tussock grasses propagate from horizontal stems that grow from buds at the tip of the rhizomes.



The roots growing out of this potato will form new tubers and eventually independent plants.

1. What is meant by **vegetative propagation**? _____

_____

_____

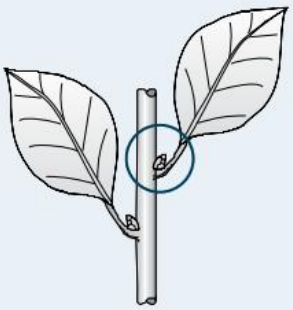
2. Describe one major advantage (to the plant) of having a stem, tuber, or bulb filled with stored food:

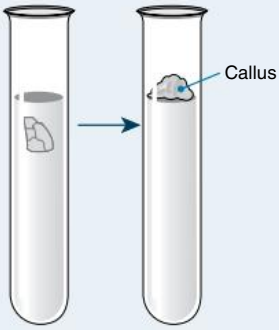
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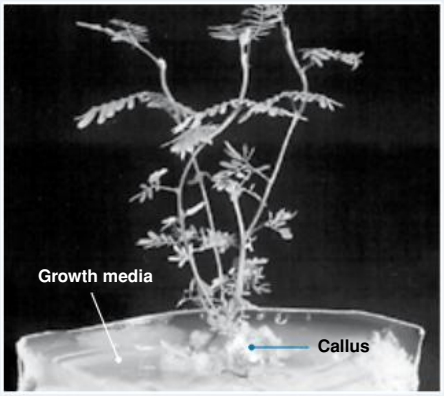
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Micropropagation



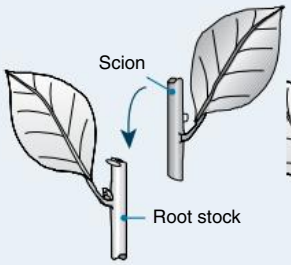


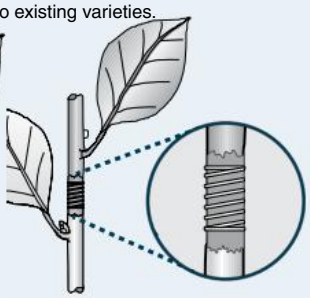


1. An **explant** (in this case it is an axial bud) is removed from a disease free (axenic) stock plant. Explants are commonly taken from cotyledons, axial buds, or roots.
2. Explant tissue is cultured in a sterile nutrient medium until a callus forms. The callus is transferred to another test tube containing growth hormones, and shoots are encouraged to grow.
3. Shoots develop from the callus and begin to photosynthesise. The new shoots are removed from the callus and placed in individual culture media. The process is repeated every few weeks so that a single explant will give rise to many plants

Grafting

Grafting involves joining structures from two or more plants. Typically a twig section (scion) from one plant is joined to the shoot of another (root stock). Grafting is used to produce new varieties, which combines the favourable characteristics of two existing varieties.

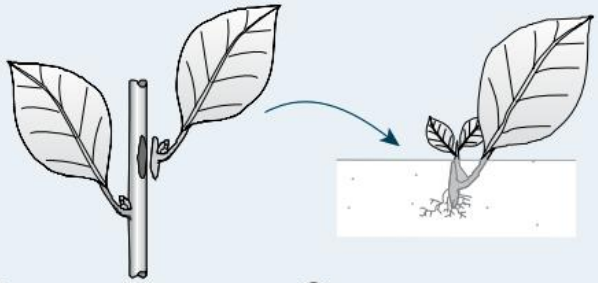




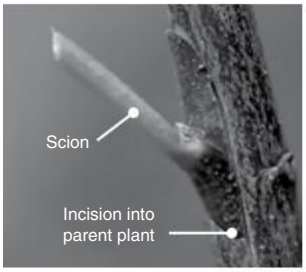
1. A **scion** is prepared by taking a cutting. The scion is then grafted to another plant (root stock).
2. The graft is covered in wax to prevent infection and held together with twine or raffia.

Cutting

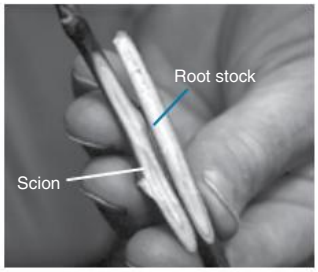
Cuttings are sections of a parent plant, which are removed and grown as new individuals. Cuttings are used to propagate herbaceous plants, but can be used on woody plants with the use of hormones to promote root growth.



1. A leaf and accompanying axial bud is cut from the parent stock.
2. The cutting is placed in a growth medium containing rooting hormones.



A scion is removed from the parent plant prior to grafting.



Scion being grafted onto the stem of the root stock.



The graft is sealed and covered to prevent water loss and infection.



The graft is then labelled for future reference and monitoring.

3. How have humans benefited from the vegetative propagation of plants? _____

4. How do plants benefit by reproducing vegetatively? _____

5. Distinguish between **cutting** and **grafting**: _____

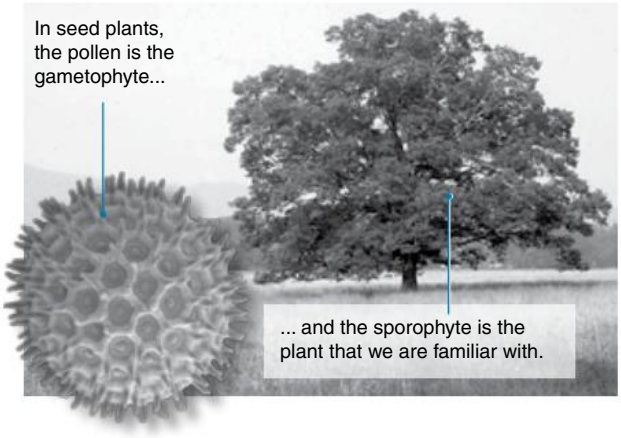
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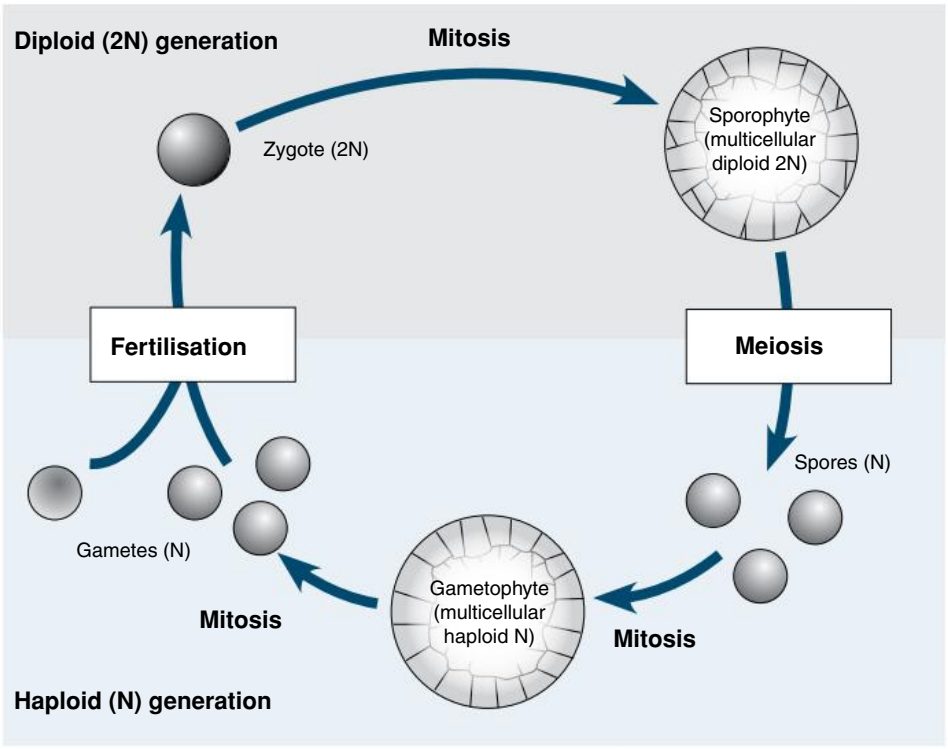
137 Alternation of Generations

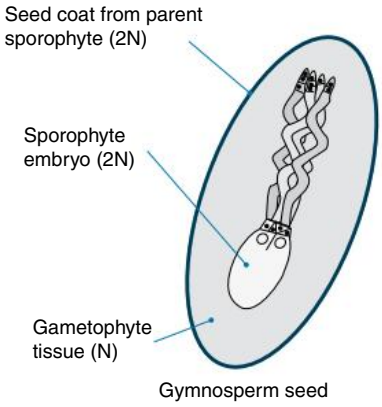
Key Idea: The life cycle of plants includes alternation between a haploid (N) gametophyte generation and a diploid (2N) sporophyte generation.

The life cycles of all plants are characterised by **alternation of generations**, in which a haploid (N) gametophyte generation alternates with a diploid (2N) sporophyte generation, each giving rise to the other. In vascular plants, the sporophyte generation is dominant.

- The **sporophyte** and **gametophyte** generations are named for the type of reproductive cells they produce. Haploid gametophytes (N) produce gametes by mitosis, whereas diploid sporophytes (2N) produce spores by meiosis.
- Spores develop directly into organisms. Gametes (egg and sperm) unite during fertilisation to form a zygote which gives rise to an organism.
- Pollen carries the gametes from the male reproductive structures to the female reproductive structures







Alternating generations can result in multiple generations within one structure. In conifers, the seed contains the parent and new sporophyte generations, and the gametophyte generation.

1. Describe the alternation of generations in plants: _____

_____

_____

2. (a) Give an example of a sporophyte: _____

   (b) Give an example of a gametophyte: _____

3. Complete the table below to show what produces each structure:

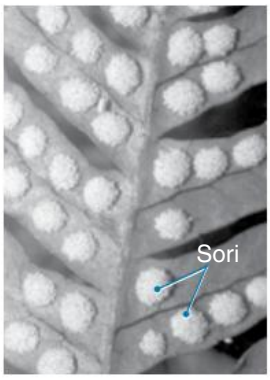
Structure	Spores	Gametes	Zygote
Produced by			
Process			

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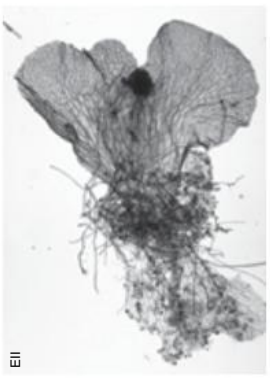
138 Reproduction in Ferns

Key Idea: In ferns, the gametophyte is a small free-living plant that produces gametes, which rely on water to unite. The sporophyte (the fern) produces haploid, unicellular spores. Reproduction in ferns is achieved by the alternating release of spores and gametes (there are no seeds). Spores from the sporophyte develop in sporangia which are typically found on the underside of the fronds in clusters called sori. Spores are single celled and small enough to be spread by the wind.

- If a spore settles in a suitable spot, it develops into a heart-shaped prothallus (the gametophyte), which is typically only one or two cells thick, small, free-living, and photosynthetic. It produces egg cells and motile sperm cells, which require a film of water to reach the egg cells.
- The division of the zygote begins immediately after fertilisation to produce the embryonic sporophyte. This becomes rooted in the soil and develops fronds. The gametophyte then disintegrates.

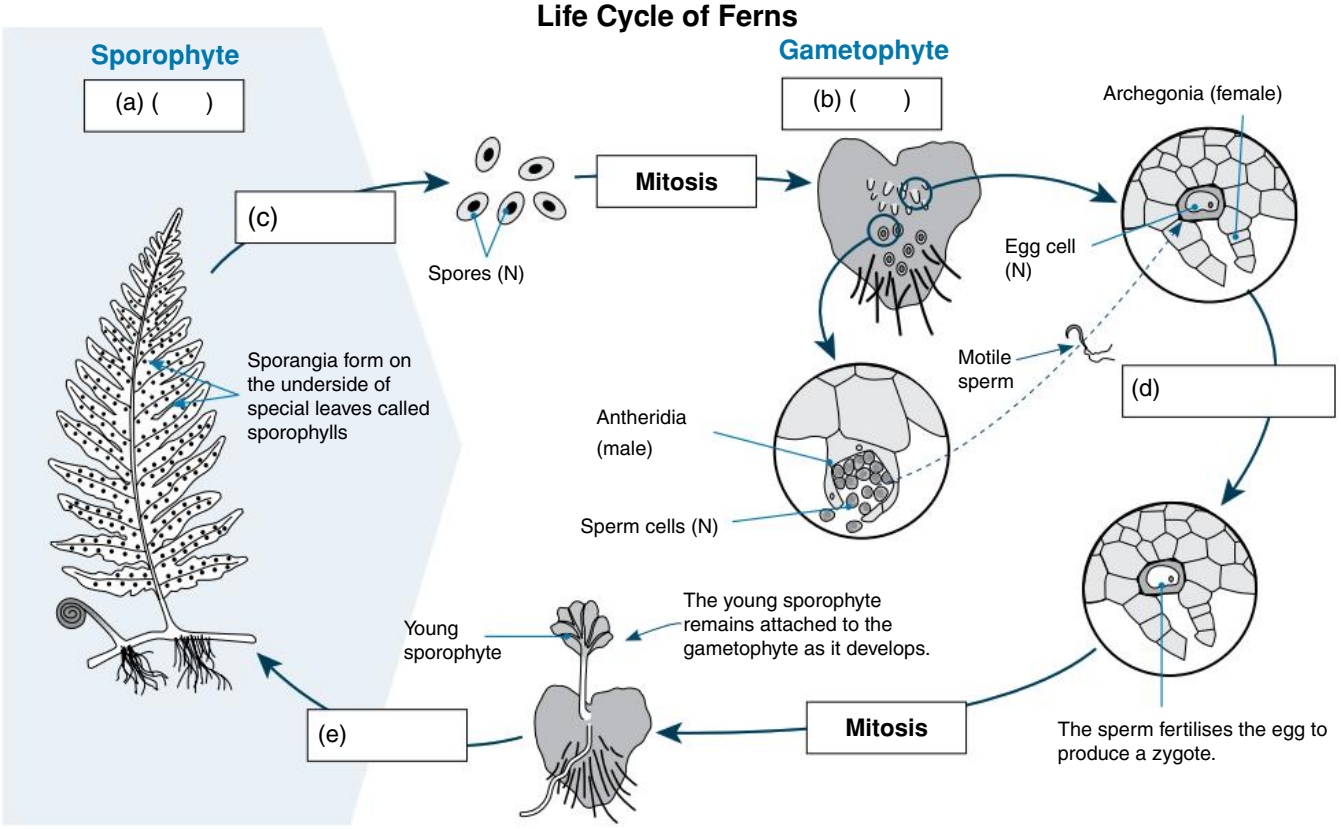


The spores are found in clusters underneath the frond called sori.



The free living prothallus (the gametophyte) develops from the spore.

Life Cycle of Ferns



1. (a) - (e) Complete the diagram above using the labels *N, 2N, fertilisation, meiosis, mitosis*:

2. What feature distinguishes ferns from seed plants (angiosperms and gymnosperms)? _____

_____

_____

3. (a) Why do ferns require moist environments in order to reproduce? _____

_____

(b) Explain why this requirement ultimately limits where they can survive in the long term: _____

_____

_____

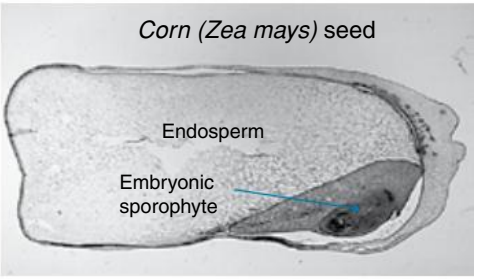
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139 Reproduction in Angiosperms

Key Idea: Angiosperms are flowering plants. The sporophyte produces flowers, which house the tiny gametophytes. Fertilisation of the gametes gives rise to the seed.

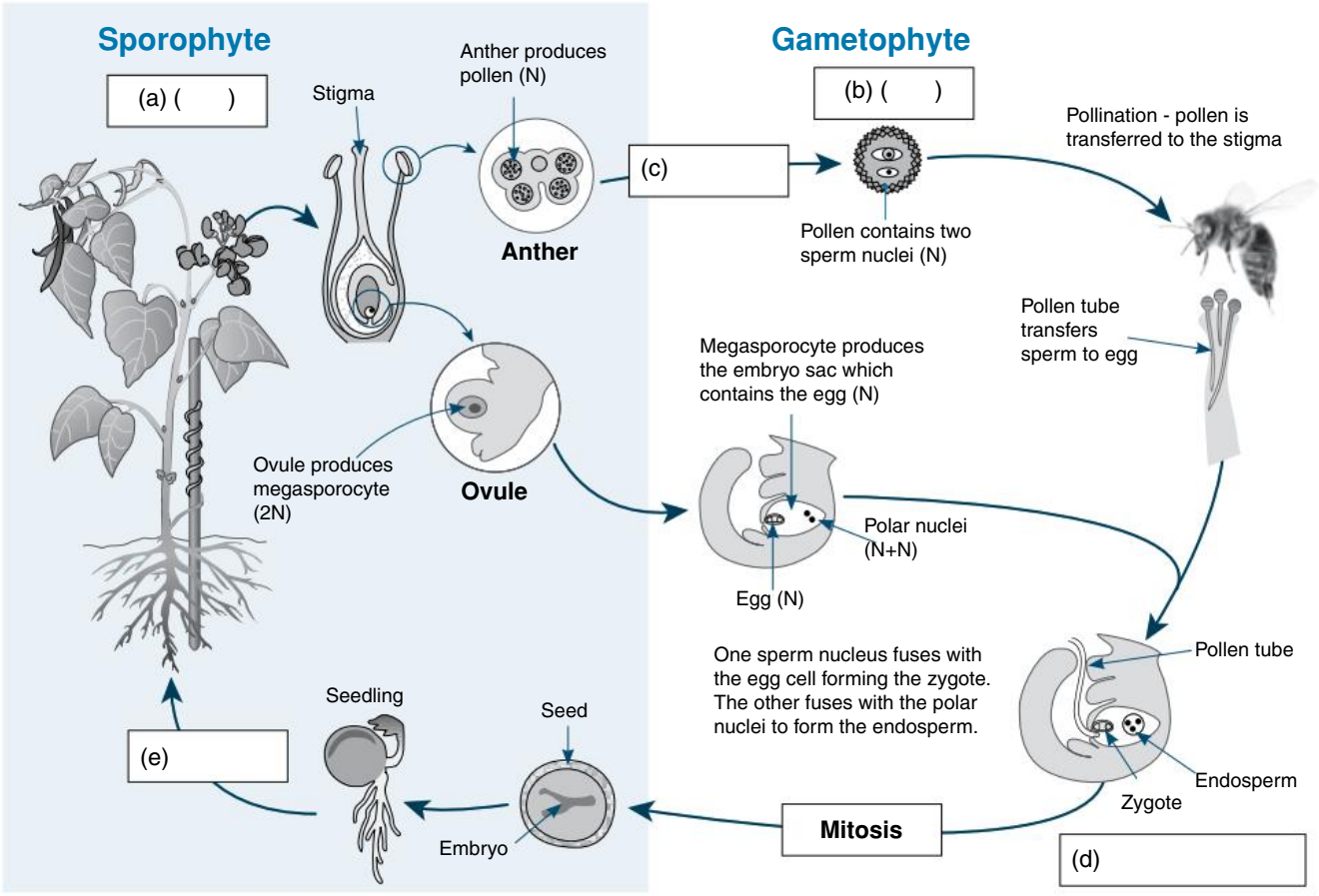
Angiosperms are flowering seed plants. In seed plants, pollen (not water) is the vehicle to carry the male gametes to the female gametes. The leafy plant that bears the flowers represents the sporophyte generation of the life cycle. The flowers contain specialised male and female structures (anthers and ovules), in which the male and female gametophytes are formed

- The pollen grain is the male gametophyte and the embryo sac is the female gametophyte. Each mature pollen grain contains two sperm nuclei and each mature embryo sac contains the egg and two polar nuclei.
- The typical life cycle of angiosperms (below) involves the formation of gametes (egg and sperm) from the haploid gametophytes, the fertilisation of the egg by a sperm cell to form the zygote, the production of fruit around the seed, and the germination of the seed and its growth by mitosis.



The gametophyte generation may be important to a plant for reasons other than producing gametes. Endosperm (3N) derived from male and female gametophytes provides nutrients for embryonic sporophyte.

Life Cycle of Angiosperms (Flowering Plants)



1. (a) - (e) Complete the diagram above using the labels *N, 2N, fertilisation, meiosis, mitosis*:

2. (a) In which part of a flowering plant do the male gametophytes develop? _____

   (b) In which part of a flowering plant do the female gametophytes develop? _____

3. Why don't angiosperms need a moist environment for fertilisation to occur? _____

_____

_____

KNOW WEB 139 LINK 140 LINK 143 LINK 173

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140 Reproduction in Gymnosperms

Key Idea: Gymnosperms are a group of seed plants that includes the conifers. The sporophytes produce cones, which produce either pollen or egg cells (not both).

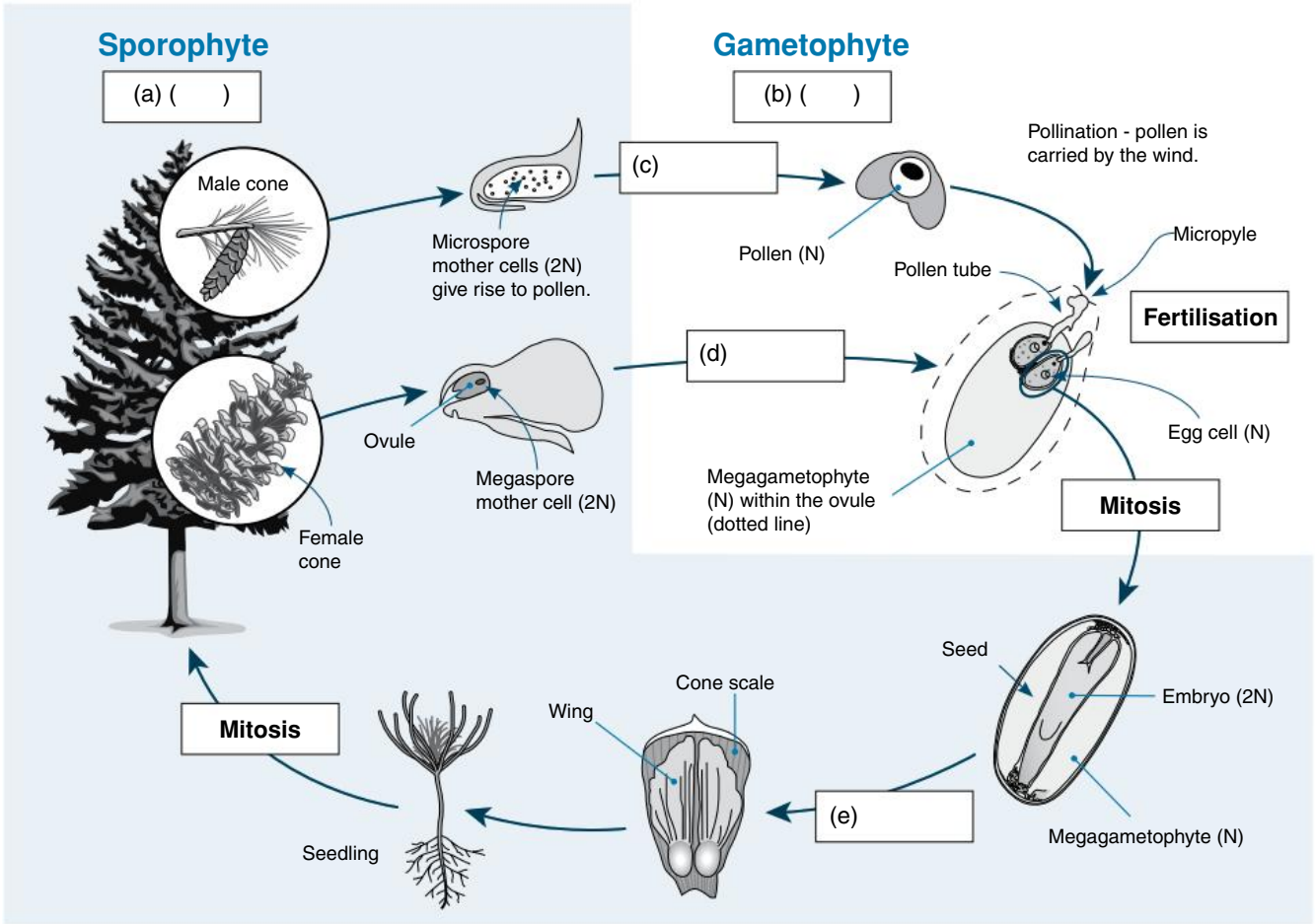
Conifers and cycads are gymnosperms. Conifers usually bear the smaller male and the much larger female cones on the same plant. Conifers are wind pollinated.

- All gymnosperms are wind pollinated. In conifers, the wind-carried pollen sticks to a drop of fluid within a tiny hole (the micropyle) at the end of the ovule. When the fluid evaporates, it draws the pollen into the ovule. The pollen develops a pollen tube, which grows towards the egg cell (this can take up to 15 months).
- After fertilisation, a zygote forms which develops into an embryo then into a seed, which is often 'winged'. Some conifers require the intense heat from a fire to open the cones and release the seeds.



Male (left) and female (right) cones

Life Cycle of Conifers (Cone-bearing Plants)



1. (a) - (e) Complete the diagram above using the labels *N, 2N, meiosis, mitosis*:

2. Briefly describe how the sperm cell reaches the egg cell in conifers: _____

_____

_____

3. Which structure in a conifer is equivalent to the embryo sac of angiosperms? _____

4. What is the role of wind in the complete life cycle of a conifer? _____

_____

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LINK 173 LINK 143 LINK 142 KNOW

141 Insect Pollination

Key Idea: Many angiosperms have a mutualistic relationship with their pollinators in which the plants achieve pollination by rewarding insects with food such as nectar or pollen.

Pollination is the transfer of pollen from the male anther to the female stigma. Pollination of flowers by insects is usually mutualistic. **Mutualistic** relationships involve exchanges between two species so that each species benefits. The benefit need not be equal for each party, because each species acts in its own interests. In the case of insect pollination, the insect benefits from the energy in the plant nectar or pollen it consumes. The plant benefits by having its gametes transferred to another plant. Nearly 88% of all flowering plants are pollinated by animals with the vast majority of these being insects.

Cross Section of an Insect Pollinated Flower

Female Reproductive Structures

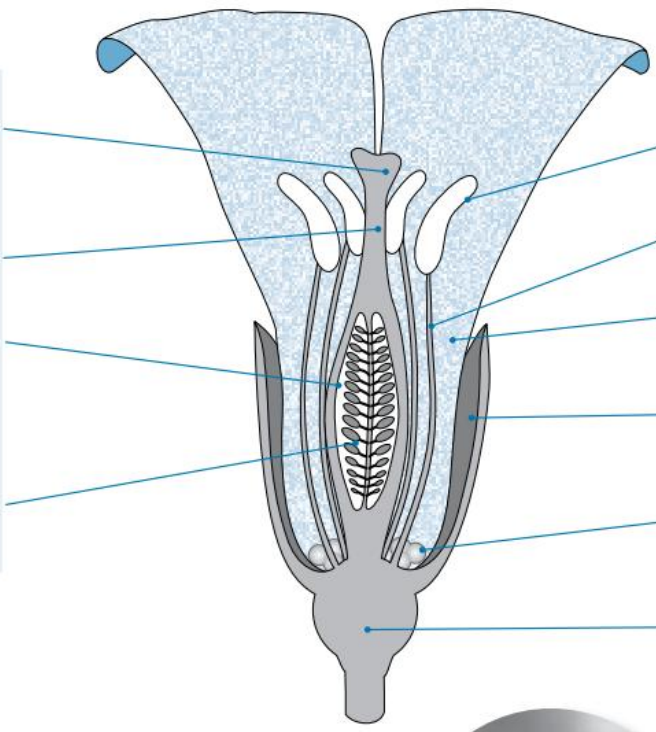
Stigma: The receptive part of the carpel. Pollen grains will germinate only if they land here.

Style: The structure that supports the stigma.

Ovary: The base of the carpel where the ovules develop.

Ovules: These are eggs and once fertilised, become the seeds. The ovule skin becomes the seed coat or testa.

An entire female part is the carpel. There may be one or more carpels per flower.



Male Reproductive Structures

Anther: Top portion of the stamen, the male organ of reproduction.

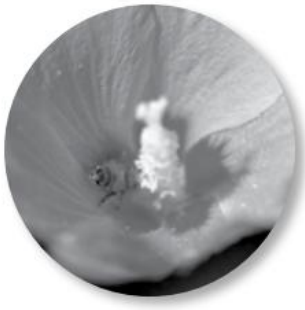
Filament: The slender stalk of the stamen that supports the anther.

Petals: Collectively, these form the corolla. Often brightly coloured.

Sepals: Together form the calyx. Usually green, but sometimes the same colour as the petals.

Nectary: Plants produce a sugary liquid called nectar to attract insects to the flower.

Receptacle: The swollen base of the flower. Sometimes it forms the succulent tissue of the fruit.



The petals of flowers guide insects towards the pollen or nectar at the centre of the flower using various colours and lines known as nectar guides. In this way, wandering insects are enticed into entering the flower and transfer pollen in the most efficient way.



Bees and many other insects are able to detect ultraviolet light. Many flowers contain pigments that reflect UV producing a specific pattern visible to insects but not to other animals. In this way, plants can use their flowers to specifically attract preferred insect pollinators.

1. Describe the difference between the stigma and the anther: _____

_____

2. (a) Explain why flowering plants need to attract pollinators to their flowers: _____

_____

_____

(b) Describe the adaptations that angiosperms have to attract specific pollinators to their flowers: _____

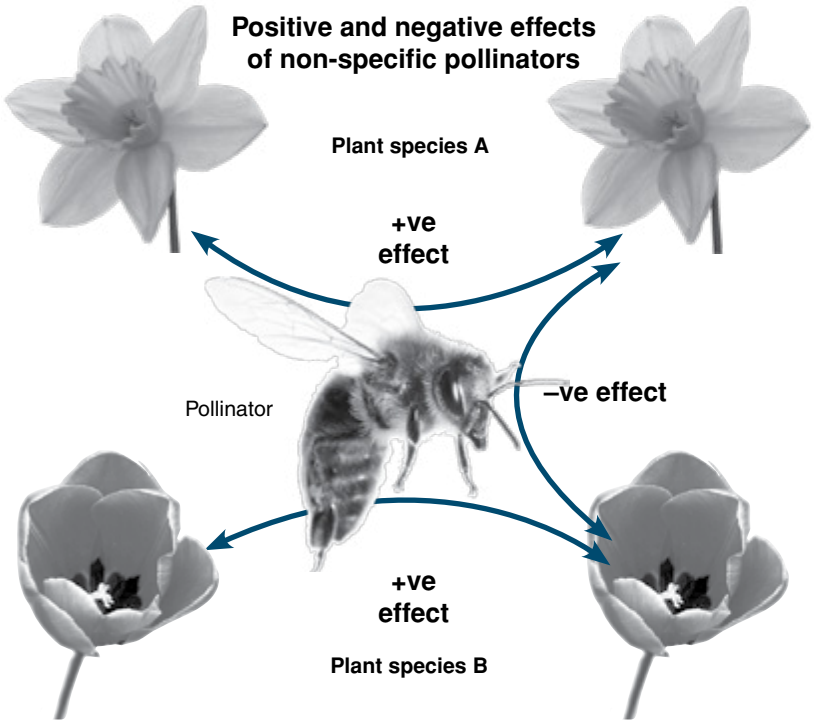
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Most insect pollinators are generalists, meaning they do not form pollination relationships with specific plants. Honey bees, for example, pollinate many different kinds of plants. This can be of negative value to a particular plant, as the energy expended in producing pollen and nectar is wasted if the bee does not next fly to a plant of the same species.



A mutualism is **facultative** when the species involved do not rely on either for survival, but take advantage of each other when present. Many insects will take pollen and nectar from many plant species and do not rely on just one for survival.



Photo: J. Arthur Thomson.

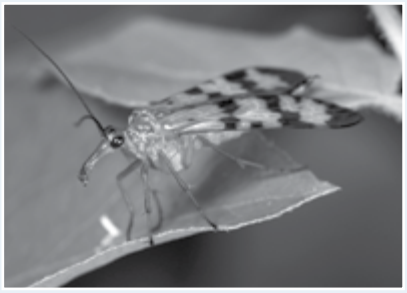
Obligate mutualism occurs when one species relies entirely on another for its survival. One example is the relationship between the yucca and the yucca moth. The yucca cannot make seeds without the moth and the moth larvae only eat yucca seeds.



Orchid flowers are highly variable in their structure and often highly specialised. They often have only one specific insect pollinator. This relationship is the result of the plant and its pollinator evolving together.



Magnolias are an ancient plant group with generalised flowers. They evolved before bees and evolved with beetles as their main pollinators. Magnolias produce large amounts of pollen, some of which is food for the beetles.



Angiosperms may not have always been the only plants to rely on insect pollination. Gymnosperms may have been pollinated by scorpionflies (above) in the Jurassic, long before flowers evolved.

3. Describe the benefits of **mutualism** to both the flower and the pollinator: _____

4. Discuss the advantages and disadvantages of flowers having obligate pollinators: _____

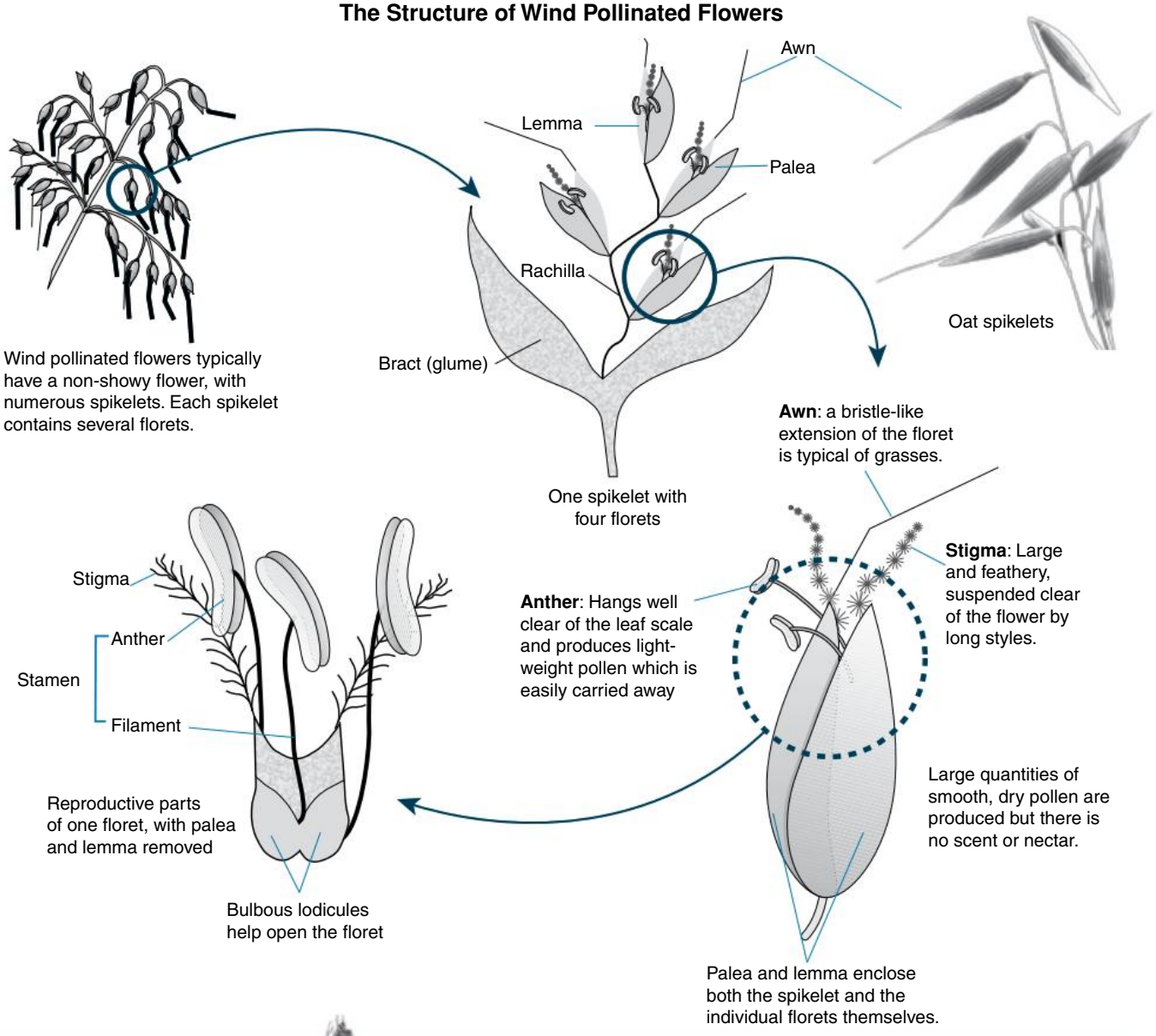
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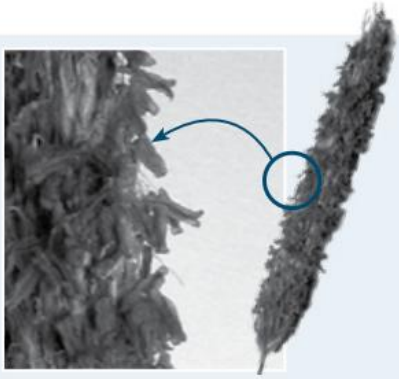
142 Wind Pollination

Key Idea: The flowers of wind pollinated plants are usually small and pale coloured. Vast quantities of pollen are needed to achieve successful cross-pollination.

The flowers of wind pollinated plants are not as large or brightly coloured as those of insect pollinated plants. Their flowers are generally small and may lack petals altogether, while the anthers and stigma are large and hang clear of the surrounding structures. Wind pollen is highly inefficient, with most pollen falling to the ground within 100 m, so large amounts of pollen are produced to ensure successful cross pollination with other plants. All gymnosperms but only around 10% of flowering plants are wind pollinated. However, this 10% includes the grasses, which are one of the most successful of all the angiosperm groups.

The Structure of Wind Pollinated Flowers





As with most wind pollinated plants, grass flowers are small, but are produced in large numbers. The arrow in the photograph above points to the anthers of a grass plant, which are held above the ground on a stalk.



The flowers of wind-pollinated trees are small, often with green petals, and very numerous. Wind pollinated trees are common in temperate regions where wind movements through deciduous trees easily disperses the pollen.



Gymnosperms are all wind pollinated. In conifers, the male cones are often borne on the lower branches. They produce vast quantities of pollen, which must be blown upwards towards female cones in higher branches of other trees.

LINK
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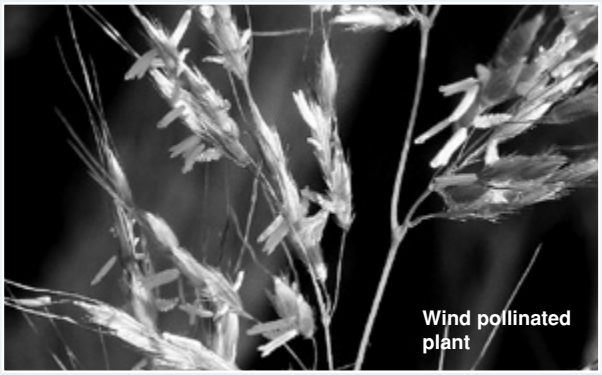
1. Describe three differences between the insect and wind pollinated flowers shown in the photographs below:

   (a) _____

   (b) _____

   (c) _____





2. Using the photographs and your answers above to help you, contrast wind and insect pollinated flowers with respect to each of the following characteristics. For each, give reasons for the differences observed:

   (a) Appearance of the flowers: _____

   (b) Production of scent and nectar: _____

   (c) Amount of pollen produced: _____

   (d) Position of the reproductive parts (stigma, stamens): _____

3. Describe two adaptations of wind pollinated flowers:

   (a) _____

   (b) _____

4. Contrast the efficiency of wind and animals as pollinating agents, giving a reason for your answer: _____

5. Describe the main the advantage of **cross pollination**: _____

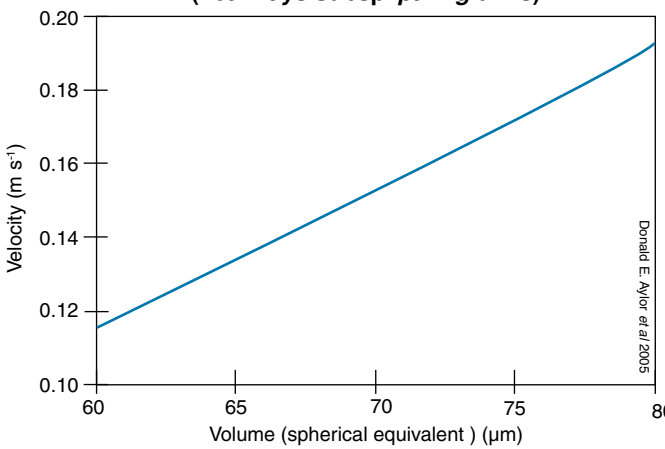
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143 Pollination and Fertilisation

Key Idea: In plants, pollination is essential to ensure fertilisation and production of seeds.

Pollination is the transfer of pollen grains from the male reproductive structures to the female reproductive structures of plants. This must happen before **fertilisation** (the joining of the egg and sperm) can occur. Adaptations to ensure **cross pollination** (pollination between different plants) include structural and physiological mechanisms associated with the flowers or cones themselves, and reliance on wind and animal pollinators.

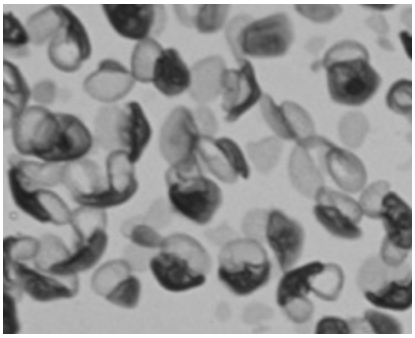
Settling Speed in Still Air of Teosinte Pollen (*Zea mays* subsp. *parviglumis*)



Pollen



SEM: *Primula* (primrose) pollen



Light microscope: Pine pollen

The size of the pollen grain in wind pollinated plants affects the distance the pollen can travel (see graph above). The pollen grains of *Pinus* and many other conifers have two air filled bladders on the outside of the pollen grain. These increase the length of time the pollen remains in the air by decreasing their rate of fall. Different pollens are variable in shape and pattern, and genera can be easily distinguished on the basis of their pollen. This feature is exploited in forensic botany where a crime is traced through botanical evidence. The species-specific nature of pollen ensures that only genetically compatible plants will be fertilised. Some species, e.g. *Primula*, produce two pollen types. This helps cross pollination.

Mechanisms to Ensure Cross Pollination



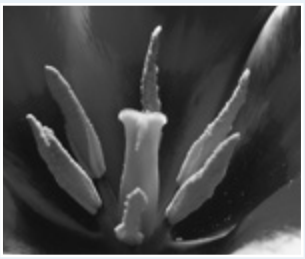
Male willow catkin

An effective way of ensuring cross pollination is to have separate male and female plants. This occurs in about 6% of angiosperms including willows and holly.



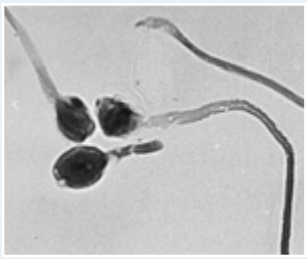
Male and female pine cones

Other plants produce separate male and female flowers or cones on the same plant. They may develop at different times so pollen does not fertilise the same plant.



Tulip anthers and stigma

Some angiosperms have flowers with both male and female structures. They can ensure cross pollination if the anthers and stigma mature at different times.



Germinating pollen grains

In many plants, pollen landing on the stigma of the same plant will not even germinate. This ensures that the egg cells are not fertilised by sperm from the same plant.

1. Explain how having variable pollen sizes increases the chances of pollination in a population of *Zea mays* plants:

2. Explain why plants have generally evolved to limit self pollination:

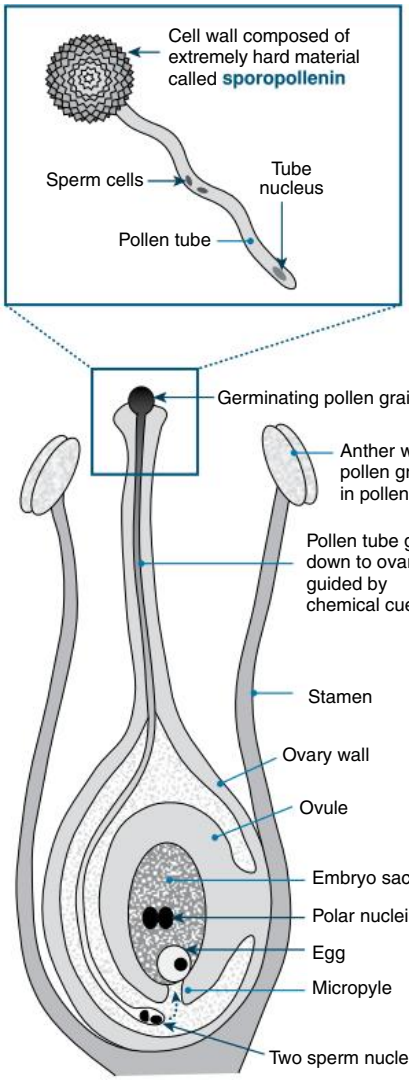
3. Describe three ways in which plants avoid self-pollination:

   (a)

   (b)

   (c)

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Angiosperm

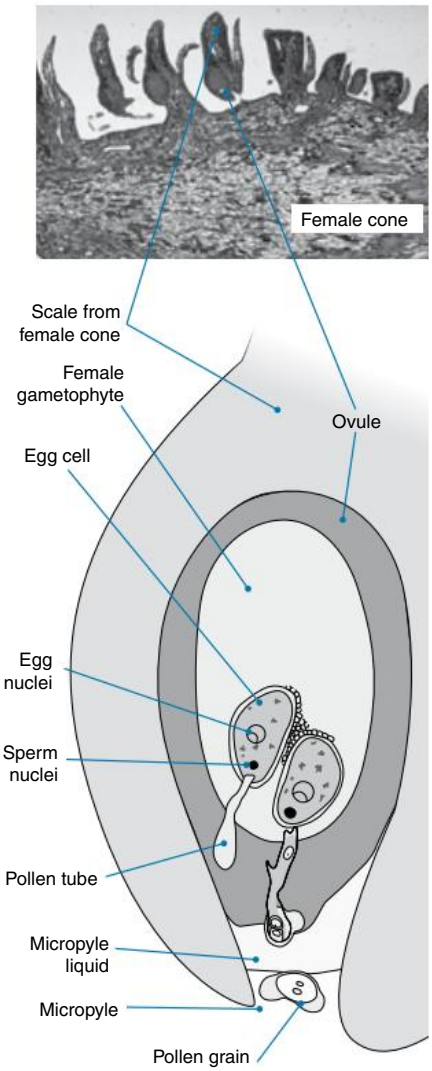
Pollen grains are immature male gametophytes, formed by mitosis of haploid microspores within the pollen sac. Pollination is the actual transfer of the pollen from the stamens to the stigma or from the male cone to the female cone. Pollen grains cannot move independently. They are usually carried by wind or animals.

Fertilisation in Angiosperms

In **angiosperms** pollen lands on the sticky stigma and completes development, germinating and growing a pollen tube that extends down to the ovary. The pollen tube is directed by chemicals (usually calcium) to the ovule. It enters through the micropyle, a small gap in the ovule. A **double fertilisation** takes place. One sperm nucleus fuses with the egg to form the zygote. A second sperm nucleus fuses with the two polar nuclei within the embryo sac to produce the endosperm tissue (3N). There are usually many ovules in an ovary, therefore many pollen grains (and fertilisations) are needed before the entire ovary can develop.

Fertilisation in Gymnosperms

In conifers, the pollen lands on a drop of fluid covering the micropyle and is drawn down into the micropyle to the ovule as the fluid evaporates. The pollen tube germinates shortly afterwards, but may take 15 months to reach the egg cell. The pollen grain produces the sperm-producing cell which produces two sperm nuclei. One nuclei fuses with the egg cell while the other degenerates. About 4% of seeds contain multiple embryos, which are formed when more than one egg cell in the ovule develops.



Gymnosperm

4. Describe the mechanisms to ensure cross pollination in plants: _____

5. Distinguish clearly between **pollination** and **fertilisation**: _____

6. Describe the role of the double fertilisation in angiosperms and explain how this is different to gymnosperms:

7. Name the main chemical responsible for pollen tube growth: _____

8. Explain what would happen if a seed containing multiple embryos germinated: _____

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144 Seed Structure and Germination

Key Idea: The seed houses the dormant embryonic plant and its food store until conditions for germination are met.

After fertilisation, the ovules within the ovary become the **seeds**. Recall the double fertilisation in angiosperms; one fertilisation produces the embryo and the other produces the endosperm. The development of the endosperm is important as it provides a nutrient store for the young plant. A seed is an entire reproductive unit, housing the embryonic plant in a state of dormancy. During the last stages of maturing, the seed dehydrates until its water content is only 5-15% of its weight. The embryo stops growing and remains dormant until the seed germinates. At germination, the seed takes up water and the food store is mobilised to provide the nutrients for plant growth and development.

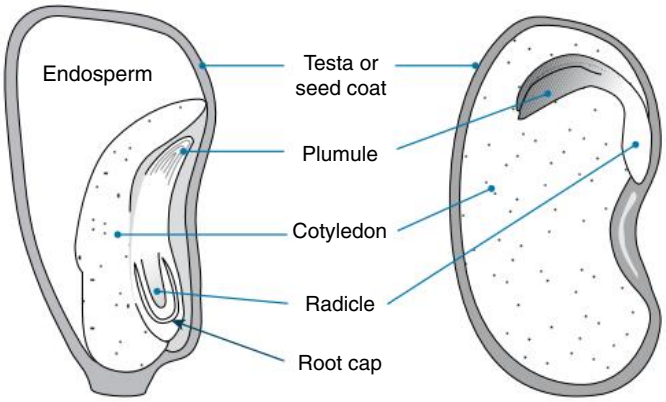


Dicot seeds: soy (above) **cashew** (below) There are two fleshy cotyledons. These store food absorbed from the endosperm.



In **germination**, the seed must rehydrate and reactivate its metabolism. The seed absorbs water through the seed coat (testa) and micropyle. As the seed tissue takes up water, the cells expand, metabolism is reactivated, and embryonic growth begins. Activation begins with the release of gibberellin (GA) from the embryo. GA promotes cell elongation, so the root can penetrate the testa. It also stimulates the synthesis of enzymes, which hydrolyse the starch to produce sugars. The mobilised food is delivered to the developing roots and shoots.

Seed Structure and Formation



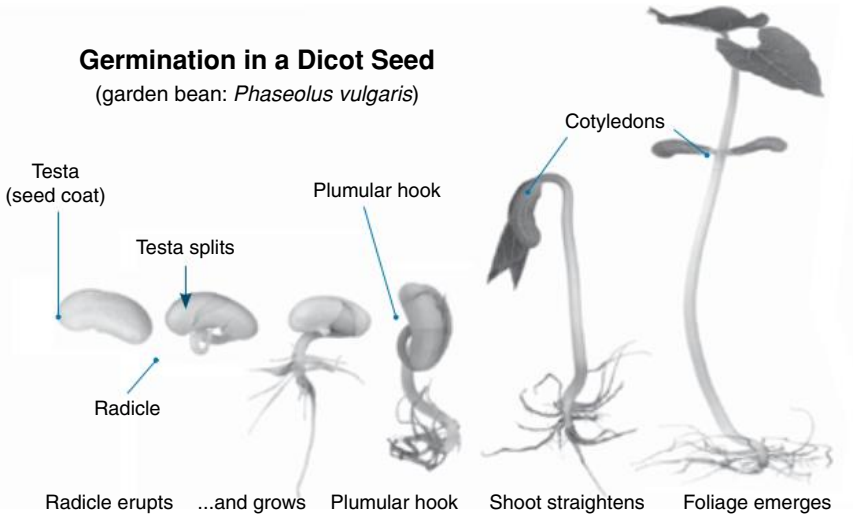
Monocot seed
(maize: *Zea mays*)

Dicot seed
(garden bean: *Phaseolus vulgaris*)

Every seed contains an embryo comprising a rudimentary shoot (plumule), root (radicle), and one or two cotyledons (seed leaves). The embryo and its food supply are encased in a tough, protective seed coat or **testa**. In monocots, the endosperm provides the food supply, whereas in most dicot seeds, the nutrients from the endosperm are transferred to the large, fleshy cotyledons.

Germination in a Dicot Seed

(garden bean: *Phaseolus vulgaris*)



1. What is the purpose of a **seed**? _____

_____

2. (a) State the function of the endosperm in angiosperms: _____

   (b) State how the endosperm is derived: _____

3. What is the role of the testa? _____

4. Explain why the seed requires a food store: _____

_____

5. Why must stored seeds be kept dry? _____

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145 Seed Dispersal

Key Idea: Seeds are dispersed from the parent plant to reduce competition for light and nutrients.

Plants disperse their seeds to expand their range and reduce competition. In some cases the seed itself is the agent of dispersal, but often it is the fruit or an associated attached structure. Seeds are mainly dispersed by wind, water, and animals. Wind dispersed seeds have wing-like or feathery structures that catch the air currents and carry the seeds. Plants that rely on animals to spread their seeds may have hooks or barbs that catch the animal hair, sticky secretions that adhere to the skin or hair, or fleshy fruits that are eaten leaving the seed to be deposited in feces away from the parent plant. Other dispersal mechanisms rely on explosive discharge or shaking from pods or capsules.

For each of the examples below, describe the method of dispersal and the adaptive features associated with the method:



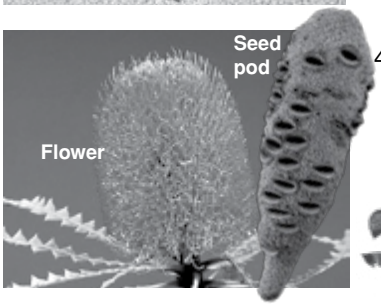
1. **Dandelion** seeds are held in a puff-like cluster:
   (a) Dispersal mechanism: _____
   (b) Adaptive features: _____



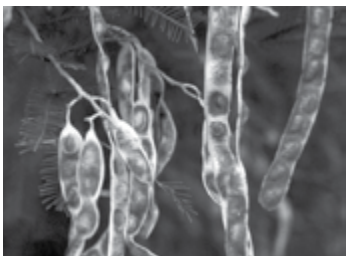
2. **Acorns** are heavy fruits in which the fleshy seeds are encased in a resistant husk:
   (a) Dispersal mechanism: _____
   (b) Adaptive features: _____



3. **Coconuts** are heavy buoyant fruits with a thick husk:
   (a) Dispersal mechanism: _____
   (b) Adaptive features: _____



4. **Banksia** seeds are attached to a light wing structure:
   (a) Dispersal mechanism: _____
   (b) Adaptive features: _____



5. **Wattle** (*Acacia* spp.) seeds are enclosed in pods. A fleshy strip surrounds each seed:
   (a) Dispersal mechanism: _____
   (b) Adaptive features: _____



6. **LillyPilly** (*Acmena* spp., *Syzgium* spp.) seeds are surrounded by fleshy fruits:
   (a) Dispersal mechanism: _____
   (b) Adaptive features: _____

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146 A Most Accomplished Traveller



Above: Coconut palms fringing a beach, Thailand

Key Idea: Coconuts have dispersed so widely through the tropics that their origin and path of dispersal is still the subject of research.

The origin of the coconut (*Cocos nucifera*) is one of botany's mysteries. It is so extensively cultivated and so widespread in the wild, determining its origin and dispersal around the globe is extremely difficult. Suggestions have been made that the coconut originated on the coastline of the Gondwanan continent, and spread to volcanic islands where competition had been eliminated by volcanic activity. It has also been suggested that the coconut originated in South Asia or South America. Fossils show that it has been wide spread for some time, with the oldest known fossils of coconut-like palm trees found in Bangladesh and fossils from New Zealand showing it was established there some 15 million years ago.

Coconuts are a single seeded fruit (a type known as a drupe and not, in fact, a nut at all), most commonly seen as the seed with the fibrous husk removed. The coconut fruit possesses a number of features that have allowed it to spread throughout the tropics. The fibrous husk allows it to float and keeps out the seawater. Its oval shape is very stable and allows it to ride high in the water. The seed is the largest of any plant except the coco-de-mer (*Lodoicea maldivica*) and it has a thin but tough shell. The endosperm takes up only a small lining inside the seed, leaving a hollow that is filled with liquid. As the seed matures on its voyage across the sea, the liquid is absorbed. This adds to the buoyancy of the fruit. Additionally, the seed takes a long time to germinate, from 30 to 220 days. The seed is never dormant, as this is not necessary in an equable tropical climate, so the long germination period is an adaptation to extended periods of ocean-going travel between islands. Coconuts can still be viable after travelling for as long as 200 days and covering up to 4000 km.



Right: Coconut germinating on black sand on the island of Hawaii

Before the arrival of humans in the Pacific, coconuts were already widespread, but because of its valuable features, it has been even more widely dispersed by humans, both in prehistory and in modern times. Not only is it a portable, storable food and water source conveniently sealed in a hard shell, but the husk fibres can be used for making ropes, bedding, and many other products. Coconut oils, flesh, and fibres are still extensively used today.

The only tropical coastlines the coconut failed to reach naturally were those of the Atlantic and Caribbean as these bodies of water do not mix with the Pacific or Indian Oceans except in polar regions. However around 1500 AD Europeans travelling west from India transported the coconut around the bottom of Africa and across the Atlantic to Central America. The coconut is now common in every tropical and subtropical region on Earth.

1. Explain why the origin of the coconut palm is difficult to determine: _____

2. Describe the features of the coconut that allowed it to spread across the Pacific and Indian oceans: _____

3. Explain why humans found the coconut so useful: _____

4. Explain why the coconut never established in the Atlantic before humans introduced it: _____

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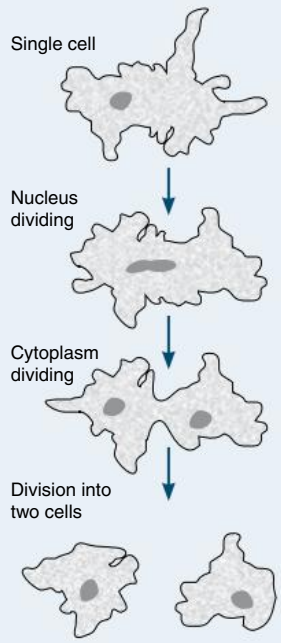
147 Asexual Reproduction

Key Idea: Asexual reproduction produces offspring that are identical to the parent (clones).

In most forms of asexual reproduction, the parent splits, fragments, or buds to produce offspring identical to itself. Parthenogenesis is a special type of asexual reproduction in which unfertilised eggs give rise to clones. Asexual organisms do not need to find a mate, and this saves them energy. Although asexual reproduction is rapid and highly efficient, all the offspring are genetically identical. If environmental conditions change there is little ability to adapt.

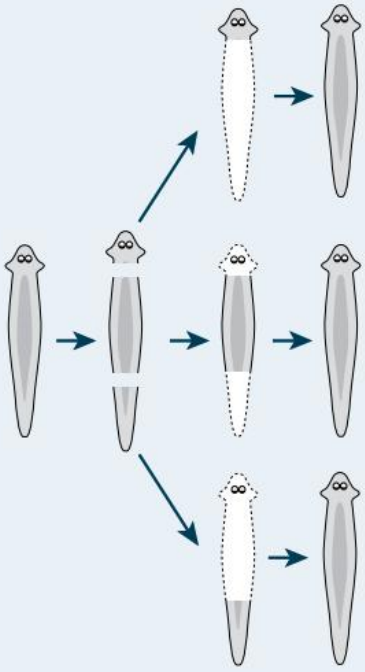
Fission in Unicellular Eukaryotes

Unicellular eukaryotes can reproduce asexually by splitting in two. This process involves mitosis and cytokinesis, and is not to be confused with the binary fission of bacteria which does not involve mitosis and cytokinesis. Fission is shown (below) for an *Amoeba*. Note that some multi-nucleated amoebas and some life cycle stages of parasitic protozoa, such as the malarial parasite *Plasmodium*, undergo **multiple fission**. The nucleus divides repeatedly before the final division of the cytoplasm to produce many new cells. Repeated cycles of multiple fission rapidly produce large numbers of offspring.



Fragmentation

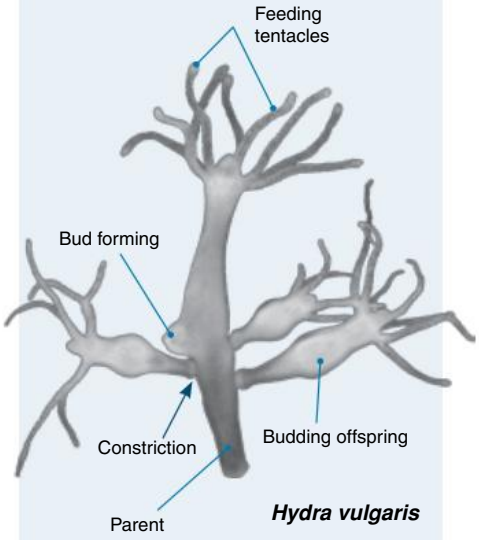
Some cnidarians, sponges and flatworms can reproduce by **fragmentation**. In this process, the organism spontaneously divides into fragments. Each fragment develops into a mature, fully grown individual identical to the original organism. In flatworms, a physiological gradient exists resulting in polarisation of the body. One pole represents the anterior (head) region, and the other pole the posterior (tail) region. This ensures that each new organism develops normally (e.g. they don't have two heads).



Budding

Sponges and most cnidarians (e.g. *Hydra*) can reproduce by **budding**. A small part of the parent body separates from the rest and develops into a new individual, which is smaller than the parent. This new individual may remain attached as part of the colony, or the bud may constrict at its point of attachment and be released as an independent organism.

This photo (below) shows *Hydra* budding. The new individuals are budding from the main body of the parent animal. The photograph shows the bulge and constriction where each new offspring will separate to form an independent individual.



1. How does binary fission in unicellular eukaryotes differ from that of prokaryotes? _____

2. What are the genetic consequences of asexual methods of reproduction? _____

3. (a) Why does multiple fission produce offspring more rapidly than simple binary fission? _____

   (b) Explain the advantage of multiple fission to an intracellular parasite such as *Plasmodium*: _____

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148 Animal Sexual Reproduction

Key Idea: Fertilisation refers to the union of male and female gametes to form a zygote. In animals, both fertilisation and development may occur externally or internally.

Sexual reproduction involves the production of sex cells (**gametes**) produced by sex organs (gonads). Female gametes are called **eggs**, male gametes are called **sperm**. Animal sexual reproduction follows one of three main patterns (below), determined by the location of fertilisation and embryonic development. Many aquatic invertebrates and fish have **external fertilisation**, in which the parents release their gametes into the water at the same time. Other invertebrates, reptiles, sharks, birds, and mammals have **internal fertilisation**, in which sperm is transferred directly into the female to increase the chances of successful fertilisation. In birds and most reptiles, one adaptation to life on land has been the evolution of the **amniote egg**: a structure that enables the embryo to complete its development outside the parent surrounded by a protective shell and nourished by a yolk sac. The pattern of internal development in mammals (termed gestation or pregnancy) provides the most advantages for the embryo in terms of nourishment and protection during development.

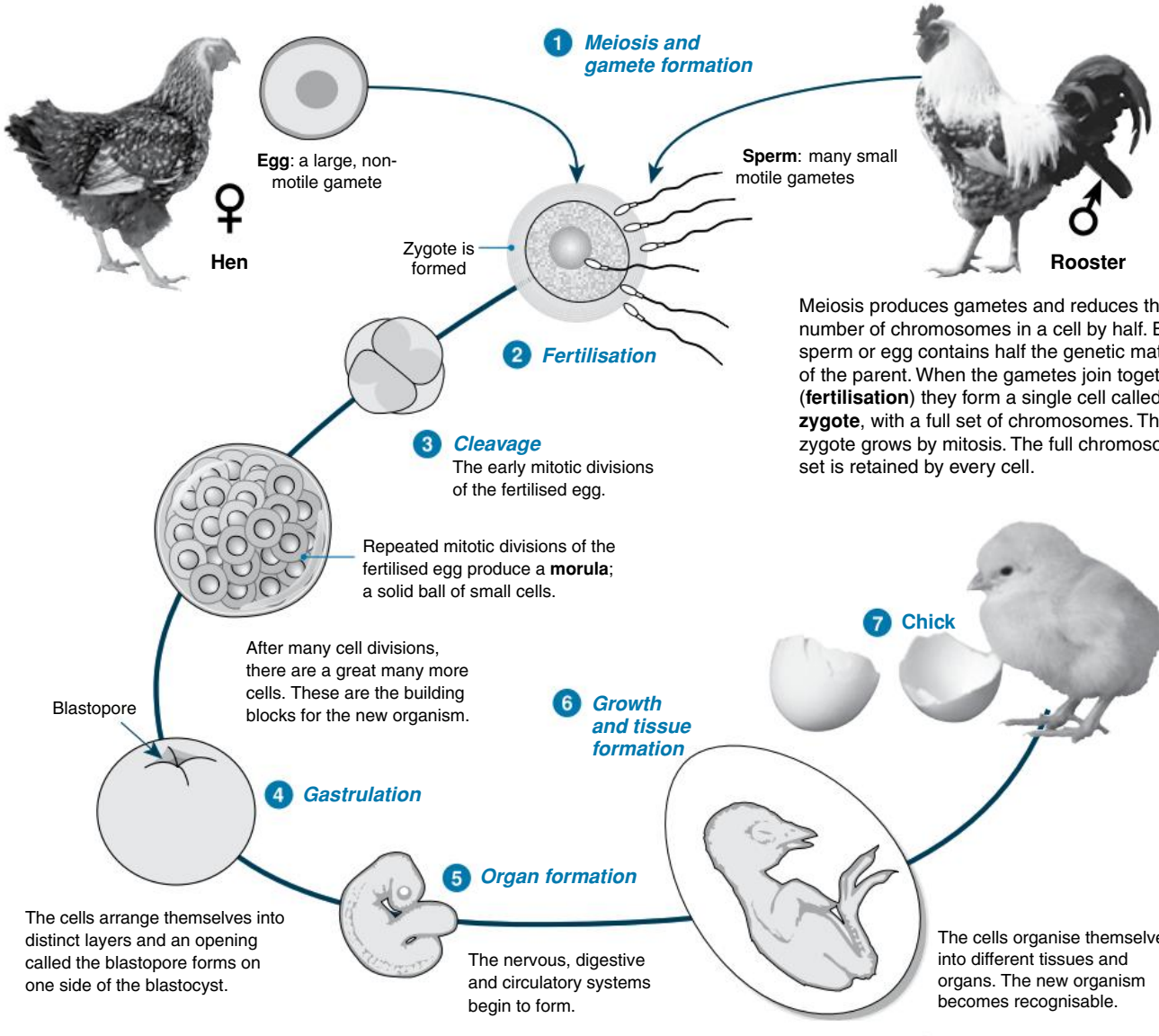
Three strategies for fertilisation and development



1. External fertilisation and development
Many marine invertebrates release gametes into the sea. Large numbers of gametes are produced. *Example: giant clam (above, left).* In amphibians, a prolonged coupling, called amplexus, precedes gamete release and external fertilisation and development. *Example: frogs (above, right).*

2. Internal fertilisation and external development
Insects often have elaborate courtship rituals. Fertilisation is internal, but the eggs are laid and develop externally. *Example: dipteran flies (above left).* In birds and reptiles, gamete fertilisation is internal but the eggs are laid (usually in nests) and develop externally. *Example: quail (above, right).*

3. Internal fertilisation and development
In mammals, fertilisation is internal and there is a long period of internal development. *Example: lions*



Meiosis produces gametes and reduces the number of chromosomes in a cell by half. Each sperm or egg contains half the genetic material of the parent. When the gametes join together (**fertilisation**) they form a single cell called the **zygote**, with a full set of chromosomes. The zygote grows by mitosis. The full chromosome set is retained by every cell.

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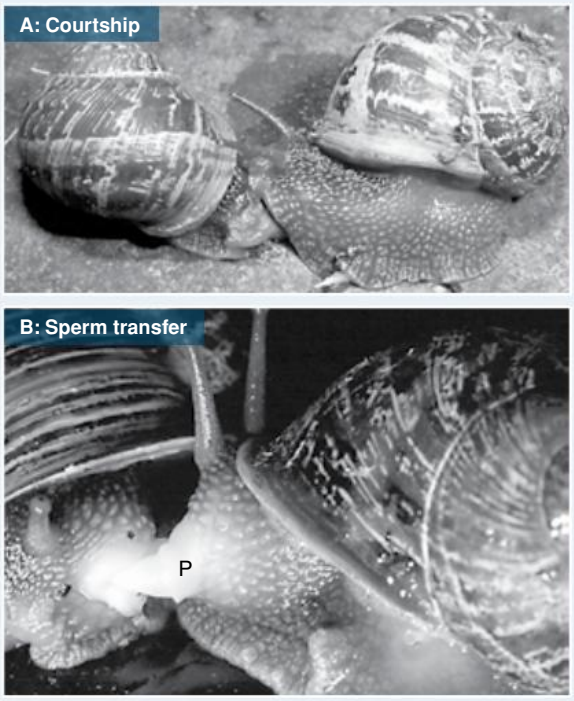
Hermaphroditism

Most animals have separate sexes (individuals are either male or female). However, in some animals both sperm and eggs can be produced in the same individual. Such animals are known as **hermaphrodites**. In earthworms (below), flatworms, and some molluscs (e.g. land snails), both male and female organs are active in the same animal and there is typically a reciprocal transfer of sperm (each receives sperm from the other during copulation). In this type of hermaphroditism, there is no self-fertilisation: a mate is necessary for any fertilisation to occur. However, some specialised hermaphroditic animals, such as parasitic tapeworms, are capable of self-fertilisation.



RA

The photo above shows two earthworms in a mating clasp. Each worm places its reproductive region (the clitellum) against the reproductive region of the other worm, and sperm are exchanged.



DH
DH

Courtship and mating in the snail *Cantareus aspersus* (formerly *Helix aspersa*, above). During an elaborate courtship (A), calcareous darts are fired from the genital opening (behind the tentacle) into the body of the partner. Mating (B) involves reciprocal transfer of sperm via a penis (P).

1. Describe one advantage of sexual reproduction: _____

_____

2. Describe one potential disadvantage of sexual reproduction: _____

_____

3. For the bird example on the previous page, compare the key differences between male and female gametes:

   (a) The size of gametes: _____

   (b) Number of gametes produced: _____

   (c) Motility of gametes: _____

4. Distinguish between **internal fertilisation** and **external fertilisation**, identifying advantages of each strategy:

_____

_____

_____

_____

5. (a) Name an animal group with internal fertilisation but external development: _____

   (b) Name an animal group with internal fertilisation and internal development: _____

   (c) Describe one benefit and one cost involved in providing for internal development of an embryo:

   Benefit: _____

   Cost: _____

6. Describe two features of the amniote egg (e.g. in birds) that make it an ideal adaptation to reproduction on land:

   (a) _____

   (b) _____

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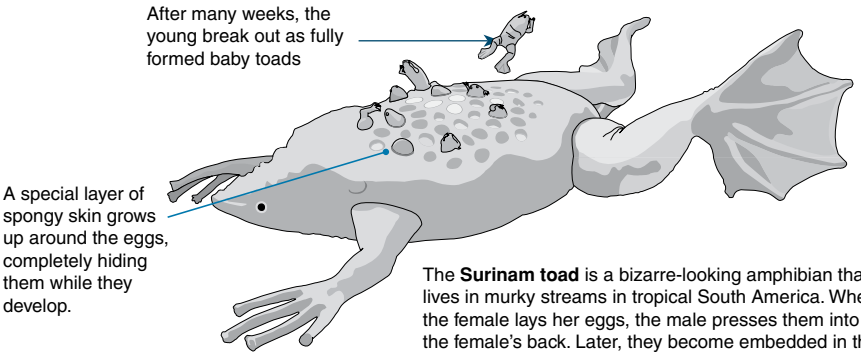
149 Animal Reproductive Strategies

Key Idea: Animals have evolved diverse structural, physiological, and behavioural strategies to maximise the production of viable young.

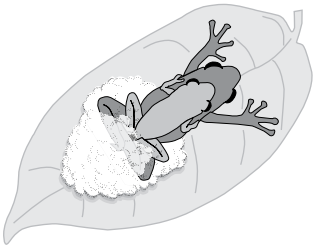
To reproduce sexually, animals must have systems to ensure that gametes meet and fertilisation takes place. The least complex reproductive systems do not even have distinct gonads, whereas the most complex comprise numerous structures to produce the gametes and protect the eggs and developing embryos. Invertebrates have evolved some of the most diverse reproductive systems. Insects have separate sexes and highly developed reproductive systems, and often have elaborate courtship and mating behaviours associated with successful transfer of gametes. Amongst the vertebrates, the basic structures of the reproductive system are relatively uniform, but there is huge variation in the strategies shown by different vertebrate groups. Biologists distinguish **oviparous** (egg laying) animals from **viviparous** (live bearing) animals. A small number of vertebrates are also **ovoviviparous**, i.e. the young are born live but their nutrition inside the mother is derived from stores within the egg.

Reproductive Strategies of Frogs

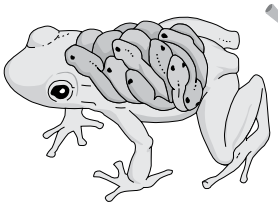
Fertilisation is external in most frogs and toads. It is achieved following **amplexus**, during which the male clasps the female. Amplexus may last several hours or even days until the female lays her eggs. Not all frogs lay eggs in water. Some frogs have adopted novel behaviour and physiological strategies to avoid their eggs becoming an easy meal. The examples here (right and below) illustrate the variety of solutions developed by different frog species.



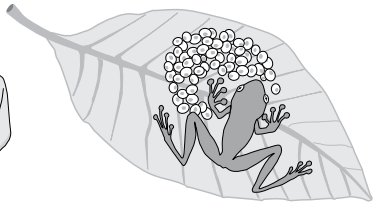
The **Surinam toad** is a bizarre-looking amphibian that lives in murky streams in tropical South America. When the female lays her eggs, the male presses them into the female's back. Later, they become embedded in the back as the skin swells up around the eggs.



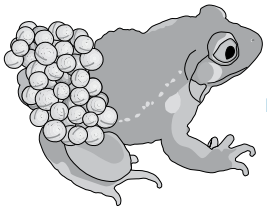
Some frogs lay their eggs in a nest of foam either on land (attached to leaves) or floating on water. The foam not only hides the eggs from predators, but it keeps them moist and prevents them from drying out.



Some species of small frogs in both South America and Africa lay eggs that hatch into tadpoles on land. The tadpoles stick to the back of one of the parents with mouthparts modified to function as suckers. The parent carries the tadpoles to water.



Some frog species lay eggs on leaves or branches overhanging the water. In some of these species one of the parents remains with the eggs until they hatch. The tadpoles that emerge from the eggs drop into the water below to complete their development.

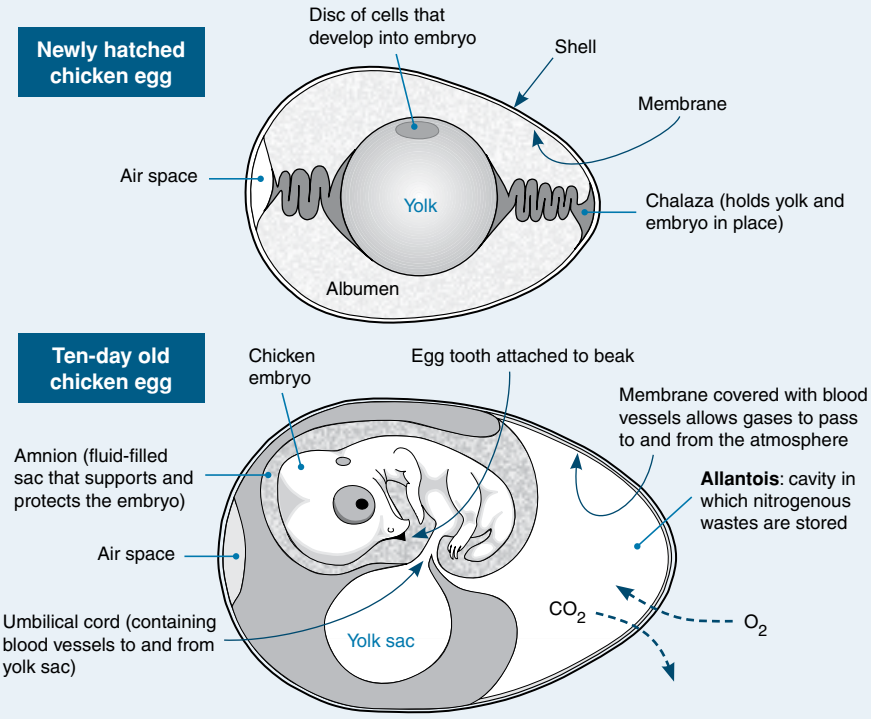


When a female midwife toad lays her string of eggs, the male winds them around his back legs. He carries the eggs for about a month, visiting puddles to keep them moist. When the eggs are ready to hatch he places them in a suitable pool.

The Structure of a Bird's Egg

Both reptiles and birds (which evolved from reptilian ancestors) developed water-tight shelled eggs, called **cleidoic eggs**. The egg is supplied with all the necessary food material as well as fats that yield water when metabolised. The shell enclosing the egg provides protection and reduces water loss, yet permits gas exchange. Waste materials from the developing chick embryo are stored in the egg.



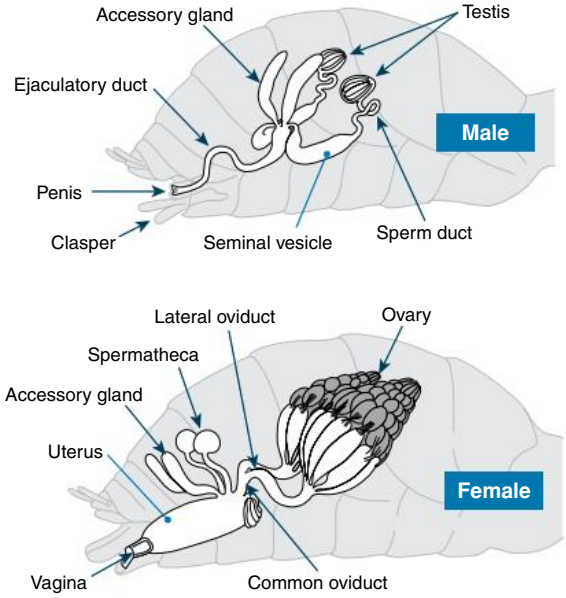


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Reproductive Strategies of Insects

Insects reproduce sexually, mainly by internal fertilisation followed by the production of yolk-filled eggs. A single pair of gonads is located in the abdomen. Most insects transfer sperm within small packets called **spermatophores**. Claspers at the end of the male's abdomen hold the female's abdomen during copulation. The terminal segments of the female's abdomen may form an **ovipositor**, which is often extendable or needle-like, with which they lay their eggs. Depending on the insect species, eggs may be buried in soil, animal dung, or rotting carcasses, injected into plant tissue or living hosts, or cemented to twigs or leaves.

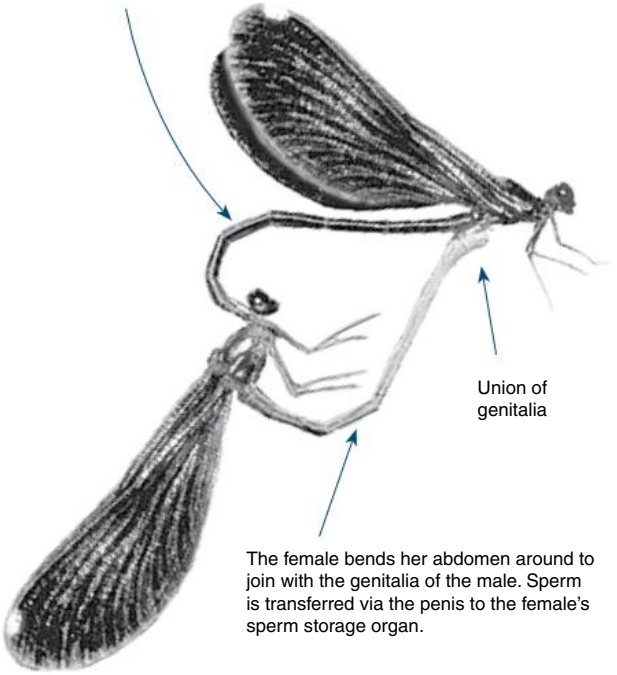
Insect Reproductive Organs



Mating Between Damselflies

The Odonata (damselflies and dragonflies) are unique amongst the insects in that the male copulatory apparatus is situated on abdominal segments close to its thorax. However the testes are located at the end of its abdomen so that, prior to mating, the male has to bend the abdomen round to transfer semen from the testes to the penis. The location of the male genitals also accounts for the unique "wheel position" adopted by Odonata as shown below.

The male damselfly grips onto a twig with its front legs during mating while holding the female behind the head with clasping organs at the end of its abdomen.



1. Giving examples, distinguish between **oviparous** and **viviparous** vertebrates: _____

_____

_____

2. Some frogs and toads have evolved novel ways of enhancing the survival of their eggs.

   (a) What are the two main threats to survival of frog/toad eggs? _____

   (b) How does the midwife toad enhance the survival of its eggs? _____

   _____

   (c) How does the Surinam toad enhance the survival of its eggs? _____

   _____

3. (a) Name two types of animal that produce **cleidoic eggs**: _____

   (b) Which feature of a cleidoic egg has been primarily responsible for its success? _____

   _____

   (c) Explain how a cleidoic egg provides for the following needs of a developing embryo:

   Elimination of wastes: _____

   _____

   Gas exchange: _____

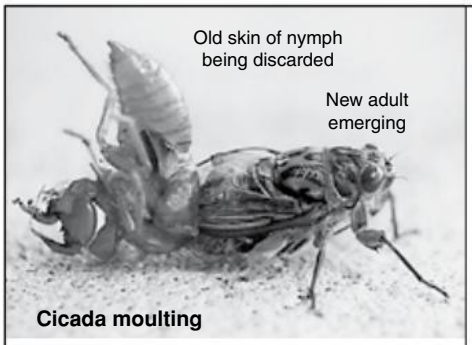
   Nutrition (food supply): _____

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150 Insect Life Cycles

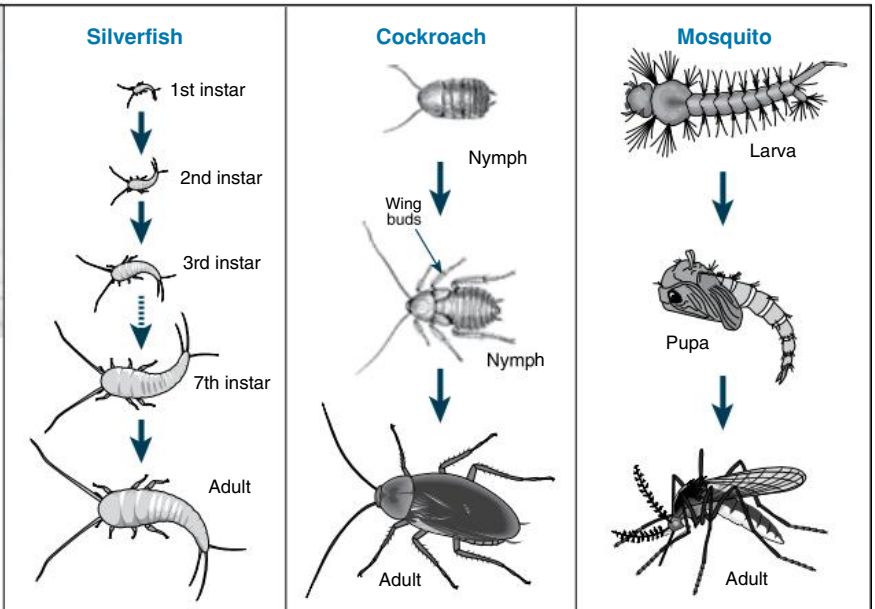
Key Idea: The life cycle of most insects involves metamorphosis from an immature form to an adult.

Insects possess an exoskeleton: a tough outer layer of chitin that must be **moulted** (shed) to allow growth. The growth and development of most insects from an immature form into an adult is achieved by a process called **metamorphosis**. Most insects undergo a complete metamorphosis, which involves egg, larval, pupal, and adult stages. Other insects go through a process of incomplete metamorphosis, which involves several nymphal stages but no pupal stage. The term instar usually denotes the developmental stage of the larval or nymphal forms. In all insects, there may be several larval instars, which are characterised by size, altered body proportions, or changes in body segments. In insects with complete metamorphosis, the adult may have a different morphology and lifestyle to the larval stage.



Cicada moulting

The three distinct life cycle patterns seen in insects are shown on the right. Some, such as the primitive, wingless silverfish, exhibit little change with each moult. Insects from more primitive orders (e.g. cockroaches) hatch from eggs to resemble miniature adults but with undeveloped reproductive organs and lacking wings. With each moult their wings gradually increase in size and their reproductive organs develop. More advanced insects (e.g. butterflies and mosquitoes) exhibit egg, larva, pupa, and adult sequence.



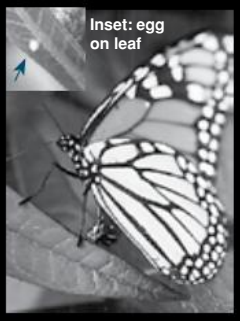
No metamorphosis | *Incomplete metamorphosis* | *Complete metamorphosis*

The life cycle of the wanderer or monarch butterfly *Danaus plexippus*

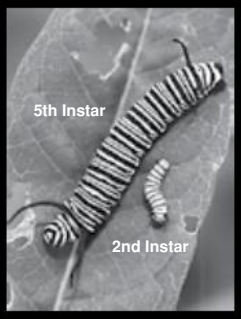
The monarch butterfly has a life cycle typical of an insect exhibiting complete **metamorphosis**, passing through four completely different forms: from a tiny **egg**, through 5 stages of larval or caterpillar growth, to a dormant **pupa** (chrysalis), and finally emerging as an **adult** butterfly. The whole growth process of the monarch takes a little over a month to complete in midsummer, longer at other (cooler) times of the year. Cold days slow down their metabolism and hence their growth rate. The lifespan of the monarch has been estimated at 60-70 days. This lifespan becomes as much as 6 or 7 months if the butterfly emerges in the autumn and needs to hibernate through the winter before egg-laying commences.



1. Two adults mating



2. Female laying eggs



3. Two caterpillar larvae



4. Pupating (early stage)



5. Chrysalis emerges



6. An immature chrysalis



7. Chrysalis about to hatch



8. An adult hatching

Stage in life cycle:	Egg	Larva	Pupa	Adult
Function:	Embryo	Growth	Reconstruction	Reproduction and dispersal
Instar:		1 2 3 4 5	6	7
Event:	*Oviposition*	*Hatching*	*Instar moults*	*Pupation*	*Emergence*	*Courtship*	*Egg laying*	*Death*

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1. List the stages in the following types of insect life cycles:

   (a) Complete metamorphosis: _____

   (b) Incomplete metamorphosis: _____

   (c) Growth and moulting: _____

2. Describe the purpose of each of the following stages in an insect life cycle exhibiting complete metamorphosis:

   (a) Egg: _____

   (b) Larva: _____

   (c) Pupa: _____

   (d) Adult: _____

3. Provide two examples of insects exhibiting each of the following types of life cycles:

   (a) Complete metamorphosis: _____

   (b) Incomplete metamorphosis: _____

   (c) Growth and moulting: _____

4. Describe one advantage of having a life cycle where the young undergo metamorphosis into the adult stage:

   _____

   _____

   _____

5. Identify a type of vertebrate that exhibits complete metamorphosis between the juvenile and adult stages:

   _____

6. Insects, unlike vertebrates, experience a problem when growing in size because they possess an exoskeleton.

   (a) Why does the exoskeleton create a problem for insect growth? _____

   _____

   (b) How do insects solve this problem? _____

   _____

7. Discuss the adaptive role of metamorphosis in the life cycles of insects, including reference to the exploitation of habitat and resources:

   _____

   _____

   _____

   _____

   _____

   _____

   _____

8. Why is the life cycle of the monarch butterfly considerably longer over winter (relative to summer) months?

   _____

   _____

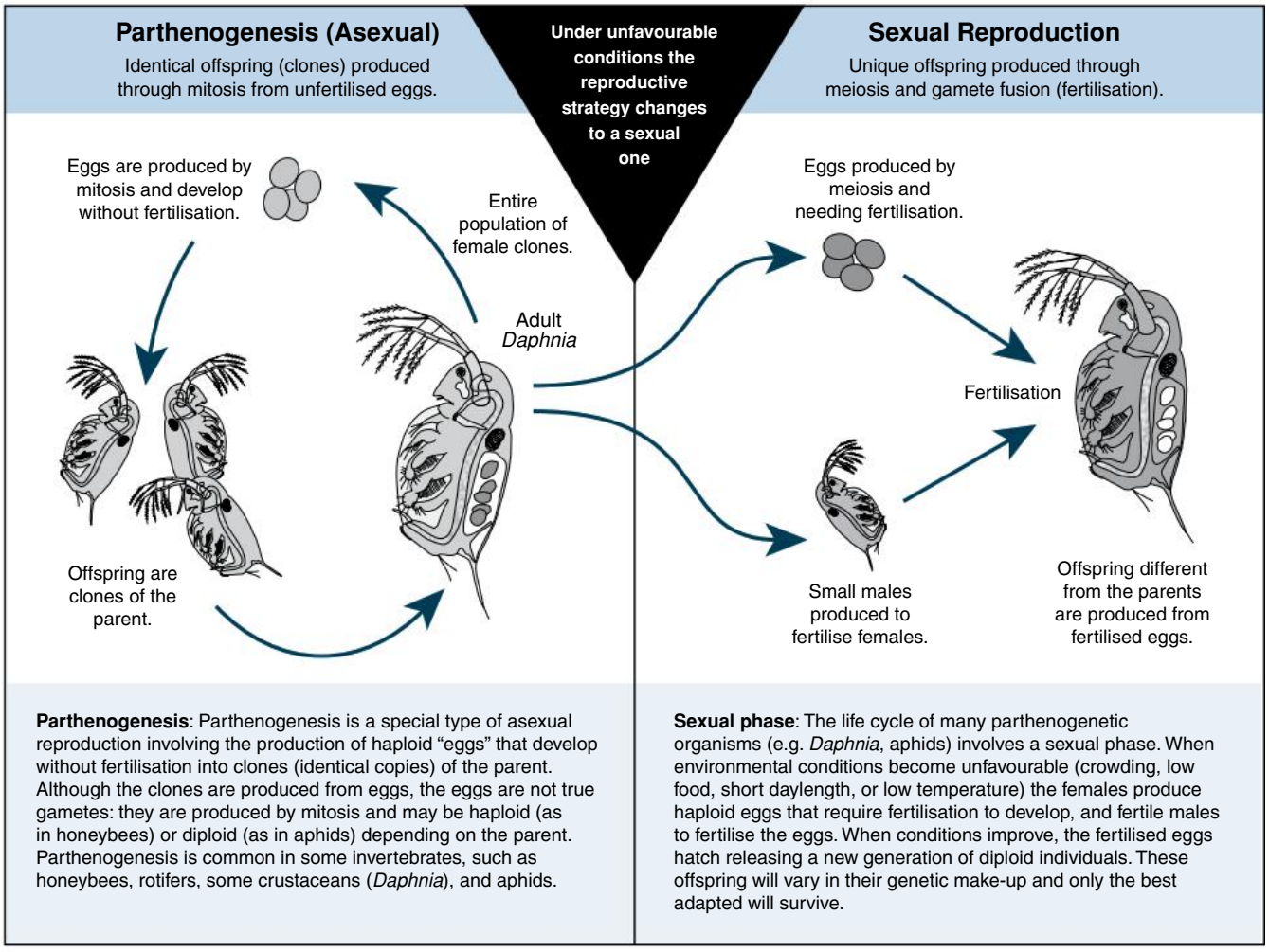
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151 Alternating Asexual and Sexual Cycles

Key Idea: Some organisms reproduce asexually in favourable conditions and sexually when the environment deteriorates.

Some organisms combine cycles of asexual reproduction by **parthenogenesis** with periods when they reproduce sexually. The parthenogenetic phase enables the rapid reproduction of a well adapted clone. The sexual phase is induced when environmental change results in unfavourable conditions for survival of the clone. The new generation, produced by sexual reproduction, may include some individuals that are better adapted to a new set of environmental conditions.



Parthenogenesis: Parthenogenesis is a special type of asexual reproduction involving the production of haploid "eggs" that develop without fertilisation into clones (identical copies) of the parent. Although the clones are produced from eggs, the eggs are not true gametes: they are produced by mitosis and may be haploid (as in honeybees) or diploid (as in aphids) depending on the parent. Parthenogenesis is common in some invertebrates, such as honeybees, rotifers, some crustaceans (*Daphnia*), and aphids.

Sexual phase: The life cycle of many parthenogenetic organisms (e.g. *Daphnia*, aphids) involves a sexual phase. When environmental conditions become unfavourable (crowding, low food, short daylength, or low temperature) the females produce haploid eggs that require fertilisation to develop, and fertile males to fertilise the eggs. When conditions improve, the fertilised eggs hatch releasing a new generation of diploid individuals. These offspring will vary in their genetic make-up and only the best adapted will survive.

1. Describe one potential disadvantage of reproducing asexually: _____

2. Why is parthenogenesis categorised as asexual reproduction? _____

3. Describe two advantages of having a reproductive strategy where parthenogenesis (the asexual phase) is interrupted occasionally by a period of sexual reproduction:

   (a) _____

   (b) _____

4. Why would certain environmental conditions (e.g. crowding, low food, temperature or daylength changes) stimulate some asexually reproducing organisms (e.g. *Daphnia*, rotifers, aphids) to enter a phase of sexual reproduction?

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152 Mammalian Reproduction

Key Idea: The three mammalian taxa have evolved different reproductive strategies with quite different energy allocations.

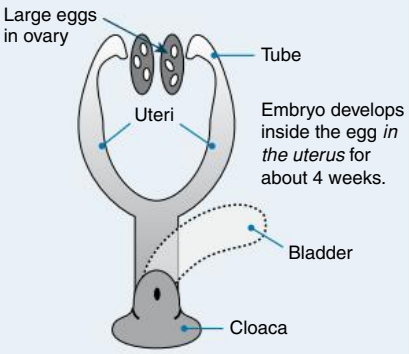
All mammals produce milk to feed the young; it is the defining feature of the class. However, in other features of their reproduction and development, the three mammalian taxa (monotremes, marsupials, and placentals) are quite different. Monotremes, which are egg laying, are regarded as being the most primitive.

Monotremes



Examples:
Platypus
Echidna

- Egg-laying habit (two at a time)
- Common cloaca (not separate anal and urine/genital openings)
- Large, yolky eggs
- Eggs incubated after laying
- After hatching, young lap milk from teatless mammary glands

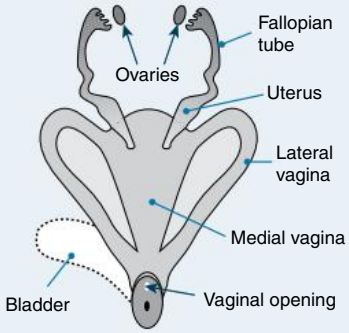


Marsupials



Examples:
Wallabies
Kangaroos
Wombats
Koala
Possums
Bandicoots
Quolls

- At least two, sometimes three, vaginae
- Very short gestation young in the uterus
- A very simple placenta is sometimes formed but only for a very short time
- Tiny, embryo-like young at birth
- Development completed inside a pouch
- Young attach to teat in pouch to suckle

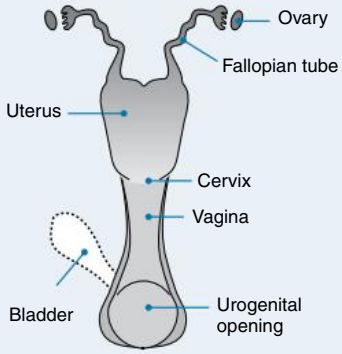


Placentals



Examples:
Rodents
Primates
Carnivores
Whales
Deer etc.

- Single common vagina and sometimes a common large uterus (e.g. humans)
- Eggs are small with very little yolk
- Placenta (complex embryonic-maternal connection) nourishes the embryo
- Young relatively well-developed at birth
- Young are suckled with milk after birth



1. Why are monotremes, marsupials, and placentals all classed as mammals? _____

2. Why are monotremes regarded as being very primitive mammals? _____

3. Describe two features of marsupial reproduction that are advancements on the monotreme reproductive pattern:

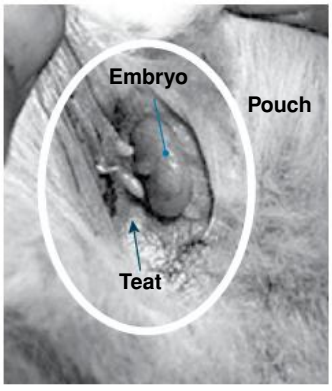
4. In what way is the reproductive plan in placentals more highly developed than that of marsupials?

5. The photo on the right shows a wallaby young in the pouch. The embryo must reach the pouch from the vaginal opening some distance away:

   (a) How does the young reach the pouch? _____

   (b) Describe one adaptation that enables it to make the journey: _____

   (c) Compare the state of development of this young with a placental young at birth:



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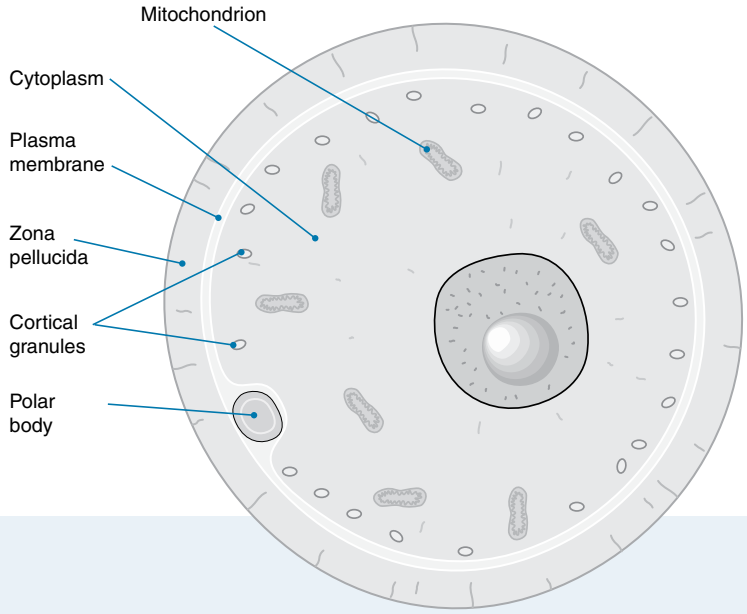
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153 Gametes

Key Idea: Gametes are the sex cells of organisms. Male and female gametes differ in their size, shape, and number.

Gametes (sex cells) are produced for the purposes of sexual reproduction. The gametes of male and female mammals differ greatly in size, shape, and number. These differences reflect their different roles in fertilisation and reproduction. Male gametes (**sperm**) are highly motile and produced in very large numbers throughout life. Female gametes (**eggs** or ova) are large, relatively few in number, and immobile. Eggs and sperm are produced by meiosis in a process called **gametogenesis**. Gametogenesis in males is called **spermatogenesis**. In females, it is called **oogenesis**.

Egg Structure and Function



The ovum is a simpler structure than the sperm cell. It has no propulsion mechanism and moves as a result of the wave-like motion of the ciliated cells lining the Fallopian tubes of the female reproductive tract. The ovum is required to survive for a much longer time than a sperm, so it contains many more nutrients and metabolites and, as a result, it is much larger than a sperm cell (up to 100 µm).

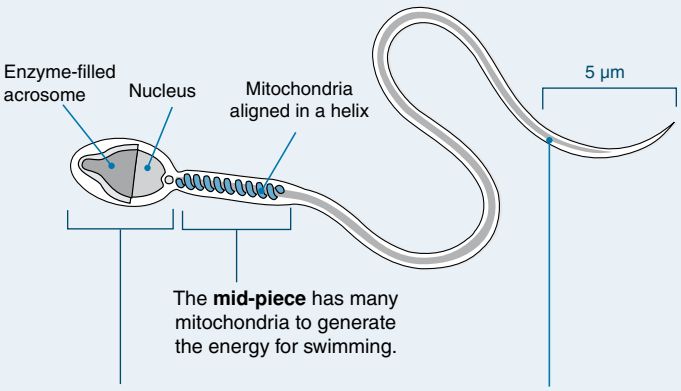
The contents of the ovum are similar to that of a typical mammalian cell, although it is externally surrounded by a jelly-like glycoprotein called the zona pellucida. A small polar body (the remnants of a sister cell) lies between the plasma membrane and zona pellucida. Cortical granules around the inner edge of the plasma membrane contain enzymes that are released once a sperm has penetrated the egg, forming a block to prevent further sperm entry (the cortical reaction).

Sperm Structure and Function

Mature spermatozoa (sperm) are produced in the testes. Meiotic division of spermatocytes produces spermatids, which then differentiate into mature sperm.

The sperm's structure reflects its purpose, which is to swim through the female reproductive tract to the ovum, penetrate the ovum's protective barrier, and donate its genetic material. A sperm cell comprises three regions: a headpiece, containing the nucleus and penetrative enzymes, an energy-producing mid-piece, and a tail for propulsion.

Human sperm live only about 48 hours, but they swim quickly and there are so many of them (millions per ejaculation) that usually some are able to reach the egg to fertilise it.



The **mid-piece** has many mitochondria to generate the energy for swimming.

The **headpiece** contains the nucleus and the acrosome, which contains the enzymes that help penetrate the egg.

The **tail** is a long flagellum that propels the sperm in its swim to the egg.

1. Why do sperm need to be motile? _____

_____

2. (a) How does an egg move along the Fallopian tube? _____

_____

(b) Why does a mature egg need to be so many times larger than a sperm? _____

_____

_____

3. Describe how each of the following three features of a sperm cell contribute to its role in reproduction:

(a) Tail: _____

(b) Mitochondria: _____

(c) Acrosome: _____

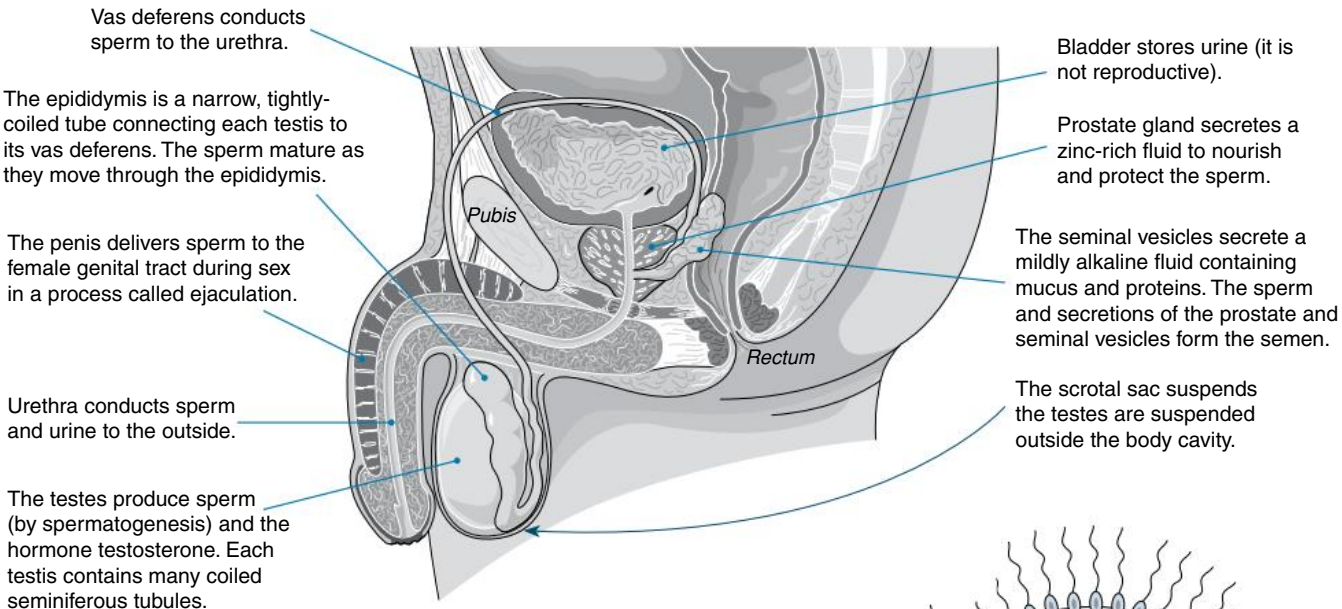
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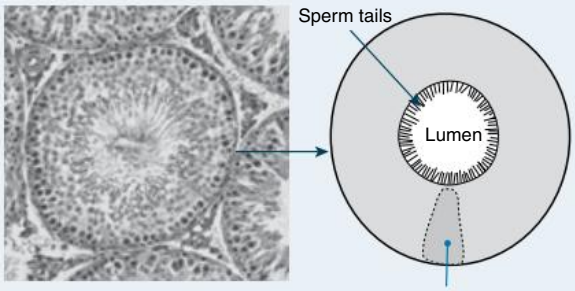
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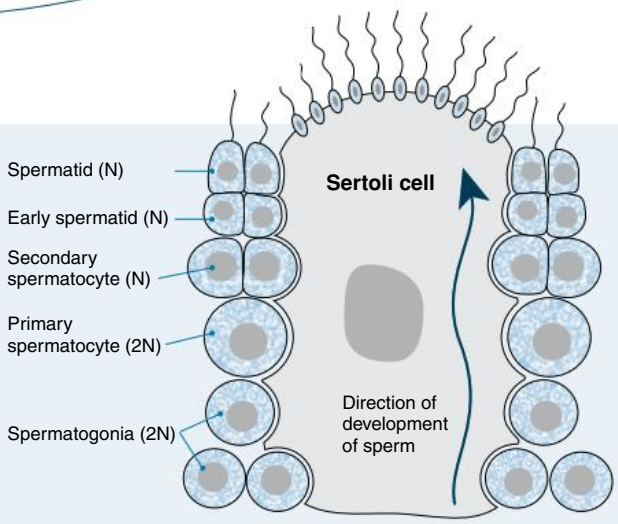
154 Male Reproductive System

Key Idea: The reproductive role of the male is to produce, maintain, and transport sperm and deliver them to the female, and to produce and secrete the male sex hormones responsible for maintaining the male reproductive system.

When a sperm combines with an egg, it contributes half the genetic material of the offspring and, in humans and other mammals, determines its sex. The reproductive structures of the human male is shown below.







Spermatogenesis

Sperm (the male gametes) are produced by meiotic division of spermatogonia in the seminiferous tubules of the testes. The nucleus of the **germ cell** in the male divides twice to produce four similar-sized sperm cells. Spermatogenesis continues throughout an adult male's life.

The developing sperm are nourished by supportive Sertoli cells. Sperm production occurs in response to the male steroid hormone, testosterone. Sperm formed in the testis enter the epididymis, where they mature and develop motility.

1. State the main roles of the male reproductive system:_____

2. What is semen made up of and what is its purpose?_____

3. (a) Where does spermatogenesis occur?_____

   (b) What hormone controls this process?_____

   (c) What evidence do you have that spermatogenesis is most efficient at temperatures just below core body temperature?

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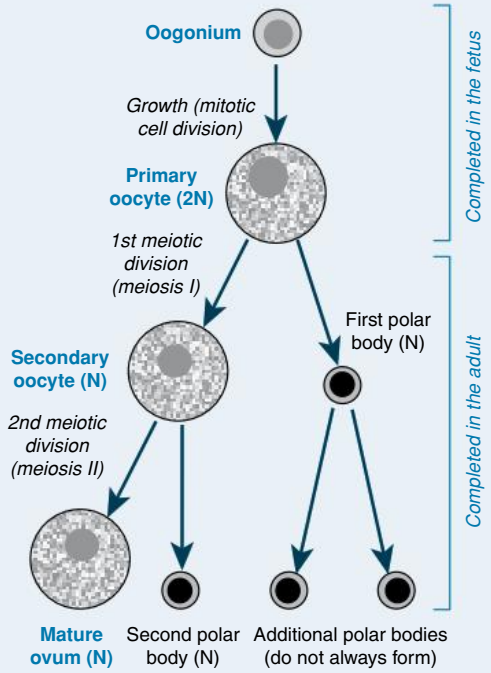
155 Female Reproductive System

Key Idea: The structures of the female reproductive system produce female gametes (ova) and maintain the fertilised ovum through its period of embryonic development.

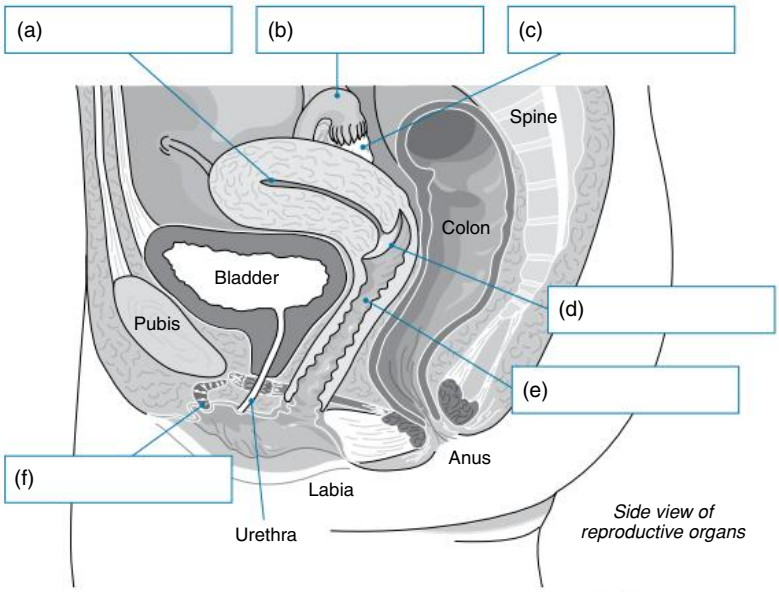
The female reproductive system produces ova (eggs), receives the penis and sperm during sexual intercourse, protects and houses the developing fetus, and produces milk to nourish the young after birth. It consists of the ovaries, Fallopian tubes, uterus, the vagina and external genitalia, and the breasts. The ova are produced by a process called oogenesis, which is only completed if the egg is fertilised.

Oogenesis

Oogenesis is the process by which mature **ova** are produced in the ovary. The ova are produced by meiosis of the primary oocytes, which are diploid and arise by mitosis from the oogonia in the fetus. Primary oocytes remain in prophase of meiosis I until puberty. At puberty, meiosis resumes. Each menstrual cycle, one or two ova resume development but, again, meiosis is arrested, this time in metaphase of meiosis II. The second meiotic division is only completed if the egg is fertilised. Unlike males, who produce sperm throughout their lifetime, females are born with their full complement of eggs and do not produce more.



The division of the cytoplasm during oogenesis is unequal. Most of the cytoplasm and one of the four nuclei form the ovum. The remainder of the cytoplasm and the other three nuclei, form small polar bodies, which do not take part in forming the zygote.

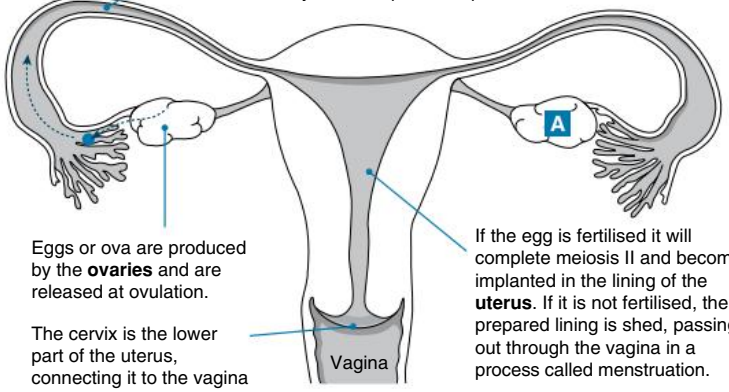


Side view of reproductive organs

Ovulation and Implantation



The unfertilised egg lives only for a day or so. It travels along the **Fallopian tube**, where fertilisation may occur if sperm are present.



Eggs or ova are produced by the **ovaries** and are released at ovulation.

The cervix is the lower part of the uterus, connecting it to the vagina

If the egg is fertilised it will complete meiosis II and become implanted in the lining of the **uterus**. If it is not fertilised, the prepared lining is shed, passing out through the vagina in a process called menstruation.

Front view of uterus and associated structures

1. The female human reproductive system and associated structures are illustrated above. Using the word list and the weblinks below to identify the labelled parts. **Word list**: *ovary, uterus (womb), vagina, Fallopian tube (oviduct), cervix, clitoris.*

2. (a) Name the organ labelled (**A**) in the diagram: _____

   (b) Name the event associated with this organ that occurs every month: _____

   (c) Name the process by which mature ova are produced: _____

3. Where does fertilisation occur? _____

4. (a) Describe one difference between gametogenesis in females and males: _____

   _____

   (b) What is the trigger for the completion of oogenesis: _____

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156 The Menstrual Cycle

Key Idea: The menstrual cycle involves cyclical changes in the ovaries and uterus to prepare for fertilisation of an egg.

In humans, fertilisation of the ovum (egg) is most likely to occur around the time of ovulation. The uterine lining (endometrium) thickens in preparation for pregnancy, but is shed as a bloody discharge through the vagina if fertilisation does not occur. This event, called **menstruation**, characterises the human reproductive or **menstrual cycle**. The menstrual cycle starts from the first day of bleeding and lasts for about 28 days. It involves predictable changes in response to pituitary and ovarian hormones and is divided into three phases (follicular, ovulatory, and luteal) defined by the events in each phase.

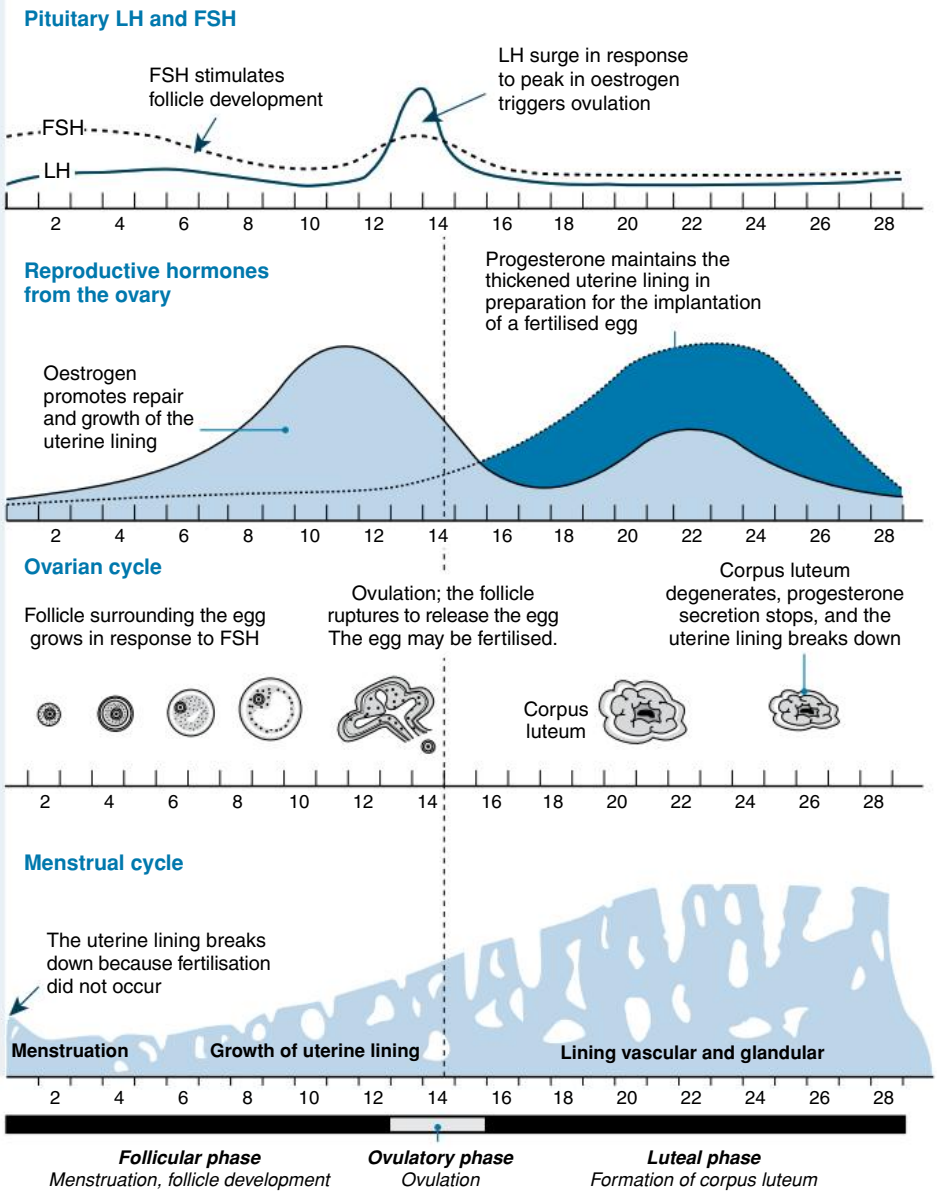
The Menstrual Cycle

Luteinising hormone (LH) and follicle stimulating hormone (FSH): These hormones from the anterior pituitary have numerous effects. FSH stimulates the development of the ovarian follicles resulting in the release of oestrogen. Oestrogen levels peak, stimulating a surge in LH and triggering ovulation.

Hormone levels: Of the follicles that begin developing in response to FSH, usually only one (the Graafian follicle) becomes dominant. In the first half of the cycle, oestrogen is secreted by this developing Graafian follicle. Later, the Graafian follicle develops into the corpus luteum (below right) which secretes large amounts of progesterone (and smaller amounts of oestrogen).

The corpus luteum: The Graafian follicle continues to grow and then (around day 14) ruptures to release the egg (ovulation). LH causes the ruptured follicle to develop into a corpus luteum (yellow body). The corpus luteum secretes progesterone which promotes full development of the uterine lining, maintains the embryo in the first 12 weeks of pregnancy, and inhibits the development of more follicles.

Menstruation: If fertilisation does not occur, the corpus luteum breaks down. Progesterone secretion declines, causing the uterine lining to be shed (menstruation). If fertilisation occurs, high progesterone levels maintain the thickened uterine lining. The placenta develops and nourishes the embryo completely by 12 weeks.



1. Identify the hormone responsible for:

   (a) Follicle growth: _____ (b) Ovulation: _____

2. Each month, several ovarian follicles begin development, but only one (the Graafian follicle) develops fully:

   (a) What hormone is secreted by the developing follicle? _____

   (b) What is the role of this hormone during the follicular phase? _____

   (c) What happens to the follicles that do not continue developing? _____

3. (a) What is the principal hormone secreted by the corpus luteum? _____

   (b) What is the purpose of this hormone? _____

4. What is the hormonal trigger for menstruation? _____

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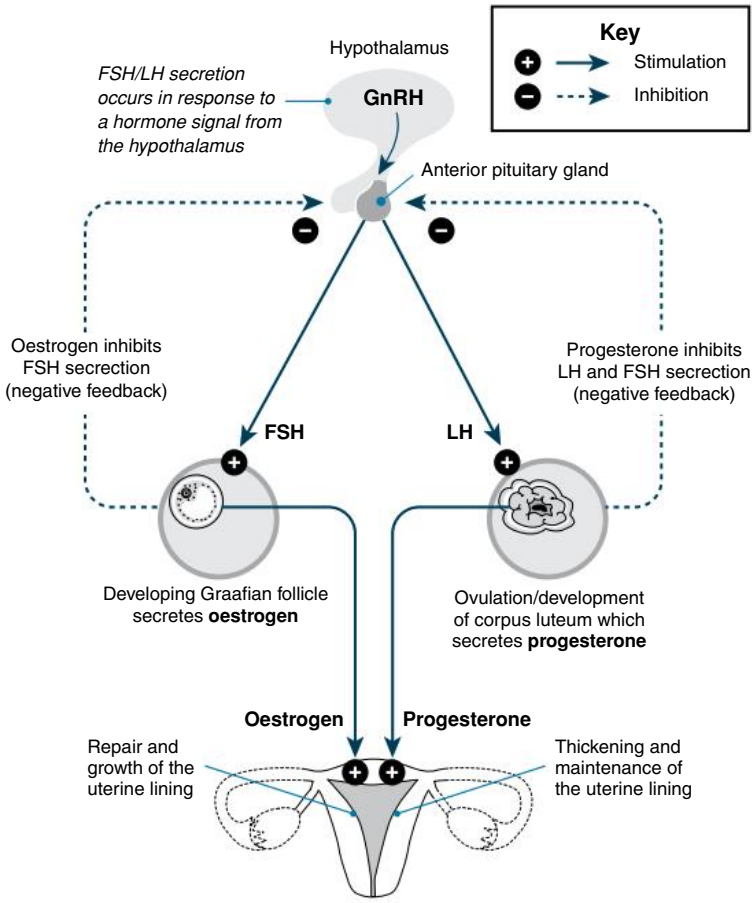
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157 Control of the Menstrual Cycle

Key Idea: Hormones from the hypothalamus and anterior pituitary regulate the menstrual cycle. The cycles of hormonal fluctuations can be manipulated to control fertility.

The female menstrual cycle is regulated by the interplay of several reproductive hormones. The main control centres for this regulation are the hypothalamus and the anterior pituitary gland. The hypothalamus secretes gonadotrophin releasing hormone (GnRH),which is transported in capillaries to the anterior pituitary where it induces the release of two hormones: follicle stimulating hormone (FSH) and luteinising hormone (LH). It is these two hormones that bring about the cyclical changes in the ovaries and uterus. Hormone levels during the menstrual cycle are regulated through negative feedback mechanisms, except for the mid cycle LH surge. The normal regulation of the cycle can be manipulated with artificial hormones for the purposes of contraception.

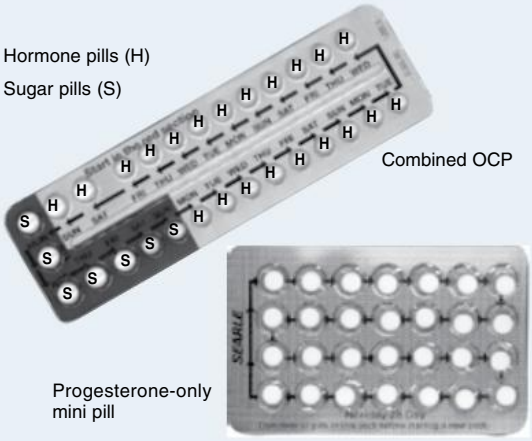
Control of the Menstrual Cycle



- **In the first half of the cycle**, FSH stimulates follicle development in the ovary. The developing follicle secretes oestrogen which acts on the uterus and, in the anterior pituitary, inhibits FSH secretion.
- **In the second half of the cycle**, LH induces ovulation and development of the corpus luteum. The corpus luteum secretes progesterone which acts on the uterus and also inhibits further secretion of LH (and also FSH).

Contraception

Contraception is used to prevent fertilisation of an egg by a sperm. Contraceptive methods include physical barriers (e.g. condoms) that prevent the egg and sperm meeting or chemical interference with the menstrual cycle to inhibit egg production. This is done through oral contraceptives or hormone implants.



Hormonal Contraception

The oral contraceptive pill (OCP) is a commonly used, reliable contraceptive method. Combined oral contraceptive pills exploit the feedback regulation of the menstrual cycle. They contain combinations of synthetic oestrogens and progesterone. They are taken daily for 21 days, and raise the levels of these hormones in the blood so that FSH secretion and the development of ova are inhibited. Sugar pills are taken for 7 days. This allows menstruation to occur but is not long enough to allow ova to develop.

A second type of contraception is a progesterone-only mini-pill. The pill works by thickening the cervical mucus and preventing endometrial thickening, but it does not prevent ovulation.

1. Describe the roles of FSH and LH in the control of the menstrual cycle: _____

2. How does **negative feedback** regulate the secretion of FSH and LH in the menstrual cycle? _____

3. How does the OCP prevent conception (fertilisation of an egg by a sperm)? _____

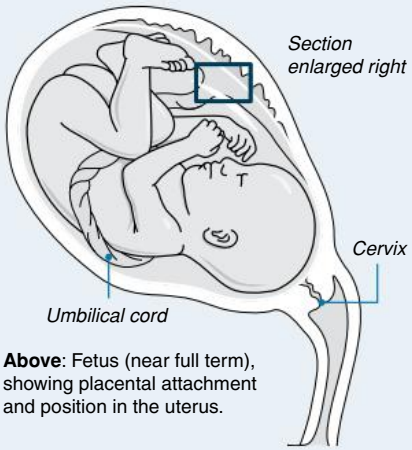
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158 The Placenta

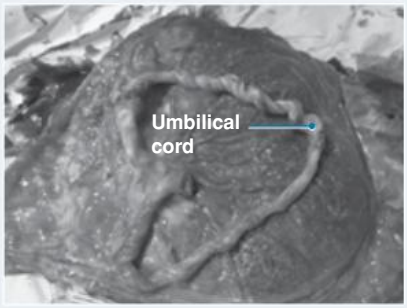
Key Idea: The placenta allows materials to be exchanged between the fetus and its mother. It also acts as a temporary endocrine organ, secreting hormones to maintain pregnancy.

The human fetus depends entirely on its mother for nutrients, oxygen, and the elimination of wastes. The **placenta** is the specialised organ that performs this role, enabling exchange between fetal and maternal tissues and allowing a prolonged period of fetal growth and development within the uterus. The placenta also has an endocrine role, producing progesterone and oestrogen to maintain the pregnancy.



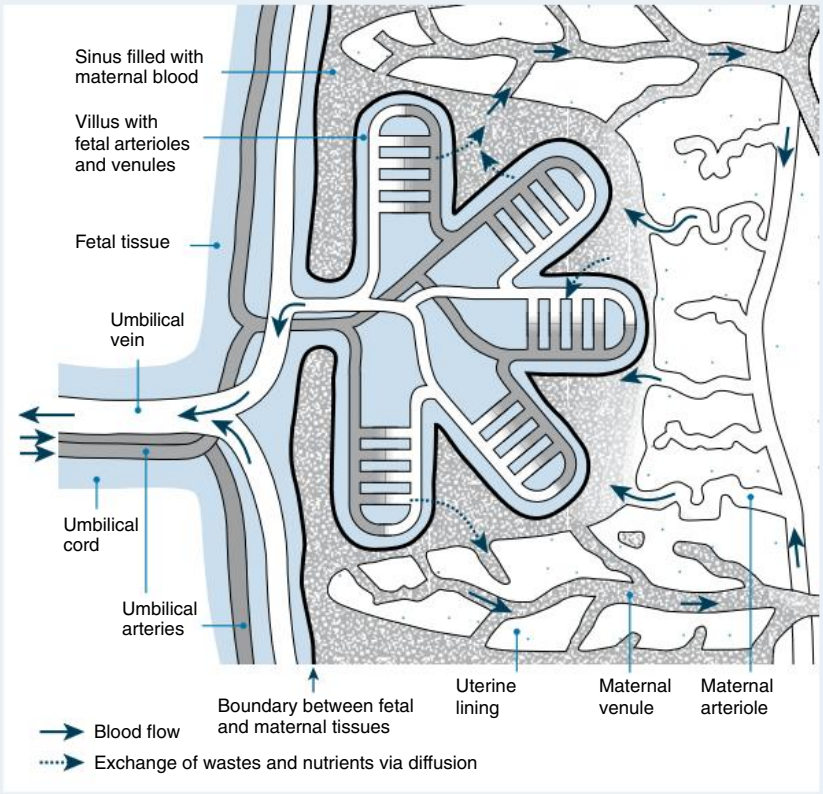
Above: Fetus (near full term), showing placental attachment and position in the uterus.

Below: Photograph of a human placenta, just after delivery.



Hadassah Ein Kerem Medical Center, cc3.0

Schematic diagram showing part of the placenta in section



The placenta is a disc-like organ, about the size of a dinner plate and weighing about 1 kg. It develops when finger-like projections (villi) from the fetal membranes grow into the uterine lining. The villi contain the capillaries connecting the fetal arteries and vein. They continue invading the maternal tissue until they are bathed in the maternal blood sinuses. The maternal and fetal blood vessels are in such close proximity that oxygen and nutrients can diffuse from the maternal blood into the capillaries of the villi. From the villi, the nutrients circulate in the umbilical vein, returning to the fetal heart. Carbon dioxide and other wastes leave the fetus through the umbilical arteries, pass into the capillaries of the villi, and diffuse into the maternal blood. The fetal and maternal blood do not mix. The exchanges occur via diffusion through capillaries.

1. Describe the structure of the human placenta and explain its function: _____

2. The umbilical cord contains the fetal arteries and vein. Describe the status of the blood in each type of fetal vessel:

   (a) Fetal arteries: Oxygenated and containing nutrients / Deoxygenated and containing nitrogenous wastes (delete one)

   (b) Fetal vein: Oxygenated and containing nutrients / Deoxygenated and containing nitrogenous wastes (delete one)

3. **Teratogens** are substances that may cause malformations in embryonic development (e.g. nicotine, alcohol):

   (a) Why do substances ingested by the mother have the potential to be harmful to the fetus?

   (b) Why is cigarette smoking so harmful to fetal development? _____

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159 Fertilisation and Early Growth

Key Idea: The union of a male and a female gamete to form a zygote is called fertilisation. It involves several distinct stages.

Fertilisation occurs when a sperm penetrates an egg cell at the secondary oocyte stage and the sperm and egg nuclei unite to form the zygote. In mammals, the entry of a sperm into the egg triggers specific mechanisms to prevent polyspermy (fertilisation of the egg by more than one sperm). These include a change in membrane potential, and the cortical reaction (see below). A zygote resulting from polyspermy contains too many chromosomes, and is not viable (does not develop). Fertilisation is seen as time 0 in a period of gestation (pregnancy) and has five stages (below). After fertilisation, the zygote begins its development, i.e. its growth and differentiation into a multicellular organism.

Fertilisation (Time 0)

The stages in fertilisation are represented below in a numbered sequence (1-5)

1. Capacitation

The surface of the sperm cell undergoes changes that are essential to enabling the acrosome reaction and sperm entry.

2. The Acrosome Reaction

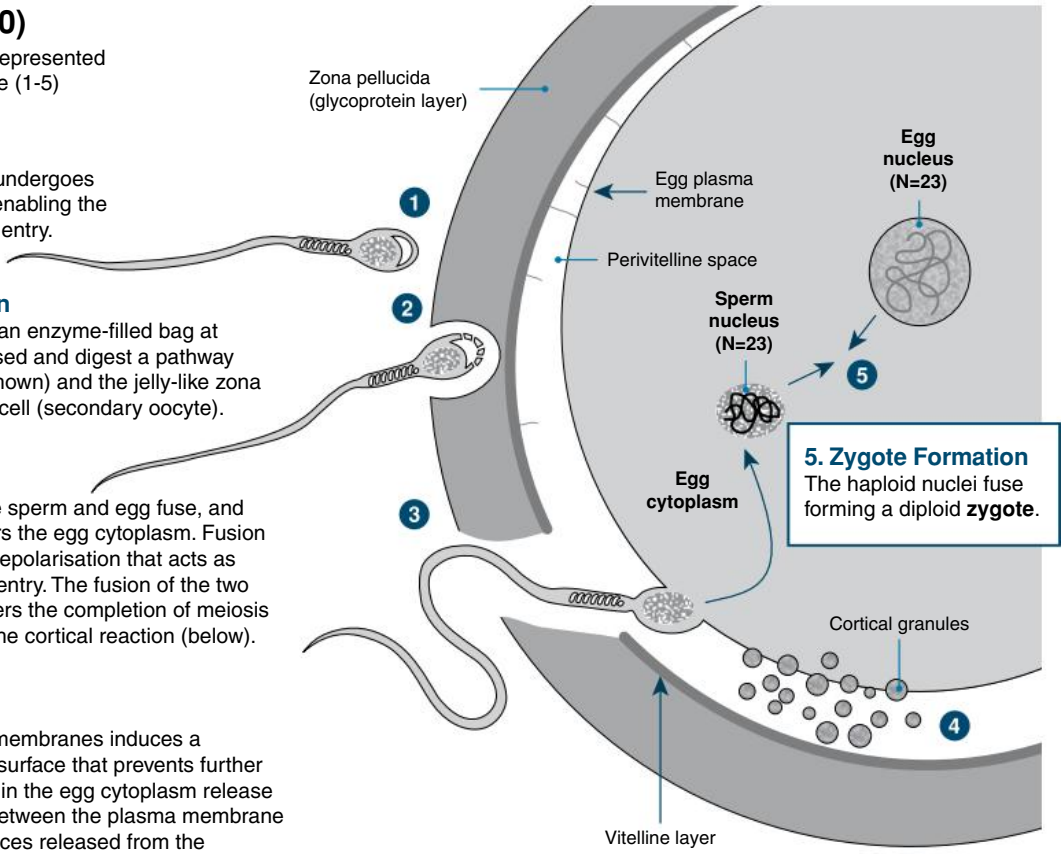
Enzymes from the acrosome (an enzyme-filled bag at the tip of the sperm) are released and digest a pathway through the follicle cells (not shown) and the jelly-like zona pellucida surrounding the egg cell (secondary oocyte).

3. Fusion of Sperm Head

The plasma membranes of the sperm and egg fuse, and the nucleus of the sperm enters the egg cytoplasm. Fusion causes a sudden membrane depolarisation that acts as a "fast block" to further sperm entry. The fusion of the two plasma membranes also triggers the completion of meiosis II in the egg cell and induces the cortical reaction (below).

4. The Cortical Reaction

The fusion of the two plasma membranes induces a permanent change in the egg surface that prevents further sperm entry. Cortical granules in the egg cytoplasm release their contents into the space between the plasma membrane and the vitelline layer. Substances released from the granules raise and harden the vitelline layer to form a slow (permanent) block to further sperm entry.



1. Briefly describe the significant events (and their importance) occurring at each of the following stages of fertilisation:

   (a) Capacitation: _____

   _____

   (b) The acrosome reaction: _____

   _____

   (c) Fusion of egg and sperm plasma membranes: _____

   _____

   (d) The cortical reaction: _____

   _____

   (e) Fusion of egg and sperm nuclei: _____

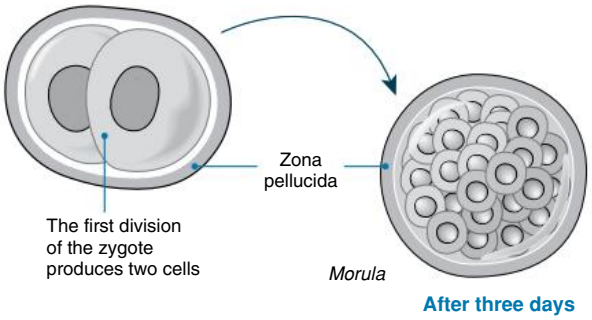
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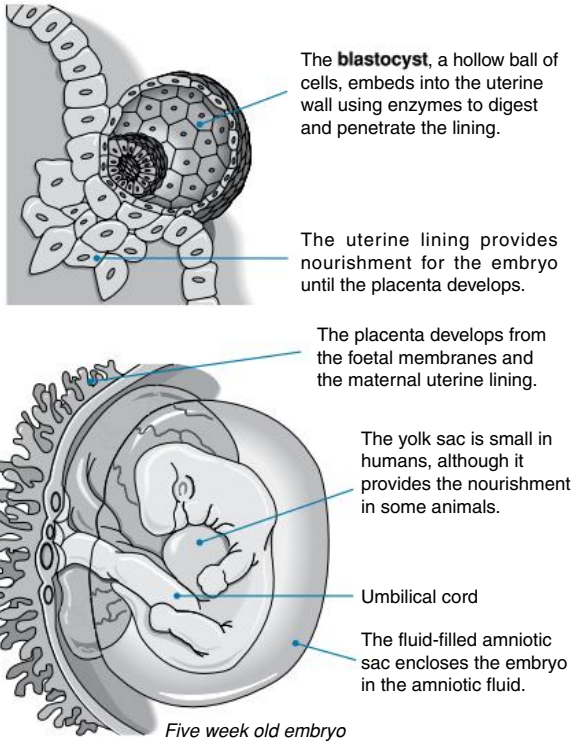
2. Why is it important that fertilisation of the egg by more than one sperm (polyspermy) does not occur? _____

   _____

   _____

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Early Growth and Development

Cleavage and the development of the morula

Immediately after fertilisation, rapid cell division takes place. These early cell divisions are called **cleavage** and they increase the number of cells, but not the size of the zygote. The first cleavage is completed after 36 hours, and each succeeding division takes less time. After 3 days, successive cleavages have produced a solid mass of cells called the **morula**, (left) which is still about the same size as the original zygote.

Implantation of the blastocyst (after 6-8 days)

After several days in the uterus, the morula develops into the blastocyst. It makes contact with the uterine lining and pushes deeply into it, ensuring a close maternal-fetal contact. Blood vessels provide early nourishment as they are opened up by enzymes secreted by the blastocyst. The embryo produces **HCG** (human chorionic gonadotropin), which prevents degeneration of the corpus luteum and signals that the woman is pregnant.

The embryo at 5-8 weeks

Five weeks after fertilisation, the embryo is only 4-5 mm long, but already the central nervous system has developed and the heart is beating. The embryonic membranes have formed; the amnion encloses the embryo in a fluid-filled space, and the allanto-chorion forms the fetal portion of the placenta. From two months the embryo is called a fetus. It is still small (30-40 mm long), but the limbs are well formed and the bones are beginning to harden. The face has a flat, rather featureless appearance with the eyes far apart. Fetal movements have begun and brain development proceeds rapidly. The placenta is well developed, although not fully functional until 12 weeks. The umbilical cord, containing the fetal umbilical arteries and vein, connects fetus and mother.

3. (a) Explain why the egg cell, when released from the ovary, is termed a secondary oocyte: _____

_____

(b) At which stage is its meiotic division completed? _____

4. What contribution do the sperm and egg cell make to each of the following:

(a) The nucleus of the zygote? Sperm contribution: _____ Egg contribution: _____

(b) The cytoplasm of the zygote? Sperm contribution: _____ Egg contribution: _____

5. What is meant by cleavage? Explain its significance to the early development of the embryo: _____

_____

_____

6. (a) What is the importance of implantation to the early nourishment of the embryo? _____

_____

(b) What is the purpose of HCG production by the embryo? _____

_____

_____

7. Why is the fetus particularly prone to damage from drugs towards the end of the first trimester (2-3 months):

_____

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160 The Hormones of Pregnancy

Key Idea: Hormones secreted during pregnancy maintain the pregnancy and prepare the body for birth.

In a non-pregnant adult human female, the levels of oestrogen and progesterone regulate the secretion of the pituitary hormones that control the ovarian cycle. Pregnancy interrupts this cycle and maintains the corpus luteum and the placenta as endocrine organs with the specific role of maintaining the developing fetus during its development. During the last month of pregnancy the hormone oxytocin induces the uterine contractions that will expel the baby from the uterus.

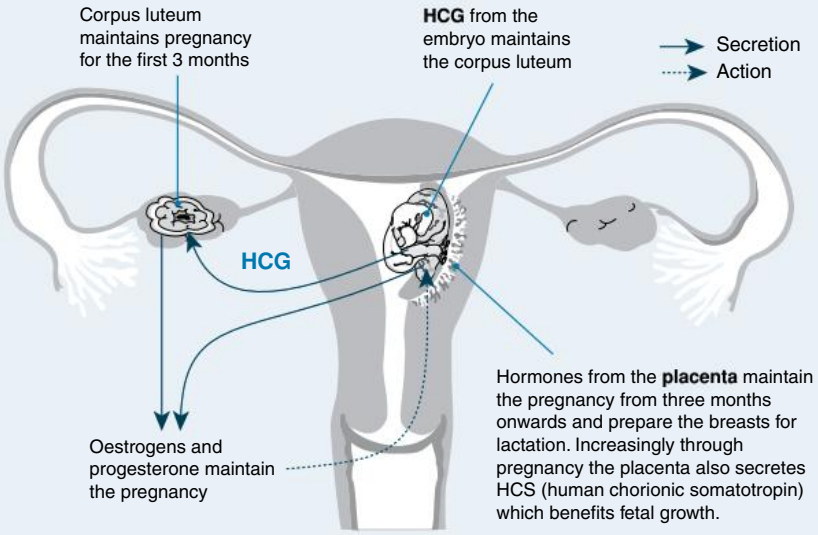
HCG (Human chorionic gonadotropin)
- Secreted by the developing embryo
- Maintains corpus luteum

Progesterone
- Maintains endometrium
- Inhibits uterine contraction

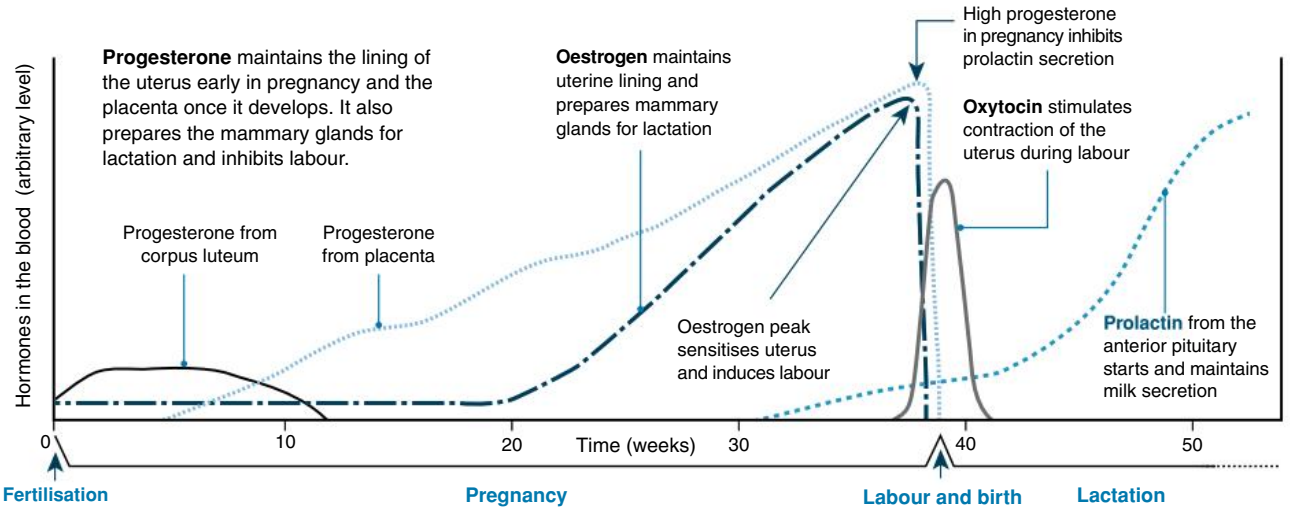
Oestrogens
- Maintain endometrium
- Prepare mammary glands for lactation
- High levels induce labour

Human placental lactogen (HPL)
- Stimulates breast growth and development

Relaxin
- Produced by the placenta towards the end of the pregnancy
- Relaxes pubic symphysis at birth
- Helps dilate cervix at birth



Hormonal Changes During Pregnancy, Birth, and Lactation



During the first 12-16 weeks pregnancy, the **corpus luteum** secretes enough progesterone to maintain the uterine lining and sustain the developing embryo. After this, the placenta takes over as the primary endocrine organ of pregnancy. **Progesterone** and **oestrogen** from the placenta maintain the uterine lining, stop further ova (eggs) developing, and prepare the breast tissue for **lactation** (milk production). At the end of pregnancy, the placenta begins to break down and progesterone levels fall. The uterus becomes sensitive to the high oestrogen levels, triggering labour to start. The oestrogen peak coincides with an increase in **oxytocin**, which stimulates uterine contractions in a positive feedback loop: the contractions and the increasing pressure on the cervix from the infant stimulates release of more oxytocin, and more contractions until the infant exits the birth canal. After birth, the secretion of **prolactin** increases. Prolactin maintains lactation during the period of infant nursing.

1. (a) Why is the corpus luteum the main source of progesterone in early pregnancy? _____

_____

(b) What hormones are responsible for maintaining pregnancy? _____

2. (a) Name two hormones involved in labour (onset of the birth process): _____

(b) Describe two physiological factors in initiating labour: _____

_____

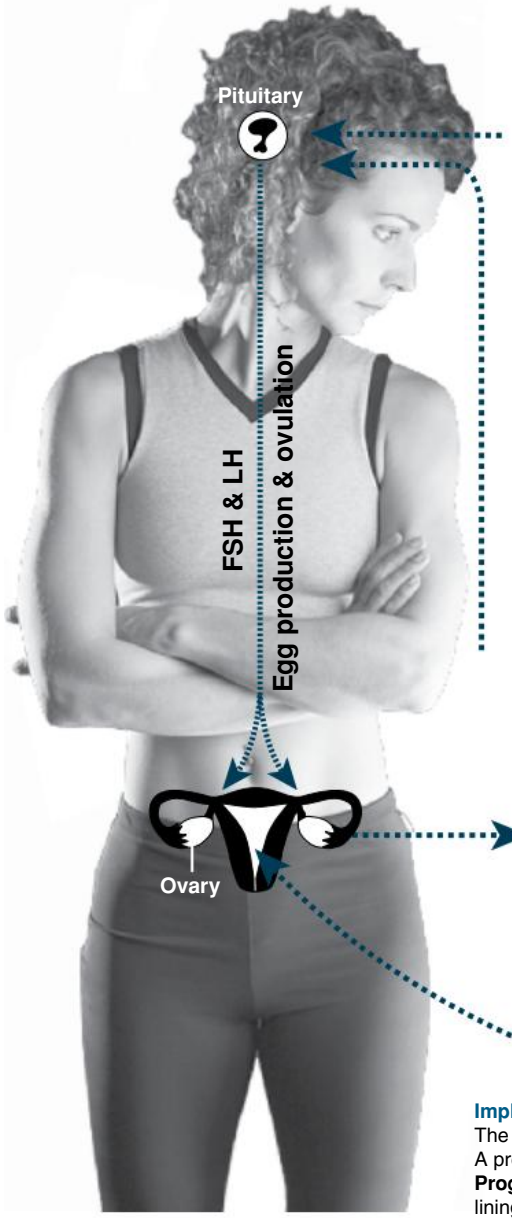
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161 Using Hormones to Treat Infertility

Key Idea: *In vitro* fertilisation involves fertilising eggs with sperm in the laboratory and placing them in into the woman's uterus to develop. The process uses fertility hormones.

***In vitro* fertilisation** (IVF) can be used to treat some infertility problems. During IVF, eggs are removed from the ovaries and fertilised with sperm in a laboratory. The fertilised egg is implanted into the mother's uterus for development. Most treatments for female infertility involve the use of synthetic female hormones, which stimulate ovulation, boost egg production, and induce egg release.



Suppression Phase

At the start of an IVF phase, suppression drugs are taken to prevent ovulation. Suppression drugs stop hormones from the pituitary sending ovulation messages to the ovaries, and prevents eggs from being released too soon. Coordinating egg release increases the chances of a successful IVF treatment.

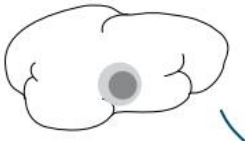


Ovarian Stimulation Phase

Daily injections of **luteinising hormone** (LH) and **follicle stimulating hormone** (FSH) are given for about 10 to 14 days. These stimulate the ovaries to produce more eggs than usual, increasing the chances of IVF being successful.

An injection of human chorionic gonadotropin (hCG) is given to trigger final maturation of the eggs.



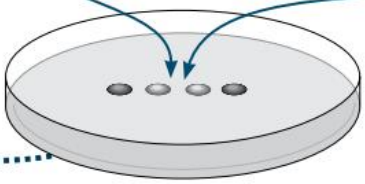


Several eggs are removed from the ovary using a needle.

IVF

The harvested eggs are fertilised in the laboratory by mixing them with sperm. They are incubated in a culture medium until blastocysts (a five day embryo) are formed.





Implantation

The blastocyst(s) is then implanted in the uterus. A pregnancy results if implantation is successful. **Progesterone** is sometimes given to support the uterine lining and maintain an early pregnancy.

1. Briefly outline the IVF process: _____

_____

_____

2. Describe the role of the following hormones in IVF treatment:

   (a) **LH**: _____

   (b) **FSH**: _____

   (c) **hCG**: _____

   (d) **Progesterone**: _____

3. Why is it important that ovulation is suppressed at the beginning of the IVF process? _____

_____

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LINK 160 LINK 157 KNOW

162 Birth and Lactation

Key Idea: Birth and lactation are both controlled by hormones and involve positive feedback.

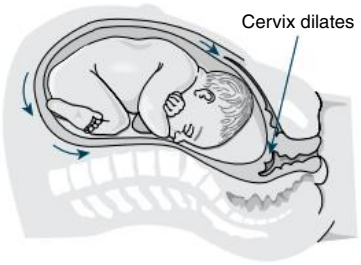
A human pregnancy lasts about 38 weeks after fertilisation. It ends in labour, the birth of the baby, and expulsion of the placenta. During pregnancy, progesterone maintains the placenta and inhibits contraction of the uterus. At the end of a pregnancy, increasing oestrogen induces labour. Prostaglandins, an ageing placenta, and the state of fetus itself also play a role. At the same time, the hormone oxytocin stimulates the contractions of the uterus that will expel the baby. After birth, the mother provides nutrition for the infant through lactation (milk production). Breast milk nourishes infants for the first 4-6 months of life. It also contains maternal antibodies, which protect the infant against infection.

Birth and the Stages of Labour

Stage 1: Dilation

Duration: 2-20 hours

The time between the onset of labour and complete opening (dilation) of the cervix. The amniotic sac may rupture at this stage, releasing its fluid. The hormone **oxytocin** stimulates the uterine contractions necessary to dilate the cervix and expel the baby. It is these uterine contractions that give the pain of labour, most of which is associated with this first stage. Oxytocin release is under positive feedback regulation until the baby is born and pressure on the cervix stops.

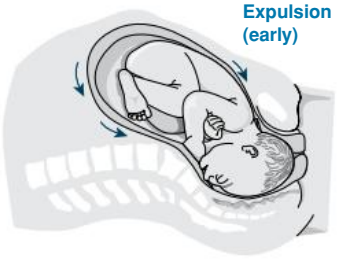


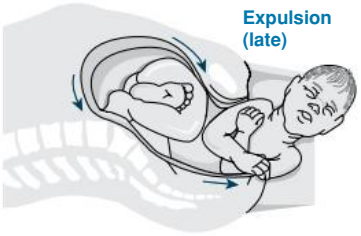
Stage 2: Expulsion

Duration: 2-100 minutes

The time from full dilation of the cervix to delivery. Strong, rhythmic contractions of the uterus pass in waves (arrows), and push the baby to the end of the vagina, where the head appears.

As labour progresses, the time between each contraction shortens. Once the head is delivered, the rest of the body usually follows very rapidly. Delivery completes stage 2.

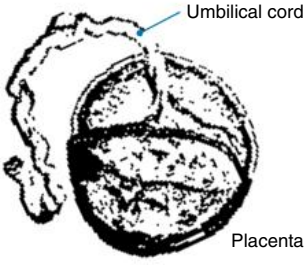




Stage 3: Delivery of placenta

Time: 5-45 minutes after delivery

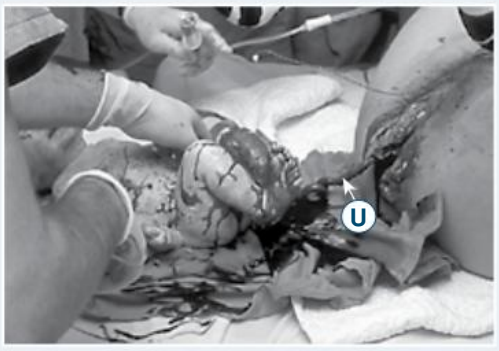
The third or **placental stage**, refers to the expulsion of the placenta from the uterus. After the placenta is delivered, the placental blood vessels constrict to stop bleeding.



Delivery of the baby: the end of stage 2



Delivery of the head. This baby is face forward. The more usual position for delivery is face to the back of the mother.



Full delivery of the baby. Note the umbilical cord (U), which supplies oxygen until the baby's breathing begins.



Post-birth check of the baby. The baby is still attached to the placenta and the airways are being cleared of mucus.

1. Name the three stages of birth, and briefly state the main events occurring in each stage:

   (a) Stage 1: _____

   (b) Stage 2: _____

   (c) Stage 3: _____

2. (a) Which hormone is responsible for triggering the onset of labour? _____

   (b) What two other factors might influence the timing of labour onset? _____

   _____

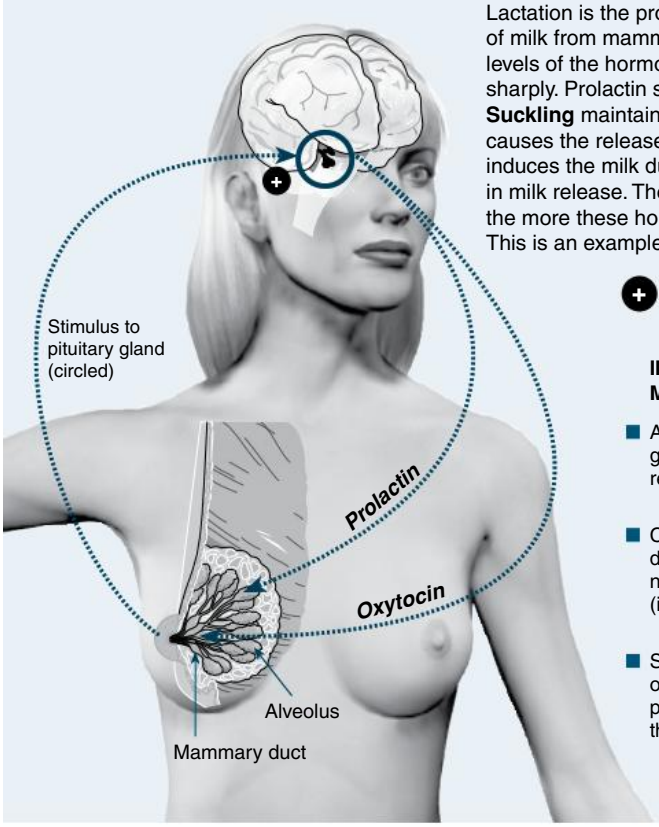
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KNOW LINK 152 LINK 160

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Lactation and its Control

Lactation is the production and release of milk from mammary glands. After birth, levels of the hormone **prolactin** increase sharply. Prolactin stimulates milk production. **Suckling** maintains prolactin secretion and causes the release of **oxytocin**. Oxytocin induces the milk ducts to contract, resulting in milk release. The more an infant suckles, the more these hormones are produced. This is an example of positive feedback.



+ Symbol indicating stimulation

IN THE LACTATING MAMMARY GLAND:

- Alveoli of the mammary gland produce milk in response to prolactin.
- Contraction of the mammary ducts ejects milk to the nipple in a reflex letdown (induced by oxytocin).
- Suckling stimulates secretion of prolactin from the antior pituitary and oxytocin from the posterior pituitary.



It is essential to establish breast feeding soon after birth, as this is when infants exhibit the strong reflexes that enable them to learn to suckle effectively. The first formed milk, colostrum, has very little sugar, virtually no fat, and is rich in maternal antibodies. Breast milk that is produced later has a higher fat content, and its composition varies as the nutritional needs of the infant change during growth.

3. Why does the umbilical cord continue to supply blood to the baby for a short time after delivery? _____

_____

4. For each of the following processes, state the primary controlling hormone and its site of production:

   (a) Uterine contraction during labour: Hormone: _____ Site of production: _____

   (b) Production of milk: Hormone: _____ Site of production: _____

   (c) Milk ejection in response to suckling: Hormone: _____ Site of production: _____

5. Which hormone inhibits prolactin secretion during pregnancy? _____

6. Describe two benefits of breast feeding to the health of the infant:

   (a) _____

   (b) _____

7. (a) Describe the nutritional differences between the first formed milk (colostrum) and the milk that is produced later:

   _____

   _____

   (b) Suggest a reason for these differences: _____

   _____

8. Why would the nutritional composition of breast milk change during the lactation period from birth to six months?

   _____

9. Infants exhibit marked growth spurts at six weeks and three months of age. At these times, their energy intake requirements also increase sharply. With reference to what you know about the control of lactation, how could a breast-feeding mother continue to provide for the increased energy requirements of her infant?

   _____

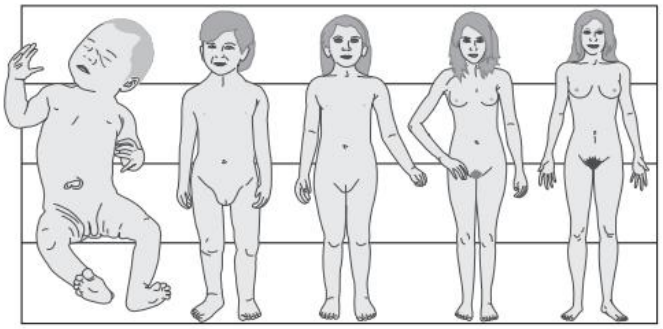
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163 Growth and Development

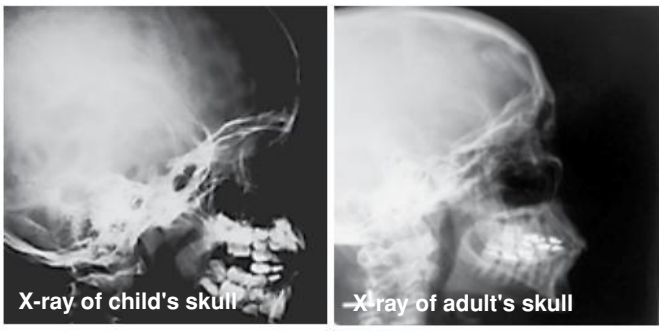
Key Idea: Development describes the process of growing to maturity, from zygote to adult.

Development is marked by stages recognised by the physical and cognitive skills present. Physical changes include the elongation of the bones, ossification of cartilage, and changes to the proportions of the body. These changes are the result of allometric growth (differential growth rates) and occur with motor, intellectual, and emotional and social development.



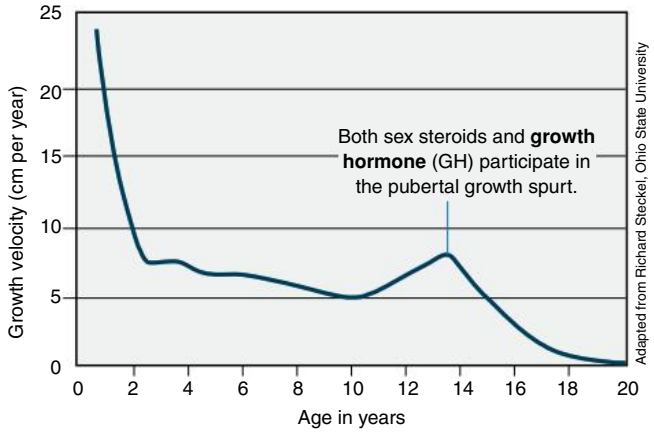
Newborn 2 years 5 years 15 years Adult

At birth the cranium is very large in comparison to the face and the skull makes up around one quarter of the infant's height. During early life, the face continues to grow outward, reducing the relative proportions of the cranium, while at adulthood the size of the skull in proportion to the body is much less.





By six weeks old, a human baby is usually able to hold its head up if placed on its stomach. At three months the infant will exercise limbs aimlessly but by five months is able to grasp objects and sit up. The infant may be able to crawl by eight months and walk by 12 months. It is more or less independent by two years and undergoes changes to adulthood at around 11 years of age (puberty).



Babies are effectively born premature so that they complete much of their early development in the first two to three years of life. The rate of growth declines slowly through childhood, but increases again to a peak in puberty (the growth spurt). By 20 years of age the cartilage in the long bones has been replaced by bone and growth stops.

1. What is the most noticeable change in body proportion from birth to adulthood? _____

2. What changes occur in the first period of rapid growth in humans? _____

3. What changes occur in the second period of rapid growth in humans? _____

4. Answer the following questions with respect to the graph depicting growth rates 0-20 years (above, right):

   (a) What happens to growth velocity in the first two years of an infant's life? _____

   (b) What does the graph infer about the rate of growth in the period before birth? _____

   (c) What age range (in years) marks the pubertal growth spurt? _____

5. Relate the changes in physical development to the changes occurring in the mental development of an infant:

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164 Sexual Development

Key Idea: Sex hormones are responsible for the development and maintenance of male and female characteristics.

Sex hormones determine gender in humans. Testosterone (in males), and oestrogen and progesterone (in females), are responsible for puberty (the onset of sexual maturity), the maintenance of gender differences, and gamete production. In females, oestrogen and progesterone regulate the menstrual cycle, and maintain pregnancy and lactation.

Before Birth

In early embryos, there is no structural difference between males and females.

The Y chromosome carries a gene for the **H-Y antigen**, which induces the gonad to become a testis. The developing testes produce **testosterone**, which induces the further development of male primary sexual characteristics (penis and testes).

Sex chromosomes XY



Sex chromosomes XX

Without the **H-Y antigen** the gonad becomes an ovary. The absence of testosterone induces further development of female primary sexual characteristics (ovaries and uterus). Primary oocytes (egg cells) enter their first meiotic division in the third month of embryonic development.

Puberty

The onset of puberty (11-13 years) is controlled by hormones.

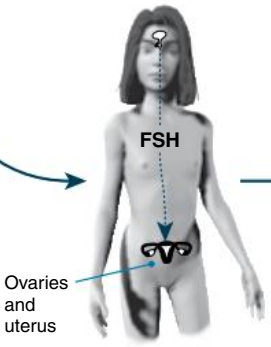


ICSH (interstitial cell stimulating hormone) stimulates the testis cells to secrete **testosterone**

*Note: *ICSH is called LH in females*

Testosterone causes the penis, testes, and scrotum to enlarge and mature and causes the development of male secondary sexual characteristics.

Testosterone

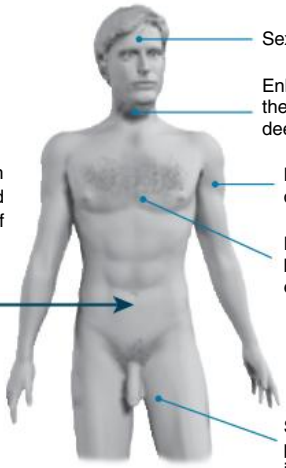


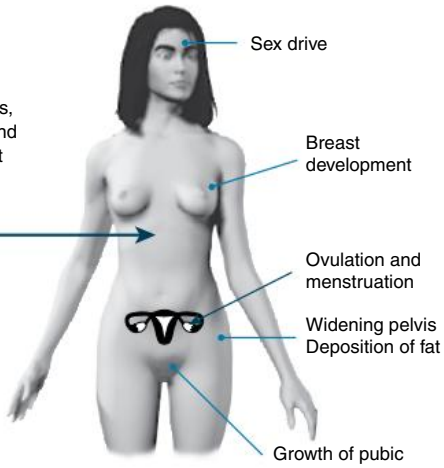
FSH (follicle stimulating hormone) stimulates the ovaries to produce **oestrogen**

Oestrogen causes the ovaries, oviducts, uterus, and vagina to mature and stimulates development of female secondary sexual characteristics.

Oestrogen

Adult





1. Distinguish between primary and secondary sexual characteristics: _____

_____

2. Which hormone is responsible for determining sex (gender) in the fetus? _____

3. Describe the effects on a normal female if she were to take male hormones to enhance muscle development for sport:

_____

4. (a) What is the role of the extra fat deposits laid down by girls at puberty? _____

_____

(b) Describe a potential reproductive side effect of starvation or severe dieting for women of child-bearing age:

_____

5. A second hormone, progesterone, is important in regulating female reproduction after puberty:

(a) Where is this hormone produced? _____

(b) What are its major roles? _____

_____

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165 Ageing

Key Idea: Ageing refers to the degenerative changes that occur as a result of cells dying and cell renewal rates slowing. Once we have reached physical maturity, we begin to age. **Ageing** (or senescence) refers to the degenerative changes that occur as a result of cells dying and renewal rates slowing or stopping. It is a general response, producing observable changes in structure and physiology. There is a decline in skeletal and muscular strength, and reduced immune function. Ageing increases susceptibility to stress and disease, so disease and ageing often accelerate together.



Older skin is thinner, more easily damaged, and slower to repair. Skin loses elasticity which leads to the more obvious signs of ageing, sagging and wrinkling.

Low oestrogen levels in post-menopausal women increase the risk of cardiovascular disease (CVD) dramatically. At age 70 and beyond, men and women are equally at risk.

Reduction in glandular activity and blood flow to the skin contribute to skin ageing. Skin discolouration (age or liver spots) is more common in older people, especially on areas exposed to the sun, such as the hands, face and neck.

In **menopause**, the ovaries stop responding to FSH and LH from the anterior pituitary. Ovarian production of oestrogen and progesterone slows and stops, and the menstrual cycle becomes at first irregular and then stops altogether. At this point, a woman is no longer fertile.

Declining oestrogen levels also accelerate bone loss, resulting in **osteoporosis**, hunching of the spine, and increased risk of fractures.

Weight bearing joints such as those in the knee, foot, hips, and spine are particularly susceptible to the degenerative disease **osteoarthritis**.

Declining levels of circulating testosterone affects sex drive in both men and women. Declining testosterone is also associated with age-related thinning and loss of hair.

Several cell types, including skeletal muscle, cardiac muscle, and neurones cannot be replaced.

Metabolic rate decreases with age and digestive and kidney function decline.

Ageing is associated with an increase in the number of aberrant cells and an increased incidence of cancers as cellular damage accumulates. Tumours of the reproductive organs are more common in old age.

1. Explain the cause of ageing, relating the physiological changes to the observable effects:_____

_____

_____

2. The figure right shows the decline in skeletal muscle fibres with age:

   (a) At what age is number of muscle fibres at a maximum?_____

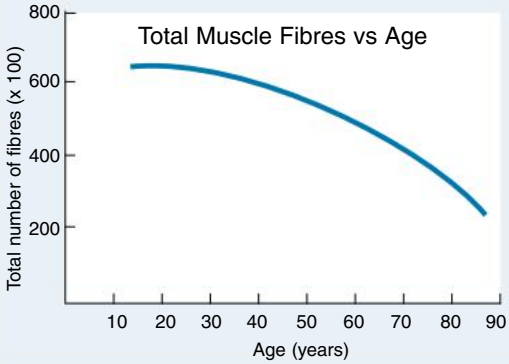
   (b) At what age have half the muscle fibres been lost? _____

   (c) Can these muscle fibres be replaced? _____

3. Ageing has a number of effects on the body as a whole, but what is the main effect of ageing on human reproductive capability?

_____

_____



LINK
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166 KEY TERMS: Mix and Match

Test your vocabulary by matching each term to its definition, as identified by its preceding letter code.

alternation of generations

asexual reproduction

contraception

copulation

embryo

external fertilisation

fertilisation

gamete

gametogenesis

gametophyte

germination

lactation

meiosis

menstrual cycle

oviparity

ovovivipary

ovulation

ovum

parthenogenesis

placenta

pollination

pregnancy

puberty

seed

sperm

sporophyte

testosterone

vivipary

zygote

A The production and secretion of milk from the mammary glands.

B The principal male sex hormone.

C A mode of reproduction in which embryos develop inside eggs that are retained within the mother's body until they are ready to hatch.

D Fertilisation occurring outside the body of the animal.

E A haploid reproductive cell.

F The reproductive strategy of giving birth to live young.

G The initial cell formed from the union of two gametes when a new organism is produced by means of sexual reproduction.

H A form of asexual reproduction in females, where growth and development of embryos occurs without fertilisation by a male.

I The cycle of changes in reproductive physiology occurring in fertile female humans.

J A reduction division involved in the production of gametes.

K An organ, characteristic of most mammals, that enables exchanges (via the blood supply) of nutrient, gases, and wastes, between mother and fetus.

L The act of transferring sperm from the male to inside the female's genital tract.

M The state of carrying offspring (a fetus), inside the uterus of a female.

N The fusion of sperm and egg. Also called conception.

O The alternation of sporophyte and gametophyte phases in plant life cycles.

P The process by which gametes are produced.

Q The process in a female's menstrual cycle by which a mature ovarian follicle ruptures and releases an ovum.

R A reproductive unit containing the embryonic plant that forms from the ovule after fertilisation.

S The transfer of pollen from the male anther to the female stigma.

T The reproductive strategy of egg laying, with little or no other embryonic development within the mother.

U The male gamete.

V The phase of the plant life cycle in which the cells are diploid.

W The growth in a seed immediately following a period of dormancy.

X An egg cell or female gamete.

Y The earliest stage of development, until about 8 weeks post-fertilisation in humans.

Z The period of physical changes during which a child's body becomes a reproductively capable adult body.

AA The haploid phase of the plant life cycle. It is the dominant phase in lower plants.

BB Reproduction that does not involve meiosis or fertilisation.

CC The use of methods or devices that prevent conception.

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167 Functioning Organisms Synoptic Question

1. Different animals have evolved different adaptations for obtaining and processing food to extract nutrients. Compare and contrast the digestive systems of a mammalian carnivore, omnivore, and herbivore. In your discussion, explain how each system is adapted to processing the particular diet involved. You may use extra paper if required.

2. All plants have adaptations to enable successful reproduction. Discuss how the reproductive strategies of angiosperms and gymnosperms ensure pollination and fertilisation. Your discussion should include details of pollination mechanisms, fertilisation of the egg cell by the sperm, and development of the seed embryo. You may use extra paper if required.

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QLD As required
VCE Unit 1 (2)
WA ATAR Unit 1
SA N/A

Classification

Key terms

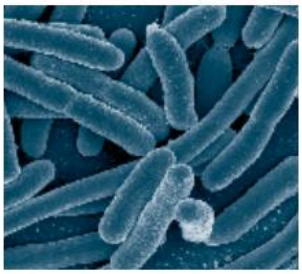
Angiospermophyta
Animalia
Annelida
Archaea
Arthropoda
Bacteria
binomial nomenclature
Bryophyta
class
Cnidaria
common name
Coniferophyta
dichotomous keys
distinguishing feature
Echinodermata
family
Filicinophyta
Fungi
genus
kingdom
Linnaeus
Mollusca
order
phylum
Plantae
Platyhelminthes
Porifera
species
taxa
taxonomic category
taxonomy
Tracheophyta
Vertebrata

Classification of life

Learning aims and skills

Activity number

☐	1	Compare and contrast current systems for the classification of life, including those based on phylogenetic relationships determined in more recent times: • the six kingdom system, which recognises Archaea, Bacteria, Protista, Fungi, Plantae, and Animalia. • the three domain system, which recognises Archaea (=Archaeabacteria), Bacteria (=Eubacteria), and Eukarya.	168
☐	2	Understand what is meant by a distinguishing feature. Describe the distinguishing features of each kingdom in the five kingdom classification system.	169 170 172 173
☐	3	Describe the principles and importance of biological classification. Recognise taxonomy as the study of the theory and practise of classification.	171
☐	4	Distinguish taxonomic categories from taxa, which are groups of organisms, e.g. 'genus' is a taxonomic category, whereas the genus *Drosophila* is a taxon. Recognise seven major taxonomic categories in the five or six kingdom classification system: kingdom, phylum, class, order, family, genus, and species. Demonstrate your understanding by classifying an example from two kingdoms.	171
☐	5	Explain how binomial nomenclature is used to classify organisms. Identify the problems associated with using common names to describe organisms.	171
☐	6	Recognise two main Divisions of the Plantae: Bryophyta and Tracheophyta. Using simple external distinguishing features, distinguish between the following plant phyla: Bryophyta, Filicinophyta, Coniferophyta, and Angiospermophyta.	169 173
☐	7	Using simple external distinguishing features, distinguish between the following invertebrate phyla: Porifera (sponges), Cnidaria, Platyhelminthes (flatworms), Annelida, Mollusca, Echinodermata, and Arthropoda.	169 174
☐	8	Using simple external distinguishing features, distinguish between the classes of vertebrates: Chondrichthyes, Osteichthyes, Amphibia, Reptilia, Aves, Mammalia.	169 174
☐	9	Explain the principles by which dichotomous keys are used to identify organisms.	175
☐	10	Use simple dichotomous keys to recognise and classify some common organisms (e.g. insects and plants).	175 176





Biodiversity

Learning aims and skills

Activity number

☐	11	Define biodiversity and explain the importance of classification in recognising, appreciating, and conserving the biodiversity on Earth.	276
☐	12	Identify Australia as one of the world's regions of high biodiversity. Describe the importance of these regions to global ecology.	177 276



168 The New Tree of Life

Key Idea: The classification of life into specific groups, or taxa, is constantly being updated in light of new information.

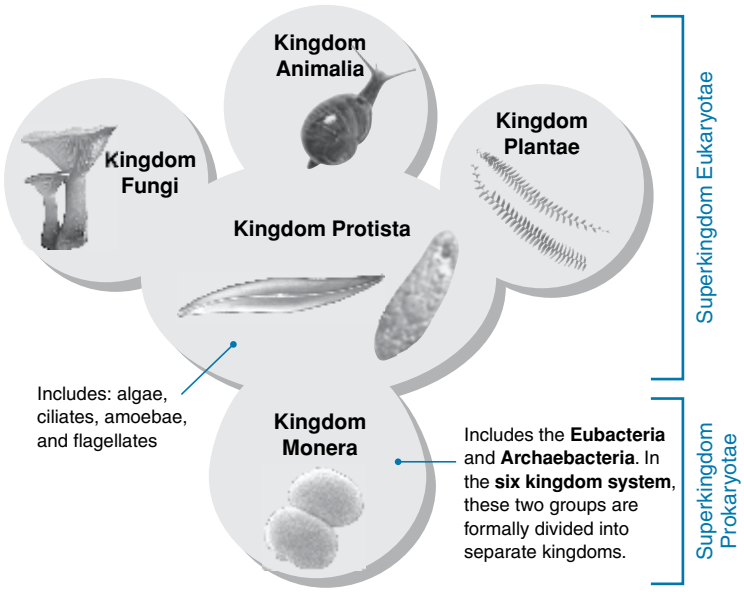
Taxonomy is the science of classification. The examination of DNA evidence confirmed that life comprises three major evolutionary lineages (domains) and not two as was previously thought. The lineages are the **Bacteria** (formerly Eubacteria), the **Eukarya** (Eukaryotes), and the **Archaea** (formerly Archaebacteria). The new classification reflects the very large differences between the archaeans and the bacteria. All three domains probably had a distant common ancestor.

A Five (or Six) Kingdom World (right)

The diagram (right) represents the **five kingdom system** of classification commonly represented in many biology texts. It recognises two basic cell types: prokaryote and eukaryote. Superkingdom Prokaryotae includes all bacteria and cyanobacteria (the Kingdom Monera). Superkingdom Eukaryotae includes protists, fungi, plants, and animals. More recently, based on 16S ribosomal RNA sequence comparisons, Carl Woese divided the prokaryotes into two kingdoms, the Eubacteria and Archaebacteria. Such **six-kingdom systems** are also commonly recognised in texts.

A New View of the World (below)

In 1996, scientists deciphered the full DNA sequence of an unusual bacterium called *Methanococcus jannaschii*. An **extremophile**, this methane-producing archaebacterium lives at 85°C; a temperature lethal for most bacteria as well as eukaryotes. The DNA sequence confirmed that life consists of three major evolutionary lineages, not the two that have been routinely described. Only 44% of this archaebacterium's genes resemble those in bacteria or eukaryotes, or both.



Domain Bacteria

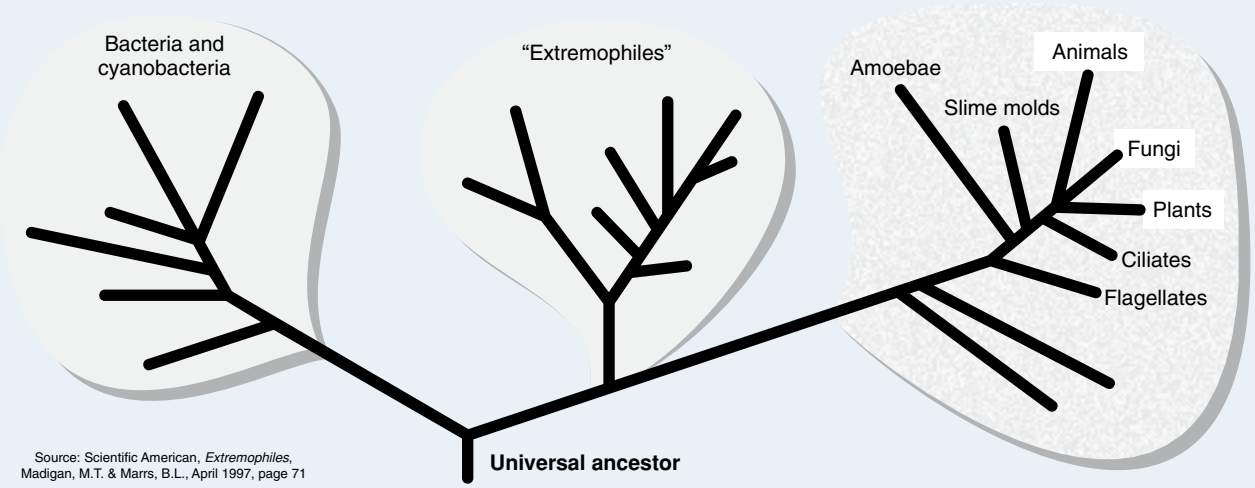
Lack a distinct nucleus and cell organelles. Generally prefer less extreme environments than Archaea. Includes well-known pathogens, many harmless and beneficial species, and the cyanobacteria (photosynthetic bacteria containing the pigments chlorophyll a and phycocyanin).

Domain Archaea

Closely resemble eubacteria in many ways but cell wall composition and aspects of metabolism are very different. Live in extreme environments similar to those on primeval Earth. They may utilise sulfur, methane, or halogens (chlorine, fluorine), and many tolerate extremes of temperature, salinity, or pH.

Domain Eukarya

Complex cell structure with organelles and nucleus. This group contains four of the kingdoms classified under the more traditional system. Note that Kingdom Protista is separated into distinct groups: e.g. amoebae, ciliates, flagellates.



Source: Scientific American, *Extremophiles*, Madigan, M.T. & Marrs, B.L., April 1997, page 71

1. Describe one feature of the three domain system that is very different from the five kingdom classification:

_____

_____

2. How are the three domain system and the six kingdom classification alike? _____

_____

3. Explain the rationale for revising traditional classification schemes and recognising a three domain scheme:

_____

_____

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169 Features of Taxonomic Groups

Key Idea: Taxonomy is the branch of science concerned with identifying, describing, classifying, and naming organisms.

Taxonomy is the science of classifying organisms. It relies on identifying and describing characteristics that clearly distinguish organisms from each other. Classification systems recognising three domains (rather than five or six kingdoms) are now seen as better representations of the true diversity of life. However, for the purposes of describing the groups with which we are most familiar, the five kingdom system (used here) is still appropriate. The distinguishing features of some major **taxa** are provided in the following pages. The examples provided give an indication of the diversity within each taxon.

SUPERKINGDOM: PROKARYOTAE (Bacteria)

- Also known as prokaryotes. The term moneran is no longer in use.
- Two major bacterial lineages are recognised: the **Archaebacteria** (Archaea) and the more derived **Eubacteria** (Bacteria).
- All have a prokaryotic cell structure: they lack the nuclei and chromosomes of eukaryotic cells, and have smaller (70S) ribosomes.
- Have a tendency to spread genetic elements across species barriers by conjugation, viral transduction, and other processes.
- Asexual. Can reproduce rapidly by binary fission.
- Have evolved a wider variety of metabolism types than eukaryotes.
- Bacteria grow and divide or aggregate into filaments or colonies of various shapes. Colony type is often diagnostic.
- They are taxonomically identified by their appearance (form) and through biochemical differences.

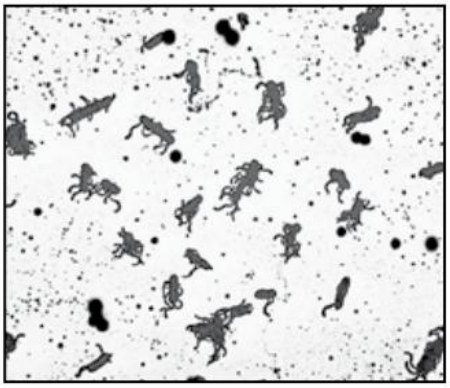
Species diversity: 10,000+ Bacteria are rather difficult to classify to species level because of their relatively rampant genetic exchange, and because their reproduction is asexual.

Eubacteria

- Also known as 'true bacteria', they probably evolved from the more ancient Archaebacteria.
- Distinguished from Archaebacteria by differences in cell wall composition, nucleotide structure, and ribosome shape.
- Diverse group includes most bacteria.
- The **gram stain** is the basis for distinguishing two broad groups of bacteria. It relies on the presence of peptidoglycan in the cell wall. The stain is easily washed from the thin peptidoglycan layer of gram negative walls but is retained by the thick peptidoglycan layer of gram positive cells, staining them a dark violet colour.

Gram Positive Bacteria

The walls of gram positive bacteria consist of many layers of peptidoglycan forming a thick, single-layered structure that holds the gram stain.

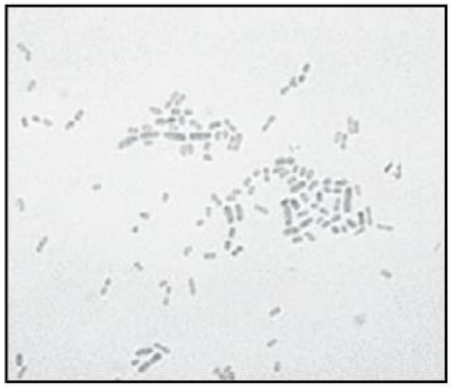


Photos: CDC

Bacillus alvei: a gram positive, flagellated bacterium. Note how the cells appear dark.

Gram Negative Bacteria

The cell walls of gram negative bacteria contain only a small proportion of peptidoglycan, so the dark violet stain is not retained by the organisms.



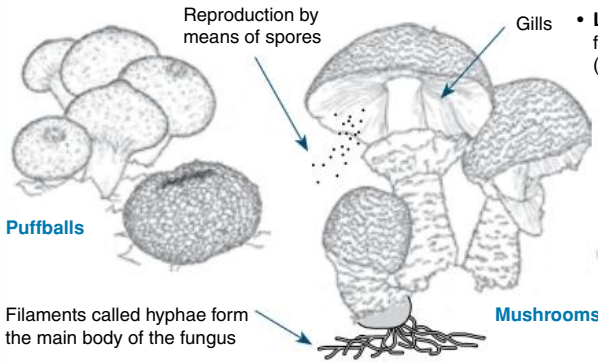
Alcaligenes odorans: a gram negative bacterium. Note how the cells appear pale.

SUPERKINGDOM: EUKARYOTAE
Kingdom: FUNGI

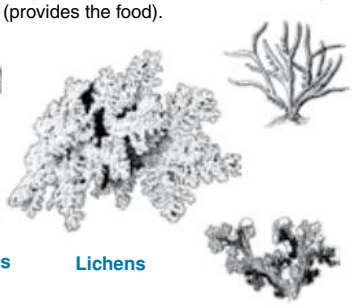
- Heterotrophic.
- Rigid cell wall made of chitin.
- Vary from single celled to large multicellular organisms.
- Mostly saprotrophic (ie. feeding on dead or decaying material).
- Terrestrial and immobile.

Examples:
Mushrooms/toadstools, yeasts, truffles, morels, molds, and lichens.

Species diversity: 80,000 +



- **Lichens** are symbiotic associations of a fungus (provides protection) and an alga (provides the food).



Kingdom: PROTISTA

- A diverse group of organisms. They are polyphyletic and so better represented in the 3 domain system.
- Unicellular or simple multicellular.
- Widespread in moist or aquatic environments.

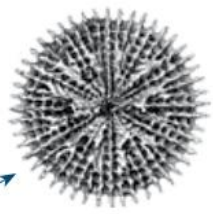
Examples of algae: green, red, and brown algae, dinoflagellates, diatoms.

Examples of protozoa: amoebas, foraminiferans, radiolarians, ciliates.

Species diversity: 55,000 +

Algae 'plant-like' protists

- Autotrophic (photosynthesis)
- Characterised by the type of chlorophyll present

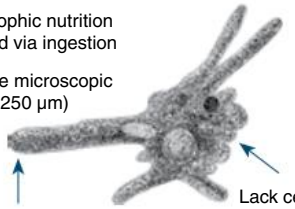


Cell walls of cellulose, sometimes with silica

Diatom

Protozoa 'animal-like' protists

- Heterotrophic nutrition and feed via ingestion
- Most are microscopic (5 µm - 250 µm)



Lack cell walls

Move via projections called pseudopodia

Amoeba

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LINK 42 LINK 40 LINK 39 LINK 38 LINK 30 REFER

Kingdom: PLANTAE

- Multicellular organisms (the majority are photosynthetic and contain chlorophyll).
- Cell walls made of cellulose; food is stored as starch.
- Subdivided into two major divisions based on tissue structure: ***Bryophytes*** (non-vascular plants) and ***Tracheophytes*** (vascular plants).

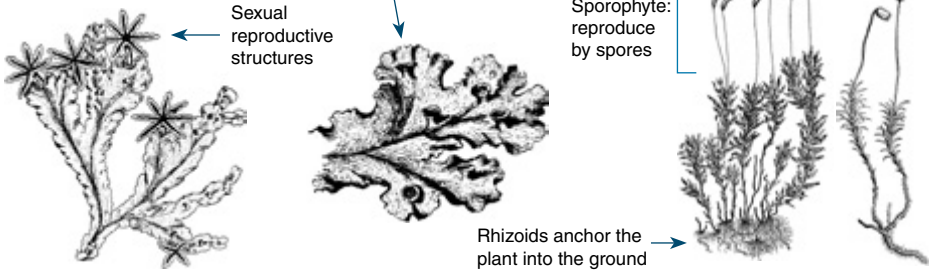
Non-Vascular Plants:

- Non-vascular, lacking transport tissues (no xylem or phloem).
- Small and restricted to moist, terrestrial environments.
- Do not possess 'true' roots, stems, or leaves.

Phylum Bryophyta: Mosses, liverworts, and hornworts.

Species diversity: 18,600 +

Phylum: Bryophyta



Liverworts | Mosses

Vascular Plants:

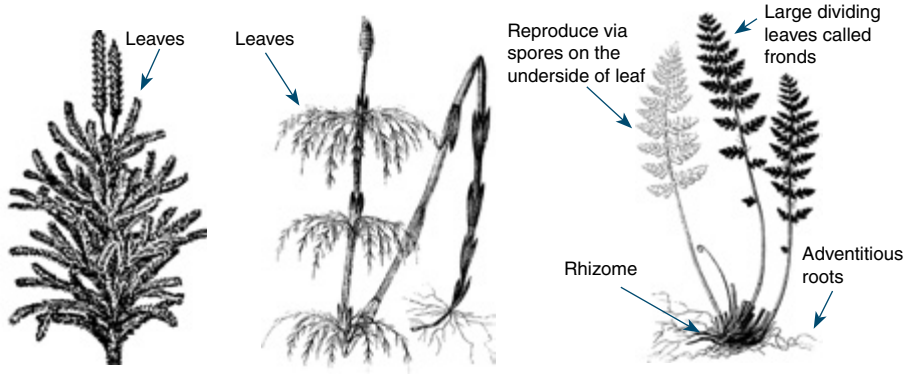
- Vascular: possess transport tissues.
- Possess true roots, stems, and leaves, as well as stomata.
- Reproduce via spores, not seeds.
- Clearly defined alternation of sporophyte and gametophyte generations.

Seedless Plants:

Spore producing plants, includes:

Phylum Filicinophyta: Ferns
Phylum Sphenophyta: Horsetails
Phylum Lycophyta: Club mosses
Species diversity: 13,000 +

Phylum: Lycophyta | Phylum: Sphenophyta | Phylum: Filicinophyta



Club moss | Horsetail | Fern

Seed Plants:

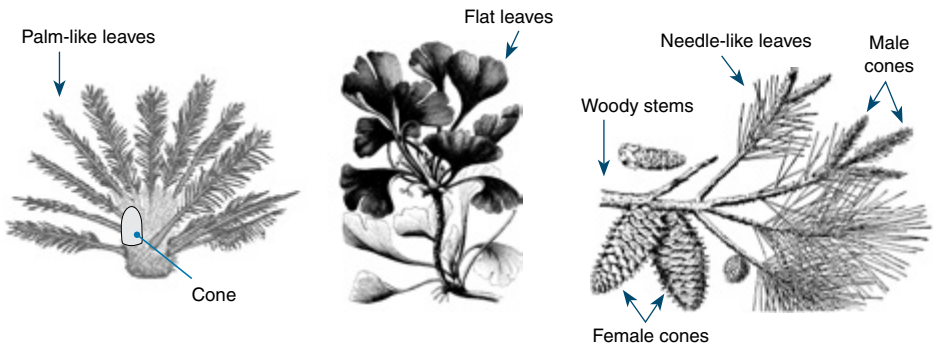
Also called Spermatophyta. Produce seeds housing an embryo. Includes:

Gymnosperms

- Lack enclosed chambers in which seeds develop.
- Produce seeds in cones which are exposed to the environment.

Phylum Cycadophyta: Cycads
Phylum Ginkgophyta: Ginkgoes
Phylum Coniferophyta: Conifers
Species diversity: 730 +

Phylum: Cycadophyta | Phylum: Ginkgophyta | Phylum: Coniferophyta



Cycad | Ginkgo | Conifer

Angiosperms

Phylum: Angiospermophyta

- Seeds in specialised reproductive structures called flowers.
- Female reproductive ovary develops into a fruit.
- Pollination usually via wind or animals.

Species diversity: 260,000 +

The phylum Angiospermophyta may be subdivided into two classes:

Class Monocotyledoneae (Monocots)
Class Dicotyledoneae (Dicots)

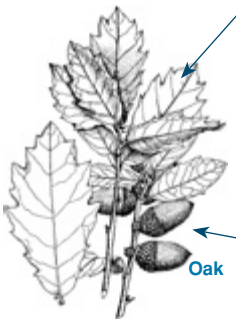
Angiosperms: Monocotyledons



- Only have one cotyledon (food storage organ)
- Normally herbaceous (non-woody) with no secondary growth

Examples: cereals, lilies, daffodils, palms, grasses.

Angiosperms: Dicotyledons



- Flower parts occur in multiples of 4 or 5
- Possible to have secondary growth (either herbaceous or woody)

Examples: many annual plants, trees and shrubs.

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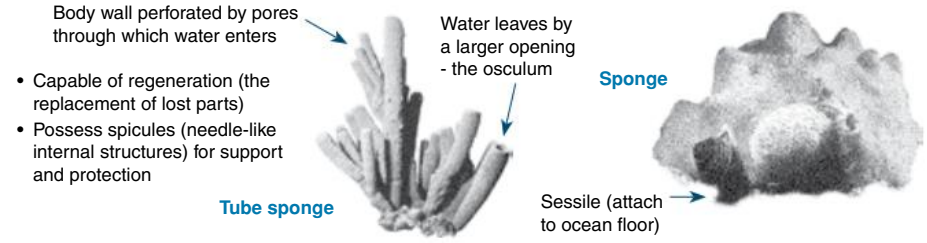
Kingdom: ANIMALIA

- Over 800,000 species described in 33 existing phyla.
- Multicellular, heterotrophic organisms.
- Animal cells lack cell walls.
- Further subdivided into major phyla on the basis of body symmetry, development of the coelom (protostome or deuterostome), and external and internal structures.

Phylum: Porifera

- Lack organs.
- All are aquatic (mostly marine).
- Asexual reproduction by budding.
- Lack a nervous system.

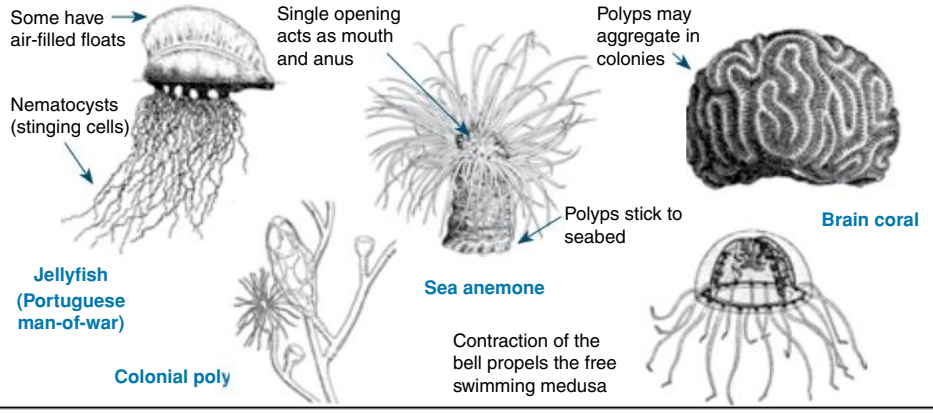
Examples: sponges.
Species diversity: 8000 +



Phylum: Cnidaria

- Diploblastic with two basic body forms:
  Medusa: umbrella shaped and free swimming by pulsating bell.
  Polyp: cylindrical, some are sedentary, others can glide, or somersault or use tentacles as legs.
- Some species have a life cycle that alternates between a polyp stage and a medusa stage.
- All are aquatic (most are marine).

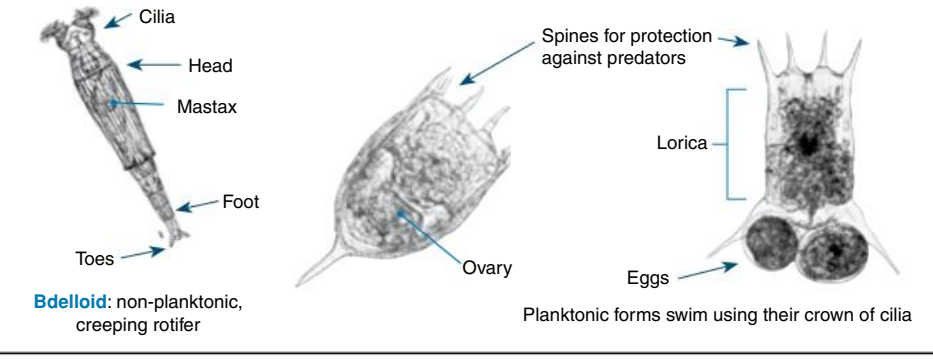
Examples: Jellyfish, sea anemones, hydras, and corals.
Species diversity: 11,000 +



Phylum: Rotifera

- A diverse group of small, pseudocoelomates with sessile, colonial, and planktonic forms.
- Most freshwater, a few marine.
- Typically reproduce via cyclic parthenogenesis.
- Characterised by a wheel of cilia on the head used for feeding and locomotion, a large muscular pharynx (mastax) with jaw like trophi, and a foot with sticky toes.

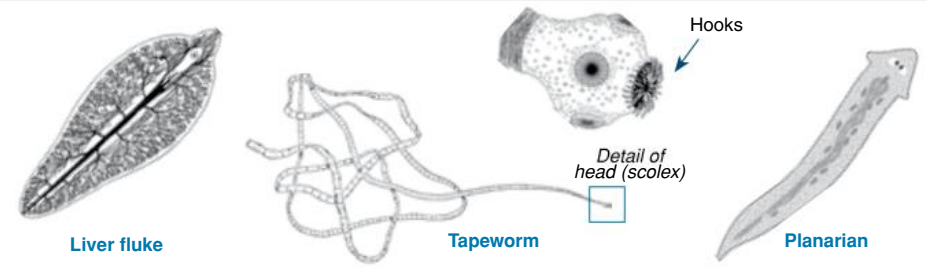
Species diversity: 1500 +



Phylum: Platyhelminthes

- Unsegmented. Coelom has been lost.
- Flattened body shape.
- Mouth, but no anus.
- Many are parasitic.

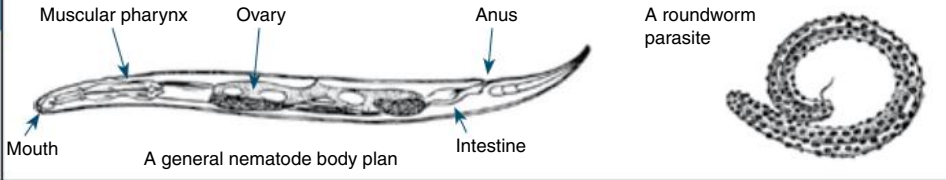
Examples: Tapeworms, planarians, flukes.
Species diversity: 20,000 +



Phylum: Nematoda

- Tiny, unsegmented roundworms.
- Many are plant/animal parasites

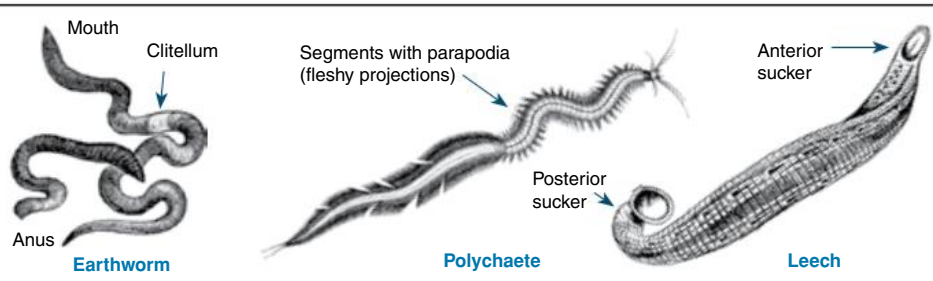
Examples: Hookworms, stomach worms, lung worms, filarial worms
Species diversity: 80,000 - 1 million



Phylum: Annelida

- Cylindrical, segmented body with chaetae (bristles).
- Move using hydrostatic skeleton and/or parapodia (appendages).

Examples: Earthworms, leeches, polychaetes (including tubeworms).
Species diversity: 15,000 +



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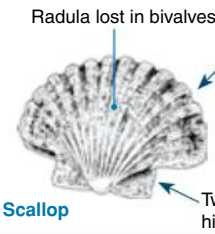
Kingdom: ANIMALIA (continued)

Phylum: Mollusca

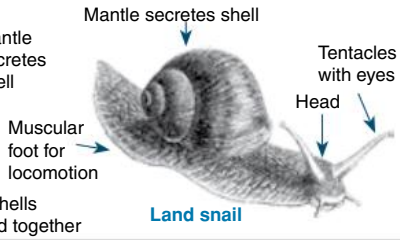
- Soft bodied and unsegmented.
- Body comprises head, muscular foot, and visceral mass (organs).
- Most have radula (rasping tongue).
- Aquatic and terrestrial species.
- Aquatic species possess gills.

Examples: Snails, mussels, squid.
Species diversity: 110,000 +

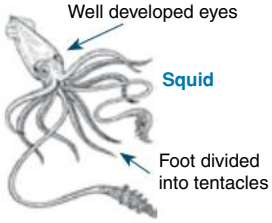
Class: Bivalvia



Class: Gastropoda



Class: Cephalopoda



Phylum: Arthropoda

- Exoskeleton made of chitin.
- Grow in stages after molting (ecdysis).
- Jointed appendages.
- Segmented bodies.
- Heart found on dorsal side of body.
- Open circulation system.
- Most have compound eyes.

Species diversity: 1 million +
Make up 75% of all living animals.

Arthropods are subdivided into the following classes:

Class: Crustacea (crustaceans)
- Mainly marine.
- Exoskeleton impregnated with mineral salts.
- Gills often present.
- Includes: Lobsters, crabs, barnacles, prawns, shrimps, isopods, amphipods
- **Species diversity**: 35,000 +

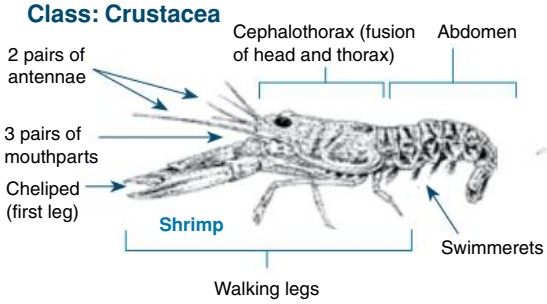
Class: Arachnida (chelicerates)
- Almost all are terrestrial.
- 2 body parts: cephalothorax and abdomen (except horseshoe crabs).
- Includes: spiders, scorpions, ticks, mites, horseshoe crabs.
- **Species diversity**: 57,000 +

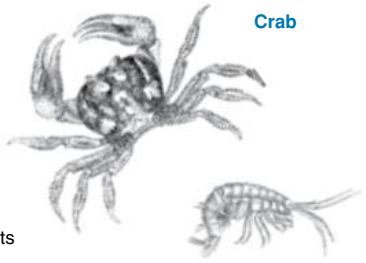
Class: Insecta (insects)
- Mostly terrestrial.
- Most are capable of flight.
- 3 body parts: head, thorax, abdomen.
- Include: Locusts, dragonflies, cockroaches, butterflies, bees, ants, beetles, bugs, flies, and more
- **Species diversity**: 800,000 +

Myriapods (=many legs)
Class Diplopoda (millipedes)
- Terrestrial.
- Have a rounded body.
- Eat dead or living plants.
- **Species diversity**: 2000 +

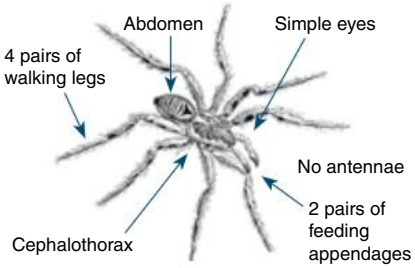
Class Chilopoda (centipedes)
- Terrestrial.
- Have a flattened body.
- Poison claws for catching prey.
- Feed on insects, worms, and snails.
- **Species diversity**: 7000 +

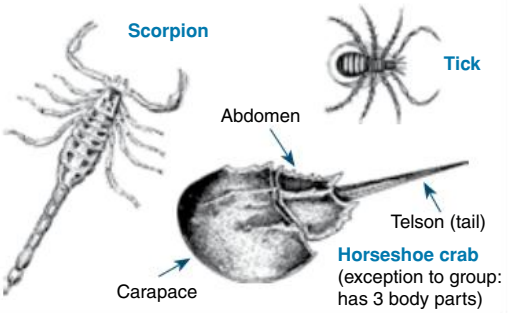
Class: Crustacea



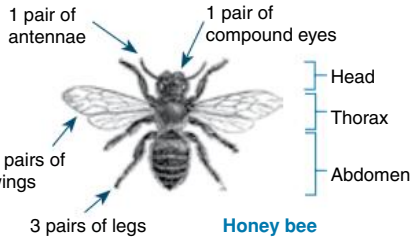


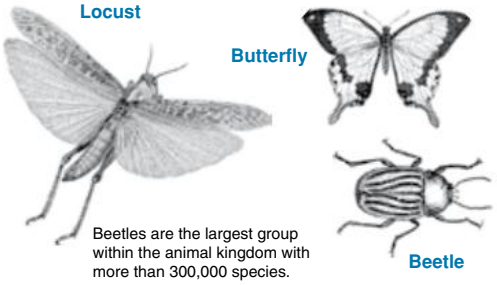
Class: Arachnida



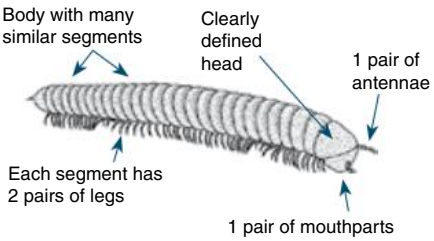


Class: Insecta

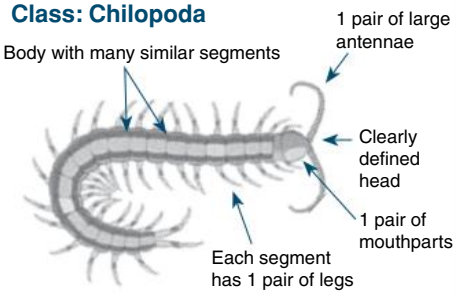




Class: Diplopoda



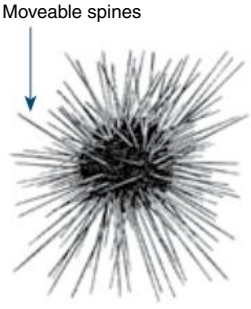
Class: Chilopoda

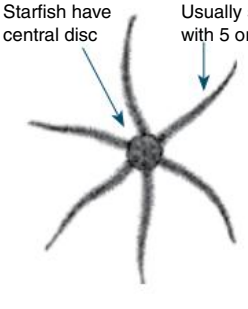


Phylum: Echinodermata

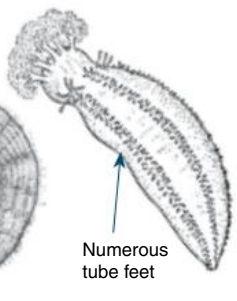
- Rigid body wall, internal skeleton made of calcareous plates.
- Many possess spines.
- Ventral mouth, dorsal anus.
- External fertilisation.
- Unsegmented, marine organisms.
- Tube feet for locomotion.
- Water vascular system.

Examples: Starfish, brittlestars, feather stars, sea urchins, sea lilies.
Species diversity: 6000 +









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Kingdom: ANIMALIA (continued)

Phylum: Chordata

- Dorsal notochord (flexible, supporting rod) present at some stage in the life history.
- Post-anal tail present at some stage in their development.
- Dorsal, tubular nerve cord.
- Pharyngeal slits present.
- Circulation system closed in most.
- Heart positioned on ventral side.

Species diversity: 48,000 +

- A very diverse group with several sub-phyla:
  - Urochordata (sea squirts, salps)
  - Cephalochordata (lancelet)
  - Craniata (vertebrates)

Sub-Phylum Craniata (vertebrates)

- Internal skeleton of cartilage or bone.
- Well developed nervous system.
- Vertebral column replaces notochord.
- Two pairs of appendages (fins or limbs) attached to girdles.

Further subdivided into:

Class: Chondrichthyes (cartilaginous fish)
- Skeleton of cartilage (not bone).
- No swim bladder.
- All aquatic (mostly marine).
- Include: Sharks, rays, and skates.

Species diversity: 850 +

Class: Osteichthyes (bony fish)
- Swim bladder present.
- All aquatic (marine and fresh water).

Species diversity: 21,000 +

Class: Amphibia (amphibians)
- Lungs in adult, juveniles may have gills (retained in some adults).
- Gas exchange also through skin.
- Aquatic and terrestrial (limited to damp environments).
- Include: Frogs, toads, salamanders, and newts.

Species diversity: 3900 +

Class Reptilia (reptiles)
- Ectotherms with no larval stages.
- Teeth are all the same type.
- Eggs with soft leathery shell.
- Mostly terrestrial.
- Include: Snakes, lizards, crocodiles, turtles, and tortoises.

Species diversity: 7000 +

Class: Aves (birds)
- Terrestrial endotherms.
- Eggs with hard, calcareous shell.
- Strong, light skeleton.
- High metabolic rate.
- Gas exchange assisted by air sacs.

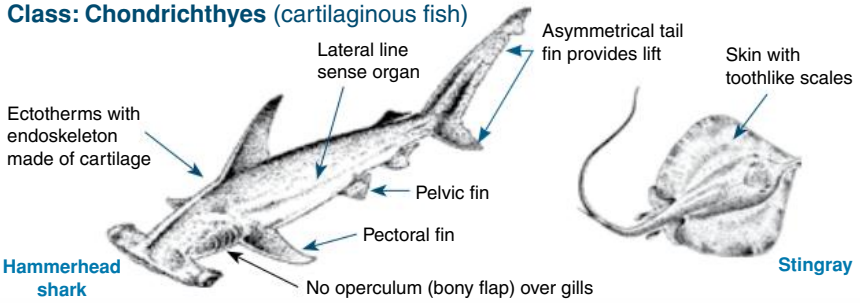
Species diversity: 8600 +

Class: Mammalia (mammals)
- Endotherms with hair or fur.
- Mammary glands produce milk.
- Glandular skin with hair or fur.
- External ear present.
- Teeth are of different types.
- Diaphragm between thorax/abdomen.

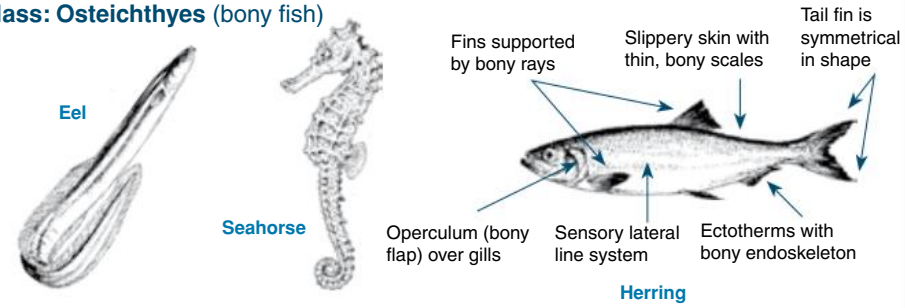
Species diversity: 4500 +

Subdivided into three subclasses: Monotremes, marsupials, placentals.

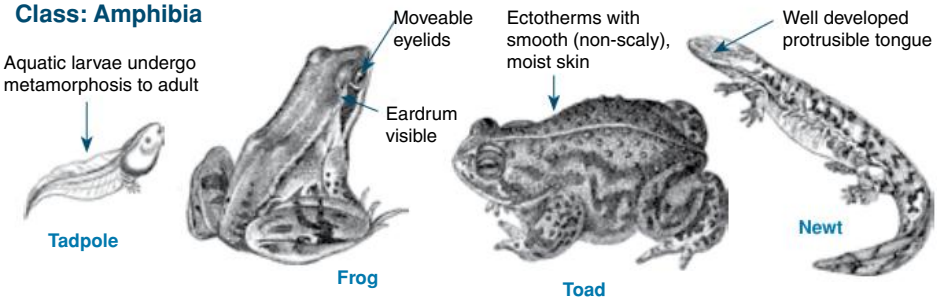
Class: Chondrichthyes (cartilaginous fish)



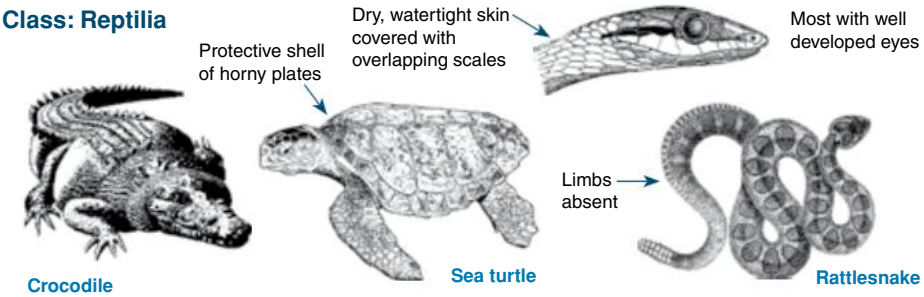
Class: Osteichthyes (bony fish)



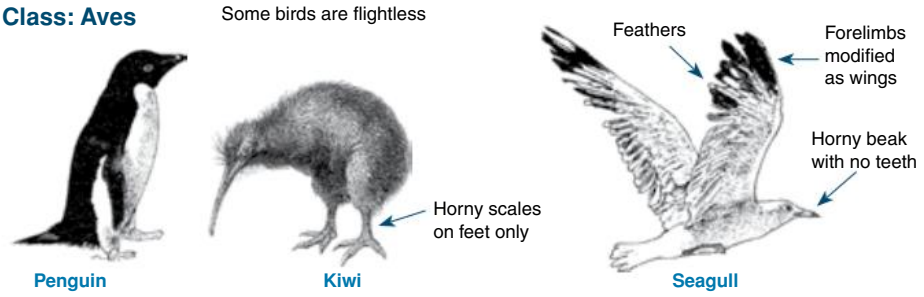
Class: Amphibia



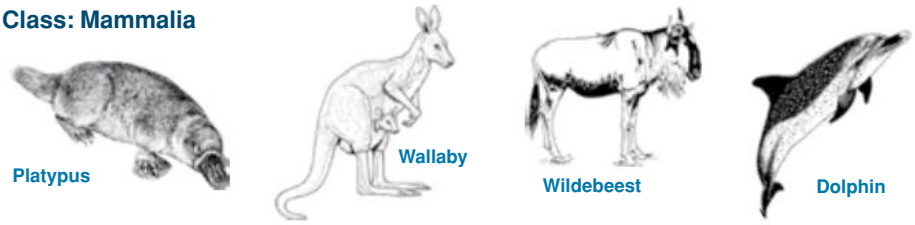
Class: Reptilia



Class: Aves



Class: Mammalia



Monotremes
Egg laying mammals

Marsupials
Give birth to live, very immature young which then develop in a pouch

Placentals
Have a placenta and give birth to live, well developed young

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170 Features of the Five Kingdoms

Key Idea: Organisms can be classified into one of five kingdoms on the basis of their distinguishing features. The classification of organisms is based on how biologists believe they are related in an evolutionary sense. Organisms that are closely related will have more features in common than more distantly related organisms. Those features that definitely distinguish one taxon from another are called distinguishing features. Alone, or sometimes collectively, they should define the group. This activity asks you to summarise the distinguishing features of each of the five kingdoms.

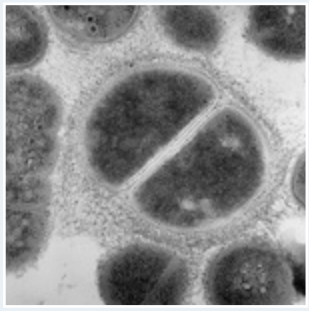
1. Distinguishing features of Kingdom **Prokaryotae**:

2. Distinguishing features of Kingdom **Protista**:

3. Distinguishing features of Kingdom **Fungi**:

4. Distinguishing features of Kingdom **Plantae**:

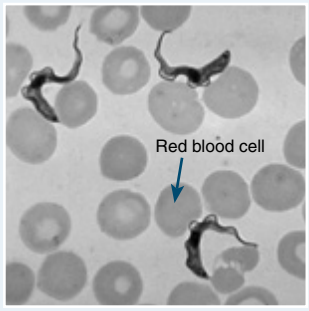
5. Distinguishing features of Kingdom **Animalia**:


EII

***Staphylococcus* dividing**

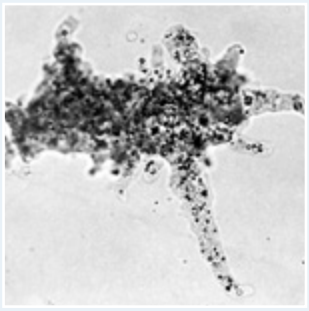

EII

Helicobacter pylori



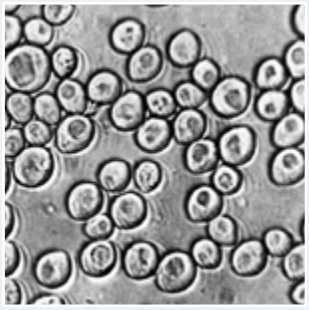
CDC

***Trypanosoma* parasite**


RCN

Amoeba


Mushrooms


Yeast cells in solution


Moss


Pea plants


RA

Cicada moulting


Gibbon

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171 Classification System

Key Idea: Organisms are named and assigned to taxa based on their shared characteristics and evolutionary relationships. Organisms are categorised into a hierarchical system of taxonomic groups (taxa) based on features they share that distinguish them from other taxa. The fundamental unit of classification is the **species**, and each member of a species is assigned a unique two part (binomial) name that identifies it. Classification systems are nested, so that with increasing taxonomic rank, related taxa at one hierarchical level are combined into more inclusive taxa at the next higher level.

Naming an organism

Most organisms have a common name as well a scientific name. Common names may change from place to place as people from different areas name organisms differently based on both language and custom. Scientifically, every organism is given a classification that reflects its known lineage (i.e. its evolutionary history). The last two (and most specific) parts of that lineage are the **genus** and **species** names. Together these are called the scientific name and every organism has its own that is specific to that organism. The term given to this two-part naming system is **binomial nomenclature**. When typed the name is always *italicised*. If handwritten, it should be underlined.



The animal *Rangifer tarandus* is known as the caribou in North America, but as the reindeer in Europe. The scientific name is unambiguous.

1. The table below shows part of the classification for humans using the seven major levels of classification. For this question, use the example of the classification of the red kangaroo, on the next page, as a guide.

   (a) Complete the list of the taxonomic groupings on the left hand side of the table below:

	Taxonomic Group	Human Classification
1.		
2.		
3.		
4.		
5.	Family	Hominidae
6.		
7.		



   (b) Complete the classification for humans (*Homo sapiens*) on the table above.

2. (a) What is the two part naming system for classifying organisms called? _____

   (b) What are the two parts of the name? _____

3. Give two reasons why the classification of organisms is important:

   (a) _____

   (b) _____

4. Construct an acronym or mnemonic to help you remember the principal taxonomic groupings (KPCOFGS):

   _____

5. Classification has traditionally been based on similarities in morphology, but new biochemical methods are now widely used to determine species relatedness. What contribution are these techniques making to the science of classification?

   _____

   _____

   _____

   _____

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Classification of the Red Kangaroo

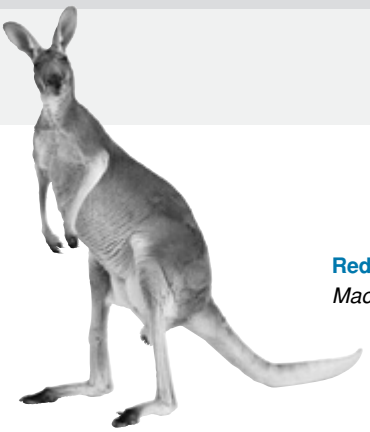
Below is the classification scheme for the red kangaroo. Only one of each group is subdivided in this chart showing the levels that can be used in classifying an organism. Not all possible subdivisions (e.g. sub-order) have been shown here. The only natural category is the species, often separated into races, or sub-species, which generally differ in appearance. *The classification below follows that in "The Australian Museum Complete Book of Australian Mammals" R. Strahan (Ed.) 1983. Cornstalk Publishing. ISBN 0 207 14454 0. It differs from many classifications in raising the marsupials to a sub-class (rather than an order) and dividing the sub-class into the orders Polyprotodonta and Diprotodonta.*

Kingdom:	**Animalia** Animals; one of 5 kingdoms	
Phylum:	**Chordata** Animals with a notochord (supporting rod of cells along the upper surface) *Sea squirts, salps, lancelets, and vertebrates*	23 other phyla
Sub-phylum:	**Vertebrata** Animals with backbones *Fish, amphibians, reptiles, birds, mammals*	
Class:	**Mammalia** Animals that suckle their young on milk from mammary glands *Placentals, marsupials, monotremes*	
Sub-class:	**Metatheria or Marsupialia** Mammals whose young develop for some time in the female's reproductive tract and then migrate to a pouch. *Marsupials*	
Order:	**Diprotodonta** Herbivorous marsupials *Possums, rat kangaroos, honey possums, cuscuses and bushtails, koala, pygmy possums, wombats, gliders, kangaroos, wallabies*	
Superfamily:	**Macropodoidea** Possess extremely long and powerful hindlegs *Potoroos, bettongs, rat-kangaroos, kangaroos, wallabies*	
Family:	**Macropodidae** Kangaroo and wallaby family with 50 species of kangaroos, *wallabies, rock-wallabies, nailtail wallabies, forest wallabies, tree kangaroos, pademelons, quokka, swamp wallabies*	
Genus:	***Macropus*** Ground-dwelling kangaroos and wallabies consisting of 14 species in this genus: *red kangaroo, eastern grey, western grey kangaroo, wallaroo, several species of wallaby*	10 other genera
Species:	***rufus*** Red kangaroo	13 other species

Description: One of the largest living marsupials and powerfully built. Colouration varies, often regionally; red to blue-grey above, and distinctly white below. Females are usually blue-grey and are often called blue-fliers. In some regions of Australia, both sexes are reddish-brown.

Synonyms: plains kangaroo, marloo, blue-flier (female).

Subspecies: Several subspecies have been described but their validity is not well established.



Red kangaroo
Macropus rufus

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172 Features of Microbial Groups

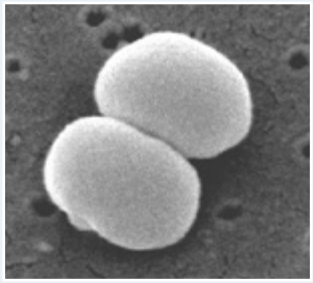
Key Idea: Bacteria, microscopic fungi, microscopic protistans, and viruses are called microorganisms (microbes).

A microorganism (or microbe) is a microscopic organism. The term is usually reserved for bacteria, microscopic fungi, microscopic protistans, and viruses. The protists and fungi also have macroscopic representatives, e.g. seaweeds are photosynthetic protists (algae) and the macrofungi include the familiar toadstools and mushrooms.

1. Describe aspects of each of the following for the bacteria and cyanobacteria (Kingdom Prokaryotae):
   (a) Environmental range: _____
   _____
   (b) Ecological role: _____
   _____
2. Identify an example within the bacteria of the following:
   (a) Photosynthetic: _____
   (b) Pathogen: _____
   (c) Decomposer: _____
   (d) Nitrogen fixer: _____
3. Describe aspects of each of the following for the microscopic protistans (Kingdom Protista):
   (a) Environmental range: _____
   _____
   (b) Ecological role: _____
   _____
4. Identify an example within the protists of the following:
   (a) Photosynthetic: _____
   (b) Pathogen: _____
   (c) Biological indicator: _____
5. Describe aspects of each of the following for the microfungi (Kingdom Fungi):
   (a) Environmental range: _____
   _____
   (b) Ecological role: _____
   _____
6. Identify examples within the microfungi of the following:
   (a) Animal pathogen: _____
   _____
   _____
   (b) Plant pathogens: _____
   _____
   _____

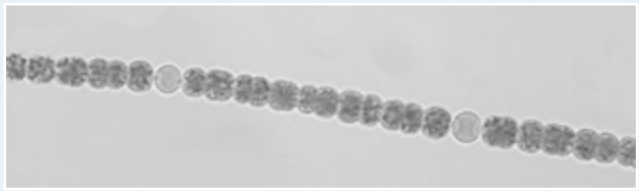


***Spirillum* bacterium**



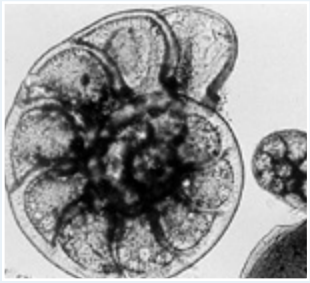
CDC

***Staphylococcus* bacteria**



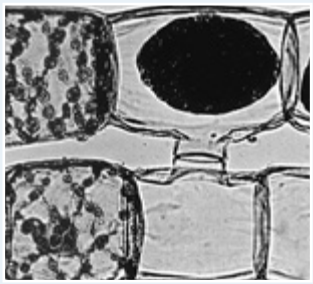
BH

***Anabaena* cyanobacterium**



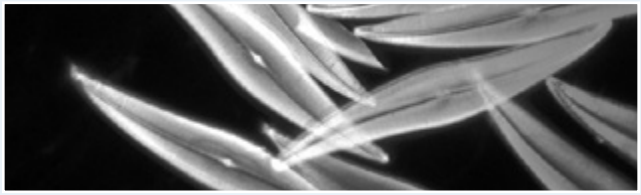
RCN

Foraminiferan

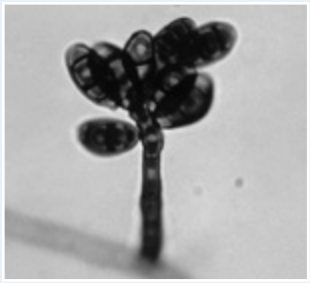


RCN

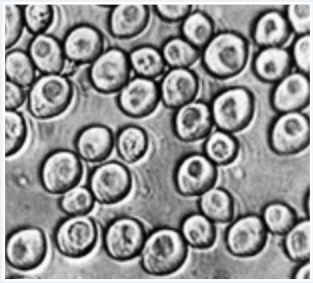
***Spirogyra* algae**



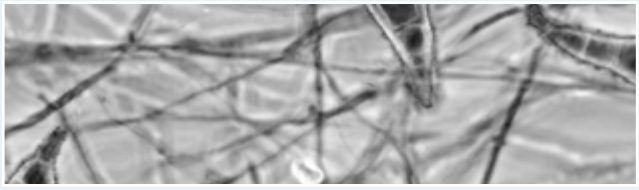
Diatoms: *Pleurosigma*



***Curvularia* sp. conidiophore**



Yeast cells in solution



***Microsporum distortum* (a pathogenic fungus)**

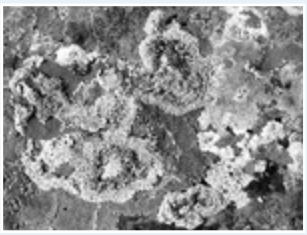
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LINK 39 LINK 38 LINK 30 KNOW

173 Features of Fungi and Plants

Key Idea: The majority of the plant kingdom is included in four familiar taxa. The Fungi have modes of nutrition, organisation, growth, and reproduction that differ from other eukaryotes.

The plant kingdom is monophyletic, meaning that it is derived from a common ancestor. The variety we see in plant taxa today is a result of their diversification from the first plants. The taxonomy of plants is well known for being unsettled, with no close agreement on placement of taxa. Here we recognise four of the most familiar plant taxa: the bryophytes, ferns, conifers, and angiosperms. The Kingdom Fungi is a taxon of organisms that differ from other eukaryotes in their nutrition, structural organisation, growth, and reproduction.



Lichen

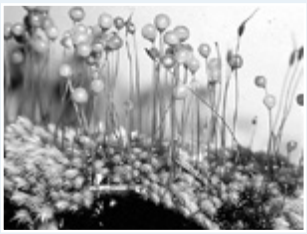


Bracket fungus



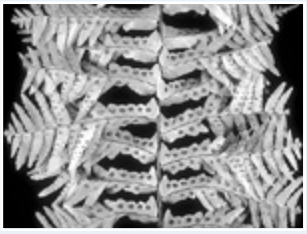
Liverwort

BOB



Moss

BOB



Fern frond



Ground fern



Pine tree with female cones



Male pine cone

RA



Coconut palms



Wheat plants

RA



Deciduous tree



Flowering plant

1. Features of Kingdom **Fungi**: _____

2. Features of division **Bryophyta** (mosses and liverworts):

3. Features of phylum **Filicinophyta** (ferns):

4. Features of phylum **Coniferophyta** (conifers):

5. Features of **Angiospermophyta** (angiosperms):

   (a) Features of monocots: _____

   (b) Features of dicots: _____

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174 Features of Animal Taxa

Key Idea: The animal kingdom is classified into about 35 phyla of which about 10 are familiar to us.

The animal kingdom is classified into about 35 major phyla. Representatives of the more familiar taxa are illustrated below: cnidarians (jellyfish, sea anemones, corals), annelids (segmented worms), arthropods (insects, crustaceans, spiders, scorpions, centipedes, millipedes), molluscs (snails, bivalve shellfish, squid, octopus), echinoderms (sea stars, sea urchins), vertebrates from the phylum chordates (fish, amphibians, reptiles, birds, mammals). The arthropods and the vertebrates have been represented in more detail, giving the classes for these phyla. Describe the distinguishing features of each of the taxa below and underline the feature you think is most important in distinguishing the taxon.


Sea anemones


Jellyfish


Tubeworms


Earthworm

BOB

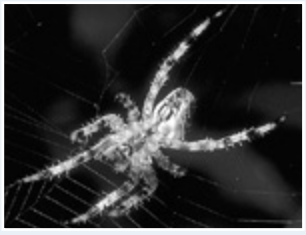

Long-horned beetle

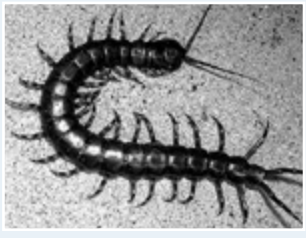

Butterfly


Crab


Woodlouse


Scorpion


Spider


Centipede (Chilopoda)


Millipede (Diplopoda)

1. Features of phylum **Cnidaria**: _____

2. Features of phylum **Annelida**: _____

3. Features of phylum **Arthropoda**: _____

(a) Features of class **Insecta**: _____

(b) Features of class **Crustacea**: _____

(c) Features of class **Arachnida**: _____

(d) Features of classes **Chilopoda** and **Diplopoda**

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Nautilus


Abalone


Sea urchin


Starfish


Grouper (Osteichthyes)


Shark (Chondrichthyes)


Frog


Salamander


Iguana


Rattlesnake


Penguin


Pelican


Horse


Bear

4. Features of phylum **Mollusca**: _____

5. Features of phylum **Echinodermata**: _____

6. Features of sub-phylum **Vertebrata**: _____

(a) Features of class **Chondrichthyes** (sharks, rays):

(b) Features of class **Osteichthyes** (bony fish):

(c) Features of class **Amphibia**: _____

(d) Features of class **Reptilia**: _____

(e) Features of class **Aves**: _____

(f) Features of class **Mammalia**: _____

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175 Classification Keys

Key Idea: Classification keys are used to identify an organism based on its distinguishing features and assign it to a species.

An organism's classification should include a clear, unambiguous description, an accurate diagram, and its unique name, denoted by the genus and species. Classification keys are used to identify an organism and assign it to the correct species. Typically, keys are dichotomous and involve a series of linked steps. At each step, a choice is made between two features. Each alternative leads to another question until an identification is made. If the organism cannot be identified, it may be a new species or the key may need revision. This activity describes two examples of the use of dichotomous keys. The first describes features to help you determine the superfamily to which each of the native Australian marsupials pictured belongs. The key on the next page identifies aquatic insect orders.



Eastern grey kangaroo
Macropus giganteus
Endemic. Large, powerful hindlegs for hopping. Feeds on bushes, shrubs and other vegetation. Twelve or more teeth each side and 1 pair of lower incisors.



Honey possum
Tarsipes rostratus
Endemic. Feeds on pollen and nectar. Tail is prehensile. Fewer teeth than other marsupials (11 or fewer on each side). Has 1 pair of lower incisors.



Common brushtail possum
Trichosurus vulpecula
Feeds on leaves, fruits, blossoms, insects. Tail prehensile. Hindfeet have 2nd and 3rd toes fused. Twelve or more teeth each side and 1 pair of lower incisors.



Tasmanian wolf/tiger (extinct)
Thylacinus cynocephalus
Endemic predatory carnivore with good vision. Dog-like molar teeth for cutting flesh and 3 pairs of incisor teeth. Hind toes are not fused.



Marsupial mole
Notoryctes typhlops
Endemic. Adapted for living under-ground, feeding on termites and other insects, and seeds. Blind (eyes vestigial). Three pairs of lower incisors.



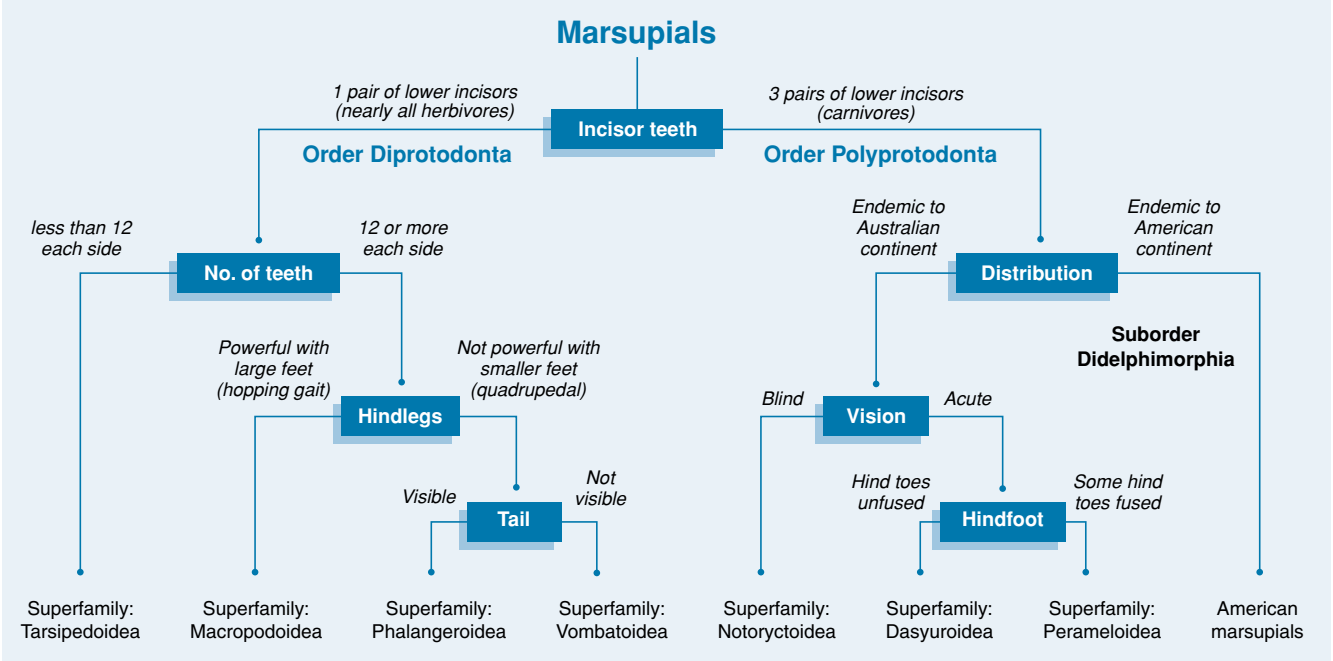
Numbat
Myrmecobius fasciatus
Endemic. Good vision but poorly developed teeth, long sticky tongue adapted to feeding on termites. Has 3 pairs of lower incisors. Hind toes not fused.



Bilby
Macrotus lagotis
Endemic. Feeds on termites, ants, larvae, seeds, bulbs and fruit. Acute vision. Has 3 pairs of lower incisors. 2nd and 3rd toes of the hindfoot are fused.



Common wombat
Vombatus ursinus
Endemic. Very short tail not visible. Feeds on native grasses, herbs and roots. Twelve or more teeth each side and 1 pair of lower incisors.



1. Use the key to identify the superfamily to which each of the following Australian marsupials belongs:

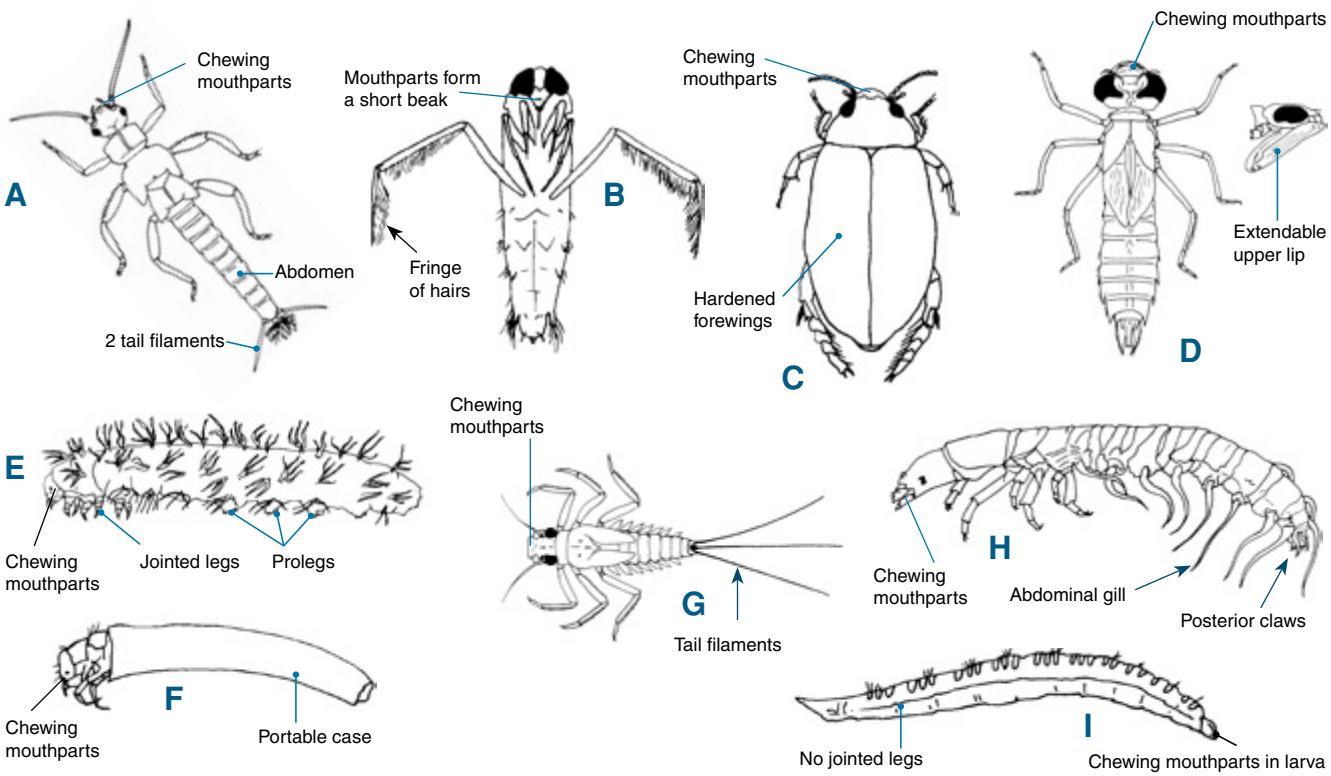
(a) Eastern grey kangaroo: _____ (d) Numbat: _____

(b) Honey possum: _____ (e) Bilby: _____

(c) Brushtail possum: _____ (f) Common wombat: _____

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2. Use the simplified key to identify each of the orders (by order or common name) of aquatic insects (A-I) pictured above:

(a) Order of insect A: _____

(b) Order of insect B: _____

(c) Order of insect C: _____

(d) Order of insect D: _____

(e) Order of insect E: _____

(f) Order of insect F: _____

(g) Order of insect G: _____

(h) Order of insect H: _____

(i) Order of insect I: _____

Key to Orders of Aquatic Insects

1	Insects with chewing mouthparts; forewings are hardened and meet along the midline of the body when at rest (they may cover the entire abdomen or be reduced in length).	**Coleoptera** (beetles)
	Mouthparts piercing or sucking and form a pointed cone With chewing mouthparts, but without hardened forewings	*Go to 2* *Go to 3*
2	Mouthparts form a short, pointed beak; legs fringed for swimming or long and spaced for suspension on water.	**Hemiptera** (bugs)
	Mouthparts do not form a beak; legs (if present) not fringed or long, or spaced apart.	*Go to 3*
3	Prominent upper lip (labium) extendable, forming a food capturing structure longer than the head.	**Odonata** (dragonflies & damselflies)
	Without a prominent, extendable labium	*Go to 4*
4	Abdomen terminating in three tail filaments which may be long and thin, or with fringes of hairs.	**Ephemeroptera** (mayflies)
	Without three tail filaments	*Go to 5*
5	Abdomen terminating in two tail filaments	**Plecoptera** (stoneflies)
	Without long tail filaments	*Go to 6*
6	With three pairs of jointed legs on thorax	*Go to 7*
	Without jointed, thoracic legs (although non-segmented prolegs or false legs may be present).	**Diptera** (true flies)
7	Abdomen with pairs of non-segmented prolegs bearing rows of fine hooks.	**Lepidoptera** (moths and butterflies)
	Without pairs of abdominal prolegs	*Go to 8*
8	With eight pairs of finger-like abdominal gills; abdomen with two pairs of posterior claws.	**Megaloptera** (dobsonflies)
	Either, without paired, abdominal gills, or, if such gills are present, without posterior claws.	*Go to 9*
9	Abdomen with a pair of posterior prolegs bearing claws with subsidiary hooks; sometimes a portable case.	**Trichoptera** (caddisflies)

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176 Key to Australian Plants

Key Idea: A dichotomous key uses distinguishing features to assign organisms to a genus and species.

Dichotomous keys can enable identification to species level provided the characteristics chosen are appropriate for separating species. The following activity requires you to identify five species of the genus *Banksia* from illustrations of the leaves. It provides valuable practice in using characteristic features to identify plants to species level.

A Dichotomous Key to the Common Species of Banksia

1a Adult leaves always toothed along the edge 2
1b Adult leaves without teeth 4

2a Leaves narrow, 4-10 cm long by 1-4 mm wide, with fine teeth along the margin. Flowers orange-yellow.

Hair-pin banksia, *Banksia spinulosa*

2b Leaves broader, coarsely toothed. Flowers creamy-grey 3

3a Leaves 8-15 cm long by 2-4 cm wide. Flower spikes large (20 by 10 cm). Mostly coastal.

Saw banksia, *Banksia serrata*

3b Leaves 5-12 cm long by 1-2 cm wide. Flower spikes egg shaped 5-14 cm by 5-7 cm. Occurs mostly in inland regions.

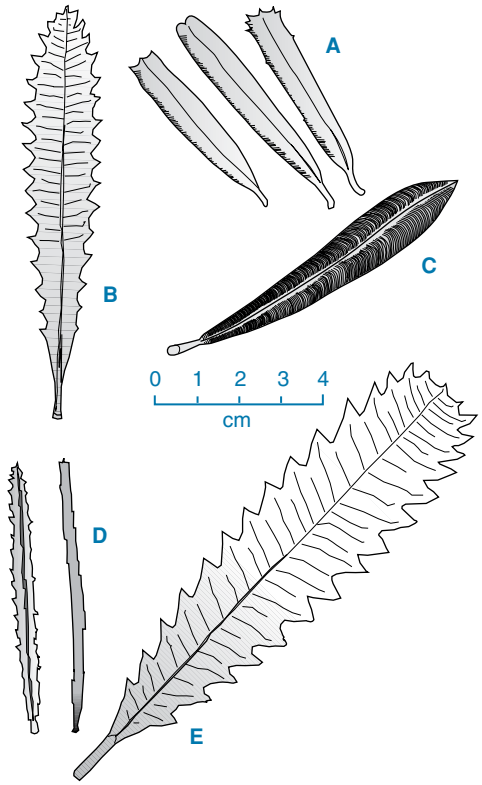
Desert banksia, *Banksia ornata*

4a Usually a tree 4-16 m. Leaves 5-10 cm long by 1-2 cm wide, in clusters of three to six. On dunes and sandy cliffs.

Coast banksia, *Banksia integrifolia*

4b Usually a shrub 1-5 m. Leaves smaller, 3-8 cm long by 3-8 mm wide, with a notched tip, scattered singly along branches.

Silver banksia, *Banksia marginata*




Banksia integrifolia


Banksia ornata


Banksia serrata


Banksia marginata


Banksia spinulosa

Photos: Kevin Collins, The Banksia Farm, Mt Barker, WA

1. Use the dichotomous key to the common species of *Banksia* to identify the species illustrated by the leaves (drawn to scale). Begin at the top of the key and make a choice as to which of the illustrations best fits the description:

   (a) Species A: _____

   (b) Species **B**: _____

   (c) Species **C**: _____

   (d) Species **D**: _____

   (e) Species **E**: _____

2. Why is it usually necessary to consider a number of different features in order to classify plants to species level?

   _____

   _____

3. What should you be sure of before using a key to classify a plant to species level? _____

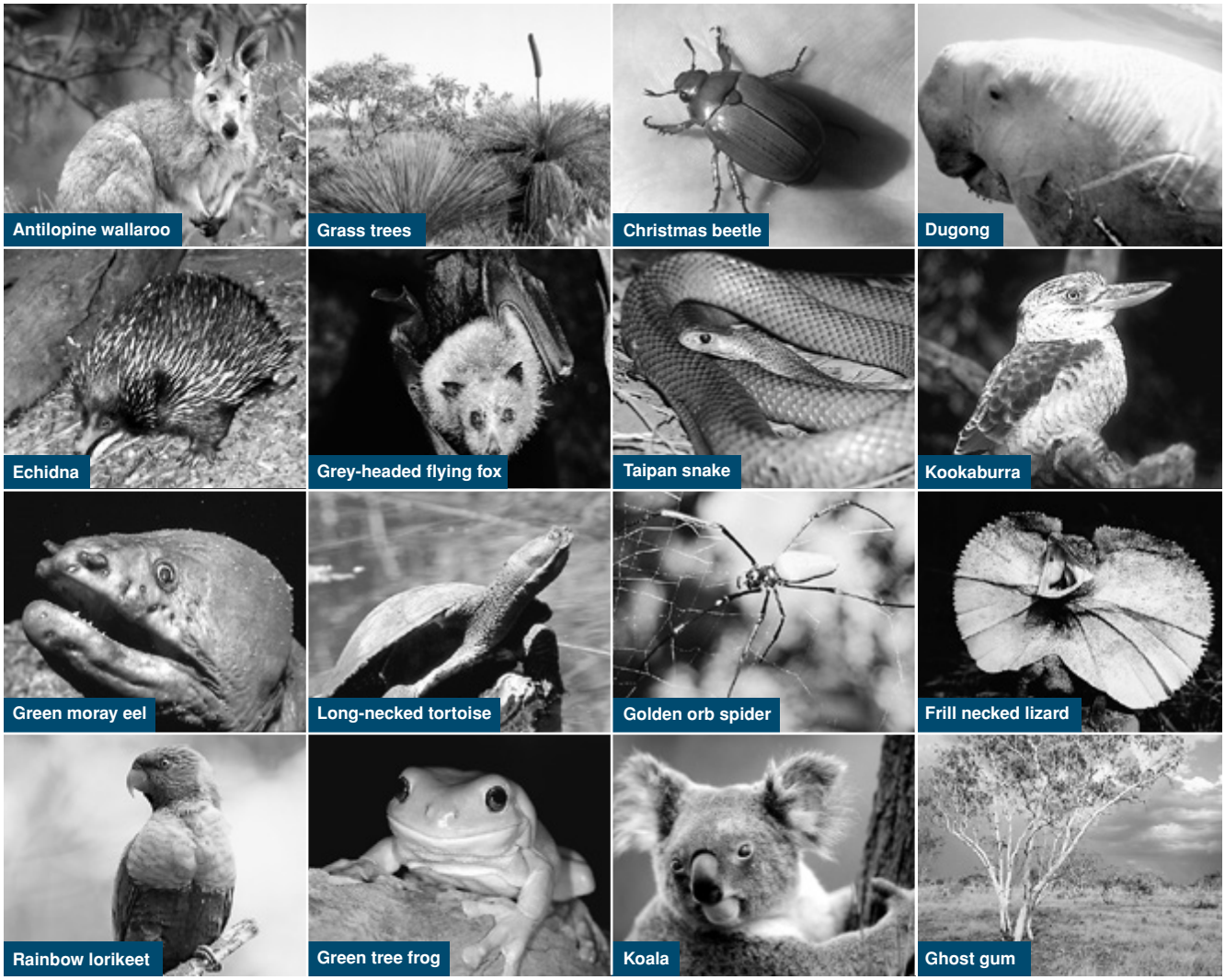
   _____

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177 Australia's Biodiversity

Key Idea: Australia's biodiversity can be described by estimating species richness and degree of endemism.

The species is the basic unit by which biodiversity is measured. Estimates of Australia's biodiversity (species richness) are shown below. Note the bias towards large, conspicuous organisms. Australia's biodiversity is unique. It is one of six floristic regions, with a characteristic flora dominated by eucalypts and acacias. It has two of the three living monotreme species and a large proportion of the living marsupials. It is the only nation with arid-adapted kangaroos. Australia also has the largest intact coral reef in the world and some of the best preserved mangrove forests.

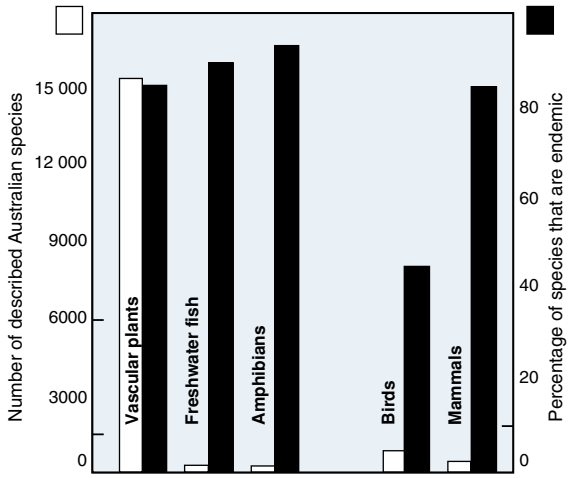


Major taxonomic groups	Estimated number of species	Number actually described	Described species known to be threatened*
Algae	11,000	5000	?
Vascular plants	22,500	15,638	1171
Non-vascular plants	2500	1500	2
Fungi (including lichens)	255,000	15,377	?
Invertebrates	192,706	92,585	4
Arthropods	121,320	70,624	*No data available for the breakdown of these groups*
Molluscs	12,250	9336	
Nematode worms	30,000	2060	
Sponges	3500	1416	
All other invertebrates	25,636	9149	
Chordates	*c* 8006	*most*	274
Tunicates and lancelets	743	544	*No data available*
Fish (including jawless)	5260	4155	30
Amphibians (frogs)	*c* 176	176	27
Reptiles	*c* 633	633	49
Birds	*c* 825	825	94
Mammals (terrestrial)	*c* 369	369	74

Source: State of Environment Australia 2001, CSIRO Publishing

Left: Estimated species diversity in Australia according to taxonomic group, but excluding bacteria and most of the Protista for which no data are available. Note: Only a proportion of the estimated number of species have been described. *For the purposes of this table, threatened includes both endangered and vulnerable species.

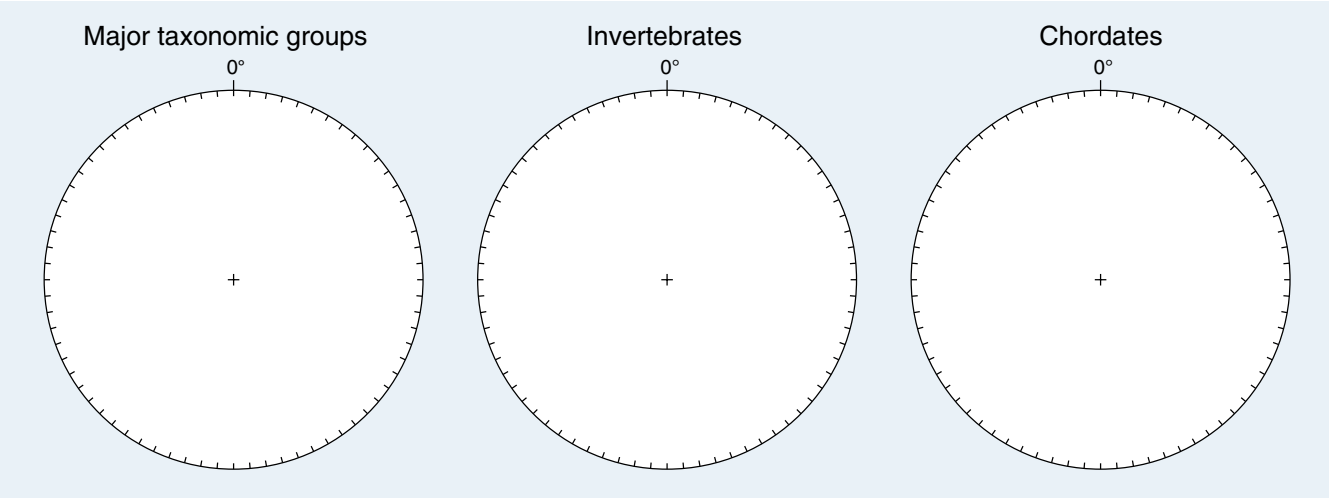
Below: Bar graph illustrating the percentage of Australian endemic species (right axis) for vascular plants and some selected vertebrate taxa.



DATA LINK 276 LINK 286 LINK 295

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Proportion of Australia's biodiversity in different major taxonomic groups



Key: Major taxonomic groups

- Invertebrates
- Plants
- Fungi
- Chordates
- Algae

Key: Invertebrates

- Arthropods
- Sponges
- Nematodes
- Others
- Molluscs

Key: Chordates

- Fish
- Land mammals
- Reptiles
- Amphibians
- Birds
- Tunicates & lancelets

1. Using the categories provided above and the data for the **estimated number of species** in the previous table, plot pie charts illustrating the relative proportions of Australia's biodiversity in major taxa. Each percentage point is equal to 3.6° of the circle's circumference (e.g. 30%=108°) and the circles have been marked with 5° divisions to help you.

2. (a) In the table on the previous page, the number of species actually described is often very much lower than the estimated number of species in any one taxonomic group. Compare the vertebrates and invertebrates in terms of the proportion of the total actually described:

   (b) Explain your findings:

   (c) What are the implications of this lack of species knowledge for the conservation of Australia's invertebrate fauna?

3. (a) Distinguish between native (also called indigenous) and endemic species:

   (b) Comment on the amount of endemism in Australia's biota (flora and fauna) and its significance:

   (c) Why is it difficult to determine percentage endemism for marine species?

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QLD As required
VCE Unit 2 (2)
WA ATAR Unit 1
SA Theme E

Habitat and Niche

Key terms

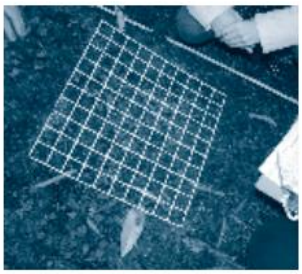
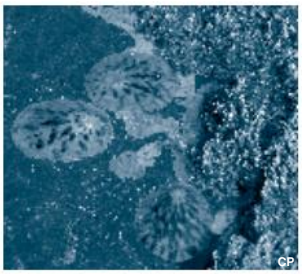
abiotic (=physical) factor altitude
belt transect
biome
biosphere
biotic factor
climate
community
competitive exclusion principle
ecological niche (=niche)
ecology
ecosystem
environmental gradient
fundamental niche
habitat
limiting factor
line transect
microclimate
microhabitat
niche breadth
physical (=abiotic) factor
population
quadrat
realised niche
species
stratification
tolerance range
transect
zonation

Biomes and Ecosystems

Learning aims and skills

Activity number

☐	1	Define the terms biosphere and biome. Describe the main features of the major biomes and explain how they are classified. Explain the effect of latitude, altitude, and rainfall in determining the distribution of the world's biomes.	178
☐	2	Define the terms ecosystem, community, population, species, and environment Categorise the components of an ecosystem as biotic or abiotic factors and explain how these influence species distribution.	179
☐	3	Identify and describe the major ecosystem types in Australia and describe how they are distributed with reference to abiotic factors. Describe an example of a local ecosystem, including reference to the community composition and the abiotic factors that determine the ecosystem's characteristics.	180
☐	4	Describe aspects of the abiotic environment in named examples. Explain how gradients in physical factors can occur over relatively short distances, e.g. on a rocky shore. Explain the role of these environmental gradients in species distribution and in contributing to community diversity.	186 190 193 196


Habitat and niche

Learning aims and skills

Activity number

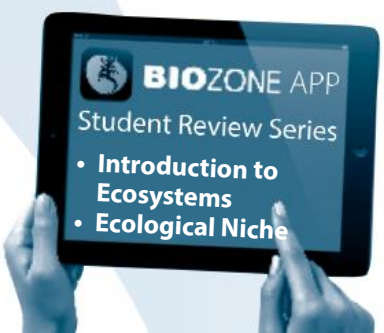
☐	5	Define the term habitat and explain how tolerance range determines, in part, where an organism can live.	181 183
☐	6	Explain the concept of the ecological niche (niche). Distinguish between the fundamental and the realised niche. Explain the competitive exclusion principle and describe the effects of competition on niche breadth.	182
☐	7	Describe physiological, structural, and behavioural adaptations for survival in a given niche. Explain that these are the result of evolutionary changes to the species, but not to individuals within their own lifetimes.	184 185

Patterns in communities

Learning aims and skills

Activity number

☐	8	Describe how community composition can vary along an environmental gradient and explain how these community patterns arise.	186 190 193 196
☐	9	Describe and explain an example of zonation, e.g. zonation in an intertidal community or zonation in a forest community with altitude.	192 194
☐	10	Describe and explain vertical stratification in a rainforest or billabong.	189 196
☐	11	Describe and explain techniques used to quantify distributional variation in communities, e.g. belt and line transects using point sampling or quadrats.	187 188 191 195



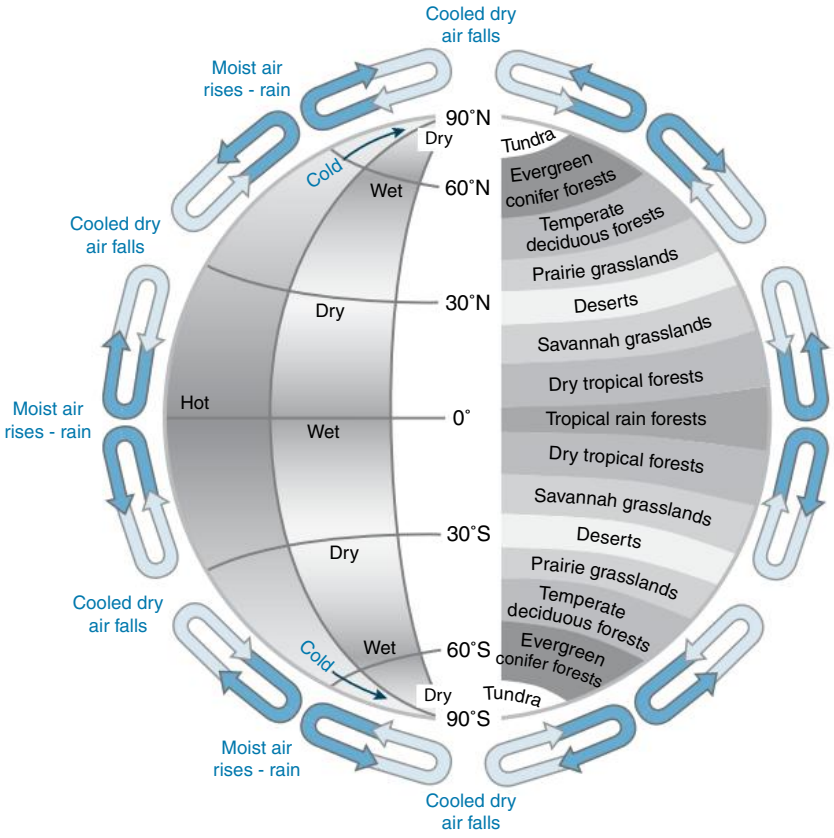
178 Biomes

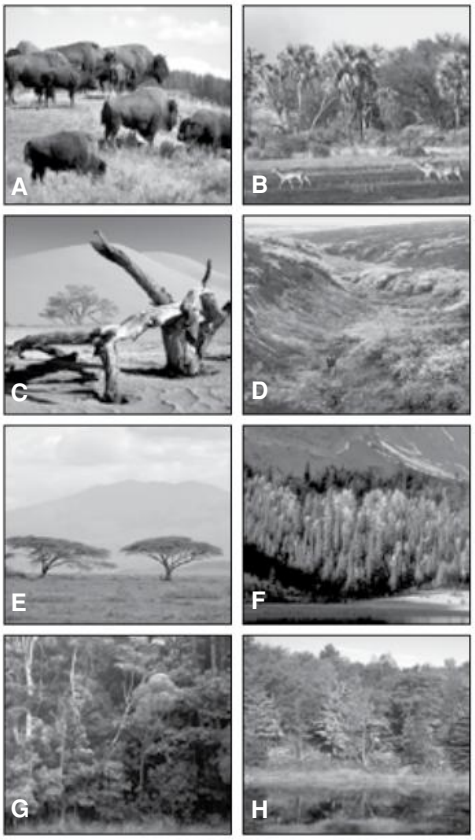
Key Idea: Biomes are geographically-based communities usually defined by climatic zone and vegetation type.

The Earth's biomes are the largest geographically based communities that can be conveniently recognised. These are large areas defined on the basis of vegetation type and climate. Biomes have characteristic features, but the same biome may occur in different regions of the world wherever the abiotic environment is similar. Terrestrial biomes are recognised for all the major climatic regions of the world. They are classified by their predominant vegetation type.

Earth's Climate and Biomes

Biomes are closely related to the major air cells that circle the Earth and are reflected in the Northern and Southern Hemispheres.



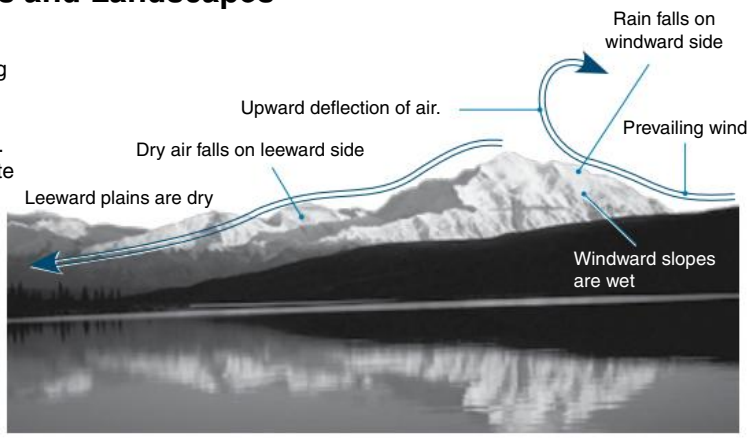


Biomes and Landscapes

Climate is heavily modified by the landscape. Where there are large mountain ranges, wind is deflected upwards causing rain on the windward side and a **rain shadow** on the leeward side. The biome that results from this is considerably different from the one that may have appeared with no wind deflection. Large expanses of ocean and flat land also change the climate by modifying air temperatures and the amount of rainfall.







1. Match the lettered biome images with the appropriate biome:

(a) Tundra: _____ (e) Evergreen conifer forest: _____

(b) Temperate deciduous forest: _____ (f) Prairie grasslands: _____

(c) Deserts: _____ (g) Savannah grasslands: _____

(d) Dry tropical forests: _____ (h) Tropical rain forests: _____

2. Which abiotic factor(s) limit the extent of temperate deciduous forests?

_____

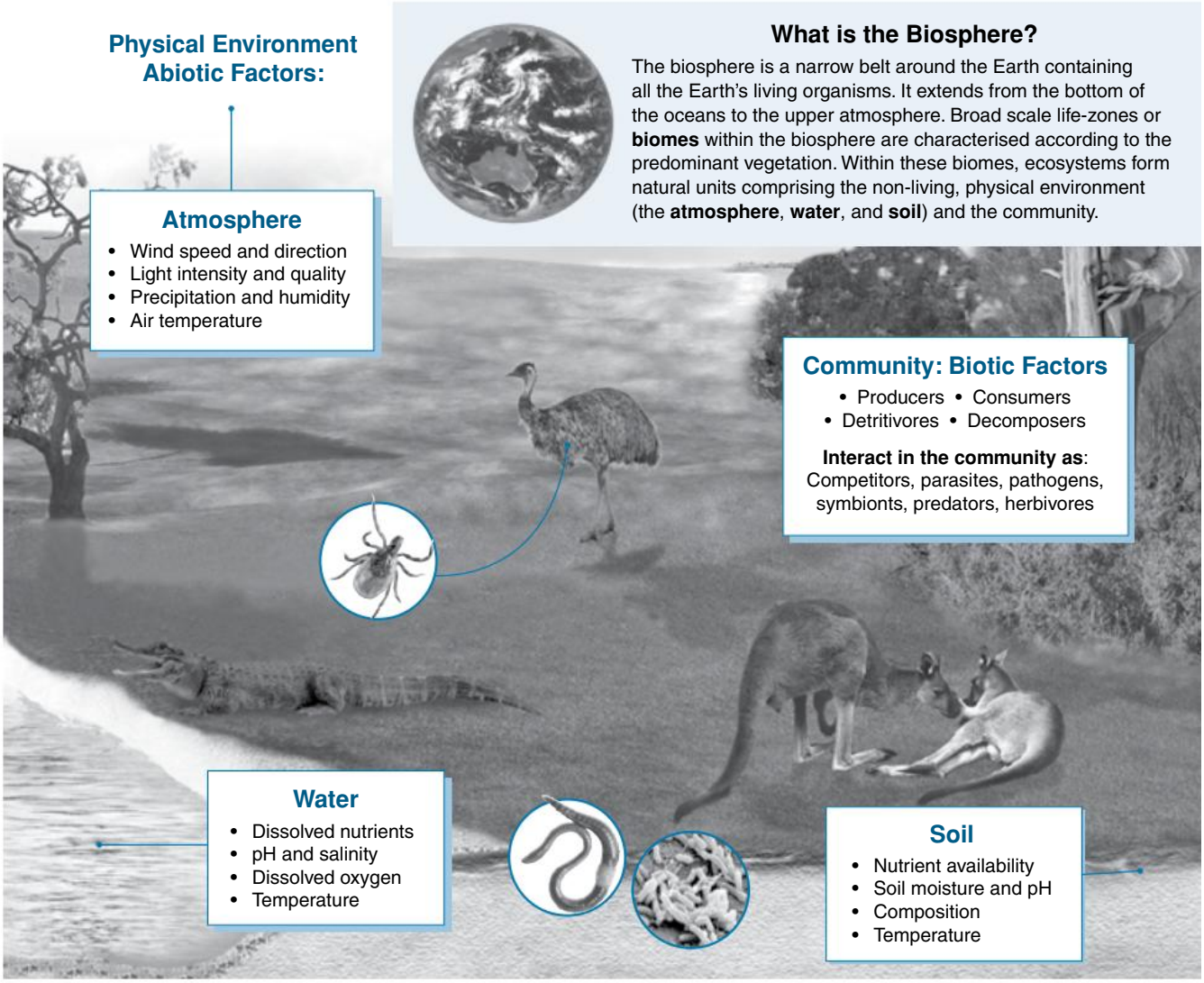
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LINK 286 LINK 179 WEB 178 KNOW

179 Components of an Ecosystem

Key Idea: An ecosystem consists of all the organisms living in a particular area and their physical environment.

An **ecosystem** is a community of living organisms and the physical (non-living) components of their environment. The community (living component of the ecosystem) is in turn made up of a number of **populations** (organisms of the same species living in the same geographical area). The structure and function of an ecosystem is determined by the physical (**abiotic**) and the living (**biotic**) factors, which determine species distribution and survival.



1. Distinguish clearly between a community and an ecosystem: _____

2. Distinguish between **biotic** and **abiotic** factors: _____

3. Use one or more of the following terms to describe each of the features of a rainforest listed below:
   Terms: *population, community, ecosystem, physical factor.*

   (a) All the green tree frogs present: _____ (c) All the organisms present: _____

   (b) The entire forest: _____ (d) The humidity: _____

4. Compare the size of the Earth to the size of the biosphere: _____

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180 Selected Australian Ecosystems

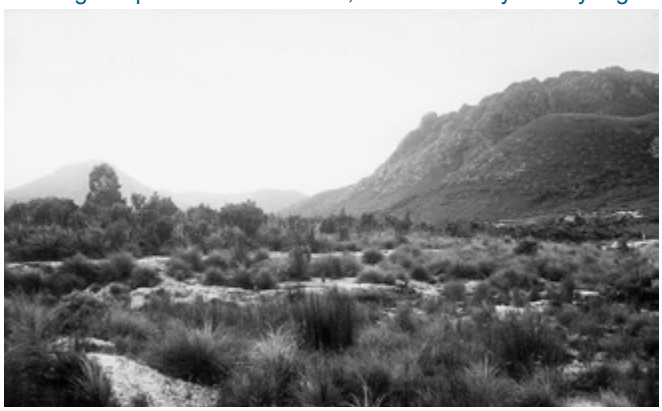
Key Idea: The diverse ecosystems of Australia, dominated by eucalypts and acacias, reflect the continent's wide range of climates, from humid tropics to desert. Although its soils are among the poorest in the world, its biodiversity is very high.



RL

Mulga Shrub Ecosystem

Shrublands are widespread over much of inland Australia, in arid and semiarid regions. There are several types of shrubland: mulga, mallee, and brigalow, each with different dominating species.



TG

Highland Heathland Ecosystem

Parts of Australia give rise to mountain chains and highlands. The increase in altitude creates conditions that lowland vegetation cannot tolerate, leading to a unique community of highland vegetation.



TG

Wet Sclerophyll Forest Ecosystem

Forests in areas of higher rainfall on the east coast have a single canopy layer of eucalypt trees with a lush undergrowth.



Rock Platform Ecosystem

Some exposed coastlines comprise wave-cut rock platforms. Wave action erodes the rock strata, at rates dependent on the rock type.



Tropical Rainforest Ecosystem

Tropical rainforests occur in warm regions of high rainfall. With few eucalypts, the trees form a dense canopy with several understorey layers.



Billabong Ecosystem

These oxbow lakes are formed from old river meanders that have been cut off and isolated from the main channel. They are usually very shallow and may dry up completely during the summer months.

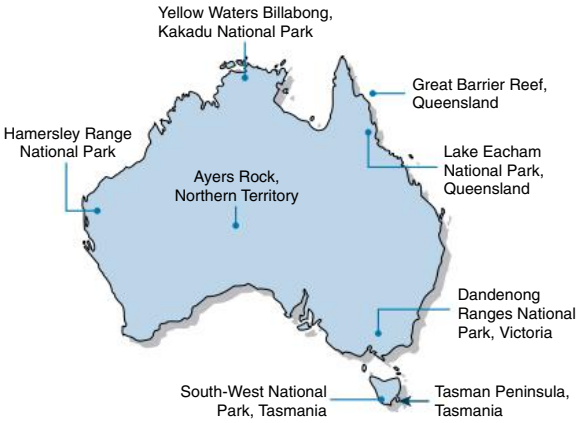


Desert Ecosystem

Australia's deserts are rich and varied. They are defined as having a rainfall of less than 250 mm in the south and less than 500 mm in the north (where temperatures are higher).

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This map provides the location of the various ecosystems illustrated on this and the preceding page. There are many more ecosystem types not illustrated here.



Coral Reef Ecosystem
In the northern regions of the Australian coastline, the water is warm enough to support the growth of coral reefs. The reefs, composed of the bodies of tiny animals, provide an immensely rich variety of habitats for many other kinds of marine organism to exploit.

1. For each of the ecosystems illustrated in the photographs on this and the preceding page, identify the likely location of the ecosystem from the map above (the billabong ecosystem has been excluded). Study the main physical features and take note of the predominant flora and fauna present. Consult an atlas showing vegetation types and the previous two pages to give you a clue to some of the locations:

   (a) Mulga shrubland ecosystem: _____

   (b) Highland heathland ecosystem: _____

   (c) Rock platform ecosystem: _____

   (d) Tropical rainforest ecosystem: _____

   (e) Wet sclerophyll forest ecosystem: _____

   (f) Desert ecosystem: _____

   (g) Coral reef ecosystem: _____

2. Describe the key physical factors (abiotic) that determine the kind of community that exists in each ecosystem (e.g. high water temperature, cool air temperature, solid rock substrate, slight wave action, high rainfall):

   (a) Mulga shrubland ecosystem: _____

   _____

   (b) Highland heathland ecosystem: _____

   _____

   (c) Rock platform ecosystem: _____

   _____

   (d) Tropical rainforest ecosystem: _____

   _____

   (e) Wet sclerophyll forest ecosystem: _____

   _____

   (f) Desert ecosystem: _____

   _____

   (g) Coral reef ecosystem: _____

   _____

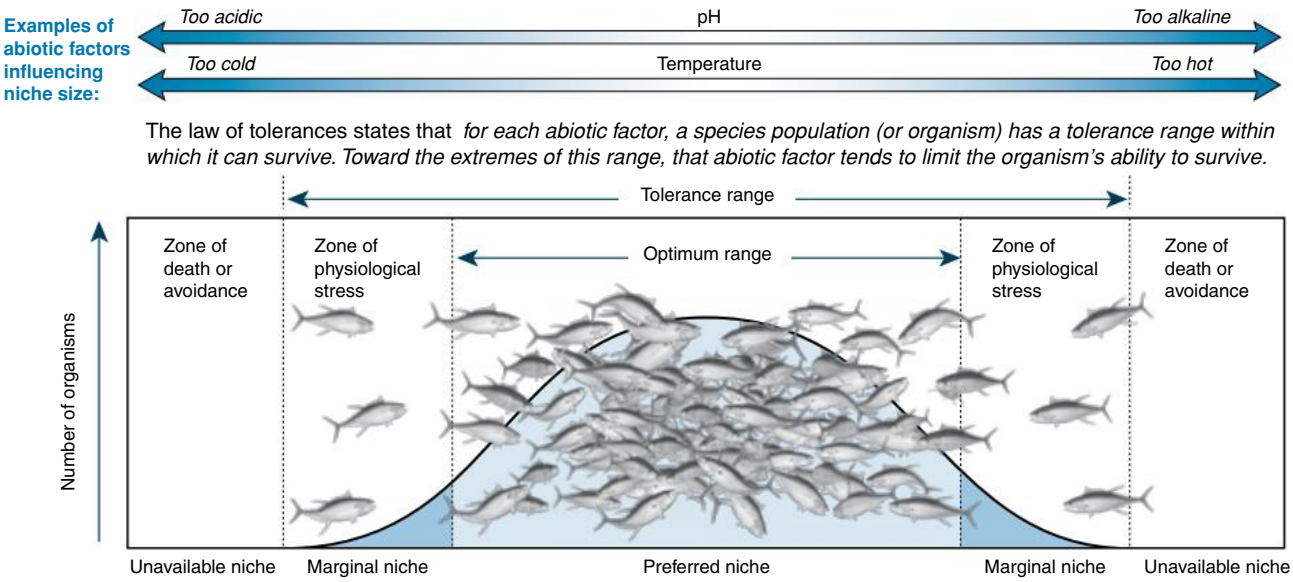
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181 Habitat

Key Idea: The environment in which an organism lives is its habitat. The habitat may not be homogeneous in its quality.

The environment in which an organism (or species) lives (including all the physical and biotic factors) is its **habitat**. Within any habitat, each species has a range of tolerance to variations in its environment. Within the population, individuals will have slightly different tolerance ranges based on small differences in genetic make-up, age, and health. The wider an organism's tolerance range for any one factor (e.g. temperature) the more likely it is that the organism will survive variations in that factor. For the same reasons, species with a wider tolerance range are likely to be more widely distributed. Organisms have a narrower **optimum range** within which they function best. This may vary seasonally or during development. Organisms are usually most abundant where the abiotic factors are closest to the optimum range.

Habitat Occupation and Tolerance Range



The Scale of Available Habitats



A habitat may be vast and relatively homogeneous, as is the open ocean. Barracuda (above) occur around reefs and in the open ocean where they are aggressive predators.



For non-mobile organisms, such as the fungus above, a suitable habitat may be defined by the particular environment in a relatively tiny area, such as on this decaying log.



For microbial organisms, such as the bacteria and protozoans of the ruminant gut, the habitat is defined by the chemical environment within the rumen (R) of the host animal, in this case, a cow.

1. What is the relationship between an organism's tolerance range and the habitat it occupies? _____

2. (a) In the diagram above, in which range is most of the population found? Explain your answer: _____

   (b) What are the greatest constraints on an organism's growth and reproduction within this range? _____

3. Describe some probable stresses on an organism forced into a marginal niche: _____

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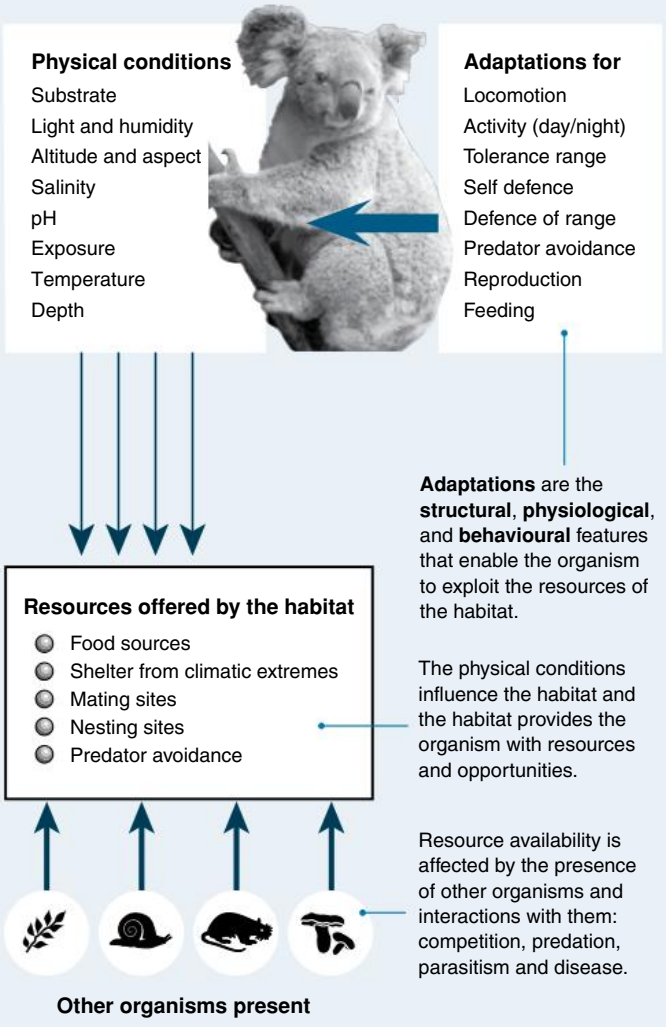
LINK 183 KNOW

182 Ecological Niche

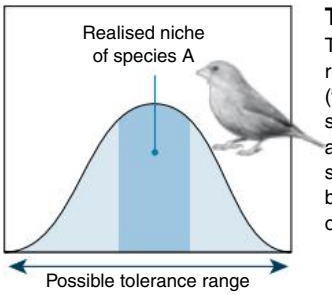
Key Idea: An organism's niche describes its functional role within its environment.

The **ecological niche** describes the functional position of a species in its ecosystem. It includes how the species responds to the distribution of resources and how it alters those resources for other species. The full range of environmental conditions under which an organism can exist describes its fundamental niche. As a result of interactions with other organisms, species usually occupy a realised niche that is narrower than this. Central to the niche concept is the idea that two species with exactly the same niche cannot coexist, because they would compete for the same resources and one would exclude the other. This is known as **Gause's competitive exclusion principle**. More often, species compete for some of the same resources. Competition will be intense where their resource use curves overlap.

The Ecological Niche

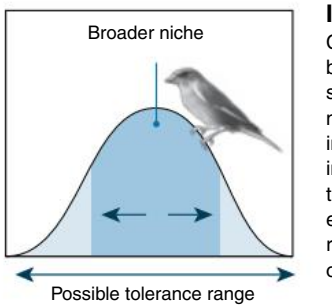


Competition and Niche Size



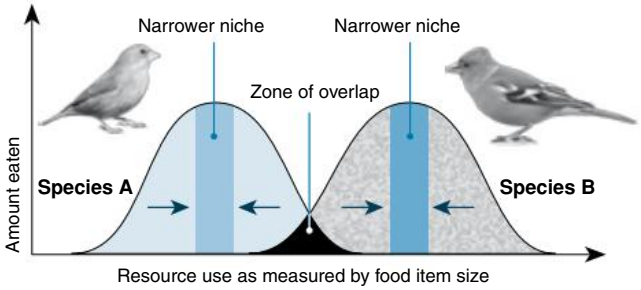
The realised niche

The tolerance range represents the potential (**fundamental**) niche a species could exploit. The actual or **realised** niche of a species is narrower than this because of competition with other species.



Intraspecific competition

Competition is strongest between individuals of the same species, because their resource needs exactly overlap. When intraspecific competition is intense, individuals are forced to exploit resources in the extremes of their tolerance range. This leads to expansion of the realised niche.



Interspecific competition

If two (or more) species compete for some of the same resources, their resource use curves will overlap. Within the zone of overlap, resource competition will be intense and selection will favour niche specialisation so that one or both species occupy a narrower niche.

1. (a) In what way could the realised niche be regarded as flexible? _____

_____

_____

(b) What factors might further constrain the extent of the realised niche? _____

_____

2. Contrast the effects of interspecific competition and intraspecific competition on niche breadth: _____

_____

_____

_____

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183 Dingo Habitats

Key Idea: Organisms may need to exploit several different habitats to get the resources they need to survive.

Some animals range over a variety of habitats, partly in order to obtain different resources from different habitats, and sometimes simply because they are forced into marginal habitats by competition. Dingoes are found throughout Australia, in ecosystems as diverse as the tropical rainforests of the north to the arid deserts of the central Australia. Within each of these ecosystems, they may frequent several habitats or microhabitats.

Habitats Provide Resources

Species may tolerate wide variations in a range of physical and biotic factors. As a result of this tolerance range, the habitat that is occupied by members of a species may be quite variable.

The important thing is that the habitat provides resources for the organisms that live there. These resources include water, food, shelter, and places to raise offspring.

Some habitats can be richer in resources than others and are usually described with reference to their main features. For example, riverine habitats (rivers and creeks containing water and thick vegetated cover) provide water, food, and cover (right).



Dingo Habitats

Dingoes (right) are wild dogs found throughout Australia. The table on the far right gives information about five dingo packs at one location, including how much of their territory is made up of riverine areas. Kangaroos are the main prey for these dingoes.



Dingo pack name	Territory area (km^2)	Pack size	Dingo density	% of total territory made up of riverine areas
Pack A	113	12	10.6	10
Pack B	94	12		14
Pack C	86	3		2
Pack D	63	6		12
Pack E	45	10		14

1. Calculate the density of each of the dingo packs using the equation below, and record it in the table above. The first one has been done for you.

Density = pack size ÷ territory area x 100

2. (a) Plot a scatter graph (right) of dingo density versus how much of their territory is made up of riverine areas for each pack.

(b) Describe the relationship between dingo density and amount of riverine area:

_____

_____

_____

_____

(c) Can you explain why this relationship might occur?

_____

_____

_____

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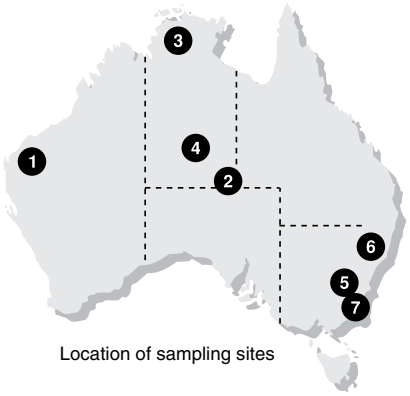
184 Dingo Home Ranges

Key Idea: A home range is the area an animal normally inhabits. Home range size is influenced by available resources.

The **home range** is the area where an animal normally lives and moves about in. An animal's home range can vary greatly in size. Animals that live in ecosystems rich in resources (e.g. good supply of food, water, shelter) tend to have smaller home ranges than animals that live in resource-poor ecosystems. This is because animals in a resource-poor ecosystem must cover a wider area to obtain the resources they need to survive and reproduce.

Dingo Home Ranges

Dingoes are found throughout Australia, in very diverse ecosystems such as the tropical rainforests of the north and the arid deserts of central Australia. The table (right) shows the home range sizes for dingo packs living in a variety of ecosystems. Some of the ecosystems in Australia in which dingoes are found are described in the photo panel below.

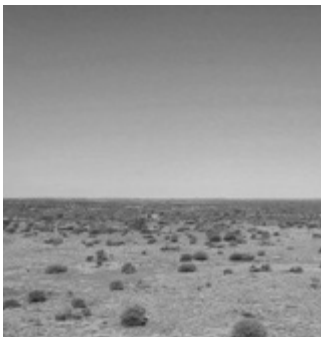


Location of sampling sites

Dingo Home Range Size in Different Ecosystems

	Location (study site)	Ecosystem	Range (km^2)
1	Fortescue River, North-west Australia	Semi-arid, coastal plains and hills	77
2	Simpson Desert, Central Australia	Arid, stony and sandy desert	67
3	Kapalga, Kakadu N.P., North Australia	Tropical, coastal wetlands and forests	39
4	Harts Ranges, Central Australia	Semi-arid, river catchment and hills	25
5	Kosciusko N.P., South-east Australia	Moist, cool forested mountains	21
6	Georges Creek N.R., East Australia	Moist, cool forested tablelands (plateaux)	18
7	Nadgee N.R., South-east Australia	Moist, cool coastal forests	10

Australian Ecosystems



Arid: Little or no rain, and very dry. Very little, or no, vegetation grows. Often desert regions.



Semi arid: Rainfall is low, but sufficient to support some scrubby vegetation and grasses.



Cool forests: Moderate temperatures. Adequate water as rainfall or snow. Abundant vegetation.



Tropical forests: Warm regions with high rainfall. Abundant lush vegetation, including large trees.

Temsabuita cc2.0

1. Using the information on dingo home range size from the table above:

   (a) Name the two regions where home ranges were largest: _____

   (b) Name the two regions where home ranges were smallest: _____

   (c) Use the information provided on Australian ecosystems to explain how ecosystem type influences the home range of the dingo packs identified in (a) and (b):

_____

_____

_____

_____

_____

_____

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185 Ecological Niches

Key Idea: Describing the ecological niche for an organism requires an understanding of its habitat, its role in the ecosystem, and its interactions with other organisms.

Use a textbook or the internet to describe the niche of the organism listed below. Include adaptive features they possess to exploit their niche.



Laughing kookaburra: *Dacelo novaeguineae*

1. Niche of the laughing kookaburra:
   - (a) Feeding: Diet: Insects, mice and small reptiles. Does not need drinking water.
   - (b) Activity: Diurnal. Territorial.
   - (c) Habitat: Open forests & woodlands in east and south west Australia.
   - (d) Adaptations: Tree nesting. Tolerates arid habitat. Extended parental care.



Taipan: *Oxyuranus scutellatus*

RA

2. Niche of the taipan:
   - (a) Feeding: _____
   - (b) Activity: _____
   - (c) Habitat: _____
   - (d) Adaptations: _____



Green and golden bell frog: ***Litoria aurea***

IS

3. Niche of the green and golden bell frog:
   - (a) Feeding: _____
   - (b) Activity: _____
   - (c) Habitat: _____
   - (d) Adaptations: _____



Bluebottle blowfly: ***Calliphora vomitoria***

EII

4. Niche of the bluebottle blowfly:
   - (a) Feeding: _____
   - (b) Activity: _____
   - (c) Habitat: _____
   - (d) Adaptations: _____



Prickly pear cactus: ***Opuntia stricta***

5. Niche of the prickly pear cactus:
   - (a) Feeding: _____
   - (b) Activity: _____
   - (c) Habitat: _____
   - (d) Adaptations: _____



Australian dingo: ***Canis lupus dingo***

6. Niche of the Australian dingo:
   - (a) Feeding: _____
   - (b) Activity: _____
   - (c) Habitat: _____
   - (d) Adaptations: _____

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LINK 245 LINK 183 LINK 182 KNOW

186 Physical Factors and Gradients

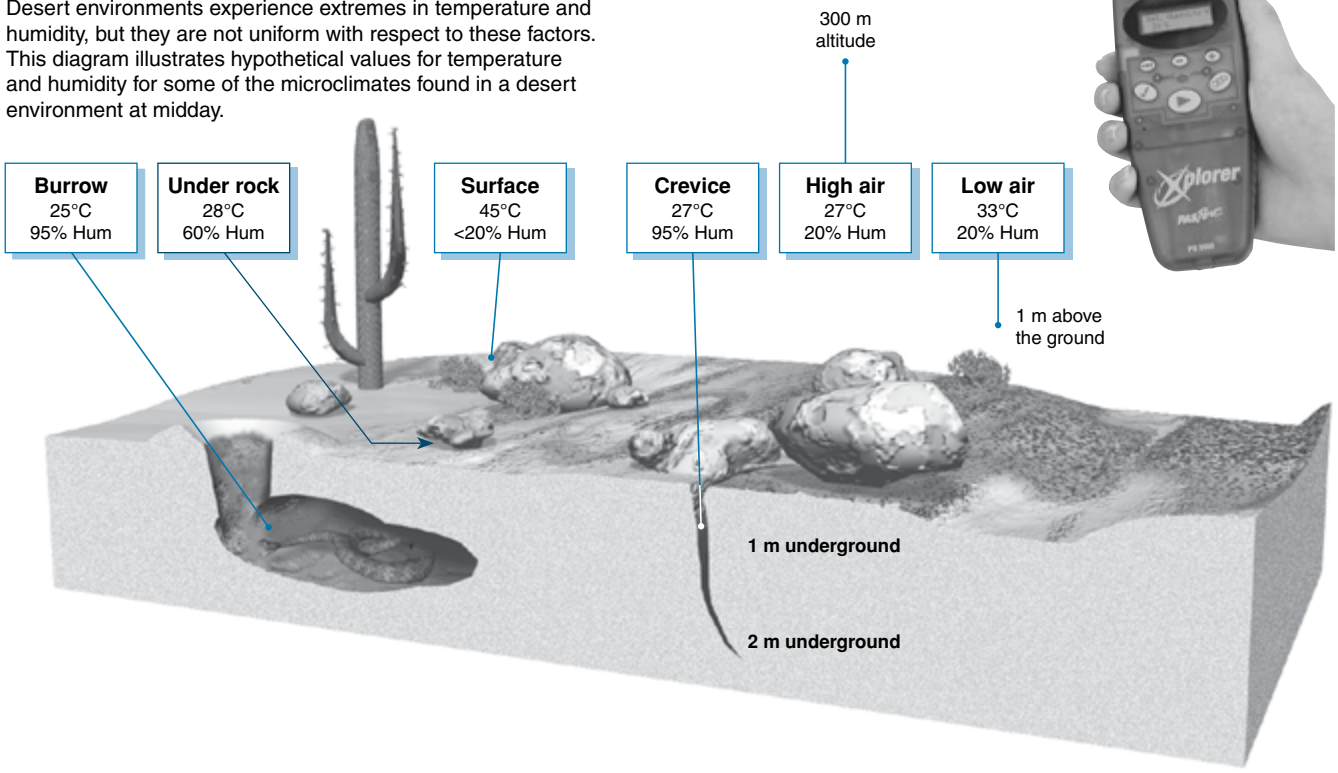
Key Idea: Within any particular habitat, physical factors may vary from one place to the next.

Gradients in abiotic factors are found in almost every environment. They influence habitats and microclimates, and determine patterns of species distribution. This activity examines the physical environment of a desert. Dataloggers (right) can be used to gather this kind of information.



A Desert Environment

Desert environments experience extremes in temperature and humidity, but they are not uniform with respect to these factors. This diagram illustrates hypothetical values for temperature and humidity for some of the microclimates found in a desert environment at midday.



1. Distinguish between **climate** and **microclimate**: _____

2. Study the diagram above and describe the general conditions where high humidity is found: _____

3. Identify the three microclimates that a land animal might exploit to avoid the extreme high temperatures of midday:

4. Describe the likely consequences for an animal that was unable to find a suitable microclimate to escape midday sun:

5. Describe the advantage of high humidity to the survival of most land animals: _____

6. Describe the likely changes to the temperature and relative humidity that occur during the night: _____

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LINK 190 LINK 192 LINK 194 LINK 196

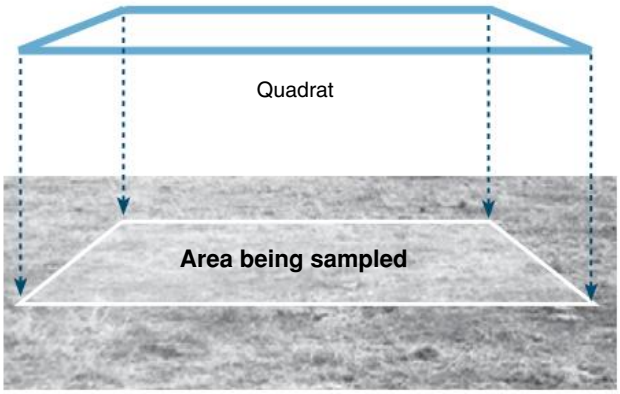
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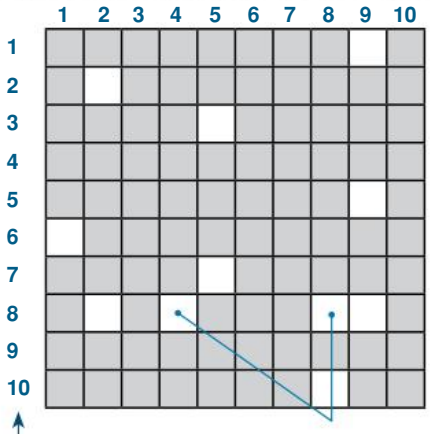
187 Quadrat Sampling

Key Idea: Quadrat sampling involves a series of random placements of a frame of known size over an area of habitat to assess the abundance or diversity of organisms.

Quadrat sampling is a method by which organisms in a certain proportion (sample) of the habitat are counted directly. It is used when the organisms are too numerous to count in total. It can be used to estimate population **abundance** (number), **density, frequency of occurrence**, and **distribution**. Quadrats may be used without a transect when studying a relatively uniform habitat. In this case, the quadrat positions are chosen randomly using a random number table.

The general procedure is to count all the individuals (or estimate their percentage cover) in a number of quadrats of known size and to use this information to work out the abundance or percentage cover value for the whole area.





The area to be sampled is divided up into a grid pattern with indexed coordinates

Quadrats are applied to the predetermined grid on a random basis. This can be achieved by using a random number table.

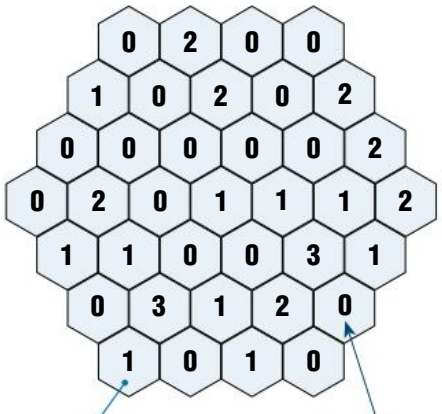
$$\text{Estimated average density} = \frac{\text{Total number of individuals counted}}{\text{Number of quadrats X area of each quadrat}}$$

Guidelines for Quadrat Use:

1. The **area of each quadrat** must be known. Quadrats should be the same shape, but not necessarily square.
2. **Enough quadrat samples** must be taken to provide results that are representative of the total population.
3. The **population of each quadrat** must be known. Species must be distinguishable from each other, even if they have to be identified at a later date. It has to be decided beforehand what the count procedure will be and how organisms over the quadrat boundary will be counted.
4. The size of the quadrat should be appropriate to the organisms and habitat, e.g. a large size quadrat for trees.
5. The quadrats must be **representative of the whole area.** This is usually achieved by **random sampling** (right).

Sampling a Centipede Population

A researcher by the name of Lloyd (1967) sampled centipedes in Wytham Woods, near Oxford in England. A total of 37 hexagon–shaped quadrats were used, each with a diameter of 30 cm (see diagram on right). These were arranged in a pattern so that they were all touching each other. Use the data in the diagram to answer the following questions.



Each quadrat was a hexagon with a diameter of 30 cm and an area of 0.08 square meters.

The number in each hexagon indicates how many centipedes were caught in that quadrat.

1. Determine the average number of centipedes captured per quadrat:

   _____

2. Calculate the estimated average density of centipedes per square metre (remember that each quadrat is 0.08 square metres in area):

   _____

3. Looking at the data for individual quadrats, describe in general terms the distribution of the centipedes in the sample area:

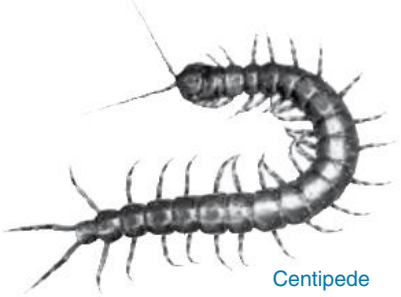
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   _____

4. Describe one factor that might account for the distribution pattern:

   _____

   _____



Centipede

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188 Quadrat-Based Estimates

Key Idea: The size and number of quadrats used to sample a community must be sufficient to be representative of that community without taking an excessively long time to use.

The simplest description of a community is a list of the species present. This does not provide information about the relative abundance of the species, although this can be estimated using abundance scales (e.g. ACFOR). Quadrats can provide quantitative information about a community. The size of the quadrat and the number of samples taken must represent the community as fairly as possible.

What Size Quadrat?

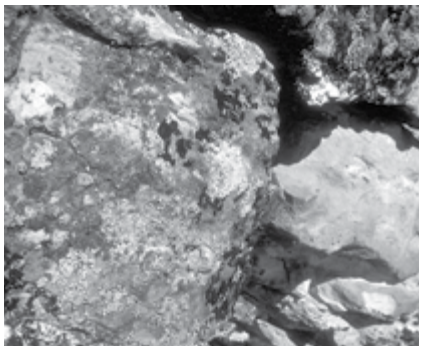
Quadrats are usually square, and cover 0.25 m^2 (0.5 m x 0.5 m) or 1 m^2, but they can be of any size or shape, even a single point. The quadrats used to sample plant communities are often 0.25 m^2. This size is ideal for low-growing vegetation, but quadrat size needs to be adjusted to habitat type. The quadrat must be large enough to be representative of the community, but not so large as to take a very long time to use.



A quadrat covering an area of 0.25 m^2 is suitable for most low growing plant communities, such as this alpine meadow, fields, and grasslands.



Larger quadrats (e.g.1m^2) are needed for communities with shrubs and trees. Quadrats as large as 4 m x 4 m may be needed in woodlands.



Small quadrats (0.01 m^2 or 100 mm x 100 mm) are appropriate for lichens and mosses on rock faces and tree trunks.

How Many Quadrats?

As well as deciding on a suitable quadrat size, the other consideration is how many quadrats to take (the sample size). In species-poor or very homogeneous habitats, a small number of quadrats will be sufficient. In species-rich or heterogeneous habitats, more quadrats will be needed to ensure that all species are represented adequately.

Determining the number of quadrats needed

- Plot the cumulative number of species recorded (on the y axis) against the number of quadrats already taken (on the x axis).
- The point at which the curve levels off indicates the suitable number of quadrats required.



Fewer quadrats are needed in species-poor or very uniform habitats, such as this bluebell woodland.

Describing Vegetation

Density (number of individuals per unit area) is a useful measure of abundance for animal populations, but can be problematic in plant communities where it can be difficult to determine where one plant ends and another begins. For this reason, plant abundance is often assessed using **percentage cover**. Here, the percentage of each quadrat covered by each species is recorded, either as a numerical value or using an abundance scale such as the ACFOR scale.

The ACFOR Abundance Scale

A = Abundant (30% +)
C = Common (20-29%)
F = Frequent (10-19%)
O = Occasional (5-9%)
R = Rare (1-4%)

The ACFOR scale could be used to assess the abundance of species in this wildflower meadow. Abundance scales are subjective, but it is not difficult to determine which abundance category each species falls into.



1. Describe one difference between the methods used to assess species abundance in plant and in animal communities:

   _____

2. What is the main consideration when determining appropriate quadrat size? _____

3. What is the main consideration when determining number of quadrats? _____

4. Explain two main disadvantages of using the ACFOR abundance scale to record information about a plant community:

   (a) _____

   (b) _____

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189 Stratification in a Forest

Key Idea: Forest stratification is a vertical layering pattern arising as a result of tree species growing to different heights.

Forest communities throughout the world show a pattern of vertical layering called **stratification**. Tropical rainforests can be divided into four layers (or strata) that represent zones of different vegetation. The enormous diversity of species found in rainforests can be supported because the vertical structure itself creates variation in physical factors and microclimate. While a general stratification pattern can be described, species composition varies from region to region according to the altitude, rainfall, light levels, soil type, and drainage. The tallest trees are the emergents and may be 60 m in height. Canopy trees fill the gaps between the emergents. The canopy trees provide habitat for perching plants (epiphytes) and large woody climbing vines called lianes clamber up through the canopy trees to the light. Below the canopy layer spreads the subcanopy of saplings, tree ferns and palms and a ground layer of shade loving plants.

Structure of a Tropical Rainforest

Australia's tropical rainforests grow in Queensland between Ingham, near Townsville and the tip of the Cape York Peninsula.

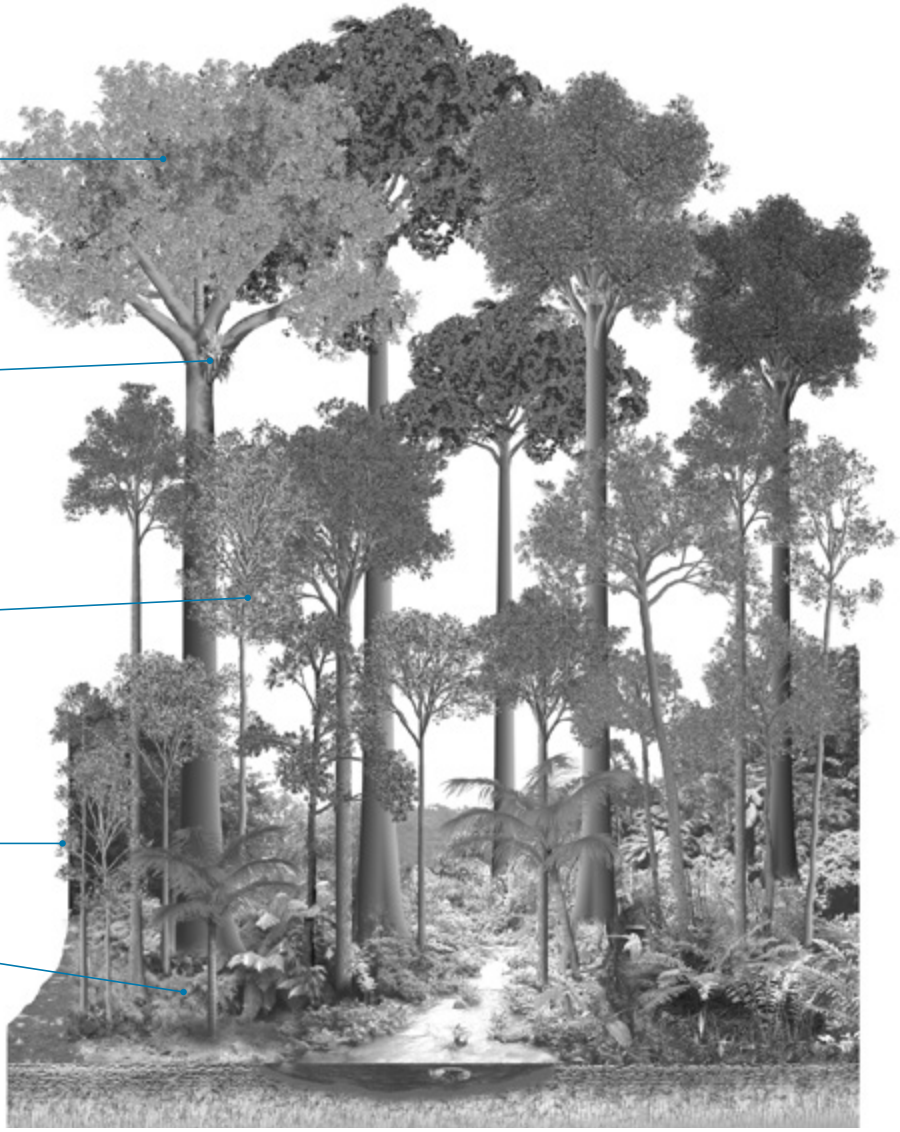
Canopy
The topmost canopy layer is usually uneven, reaching a height of 20-40 metres and intercepting most of the direct sunlight falling on the forest. In places there are scattered broad-leaved emergents, with the sides of the crowns exposed above the canopy. Species include walnuts (*Beilschmiedia* spp.), cassowary satinash, and banana fig.

Epiphytes and lianes
Some ferns and orchids have no contact with the soil. These plants are called epiphytes, and they cling to the trunks of the larger canopy trees or grow in the leaf litter accumulating on branches. Lianes (e.g. *Calamus* spp.) are rooted in the ground, but clamber into the canopy. They may develop a leaf area greater than the canopy trees themselves.

Subcanopy
This lower level contains some smaller tree species that may never reach the canopy. The layering may be obscured by intermediate sizes of potential canopy trees that are still growing (transgressives).

Understorey
Comprises saplings, tree ferns (*Cyathea*), and palms (e.g. *Calamus* and *Pandanus*)

Ground layer
A layer composed of shade adapted plants: ferns (e.g. *Selaginella*), mosses, fungi, lichens, and giant fleshy herbs with rhizomes (zingibers such as *Altphinia* and the banana, *Musa*). In some forests, this layer incorporates the understorey species. The forest floor is covered with rotting and dead vegetation.



1. Draw horizontal lines on the diagram to indicate the boundary of each stratification layer. Label each layer.
2. Review the page on physical gradients in a rainforest earlier in this section before answering this question:

   (a) Describe some of the general adaptations to physical conditions in the upper forest shown by canopy trees:

   _____

   _____

   (b) Describe some of the general adaptations to physical conditions shown by plants growing on the forest floor:

   _____

   _____

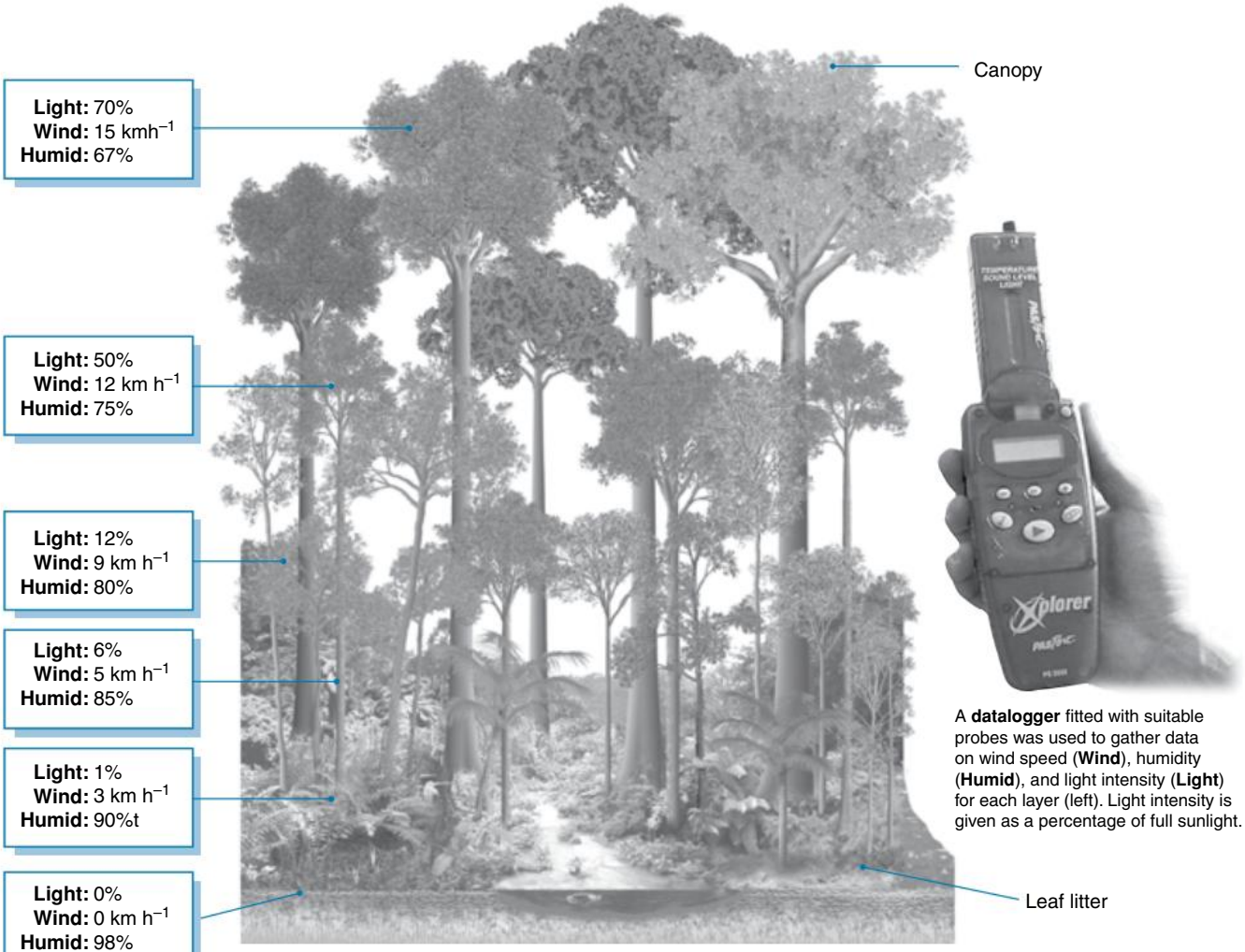
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LINK 190 WEB 189 KNOW

190 Physical Factors in a Forest

Key Idea: Gradients in physical conditions can occur vertically in a forest from the floor to the canopy.

In some communities, environmental gradients can occur with vertical distance from the ground. In a vertically structured community, such as a rainforest, the community structure gives rise to a gradient in physical factors. Light quantity and quality, humidity, wind speed, and temperature change gradually from the canopy to the forest floor. This a consequence of the modification of the physical environment by the species present at each layer.



Tropical rainforests are complex communities with a vertical structure which divides the vegetation into layers. This pattern of vertical layering is called **stratification**.

A **datalogger** fitted with suitable probes was used to gather data on wind speed (**Wind**), humidity (**Humid**), and light intensity (**Light**) for each layer (left). Light intensity is given as a percentage of full sunlight.

1. Identify the general trend from the canopy to the leaf litter for each of the following:

   (a) Light intensity: _____ (b) Wind speed: _____ (c) Humidity: _____

2. Explain why each of these factors changes as the distance from the canopy increases:

   (a) Light intensity: _____

   _____

   (b) Wind speed: _____

   _____

   (c) Humidity: _____

   _____

3. What other feature of light, other than intensity, will also change with distance from the canopy and why?

   _____

   _____

   _____

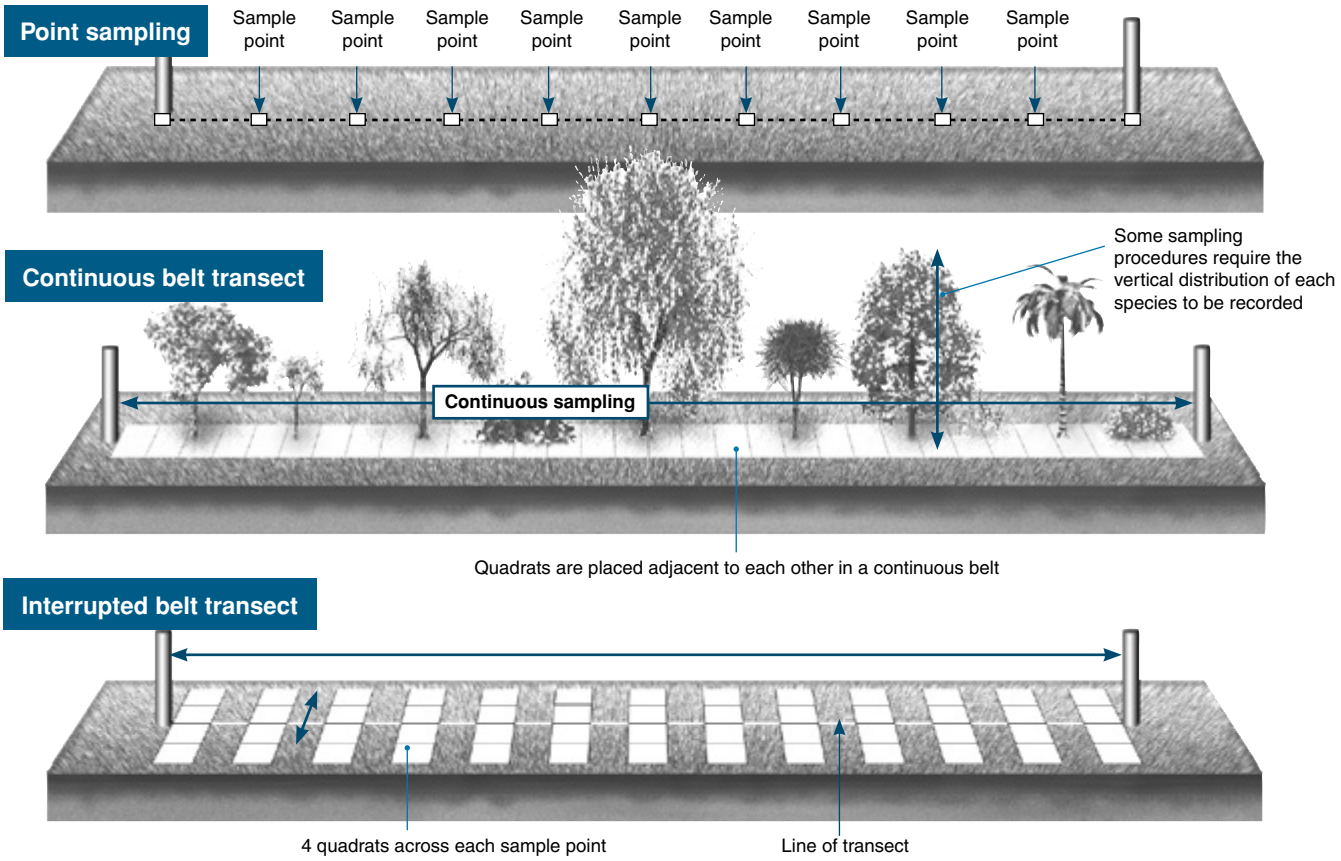
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191 Transect Sampling

Key Idea: Transect sampling is useful for providing information on species distribution along an environmental gradient.

A **transect** is a line placed across a community of organisms. Transects provide information on the distribution of species in the community. They are particularly valuable when the transect records community composition along an **environmental gradient** (e.g. up a mountain or across a seashore). The usual practice for small transects is to stretch a string between two markers. The string is marked off in measured distance intervals and the species at each marked point are noted. The sampling points along the transect may also be used for the siting of quadrats, so that changes in density and community composition can be recorded. Belt transects are essentially a form of continuous quadrat sampling. They provide more information on community composition but can be difficult to carry out. Some transects provide information on the vertical, as well as horizontal, distribution of species (e.g. tree canopies in a forest).



1. Belt transect sampling uses quadrats placed along a line at marked intervals. In contrast, point sampling transects record only the species that are touched or covered by the line at the marked points.

   (a) Describe one disadvantage of belt transects: _____

   _____

   (b) Why might line transects give an unrealistic sample of the community in question? _____

   _____

   _____

   (c) How do belt transects overcome this problem? _____

   _____

   (d) When would it not be appropriate to use transects to sample a community? _____

   _____

2. How could you test whether or not a transect sampling interval was sufficient to accurately sample a community?

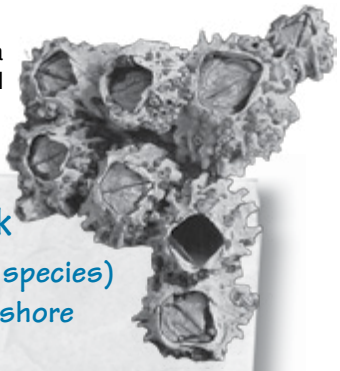
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A **kite graph** is a good way to show the distribution of organisms sampled using a belt transect. Data may be expressed as abundance or percentage cover along an environmental gradient. Several species can be shown together on the same plot so that the distributions can be easily compared.



3. The data on the right were collected from a rocky shore field trip. Four common species of barnacle were sampled in a continuous belt transect from the low water mark, to a height of 10 m above that level. The number of each of the four species in a 1 m^2 quadrat was recorded.

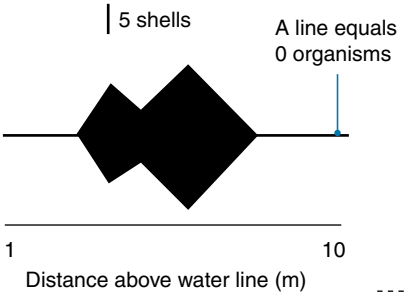
   Plot a **kite graph** of the data for all four species on the grid below. Be sure to choose a scale that takes account of the maximum number found at any one point and allows you to include all the species on the one plot. Include the scale on the diagram so that the number at each point on the kite can be calculated.

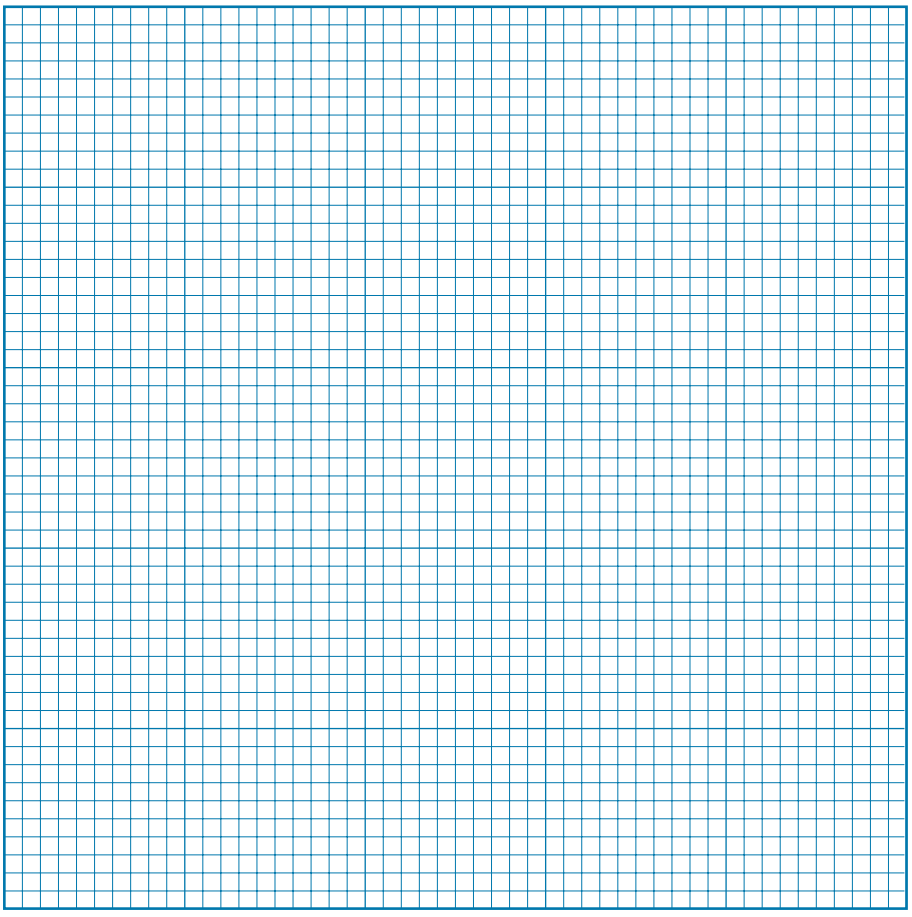
Field data notebook

Numbers of barnacles (4 common species) showing distribution on a rocky shore

Height above low water (m)	Barnacle species			
	Plicate barnacle	Columnar barnacle	Brown barnacle	Sheet barnacle
0	0	0	0	65
1	10	0	0	12
2	32	0	0	0
3	55	0	0	0
4	100	18	0	0
5	50	124	0	0
6	30	69	2	0
7	0	40	11	0
8	0	0	47	0
9	0	0	59	0
10	0	0	65	0

An Example of a Kite Graph



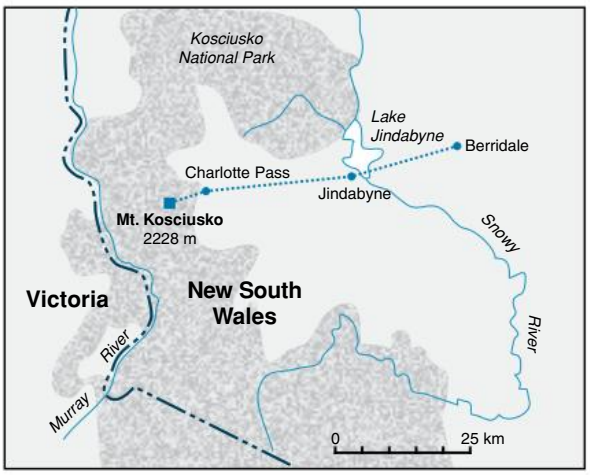


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192 Community Change With Altitude

Key Idea: Changes in physical factors associated with increasing altitude produce marked bands of vegetation (zonation).

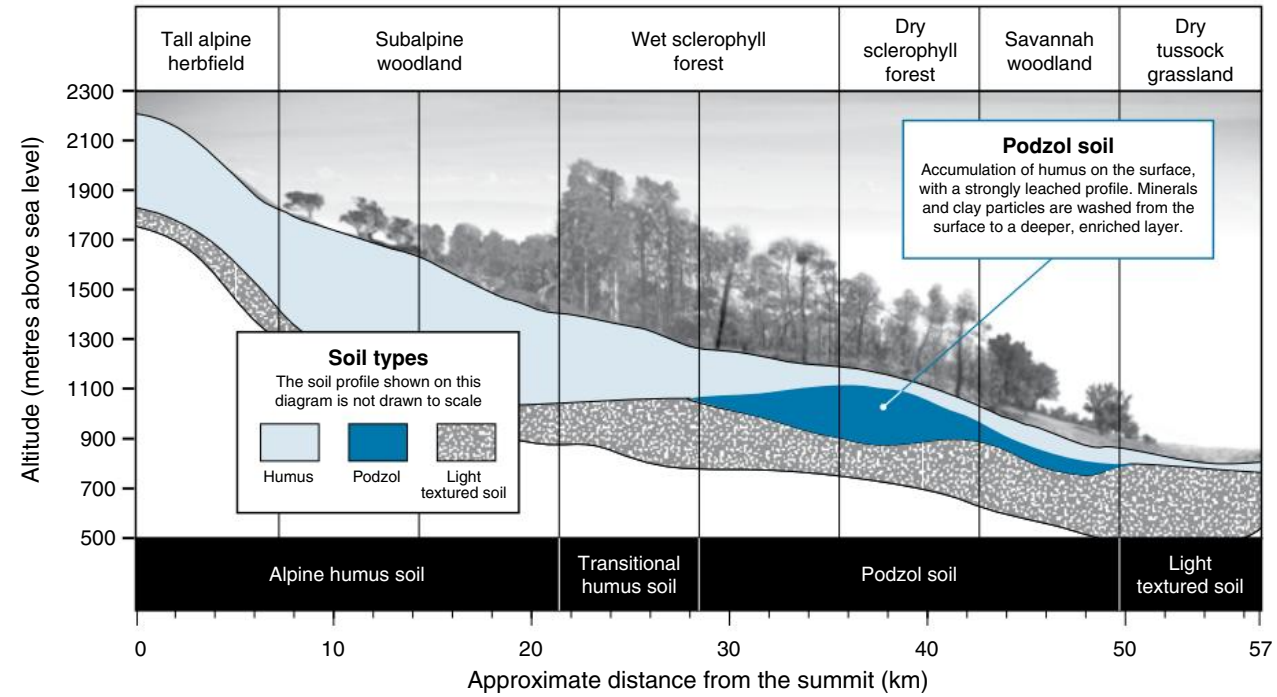
The Kosciusko National Park lies on the border between Victoria and New South Wales. In 1959, a transect between Berridale and the summit of Mt. Kosciusko was sampled. The map on the right shows the transect as a dotted line representing a distance of some 50-60 km.

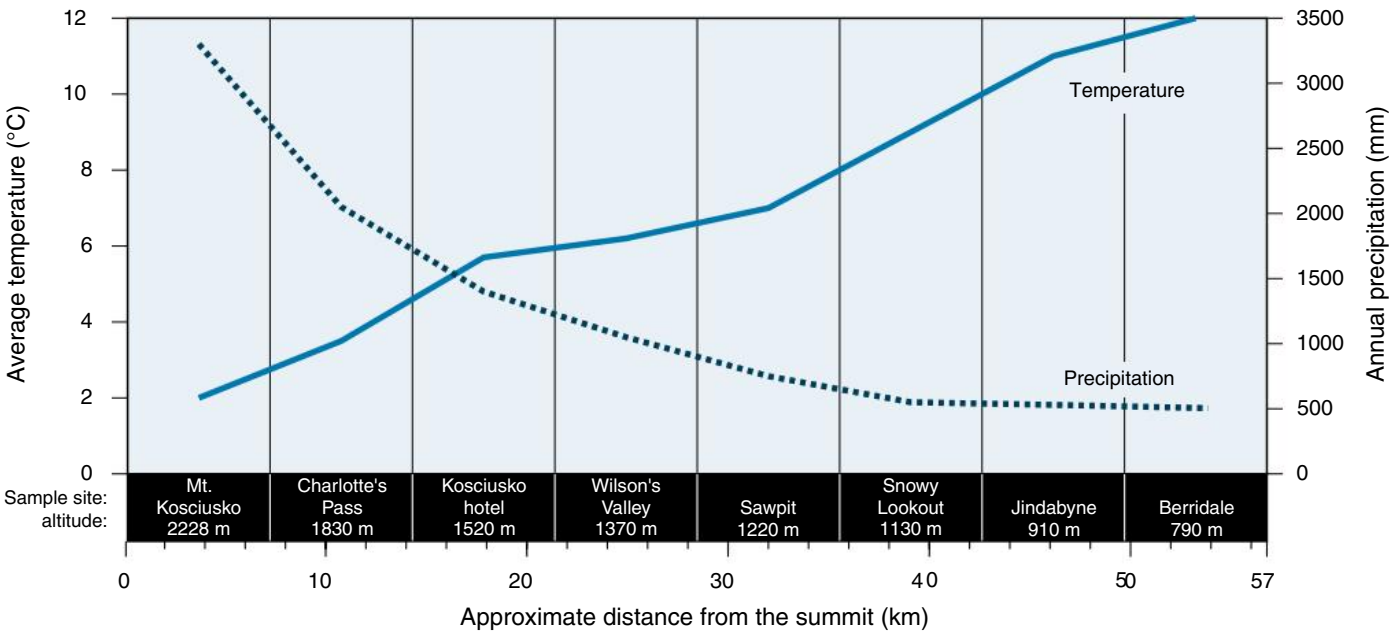


The distribution of plant species on Mount Kosciusko is affected by changes in the physical conditions with increasing altitude. The two graphs below show (1) the profile of the transect showing changes in vegetation and soil types with increasing altitude and (2) the changes in temperature and rainfall (precipitation) with altitude.

The low altitude soil around Berridale has low levels of organic matter supporting dry tussock grassland vegetation. The high altitude alpine soils are rich in organic matter, largely because of slow decay rates.

Profile of Mount Kosciusko





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LINK 191 DATA

1. Calculate the vertical distance (change in altitude) in metres, between Berridale and Mount Kosciusko: _____

2. Name the three physical factors illustrated on the previous page: _____

_____

3. Using the diagrams and graphs on the previous page, describe the following physical measurements for the three sample sites listed below:

	Altitude (m)	Temperature (°C)	Precipitation (mm)	Soil type
Berridale:				
Wilson's Valley:				
Mt Kosciusko:				

4. Study the graph of temperature vs altitude. How does the **temperature** change with increasing altitude?

_____

5. Study the graph of precipitation vs altitude. How does the **precipitation** change with increasing altitude?

_____

6. Why is the leaf litter slow to decay in alpine soil? _____

_____

7. What is the name given to the banded distribution pattern of the vegetation on the slopes of Mt. Kosciusko?

_____

8. Wet sclerophyll forest is found part way up the slope of Mt. Kosciusko.

   (a) Study the profile on the previous page and determine the **altitude range** for wet sclerophyll forest (in metres):

   _____

   (b) What physical factor probably prevents the wet sclerophyll forest growing at a lower altitude?

   _____

   (c) What physical factor probably prevents the wet sclerophyll forest growing at a higher altitude?

   _____

9. Name a physical factor other than temperature or precipitation that changes with altitude: _____

_____

10. Describe another example of a banded pattern of species distribution in response to an environmental gradient:

_____

_____

11. Discuss the contribution of environmental gradients to community diversity: _____

_____

_____

_____

_____

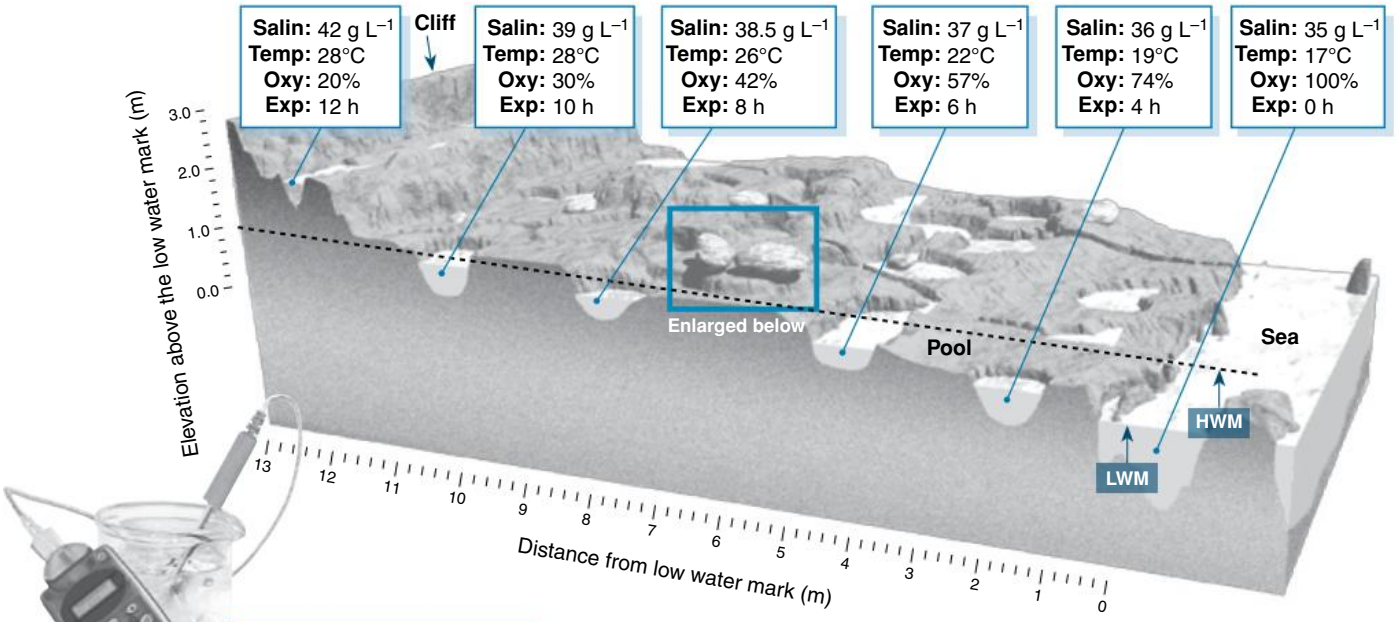
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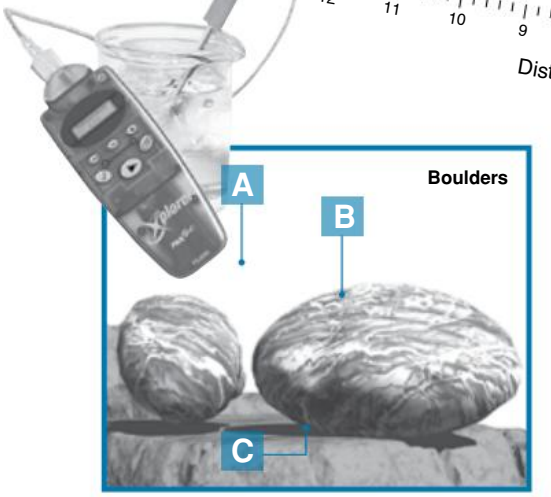
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193 Physical Factors on a Rocky Shore

Key Idea: Physical factors influence the habitat and distribution of organisms.

Gradients in abiotic factors influence habitats and create microclimates, and are important in determining community patterns. This activity examines the physical gradients and microclimates that might be found on a rocky shore, where the community often shows clear zones of species distribution.





The diagram above shows a profile of a rock platform at low tide. The **high water mark** (HWM) shown is the average height of the spring tide. In reality, the high tide level varies with the phases of the moon. The **low water mark** (LWM) is an average level subject to the same variations. The rock pools vary in size, depth, and position on the platform. They are isolated at different elevations, trapping water from the ocean for time periods that may be relatively brief or up to 10-12 hours duration. Pools near the HWM are exposed for longer periods of time than those near the LWM. The difference in exposure times results in some of the physical factors exhibiting a **gradient**; the factor's value gradually changes over a horizontal and/or vertical distance. Physical factors sampled in the pools include salinity, or the amount of dissolved salts (g) per litre (**Salin**), temperature (**Temp**), dissolved oxygen compared to that of open ocean water (**Oxy**), and exposure, or the amount of time isolated from the ocean water (**Exp**).

1. Describe the environmental gradient (general trend) from the low water mark (LWM) to the high water mark (HWM) for:

   (a) Salinity: _____

   (b) Temperature: _____

   (c) Dissolved oxygen: _____

   (d) Exposure: _____

2. Rock pools above the normal high water mark (HWM), such as the uppermost pool in the diagram above, can have wide extremes of salinity. What abiotic conditions might cause these pools to have very high salinity?

   _____

   _____

3. (a) The inset diagram (above, left) is an enlarged view of two boulders on the rock platform. How might the abiotic factors listed below differ at each of the labelled points **A**, **B**, and **C**?

   Mechanical force of wave action: _____

   _____

   Surface temperature when exposed: _____

   _____

   (b) State the term given to these localised variations in physical conditions: _____

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194 Shoreline Zonation

Key Idea: Zonation is a community pattern in which there are visible strata or zones in an ecosystem caused by changes in abiotic and biotic factors along an environmental gradient.

Zonation refers to the division of an ecosystem into distinct zones that experience similar abiotic conditions. Zonation may also refer to the broad distribution of vegetation according to latitude and altitude. Zonation is particularly clear on rocky seashores, where assemblages of different species form a banding pattern approximately parallel to the waterline. Abiotic factors largely determine the broad zonation pattern, but biotic interactions will also influence species distributions. Rocky shores occur where wave action prevents deposition of much sediment, and the rock forms a stable platform for the secure attachment of organisms such as seaweeds and barnacles. Sandy shores are less stable and the organisms found there are adapted to a more mobile substrate.



Rocky shoreline

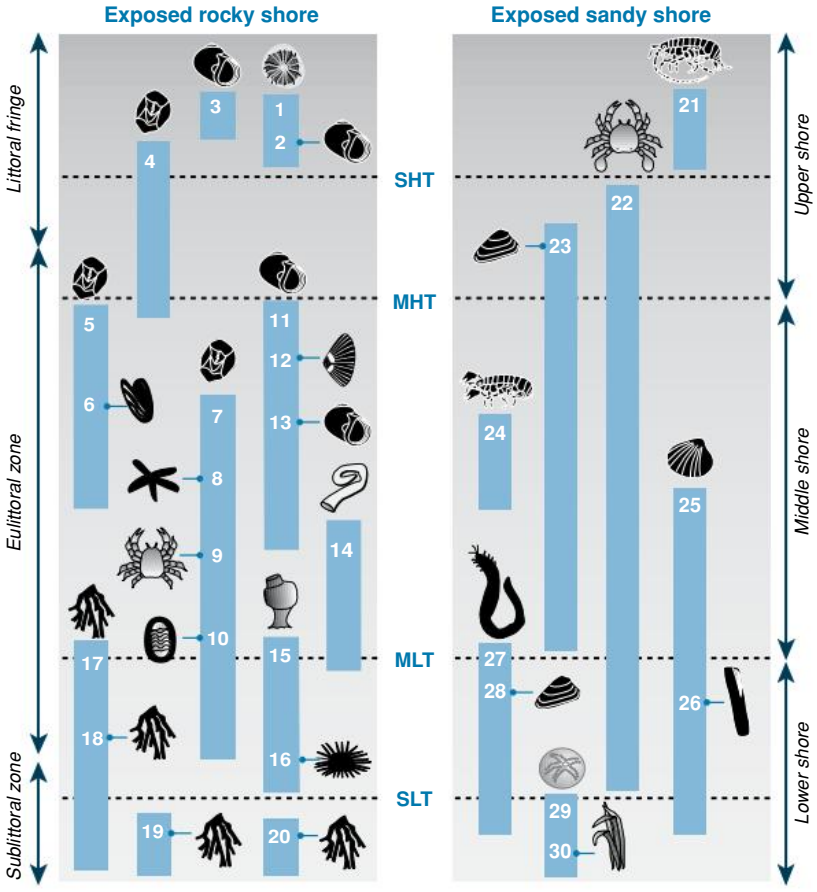
Key to Australian species

	Rocky shore		Sandy shore
1	Lichen	21	Sandhopper
2	Blue periwinkle	22	Ocean sand crab
3	Nodiwink mollusc	23	Narrow wedge shell
4	Honeycomb barnacle	24	Ghost shrimp
5	Surf barnacle	25	Flame dog cockle
6	Beaked mussel	26	Razor shell
7	Giant barnacle	27	Giant beach worm
8	Common sea star	28	Goolwa cockle
9	Rock crab	29	Sand urchin
10	Chiton	30	Sea grasses
11	Oyster borer		
12	Common limpet		
13	Striped conniwink		
14	Tubeworm		
15	Cunjevoi (sea squirt)		
16	Sea urchin		
17	Coralline algae		
18	Red algae		
19	Bubble weed		
20	Bull kelp		

Note: Where several species are indicated within a single zonal band, they occupy the entire zone, not just the position where their number appears.

Seashore Zonation Patterns

In Australia, exposed rocky shores occur along much of the coastline. Variations in low and high tide affect zonation, and in areas with little tidal variation, zonation is restricted. High on the shore, some organisms may be submerged only at spring high tide. Low on the shore, others may be exposed only at spring low tide. There is a gradation in extent of exposure and the physical conditions associated with this. Zonation patterns generally reflect the vertical movement of seawater. Sheer rocks can show marked zonation as a result of tidal changes with little or no horizontal shift in species distribution. The profiles below show generalised zonation patterns on an exposed rocky shore (left profile) with an exposed sandy shore for comparison (right profile). They are not intended to represent specific locations.
SLT = Extreme spring low tide mark, MLT = Mean low tide mark, MHT = Mean high tide mark, SHT = Extreme spring high tide mark.



Contact Newbyte Educational Software for details on their excellent *Rocky Shore Ecology* software package.

1. (a) Why is the time of exposure above water a major factor controlling species distribution on a rocky shore?

_____

(b) Identify two other abiotic factors that might influence species distribution on a rocky shore: _____

_____

(c) Identify two biotic factors that might influence species distribution on a rocky shore: _____

_____

2. Describe the zonation pattern on a rocky shore: _____

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195 Sampling a Rocky Shore Community

Key Idea: The estimates of a population gained from using quadrat sampling may vary depending on where the quadrats are placed. Larger samples can account for variation.

The diagram (next page) represents an area of seashore with its resident organisms. The distribution of coralline algae and four animal species are shown. This exercise is designed to prepare you for planning and carrying out a similar procedure to practically investigate a natural community.

1. Decide on the sampling method

For the purpose of this exercise, it has been decided that the populations to be investigated are too large to be counted directly and a quadrat sampling method is to be used to estimate the average density of the four animal species as well as that of the algae.

2. Mark out a grid pattern

Use a ruler to mark out 3 cm intervals along each side of the sampling area (area of quadrat = 0.03 x 0.03 m). **Draw lines** between these marks to create a 6 x 6 grid pattern (total area = 0.18 x 0.18 m). This will provide a total of 36 quadrats that can be investigated.

3. Number the axes of the grid

Only a small proportion of the possible quadrat positions are going to be sampled. It is necessary to select the quadrats in a random manner. It is not sufficient to simply guess or choose your own on a 'gut feeling'. The best way to choose the quadrats randomly is to create a numbering system for the grid pattern and then select the quadrats from a random number table. Starting at the *top left hand corner*, **number the columns** and **rows** from 1 to 6 on each axis.

4. Choose quadrats randomly

To select the required number of quadrats randomly, use random numbers from a random number table. The random numbers are used as an index to the grid coordinates. Choose 6 quadrats from the total of 36 using table of random numbers provided for you at the bottom of the next page. Make a note of which column of random numbers you choose. Each member of your group should choose a different set of random numbers (i.e. different column: A–D) so that you can compare the effectiveness of the sampling method.

Column of random numbers chosen: _____

NOTE: Highlight the boundary of each selected quadrat with coloured pen/highlighter.

5. Decide on the counting criteria

Before the counting of the individuals for each species is carried out, the criteria for counting need to be established. There may be some problems here. You must decide before sampling begins as to what to do about individuals that are only partly inside the quadrat. Possible answers include:

(a) Only counting individuals that are completely inside the quadrat.
(b) Only counting individuals with a clearly defined part of their body inside the quadrat (such as the head).
(c) Allowing for 'half individuals' (e.g. 3.5 barnacles).
(d) Counting an individual that is inside the quadrat by half or more as one complete individual.

Discuss the merits and problems of the suggestions above with other members of the class (or group). You may even have counting criteria of your own. Think about other factors that could cause problems with your counting.

6. Carry out the sampling

Carefully examine each selected quadrat and **count the number of individuals** of each species present. Record your data in the spaces provided on the next page.

7. Calculate the population density

Use the combined data TOTALS for the sampled quadrats to estimate the average density for each species by using the formula:

$$\text{Density} = \frac{\text{Total number in all quadrats sampled}}{\text{Number of quadrats sampled} \times \text{area of a quadrat}}$$

Remember that a total of 6 quadrats are sampled and each has an area of 0.0009 m^2. The density should be expressed as the number of individuals *per square metre (no. m^{-2})*.

Plicate barnacle: _____ Snakeskin chiton: _____

Oyster borer: _____ Coralline algae: _____

Limpet: _____

8. (a) In this example the animals are not moving. Describe the problems associated with sampling moving organisms. Explain how you would cope with sampling these same animals if they were really alive and very active:

_____

_____

_____

(b) Carry out a direct count of all 4 animal species and the algae for the whole sample area (all 36 quadrats). Apply the data from your direct count to the equation given in (7) above to calculate the actual population density (remember that the number of quadrats in this case = 36):

Barnacle: _____ Oyster borer: _____ Chiton: _____ Limpet: _____ Algae: _____

Compare your estimated population density to the actual population density for each species:

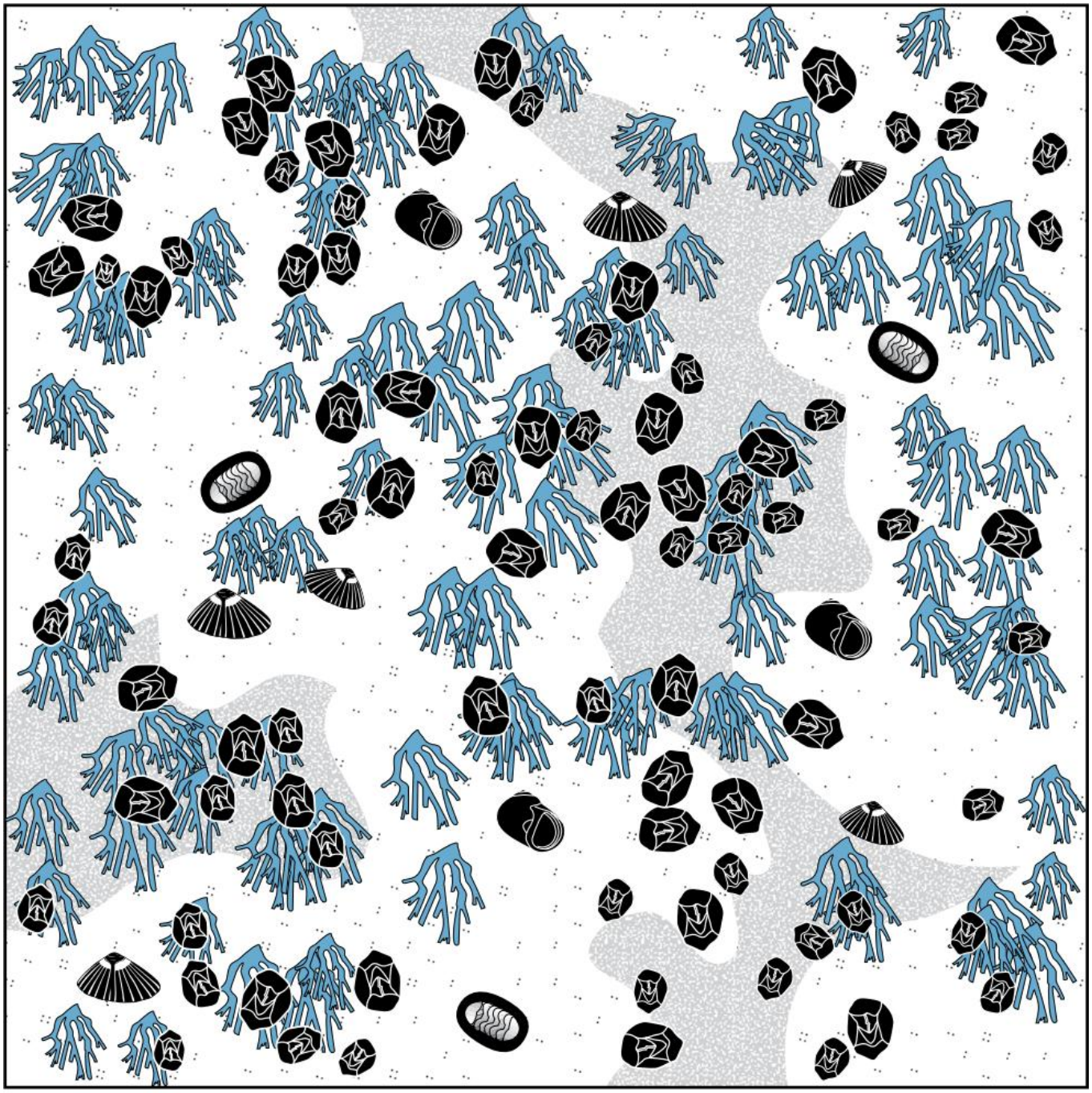
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_____

_____

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LINK 187 PRAC



Coordinates for each quadrat	Plicate barnacle	Oyster borer	Snakeskin chiton	Limpet	Coralline algae
1:					
2:					
3:					
4:					
5:					
6:					
TOTAL					

Table of random numbers

A	B	C	D
2 2	3 1	6 2	2 2
3 2	1 5	6 3	4 3
3 1	5 6	3 6	6 4
4 6	3 6	1 3	4 5
4 3	4 2	4 5	3 5
5 6	1 4	3 1	1 4

The table above has been adapted from a table of random numbers from a statistics book. Use this table to select quadrats randomly from the grid above. Choose one of the columns (A to D) and use the numbers in that column as an index to the grid. The first digit refers to the row number and the second digit refers to the column number. To locate each of the 6 quadrats, find where the row and column intersect, as shown below:

Example: 5 2 refers to the 5th row and the 2nd column

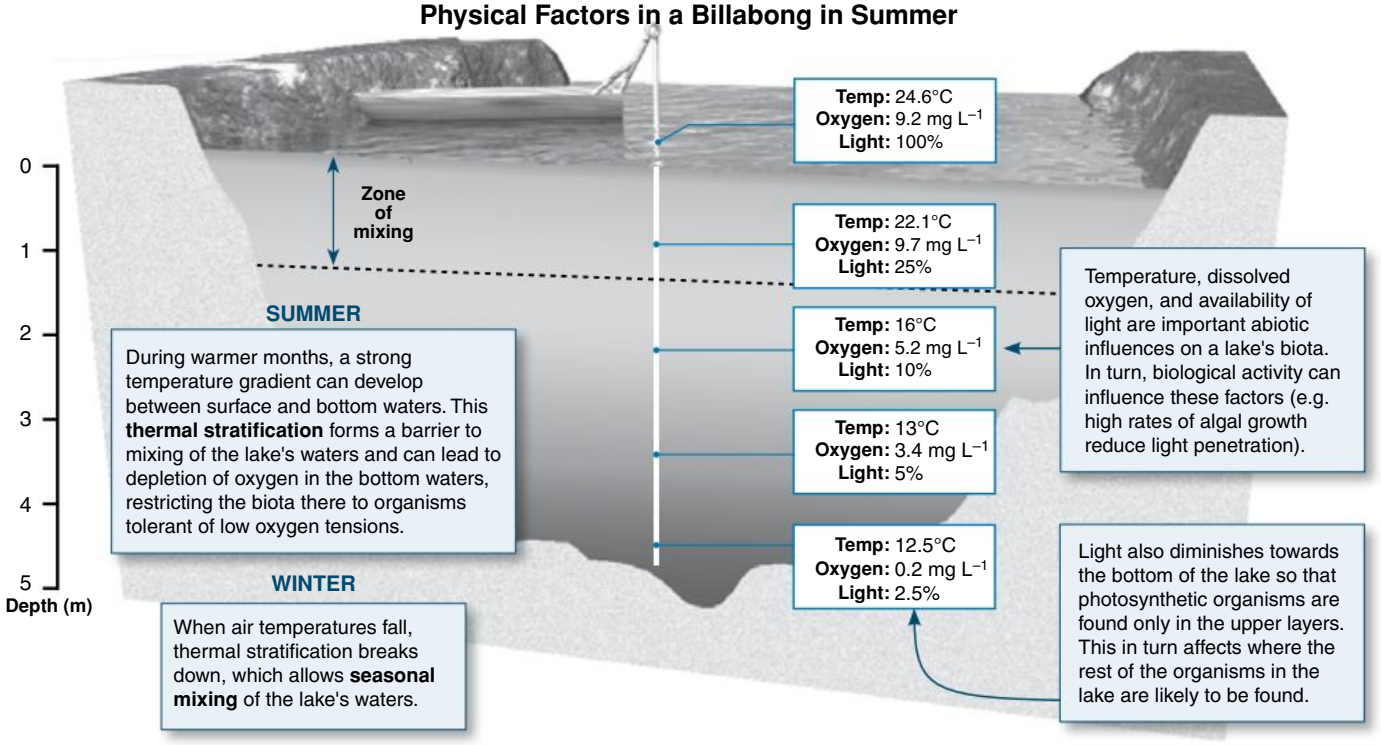
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196 Physical Factors in a Billabong

Key Idea: Changes in physical factors due to water depth can have an impact on the distribution on biota in a lake.

Billabongs (oxbow lakes) are formed from old river meanders which have been cut off and isolated from the main channel following the change of the river's course. They are usually shallow (2-4 m deep) but are sometimes deep enough to develop temporary, but relatively stable, temperature gradients from top to bottom. Billabongs are relatively closed systems and events in them are independent of those in nearby billabongs, where the water quality may be very different. The physical (abiotic) factors are not constant throughout the water column. Water at the surface and margins can have quite different values. Some of these factors are described in the diagram below.

Physical Factors in a Billabong in Summer



1. With respect to the diagram above, describe the environmental gradient (general trend) from surface to lake bottom for:

   (a) Water temperature: _____

   (b) Dissolved oxygen: _____

   (c) Light penetration: _____

2. During the summer months, the warm surface waters are mixed by wind action. Deeper cool waters are isolated from this surface water. This sudden change in the temperature profile is called a **thermocline** which itself is a further barrier to the mixing of shallow and deeper water.

   (a) What is the effect of the thermocline on the dissolved oxygen at the bottom of the lake? _____

   _____

   _____

   (b) What causes the oxygen level to drop to very low levels near the lake bottom? _____

   _____

3. Many of these shallow lakes can undergo great changes in their salinity (sodium, magnesium, and calcium chlorides):

   (a) What event could reduce the salinity of a small lake relatively quickly? _____

   (b) What process would gradually increase the salinity of a small lake? _____

4. What is the general effect of physical gradients on the distribution of organisms in habitats? _____

   _____

   _____

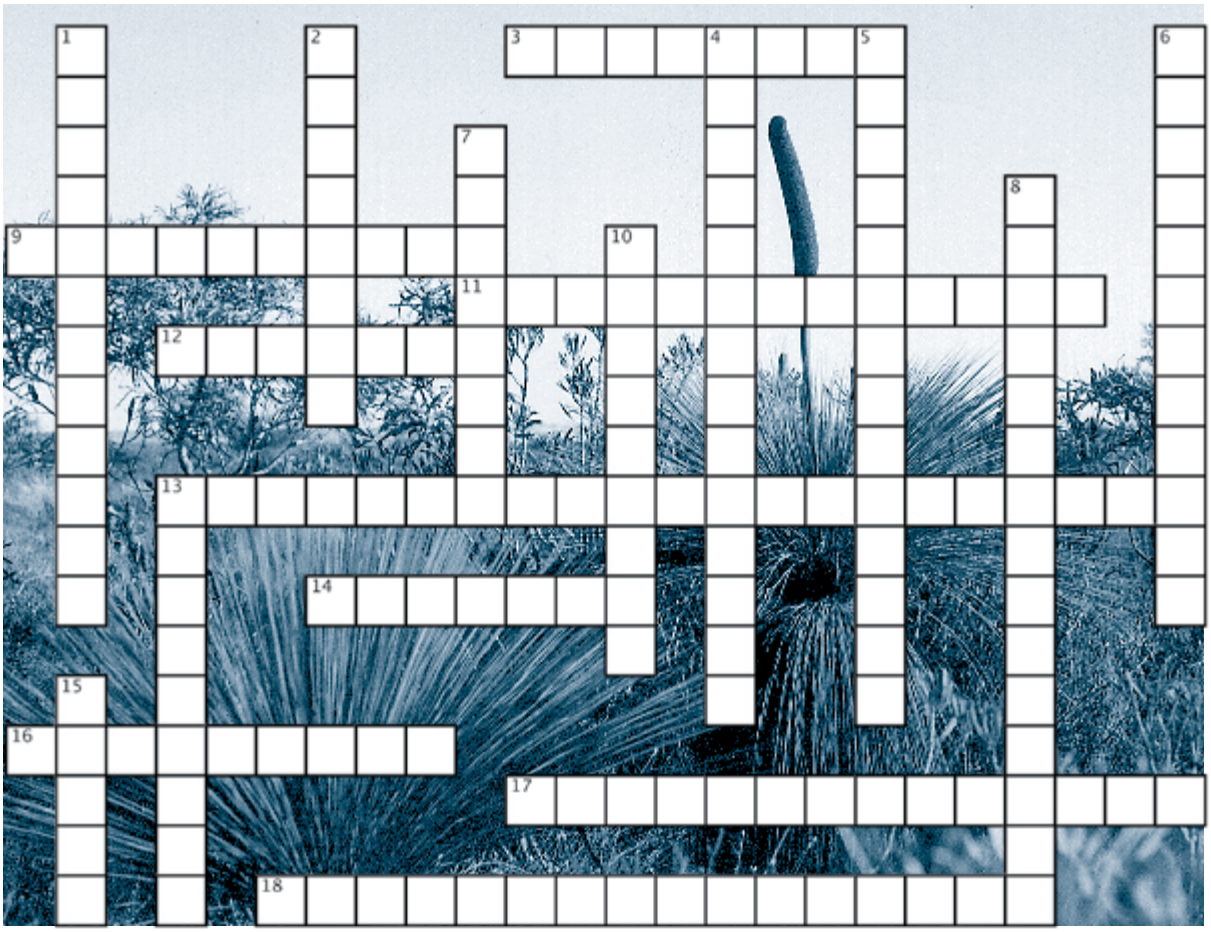
   _____

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LINK 186 KNOW

197 KEY TERMS: Crossword

Complete the crossword below, which will test your understanding of key terms in this chapter and their meanings



Clues Across

3. A line placed across a community of organisms to provide information on their distribution.
9. All the organisms that belong to the same species and live in the same geographical area.
11. The term used in ecology for any non-living part of the environment. (2 words; 7, 6)
12. A measured and marked region used to isolate a sample area for study.
13. The term to describe the gradual change in the characteristics of an environment from one region to another. (2 words; 13, 8)
14. The part of the environment which an organism occupies, e.g. stream or grassland.
16. The zone of all life on Earth, incorporating all organisms and their interactions with the lithosphere, hydrosphere and atmosphere.
17. Any factor that controls a process, such as organism growth or species population, size, or distribution. (2 words; 8, 6)
18. The potential multi-dimensional space that could be occupied by an individual. (2 words: 11, 5)

Clues Down

1. A sub-division of a habitat that possesses its own specific features.
2. The elevation above mean sea level.
4. A vertical pattern of vegetation layering in a forest that reflects changes in physical factors from the ground to the canopy.
5. The range of variations to the physical and chemical environment each species population can tolerate within the prescribed habitat. (2 words; 9, 5)
6. Factors including all living things within an environment, e.g. consumers, producers. (2 words: 6,6)
7. The division of an ecosystem into distinct areas that experience the same abiotic factors.
8. The multi-dimensional space that describes the functional position of an organism or species in the ecosystem (2 words: 10, 5).
10. A group of interacting species sharing an environment.
13. All the organisms living in a particular area, as well as all the non-living, physical components of the environment with which they interact.
15. A major regional ecological community.

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QLD As required
VCE Unit 2 (1)
WA ATAR Unit 4
SA Theme O

Environment and Adaptation

Key terms

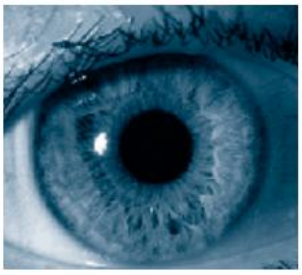
adaptation
annual
auxin
biological rhythm
circadian rhythm
circatidal rhythm
countercurrent exchange
courtship
crepuscular
diapause
dispersal
diurnal
dormancy
endotherm
ectotherm
environmental cue
halophyte
hibernation
hydrophyte
kinesis (pl. kineses)
mesophyte
migration
neurone
nocturnal
osmoregulation
parental care
perennial
phototropism
reflex
reproductive strategy
sense organ
taxis (pl. taxes)
thermoregulation
torpor
tropism
xerophyte

Plant responses and adaptation

Learning aims and skills

Activity number

- ☐ 1 Describe how plants respond to environmental factors. Describe and explain tropisms, including phototropism, and the role of auxins in tropic responses. — 198 199
- ☐ 2 Describe the physiological basis of plant responses to temperature changes. — 201 229
- ☐ 3 Describe the adaptations of plants, including:
  - (a) Life cycle adaptations, e.g. seed dormancy. — 229
  - (b) Adaptations of xerophytes, mesophytes, halophytes, or hydrophytes — 230-233
  - (c) Adaptations of Australian plants to fire. — 234


Animal responses and adaptation

Learning aims and skills

Activity number

- ☐ 4 Describe the adaptations in animals to their environment including adaptations of aquatic insects and diving animals, and the adaptations of human populations for living at high altitude. Describe adaptations in Australian animal species. — 202-204 208
- ☐ 5 Compare and contrast thermoregulation in ectotherms and endotherms. Describe the role of behaviour in regulating body temperature in an ectotherm. — 205
- ☐ 6 Describe adaptations for thermoregulation, including the role of countercurrent exchange systems in temperature regulation. Describe what happens when the physiological adaptations of the body are overwhelmed by environmental conditions and thermoregulation fails. — 206 207
- ☐ 7 Describe fluid and ion balance challenges faced by animals living in freshwater, marine, and terrestrial environments. Describe and explain the mechanisms for osmoregulation in animals. — 209 210
- ☐ 8 Describe and explain the water budgets of humans and desert rodents. — 211 212
- ☐ 9 Recognise neurones as the basic structural unit of nervous systems. Using an example, describe the basis of nervous control. Describe and explain reflexes. — 213 -215
- ☐ 10 Describe and explain the basis of hormonal control in multicellular organisms. — 214
- ☐ 11 Describe the range of sense organs for detecting stimuli in animals. — 216-219
- ☐ 12 Describe the role of behaviour in reproduction. — 220-223
- ☐ 13 Describe adaptive behaviours in animals, as below. For each, identify the environmental cue involved and how the behaviour is regulated:
  - (a) Reproductive behaviour and strategies (e.g. diapause). — 224
  - (b) Biological rhythms, e.g. circadian, circatidal, and annual rhythms. — 225
  - (c) Migration and dispersal behaviour. — 226
  - (d) Activity patterns, hibernation, and torpor. — 227
  - (e) Taxes (sing. taxis) and kineses (sing. kinesis). — 228

198 Plant Responses

Key Idea: Plants are rooted in the ground but can respond to their environment through changes in growth and physiology.

Even though most plants are firmly rooted in the ground, they can still respond to changes in their external environment, mainly through changes in patterns of growth. These responses are adaptive and serve to position the plant in a favourable environment. They may involve relatively sudden physiological changes, as in flowering, or a steady growth response, such as a **tropism**. Many of these responses involve annual, seasonal, or circadian (daily) rhythms.

Tropisms

Tropisms are growth responses made by plants to directional external stimuli, where the direction of the stimulus determines the direction of the growth response. A tropism may be positive (towards the stimulus), or negative (away from the stimulus). Common stimuli for plants include light, gravity, touch, and chemicals.

Life cycle responses

Plants use seasonal changes in the environment as cues for the commencement or ending of particular life cycle stages. Such changes are mediated by **plant growth factors**, such as phytochrome and gibberellin and enable the plant to avoid conditions unfavourable to growth or survival. Examples include flowering and other **photoperiodic responses**, dormancy and germination, and leaf fall.

Rapid responses to environmental stimuli

Plants are capable of quite rapid responses. Examples include the closing of **stomata** in response to water loss, opening and closing of flowers in response to temperature (photo, below right), and **nastic responses** (photos, below left). These responses often follow a circadian rhythm and are protective in that they reduce the plant's exposure to abiotic stress or grazing pressure.

Plant competition and allelopathy

Although plants are rooted in the ground, they can still compete with other plants to gain access to resources. Some plants produce chemicals that inhibit the growth of neighbouring plants. Such chemical inhibition is called **allelopathy**. Plants also compete for light and may grow aggressively to shade out slower growing competitors.

Plant responses to herbivory

Many plant species have responded to grazing or browsing pressure with evolutionary adaptations enabling them to survive constant cropping. Examples include rapid growth to counteract the constant loss of biomass (grasses), sharp spines or thorns to deter browsers (acacias, cacti), or toxins in the leaf tissues (eucalyptus).



1. Identify the stimuli to which plants typically respond and explain their significance: _____

_____

2. Explain how plants benefit by responding appropriately to the environment: _____

_____

_____

3. Describe one adaptive response of plants to each of the following stressors in the environment:

(a) Low soil water: _____

(b) Falling autumn air temperatures: _____

(c) High wind: _____

(d) Browsing animals: _____

(e) Low nighttime temperatures: _____

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199 Tropisms and Growth Responses

Key Idea: Tropisms are directional growth responses to external stimuli. They may be positive (towards a stimulus) or negative (away from a stimulus).

Tropisms are plant growth responses to external stimuli, in which the stimulus direction determines the direction of the growth response. Tropisms are identified according to the stimulus involved, e.g. photo- (light), gravi- (gravity), hydro- (water), and are identified as positive (towards the stimulus) or negative (away from the stimulus). Tropisms act to position the plant in the most favourable environment available.

(a) .....
A positive growth response to a chemical stimulus. *Example: Pollen tubes grow towards a chemical, possibly calcium ions, released by the ovule of the flower.*

(b) .....
Stems and coleoptiles grow away from the direction of the Earth's gravitational pull.

(c) .....
Growth response to water. Roots are influenced primarily by gravity but will also grow towards water.

(d) .....
Growth responses to light, particularly directional light. Coleoptiles, young stems, and some leaves show a positive response.

(e) .....
Roots respond positively to the Earth's gravitational pull, and curve downward after emerging through the seed coat.

(f) .....
Growth responses to touch or pressure. Tendrils (modified leaves) have a positive coiling response stimulated by touch.



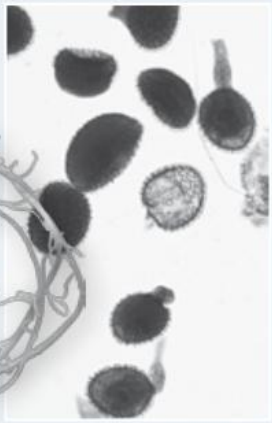
Plant growth responses are adaptive in that they position the plant in a suitable growing environment, within the limits of the position in which it germinated. They also tend to reinforce each other. For example, shoots grow away from gravity and towards the light.



Root mass in a hydroponically grown plant



Sweet pea tendrils



Germinating pollen



Thale cress bending to the light

Kristian Peters

1. Identify each of the plant tropisms described in (a)-(f) above. State whether the response is positive or negative.

2. Define the term **tropism** and explain the adaptive value of tropic responses to a plant in its environment:

3. Describe the adaptive value of the following tropisms:

   (a) Positive gravitropism in roots: _____

   (b) Positive phototropism in coleoptiles: _____

   (c) Positive thigmomorphogenesis in weak stemmed plants: _____

   (d) Positive chemotropism in pollen grains: _____

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LINK 200 WEB 199 KNOW

200 Investigating Phototropism

Key Idea: Experimental evidence supports the hypothesis that auxin is responsible for tropic responses in stems.

Phototropism in plants was linked to a growth promoting substance in the 1920s. Early experiments investigating phototropism in severed coleoptiles gave evidence for the hypothesis that the hormone **auxin** was responsible for tropic responses in stems. These experiments (below) have been criticised as being too simplistic, although their conclusions have been shown to be valid. Auxins promote cell elongation and are inactivated by light. Thus, when a stem is exposed to directional light, auxin becomes unequally distributed either side of the stem. The stem responds to the unequal auxin concentration by differential growth, i.e. it bends. The mechanisms behind this response are now well understood.

1. **Directional light**: A plant is exposed to direct sunlight near a window and, as it grows, the shoot tip turns in the direction of the sun. If rotated, the plant adjusts by growing towards the sun in the new direction.

   (a) What hormone regulates this growth response?

   _____

   (b) What is the name of this growth response?

   _____

   (c) How do the cells behave to bring about this change in shoot direction at:

   Point **A**?_____

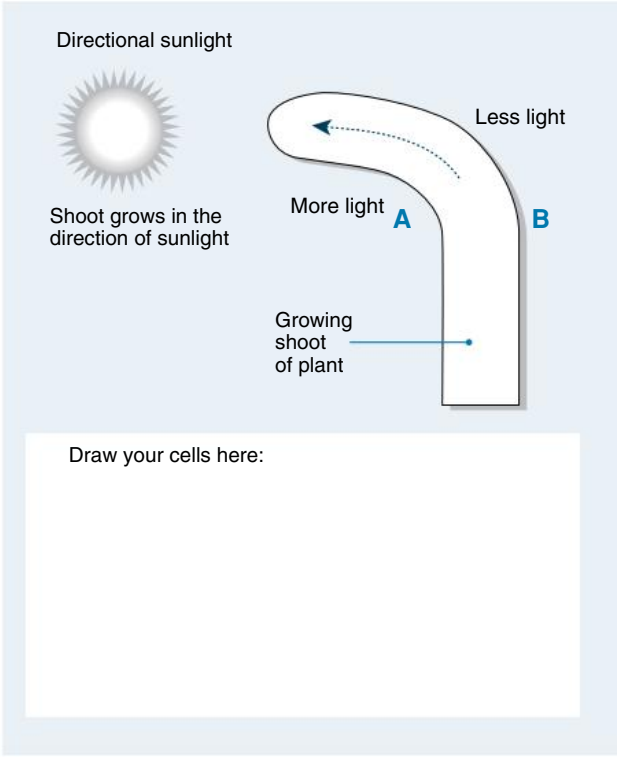
   Point **B**?_____

   (d) Which side (A or B) would have the highest concentration of hormone?

   _____

   (e) Draw a diagram of the cells as they appear across the stem from point A to B (use the rectangle on the right).

   _____



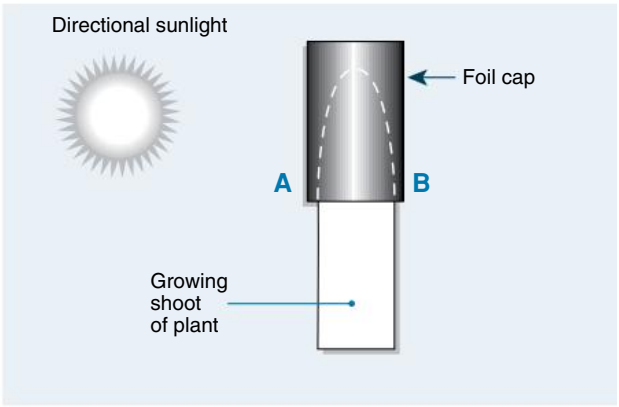
2. **Light excluded from shoot tip**: A foil cap placed over the shoot tip prevents light from reaching it. When the plant is growing under these conditions, the direction of growth does not change towards the light source; the tip grows straight up. What conclusion can you come to about the source and activity of the hormone controlling the growth response?

   _____

   _____

   _____

   _____



3. **Cutting into the transport system**: Two identical plants were placed side-by-side and subjected to the same directional light source. Razor blades were cut half-way into the stem, thereby interfering with the transport system of the stem. Plant A had the cut on the same side as the light source, while Plant B was cut on the shaded side. Predict the growth responses of:

   Plant **A**: _____

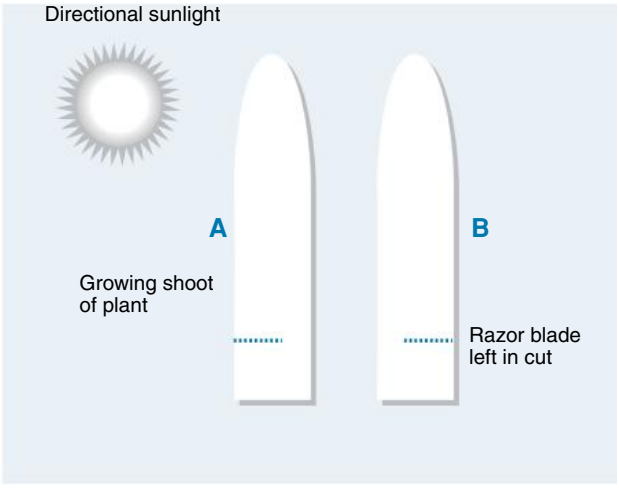
   _____

   _____

   Plant **B**: _____

   _____

   _____



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201 Responses to Temperature in Plants

Key Idea: Many plant rhythms are associated with the change of seasons and changes that need to take place in order to survive the cold of winter and prepare for the growing seasons of spring and summer.

Plants respond to changes in temperature and daylength as cues to seasonal shifts that affect growth. Woody plants are able to survive freezing temperatures because of metabolic changes that occur in the plant between summer and winter. These changes include producing thicker cell walls and accumulating growth inhibitors in the tissues. Alternating periods of growth with periods of **dormancy** allows the plant to survive water shortages and temperature extremes. Once dormant, the plant will not grow again until it receives the right environmental cue, e.g. longer daylength. Annuals produce dormant seeds, whereas in biennials and perennials the shoots may die back. Low temperature stimulation of flowering (**vernalisation**) and seed germination (**stratification**) are common in many species. These temperature responses are usually associated with the increased activity of hormones such as gibberellic acid.



Dormancy is a condition of arrested growth. The entire plant, or its seeds or buds, do not resume growth until certain environmental cues come together in spring.



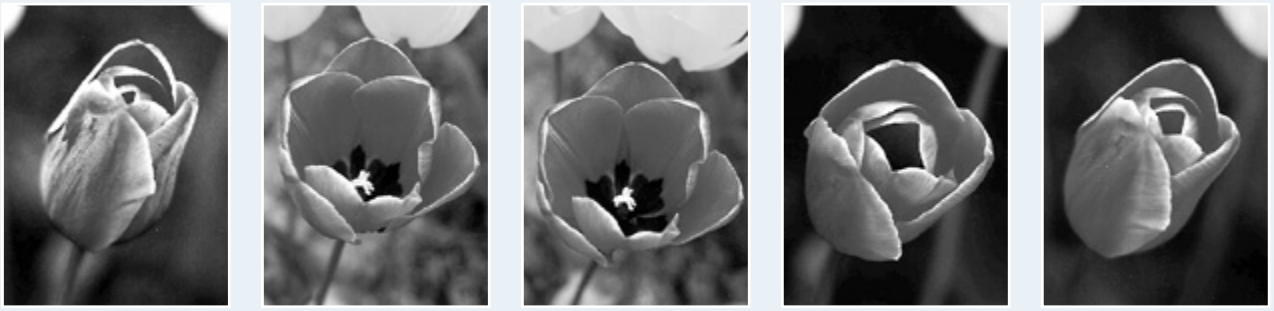
The seeds of many cold-climate plants will not germinate until they have been exposed to a period of wet, cold (5°C) conditions. This is called **cold stratification**.



Bud burst and flowering follow exposure to a cold period in many plants, including bulbs and many perennials. This process is called **vernalisation.**

Daily Rhythm in Tulips

Many flowers, including tulips, show **sleep movements**. In many species, these are triggered by daylength, but in tulips the environmental cue is temperature. This series of photographs show the sleep movements of a single tulip flower over one 12 hour period during spring.



All photos: RA

7.00 am | **9.30 am** | **11.00 am** | **5.00 pm** | **7.00 pm**

1. Describe two physiological responses of plants to seasonal changes in temperature:

   (a) _____

   (b) _____

2. (a) Describe the adaptive value of cold **stratification** in seeds: _____

   _____

   (b) Is this response endogenous or exogenous? _____

3. Suggest why evergreen trees have a growth advantage in regions with a very short growing season: _____

   _____

   _____

4. (a) Describe the sleep movements of tulips in response to temperature: _____

   _____

   (b) What is the adaptive value of these movements? _____

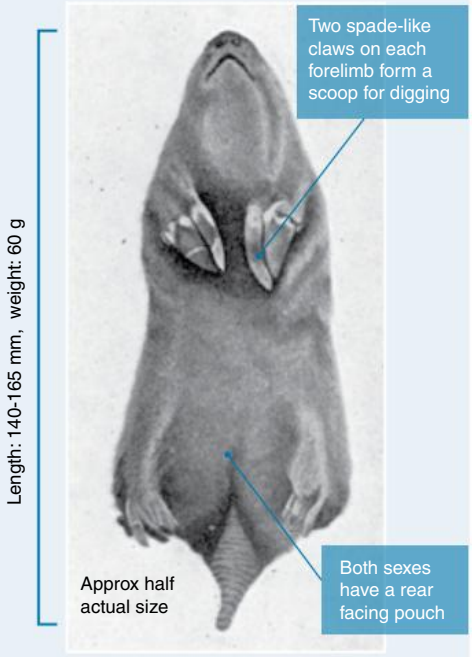
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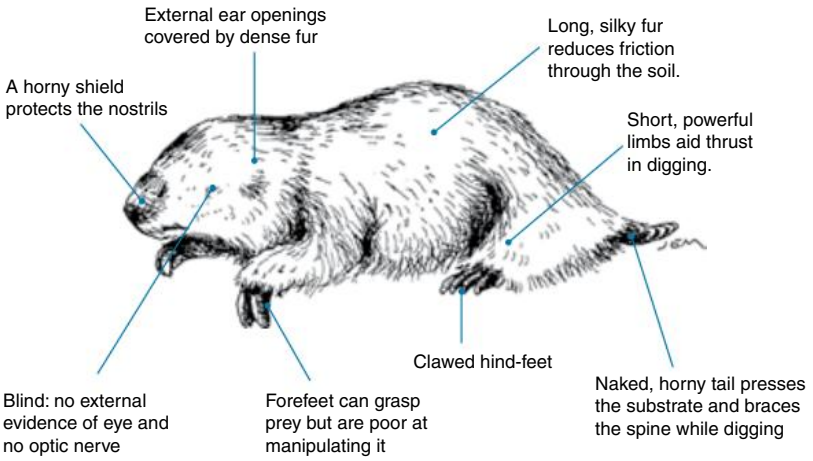
202 Animal Adaptations

Key Idea: An adaptation is any heritable trait that suits an organism to its functional role in the environment (its niche). The adaptations that species exhibit are the result of selection pressures on them through the course of their evolution. Adaptations enable the organism to function most effectively in its niche, enhancing its exploitation of its environment and therefore its survival and fitness. Adaptations may be structural (morphology), physiological, or behavioural.

Marsupial Mole
(Notoryctes typhlops)



The marsupial mole is well adapted to life underground. Its small size, tubular body shape, and heavily buttressed head and neck are typical of burrowing species.



The marsupial mole is a widespread, but little studied marsupial. There are two living species, both endemic to Australia. They are extensive burrowers, using the forefeet for digging and pushing the soil out of the way with their hind-feet as they move along. They can burrow rapidly from view, sleeping and feeding below ground. Underground they virtually swim through the soil, and no permanent tunnel is formed.

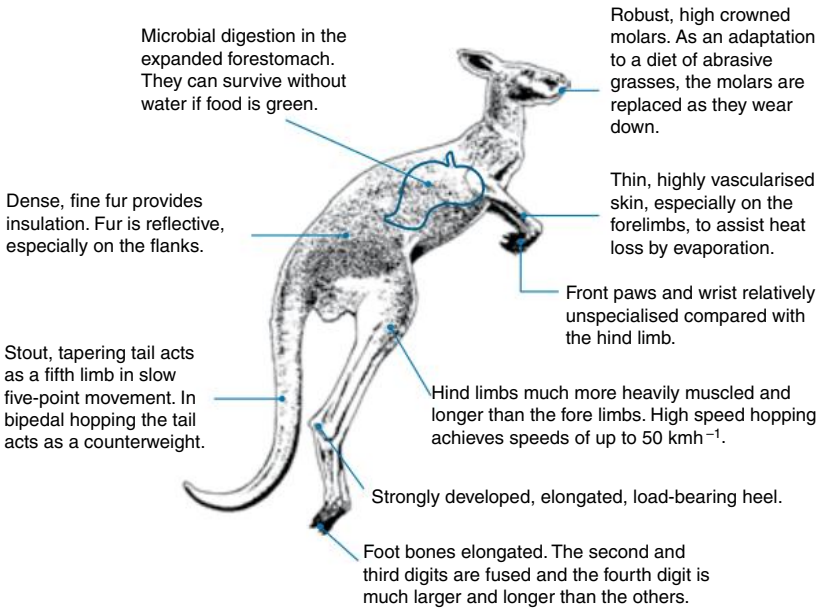
Habitat and ecology: Occur in desert regions in sandy soils associated with river flats. Feed on the eggs, larvae, and pupae of various insect species (especially scarabaeid beetles). They will also eat geckos and centipedes. No known predators apart from humans. Breeding biology largely unknown. The pouch is most developed in females and there are two teats.

Senses and behaviour: Well developed Jacobson's organ in the nasal passages (for chemical sense) and a good sense of hearing. Solitary. Mates are located using smell.

Red Kangaroo
(Macropus rufus)



Male red kangaroos (top) are muscular and broad, weighing up to 95 kg and with a total length of up to 2 m. Females are smaller at about 37 kg. In favourable breeding conditions, they may have one embryo in diapause, one young in the pouch, and one at heel (lower photo).



The red kangaroo is one of the largest living marsupials. It is powerfully built and well adapted to high speed, hopping locomotion, and to survival in arid habitats. The species is sexually dimorphic: the males being nearly three times the weight of females.

Habitat and ecology: Widespread throughout arid and semi-arid Australia. Active mainly at night, resting in scrapes under cover. They roam in groups of 2-10 covering a home range of 8 km^2 (or larger when resources are scarce).

Reproduction and behaviour: Dominant males establish exclusive mating rights by boxing. Females may breed all year, mating soon after giving birth, with the embryo remaining dormant (embryonic diapause) until the pouch is vacant. Embryos can be reabsorbed by the mother if resources are scarce.

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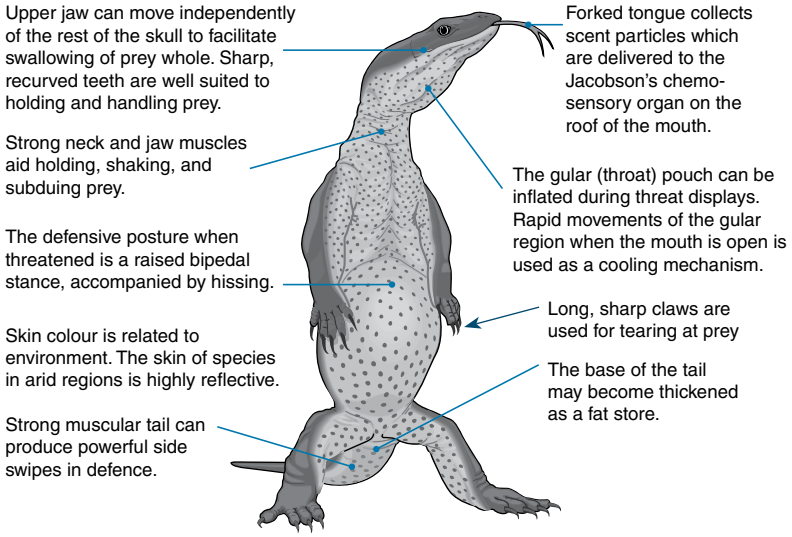
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Goannas or Monitor Lizards

(Varanus spp.)



Goanna is the Australian name for the varanid or monitor lizards that occur in Australia. All varanids are easily recognisable as belonging to the same family of lizards: they all have a similar appearance despite a wide size range. A few species are small (0.2 m long) but most are medium to large lizards (0.5-2 m long). The goannas of Australia (such as the Gould's or sand monitor: *Varanus gouldii* above), have particular adaptations with respect to their anatomy, physiology, ecology, and behaviour. Many of these have enabled them to flourish as top predators in a harsh environment.



Habitat and ecology: Found in a wide variety of habitats, from aquatic to arid semi-desert. Strict carnivores eating a range of available animal species, including carrion. They will feed opportunistically on locally abundant prey.

Physiology and behaviour: Monitors are active during the day in all seasons. They maintain high activity temperatures (up to 38°C) through basking and other behavioural mechanisms. Features of their heart, blood, muscle, and respiratory physiology are adapted to maintaining a higher activity level than most lizards.

For each of the following, describe a structural, physiological, and behavioural adaptation. For each example, explain how the adaptation assists the animal in its survival in its environment:

1. Marsupial mole:

   (a) Structural adaptation: _____

   _____

   (b) Physiological adaptation: _____

   _____

   (c) Behavioural adaptation: _____

   _____

2. Red kangaroo:

   (a) Structural adaptation: _____

   _____

   (b) Physiological adaptation: _____

   _____

   (c) Behavioural adaptation: _____

   _____

3. Varanid lizard (goanna):

   (a) Structural adaptation: _____

   _____

   (b) Physiological adaptation: _____

   _____

   (c) Behavioural adaptation: _____

   _____

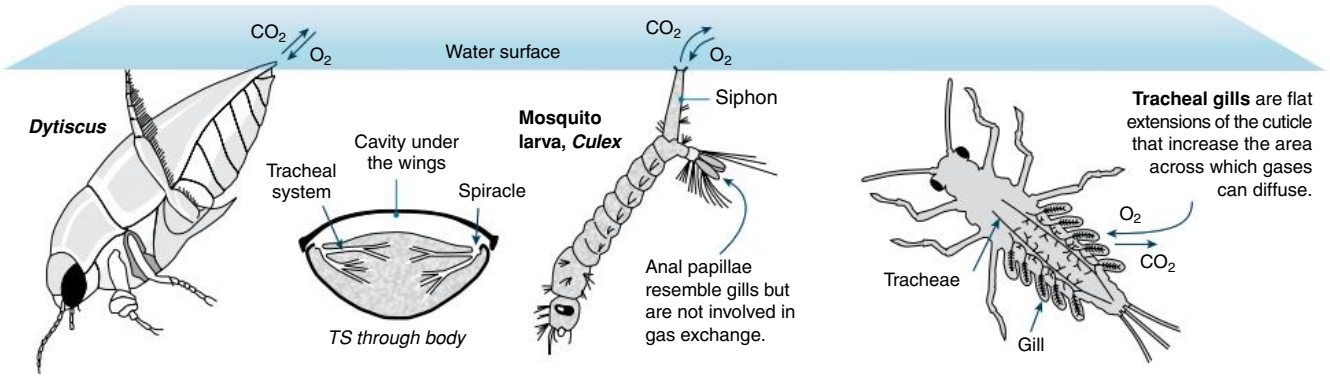
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203 Adaptations of Aquatic Insects

Key Idea: Insects living in water exchange gases with the environment via tracheae. Air can be carried with the insect or it can diffuse into the tracheal system from the water.

Aquatic insects exchange gases via a system of air-filled **tracheae**. Oxygen enters this system in various ways. Aquatic insect larvae rely on diffusion across the body surface, with or without gills. Adult insects carry air with them when submerged, either as a bubble or trapped by hairs. A thin film of air trapped by hairs is called a **plastron**. It acts as a diffusion gill, into which oxygen can diffuse from the water.

Gas Exchange in Aquatic Invertebrates

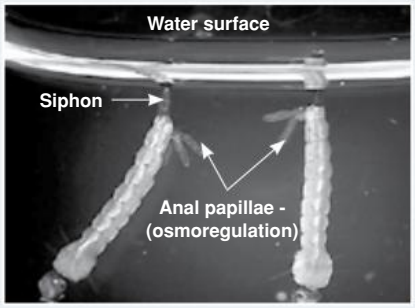


Surface Air Breathers

The **diving beetle**, *Dytiscus*, traps air from the surface beneath its wings where it forms a compressible gill. The spiracles open into the air space and lead to the tracheal tubes. As the submerged insect respires, the oxygen is gradually used up and the bubble decreases in size. A **mosquito larva** penetrates the water surface with a siphon extending from a spiracle at the tip of the abdomen. The larva hangs at the surface while gas exchange occurs by diffusion.

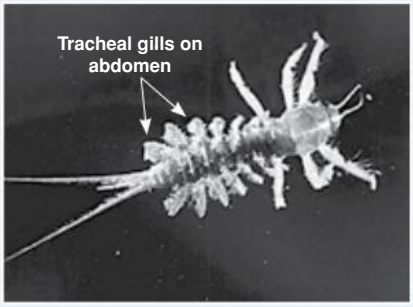
Tracheal Gills

In the larvae of many aquatic insects, gas exchange occurs by diffusion across the body surface. This is enhanced by the presence of **tracheal gills** which may account for 20-70% of O_2 uptake depending on their surface area.



CDC

Gas exchange in mosquito larvae occurs with the air and is independent of O_2 content of the water.

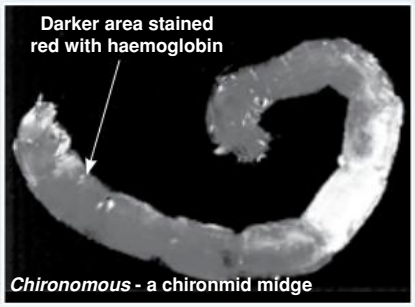


Stephen Moore

The tracheal gills of this spiny gilled mayfly (a very active species), are located on the abdomen.



Hydrophilid beetles use hydrofuge hairs to trap a film of air against the spiracles (a plastron).

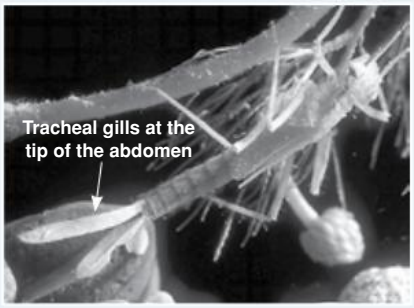


Stephen Moore

The blood of a few insect larvae, e.g. *Chironomus,* contains the O_2-carrying pigment **haemoglobin**, which allows them to survive when O_2 levels fall.



Anisops carries only a small air mass when diving but can exploit oxygen-poor waters because it has large hemoglobin-filled cells in its abdomen.



The tracheal gills of this damselfly larva are located at the tip of the abdomen (arrows). Like other insects with gills they are intolerant of low oxygen.

1. Giving an example for each, briefly describe three structural adaptations of freshwater insects for gas exchange:

   (a) _____

   (b) _____

   (c) _____

2. Describe one physiological adaptation of freshwater insects for gas exchange: _____

   _____

   _____

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204 Adaptations for Diving

Key Idea: Diving animals have structural and physiological adaptations that allow them to stay submerged for extended periods of time.

All air breathing animals that dive must cope with the problem of oxygen supply to the tissues. This is particularly a problem for mammals and birds, which have a high metabolic rate and therefore a high oxygen demand. In addition, resurfacing from dives of 20 m or more brings the risk of decompression sickness (or the bends). Primates (including humans) are one of the few orders of mammals without diving representatives. The problems that humans encounter when diving while breathing compressed air (e.g. the bends and nitrogen narcosis) are the result of continuing to breathe during the dive. Animals adapted for diving do not do this.



The Problems for Humans
Humans are poorly adapted for diving. They lack adequate body fat for long periods underwater and they inhale before diving. Snorkellers (above) and Asian pearl divers may **hyperventilate** (take a series of deep breaths in and out) before diving. This reduces the carbon dioxide content of the blood and suppresses the urge to breathe. Blood oxygen levels can fall dangerously low before the urge to breathe is felt. If the diver faints, voluntary control is lost and normal, involuntary breathing resumes, resulting in drowning. Divers using compressed air (SCUBA) may stay submerged for much longer. However, they must take care when ascending in order to equalise the pressure of their blood gases with those on the surface.



Diving Birds
Penguins show many of the adaptations typical of diving birds. During dives, their heart rate slows, and blood is diverted to the head, heart, and eyes.



Diving Reptiles
Sea turtles such as the green sea turtle have low metabolic rates, and tolerate low oxygen. They use the lining of the mouth and the cloaca for gas exchange and can overwinter at 10-15 m depth for several months.





Diving Mammals
Dolphins, whales, and seals are among the most well adapted divers. The exhale before diving and, at depth, the lungs are compressed so that only the trachea contains air. This stops nitrogen entering the blood and prevents the bends when surfacing. During dives, heart rate slows and blood flow is redistributed to supply only critical organs. Diving mammals have high levels of myoglobin and their muscles work well without oxygen. Sperm whales are the deepest divers (recorded at 3000 m). Weddell seals dive to 1000 m for 40 minutes or more. During these dives, heart rate drops to 4 or 5 beats per minute (4% of the rate at the surface).

1. (a) Describe an advantage gained from breathing out before diving: _____

   _____

   (b) Explain how this behaviour is different from a human diving (unaided by equipment): _____

   _____

   (c) Describe the adaptive advantage in reducing heart rate during a dive: _____

   _____

   _____

2. Snorkel divers who wish to remain underwater for long periods of time **hyperventilate** before diving.

   (a) Why does hyperventilation suppress the urge to breathe? _____

   _____

   _____

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(b) Why is hyperventilation a dangerous practice when diving? _____

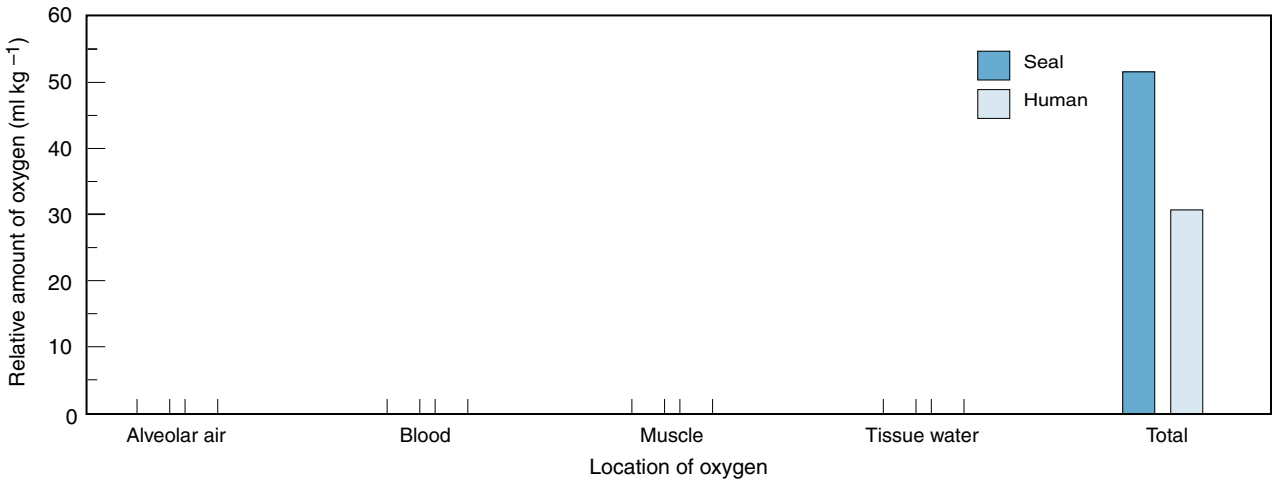
3. The ability to remain submerged for long periods of time depends on the ability to maintain the oxygen supply to the tissues. This depends on oxygen stores. The table below compares the amount of oxygen in different regions of the body during a dive in a small seal and a human (not on scuba). In the spaces provided in the table, calculate the amount of oxygen (in mL) per kilogram of bodyweight for both the seal and the human. Graph the result in the space provided.





Location of oxygen in the body	Seal (30 kg)		Human (70 kg)	
	Amount of oxygen (ml)	Oxygen (ml kg^{-1})	Amount of oxygen (ml)	Oxygen (ml kg^{-1})
Alveolar air	55		720	
Blood	1125		1000	
Muscle	270		240	
Tissue water	100		200	
Total	1550	51.67	2160	30.86

Relative amounts of oxygen (ml kg^{-1} bodyweight) in a seal and a human



4. (a) Describe the most striking difference between a seal and a human in terms of the oxygen stores during a dive:

(b) With respect to diving adaptations, suggest why this is the case: _____

5. (a) Where does the seal store a large proportion of its oxygen during a dive? _____

(b) How does this compare to a human? _____

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205 Ectotherms and Endotherms

Key Idea: The thermal classification of animals is based on their source of body heat. In endotherms, the source of body heat is metabolic activity. In ectotherms, it is the environment.

The process of controlling body temperature is called **thermoregulation**. For many years, animals were classified as either **homeotherms** (= constant body temperature) or **poikilotherms** (= variable body temperature). A more recent thermal classification of animals is based on the source of the body heat. If it is largely from the environment, the animal is **ectothermic**. If it is largely from metabolic activity, the animal is **endothermic**. In reality, many animals still fall somewhere between the two extremes.

How Body Temperature Varies



Aquatic invertebrates like jellyfish are true poikilotherms: their temperature is the same as the environment.



Tuna and some of the larger sharks can maintain body temperatures up to 14°C above the water temperature.



Hibernating rodents and bats let their body temperature drop to well below what is typical for most mammals.



Most birds and mammals maintain a body temperature that varies less than 2°C: they are true homeotherms.

Increasingly homeothermic

Poikilothermic

Body temperature varies with the environmental temperature. Traditionally includes all animals other than birds and mammals, but many reptiles, some large insects and some large fish are not true poikilotherms because they may maintain body temperatures that are different from the surrounding environment.

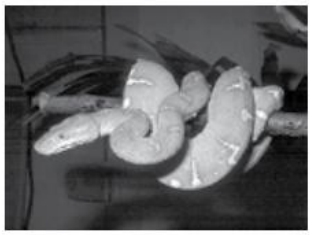
Homeothermic

Body temperature remains almost constant despite environmental fluctuations. Traditionally includes birds and mammals, which typically maintain body temperatures close to 37-38°C. Many reptiles are partially homeothermic and achieve often quite constant body temperatures through behavioural mechanisms.

Source of Body Heat



With a few exceptions, most fish are ectothermic. Unlike many reptiles they do not usually thermoregulate.



Snakes use heat energy from the environment to increase their body temperature for activity.



Some large insects like bumblebees may raise their temperature for short periods through muscular activity.



Mammals (and birds) achieve high body temperature through metabolic activity and reduction of heat losses.

Increasingly endothermic

Ectothermic

Ectotherms depend on the environment for their heat energy. The term ectotherm is often equated with poikilotherm, although they are not the same. Poikilotherms are also ectotherms but many ectotherms may regulate body temperature (often within narrow limits) by changing their behaviour (e.g. snakes and lizards).

Endothermic

Endotherms rely largely on metabolic activity for their heat energy. Since they usually maintain a constant body temperature, most endotherms are also homeotherms. As well as birds and mammals, some fast swimming fish, like tuna, and some large insects may also use muscular activity to maintain a high body temperature.

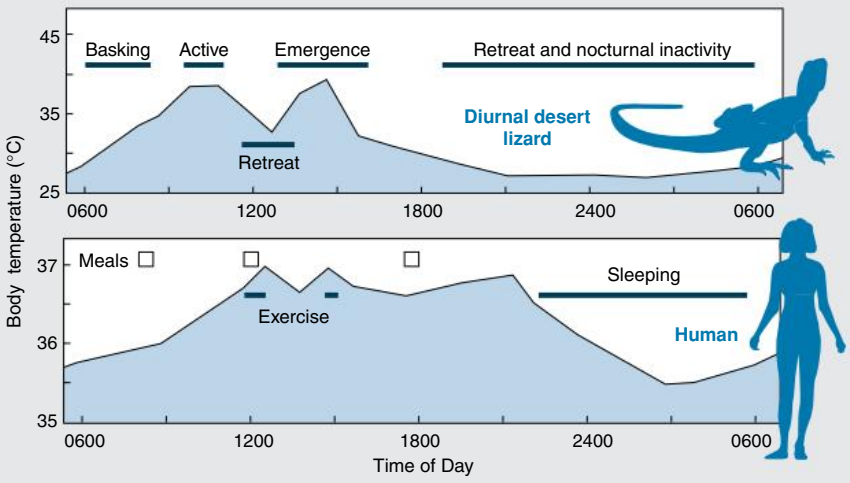
Daily temperature variations in ectotherms and endotherms

Ectotherm: Diurnal lizard (top right)

Body temperature is regulated by behaviour so that it does not rise above 40°C. Basking increases heat uptake from the sun. Activity occurs when body temperature is high. Underground burrows are used for retreat.

Endotherm: Human (bottom right)

Body temperature fluctuates within narrow limits over a 24 hour period. Exercise and eating increase body temperature for a short time. Body temperature falls during rest and is partly controlled by an internal rhythm.



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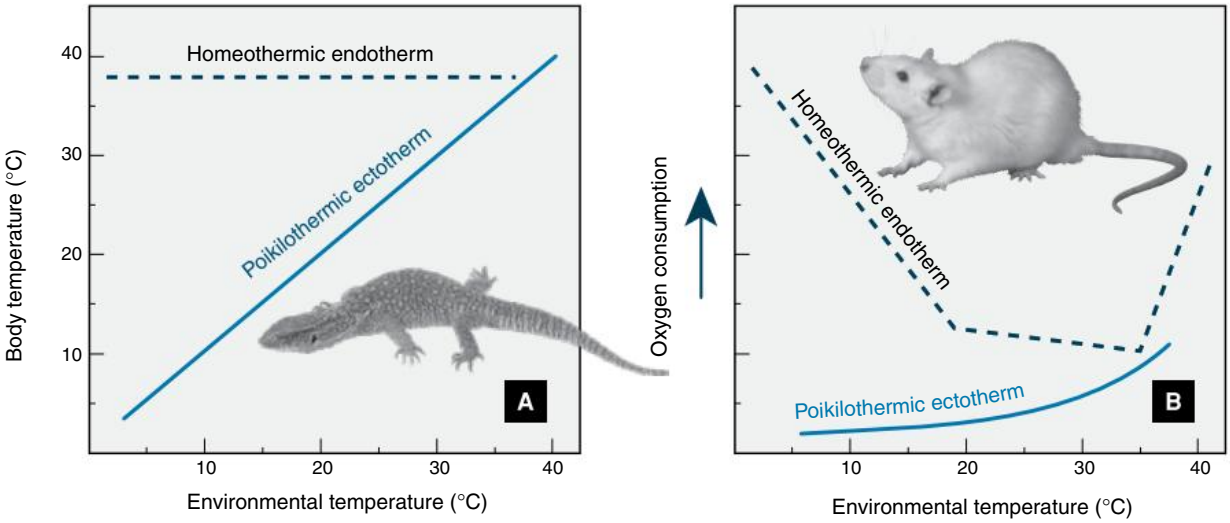
1. (a) What is a homeothermic endotherm? _____

(b) Why is "poikilotherm" not a good term for classifying many terrestrial lizards and snakes? _____

2. Ectotherms will often maintain high, relatively constant body temperatures for periods in spite of environmental fluctuations, yet they also tolerate marked declines in body temperature to levels lower than are tolerated by endotherms.
(a) What is the advantage of letting body temperature fluctuate with the environment (particularly at low temperature)?

(b) Why is ectothermy regarded as an adaptation to low or variable food supplies? _____

3. Some endotherms do not always maintain a high body temperature. Some, such as small rodents, allow their body temperatures to fall during hibernation. What might be the advantage of this behaviour?



4. The two graphs above illustrate the differences in temperature regulation between a homeothermic endotherm and a poikilothermic ectotherm (such as a fish). Graph A shows change in body temperature with environmental temperature. Graph B shows change in oxygen consumption with environmental temperature. Use the graphs to answer the following:
(a) How do ectotherms and endotherms differ in their response to changes in environmental temperature (graph **A**):

(b) Why would a poikilothermic ectotherm (no behavioural regulation of temperature) be restricted to environments where temperatures were below about 40°C:

(c) In graph **B**, state the optimum temperature range for an endotherm: _____

(d) For an endotherm, the energetic costs of temperature regulation (as measured by oxygen consumption) increase markedly below about 15°C and above 35°C. Explain why this is the case:

(e) For an ectotherm (Graph B), energy costs increase steadily as environmental temperature increases. Explain why:

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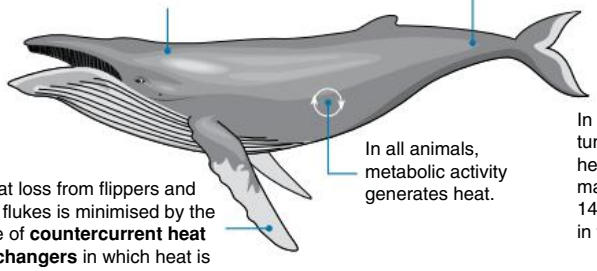
206 Control of Body Temperature

Key Idea: Animals control body temperature by exchanging heat with their environment.

For a body to maintain a constant temperature heat losses must equal heat gains. Heat exchanges with the environment occur via three mechanisms: **conduction** (direct heat transfer), **radiation** (indirect heat transfer), and **evaporation**. The importance of each of these mechanisms depends on environment, i.e. air or water.

Seals, whales and dolphins have heavily insulated surfaces of fat or blubber (up to 60% of body thickness). Blood is diverted to the outside of the blubber in warm water or if heat needs to be lost.

Large body size reduces heat loss by lowering the surface area to volume ratio.

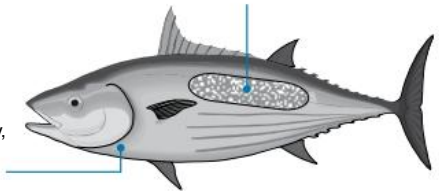


In all animals, metabolic activity generates heat.

Heat loss from flippers and tail flukes is minimised by the use of **countercurrent heat exchangers** in which heat is transferred between arterial and venous blood flows.

Water has a great capacity to transfer heat away from organisms; its cooling power can be more than 50 times greater than that of air. For most aquatic animals (with the exception of aquatic birds and mammals and a few fish) heat retention is impossible. Instead, they carry out their metabolic activities at the ambient temperature. For most marine organisms this does not fluctuate much.

In fast swimming fish, such as tuna, marlin, and some sharks, heat exchangers are used to maintain temperatures as high as 14°C above the water temperature in the swimming muscles.



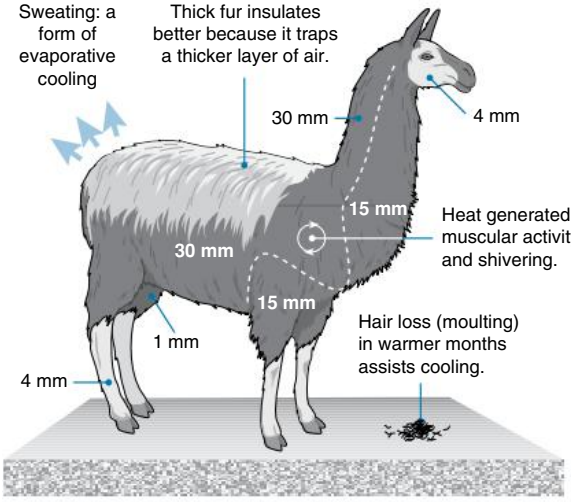
In animals with gills, there is a high rate of heat loss across the thin gill surface. There is little point in surface insulation of the body, because all the arterial blood coming from the gills is already at water temperature.

Temperature regulation mechanisms in water

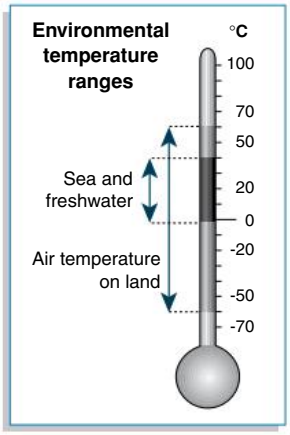
- Low metabolic activity
- Heat generation from metabolic activity
- Insulation layer of blubber
- Changes in circulation patterns when swimming
- Large body size
- Heat exchange systems in limbs or high activity muscle

Sweating: a form of evaporative cooling

Thick fur insulates better because it traps a thicker layer of air.



For most mammals, the thickness of the fur or hair varies around the body (as indicated above). Thermoregulation is assisted by adopting body positions that expose or cover areas of thin fur (the figures above are for the llama-like guanaco).



Temperature regulation mechanisms in air

- Behaviour or habitat choice
- Heat generation from metabolic activity
- Insulation (fat, fur, feathers)
- Changes in blood flow
- Large body size
- Sweating and panting
- Tolerance of fluctuation in body temperature

Animals adapted to temperature extremes (hot or cold) can often tolerate large fluctuations in their body temperature before they become stressed. In camels, the body temperature may fluctuate up to 7°C (34°C to 41°C) over a 24 hour period.



Panting to lose accumulated heat is important in dogs, which have sweat glands only on the pads of their feet.



Circulation changes slow heat loss in water and speed heat gain when basking on land in marine iguanas.



Thick blubber and large body size in seals and other marine mammals provide an effective insulation.



Mammals and birds in cold climates, like the musk oxen above, cluster together to retain body heat.



Behaviours to reduce heat uptake via conduction, e.g. standing on two legs, are important in desert lizards.



Bumblebees can heat up their flight muscles by shivering. Their thick fuzz conserves the heat they produce.



Thick hair, fur or wool traps air next to the skin. This insulating air layer reduces heat loss and slows heat gain.



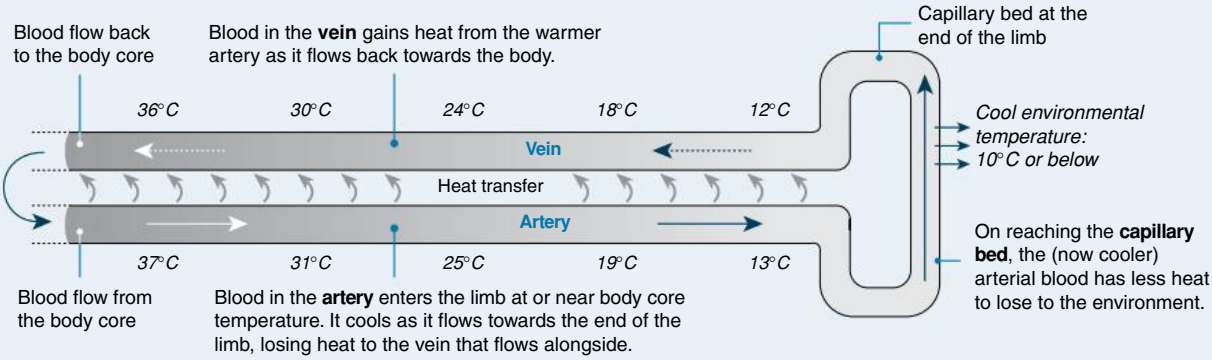
The plumage of birds acts similarly to fur or hair in mammals. The feathers trap air which slows heat gain and loss.

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Countercurrent Heat Exchange Systems

Countercurrent heat exchange systems occur in both aquatic and terrestrial animals as an adaptation to maintaining a stable core temperature. The diagram illustrates the general principle of countercurrent heat exchangers: heat is exchanged between incoming and outgoing blood. In the flippers and fins of whales and dolphins, and the legs of aquatic birds, they minimise heat loss. In some terrestrial animals adapted to hot climates, the countercurrent exchange mechanism works in the opposite way to prevent the head from overheating: venous blood cools the arterial blood before it supplies the brain.



1. (a) How does water differ from air in the way in which it transmits heat away from the body of an organism?

   (b) Identify two ways in which a "warm bodied" animal can maintain its internal temperature in water:

   (c) How does a large body size assist in maintaining body temperature in both aquatic and terrestrial species?

   (d) How do small terrestrial animals compensate for more rapid heat loss from a high surface area?

2. (a) How does thick hair or fur assist in thermoregulation in mammals?

   (b) Why is fur/hair thickness variable over different regions of a mammal's body?

   (c) How would you expect fur thickness to vary between related mammal species at high and low altitude?

   (d) How do marine mammals compensate for lack of thick hair or fur?

3. (a) Why do fast swimming fish use countercurrent exchange mechanisms in their swimming muscles?

   (b) In some large sharks (e.g. white pointer and mako), countercurrent exchangers are used to maintain a higher temperature around the gut. What is the advantage of this adaptation?

4. (a) What is the role of group behaviour in temperature regulation in some animals?

   (b) Name an animal, other than musk oxen, that uses this behaviour:

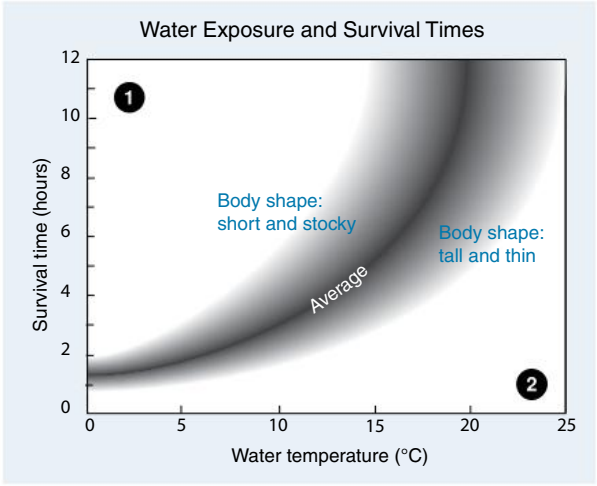
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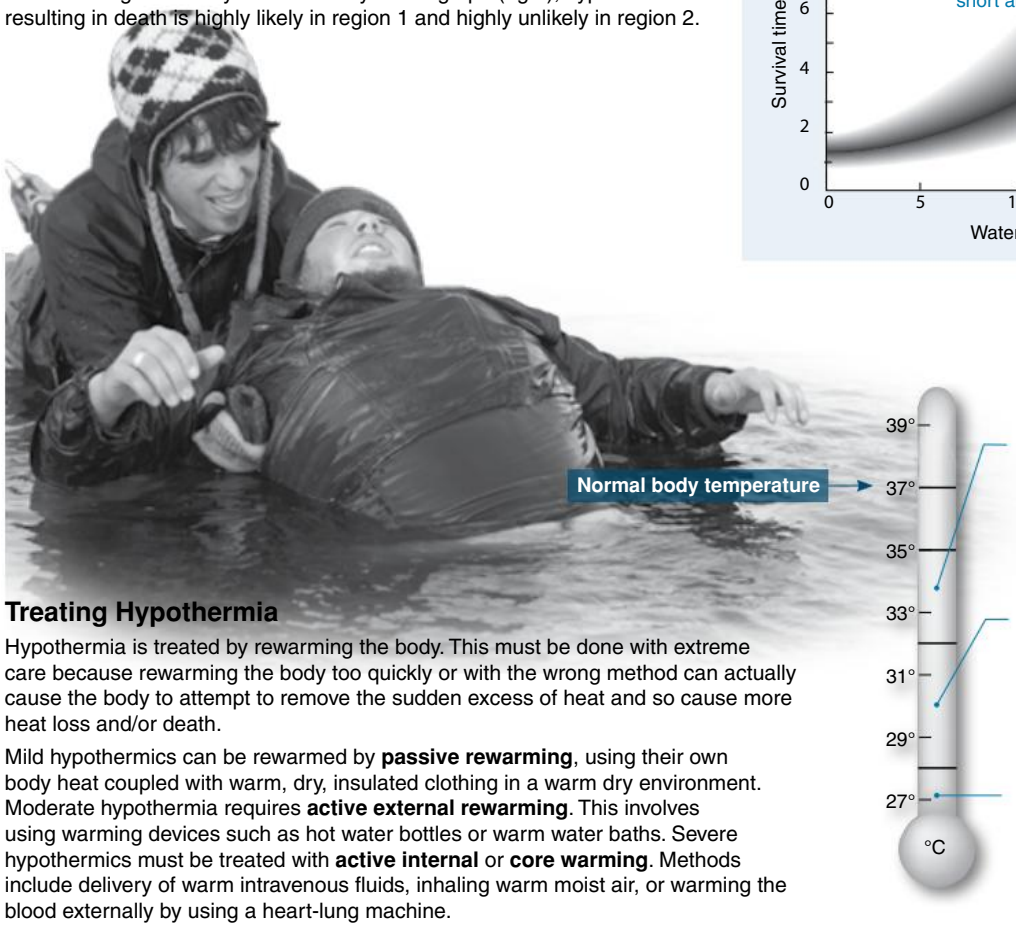
207 Hypothermia

Key Idea: Hypothermia occurs when the body cannot thermoregulate effectively and the core body temperature drops below 35ºC.

Hypothermia (low body temperature) occurs when the core body temperature drops below 35ºC. Hypothermia is caused by exposure to low temperatures, and results from the body's inability to replace the heat being lost to the environment. The severity depends on how low the body temperature has dropped. Severe hypothermia results in severe mental confusion, organ failure, and death.

Maintaining a body temperature of around 37ºC allows the body's metabolism to function optimally. At temperatures below 35ºC, metabolic reactions slow, causing a loss of coordination, difficulty in moving, and mental fatigue. Hypothermia can result from exposure to very low temperatures for a short time or to moderately low temperatures for a long time. Exposure to cold water (even just slightly cold) will produce symptoms of hypothermia far more quickly than exposure to the same temperature of air. This is because water is much more effective than air at conducting heat away from the body. In the graph (right), hypothermia resulting in death is highly likely in region 1 and highly unlikely in region 2.





Mild hypothermia: Shivering. Vasoconstriction reduces blood flow to the extremities. Hypertension and cold diuresis (increased urine production due to the cold).

Moderate hypothermia: Muscle coordination becomes difficult. Movements slow or laboured. Blood vessels in ears, nose, fingers, and toes constrict further resulting in these turning a blue colour. Mental confusion sets in.

Severe hypothermia: Speech fails. Mental processes become irrational, victim may enter a stupor. Organs and heart eventually fail resulting in death.

Treating Hypothermia

Hypothermia is treated by rewarming the body. This must be done with extreme care because rewarming the body too quickly or with the wrong method can actually cause the body to attempt to remove the sudden excess of heat and so cause more heat loss and/or death.

Mild hypothermics can be rewarmed by **passive rewarming**, using their own body heat coupled with warm, dry, insulated clothing in a warm dry environment. Moderate hypothermia requires **active external rewarming**. This involves using warming devices such as hot water bottles or warm water baths. Severe hypothermics must be treated with **active internal** or **core warming**. Methods include delivery of warm intravenous fluids, inhaling warm moist air, or warming the blood externally by using a heart-lung machine.

1. What conditions might cause a person to become hypothermic? _____

2. (a) With reference to the graph (above), which body shape has best survival at 15°C? _____

   (b) Explain your choice: _____

3. Describe the methods used to rewarm hypothermics and the importance of using the correct methods.

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208 The Effects of High Altitude

Key Idea: Physiological adaptations help the body function in the low oxygen conditions at high altitude.

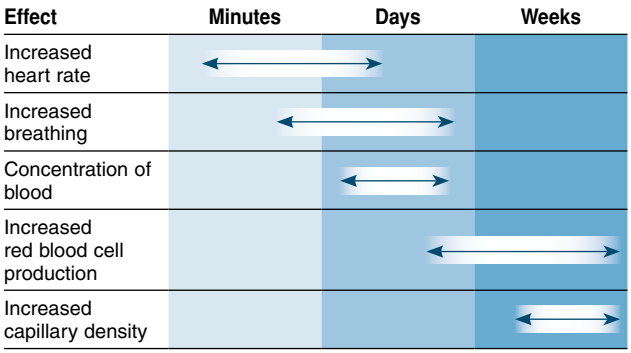
Air pressure decreases with altitude so the pressure (therefore amount) of oxygen in the air also decreases. Many of the physiological effects of high altitude arise from the low oxygen pressure, not the low air pressure in itself. Humans can make some physiological adjustments to altitude, called **acclimatisation**. Populations that have lived at altitude for generations show heritable **adaptations** to high altitude life.

Mountain Sickness

Altitude sickness or mountain sickness is usually a mild illness associated with trekking to altitudes of 5000 meters or so. Common symptoms include headache, insomnia, poor appetite and nausea, vomiting, dizziness, tiredness, coughing and breathlessness. The best way to avoid mountain sickness is to ascend to altitude slowly (no more than 300 m per day above 3000 m). Continuing to ascend with mountain sickness can result in more serious illnesses: accumulation of fluid on the brain and lungs. These complications can be fatal if not treated with oxygen and a rapid descent to lower altitude.



Physiological Adjustment to Altitude



The human body can make adjustments to life at altitude. Some of these changes take place almost immediately: breathing and heart rates increase. Other adjustments may take weeks (see above). These responses are all aimed at improving the rate of supply of oxygen to the body's tissues. When more permanent adjustments to physiology are made (increased blood cells and capillary networks) heart and breathing rates can return to normal.

Adaptations to High Altitude

Studies on three high altitude human populations (Andean, Tibetan, and Ethiopian highlands) have found three different adaptations for survival to the low levels of oxygen in the air.

Populations living in the Andean Altiplano develop higher concentrations of haemoglobin (Hb) than populations living at sea level.

Tibetan populations have similar Hb concentrations to populations at sea level, but take more breaths per minute to compensate for the lower oxygen pressure. A Tibetan has a ventilation rate of 15 L min^{-1} while an Andean has a rate of 10.5 L min^{-1}.


Tibetan porter

Concentration of Haemoglobin in the Blood

Group	Haemoglobin concentration (g $100ml^{-1}$)
U.S. sea level mean	15.3
Andean male	19.2
Andean female	17.8
Tibetan male	15.6
Tibetan female	14.2
Ethiopian highlands male	15.9
Ethiopian highlands female	15.0

Recent studies on indigenous populations in the Ethiopian highlands (altitude of >1500 m) have found that they do not experience **hypoxia** (lack of oxygen), but have none of the physiological of the adaptations seen in the Andean or Tibetan populations. Their haemoglobin concentration is normal, and they do not compensate with a higher ventilation rate.

Adaptations in indigenous Ethiopian highlanders may be due to changes in the hypoxia-inducible factor-1 (HIF-1) pathway. This pathway controls the systemic and cellular responses to hypoxic conditions. Several genes are activated at low oxygen concentrations to control the HIF-1 pathway. Positive selection may be acting on these genes in Ethiopian highlanders.

1. (a) Describe the general effects of high altitude on the body: _____

   _____

   (b) Name the general term given to describe these effects: _____

2. (a) Name one short term physiological adjustment that humans make to high altitude: _____

   _____

   (b) Explain how this helps to increase the amount of oxygen the body receives: _____

   _____

3. Describe and explain one adaptation to high altitude that has evolved in some human populations: _____

   _____

   _____

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209 Managing Fluid Balance on Land

Key Idea: Internal salt and fluid levels must be regulated for physiological processes to occur normally.

All organisms, whether living on land or in water, must maintain their water and solute (salt) levels at correct levels for life processes to occur. To achieve this ion balance, the salt and fluid content of the internal body fluids must be regulated by a process called **osmoregulation**.

Terrestrial animals show specific adaptations for obtaining and conserving water in an environment where water loss is a constant problem. These adaptations are most well developed in desert animals. Despite the lack of available water in deserts, a large a number of animal taxa have desert-dwelling representatives. The most arid tolerant are even capable of surviving without drinking.

Obtaining Water



Most animals obtain the majority of their water by **drinking.** Some, such as camels, can retain relatively large volumes of water in the gut, but most will need to regularly visit a water supply.



Obtaining water from **food** is important in dry environments where free standing water is limited. Many large predators obtain a large amount of their water in this way.



US Fish and Wildlife

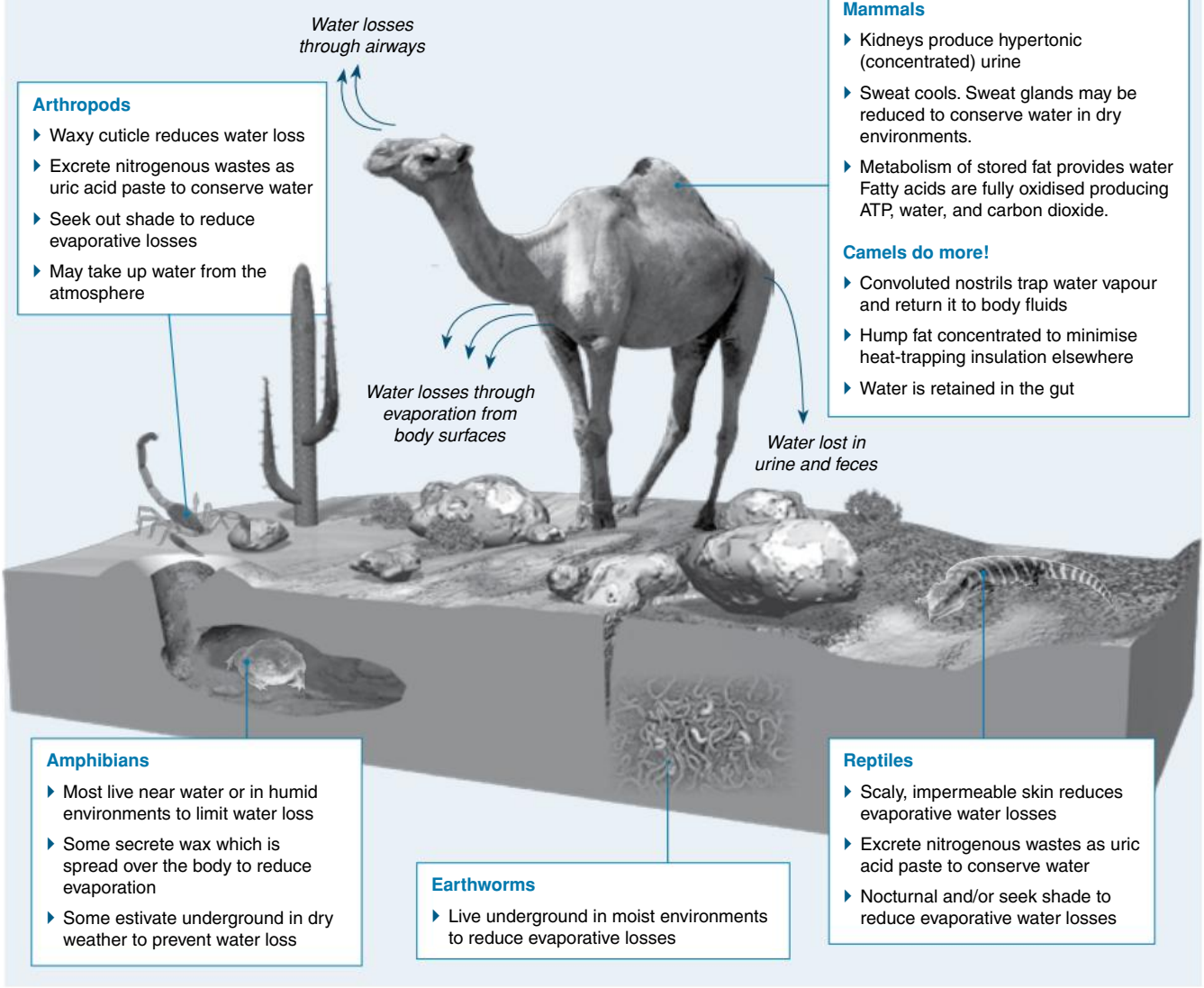
Some desert animals, such as the kangaroo rat, do not need to drink. 90% of their water comes from metabolism (oxidation of glucose to ATP, CO_2, and water). The rest comes from the small amount of water present in the food.



Ian Smith

Amphibians can take up water directly through their skin. The skin is water permeable, so they can osmotically acquire water when they need it when submerged or resting on a damp surface.

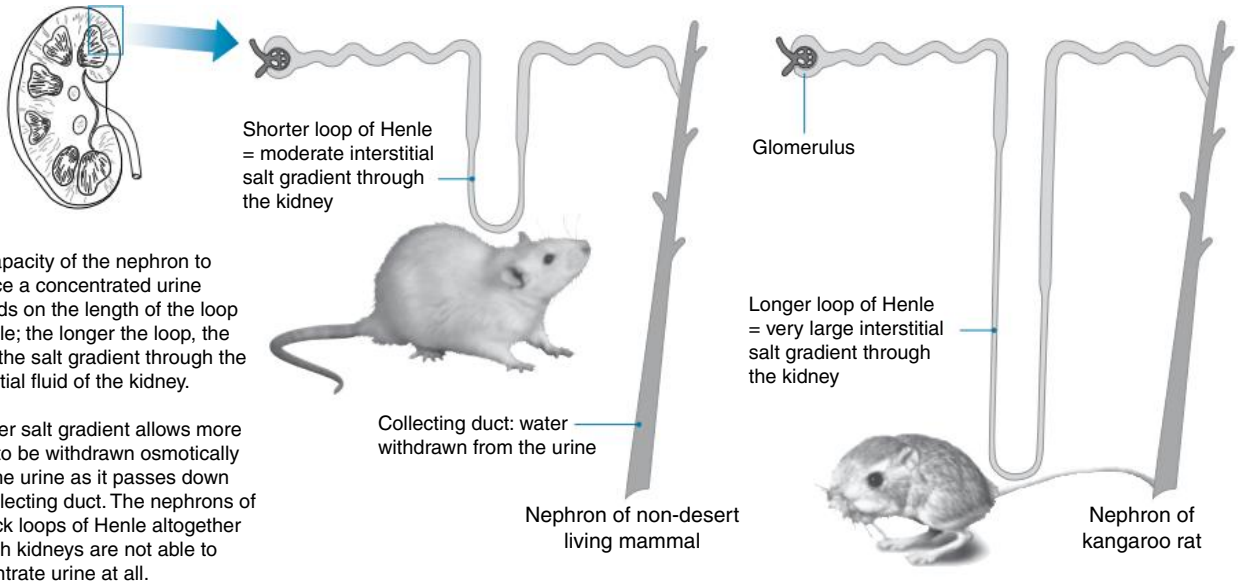
Conserving and Losing Water



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The Loop of Henle and Water Conservation



The capacity of the nephron to produce a concentrated urine depends on the length of the loop of Henle; the longer the loop, the larger the salt gradient through the interstitial fluid of the kidney.

A higher salt gradient allows more water to be withdrawn osmotically from the urine as it passes down the collecting duct. The nephrons of fish lack loops of Henle altogether and fish kidneys are not able to concentrate urine at all.

1. Name four ways in which water can be obtained: _____

2. How does metabolism provide water for the body's activities? _____

3. Identify three ways in which each of the following animals conserves water:

   (a) Mammal: _____

   (b) Reptile: _____

   (c) Arthropod: _____

   (d) Amphibian: _____

   (e) Annelid: _____

4. Animals use structural, physiological, and behavioural adaptations to reduce their water losses. Explain the difference between structural, physiological, and behavioural adaptations using examples to illustrate your answer:

5. Name three ways in which animals lose water to the environment: _____

6. (a) Explain why only mammals and birds are able to produce urine that is concentrated than their bodily fluids:

   (b) How have kangaroo rats been able to develop this ability to the extent that they do not need to drink? _____

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210 Osmoregulation in Water

Key Idea: Osmoregulators are able to regulate salt and water balance, whereas osmoconformers cannot.

The body fluids of **osmoconformers** fluctuate with the changing solute concentration of the environment. **Osmoregulators** maintain constant water and solute concentrations even when the environment conditions vary.

Osmoregulators vs Osmoconformers



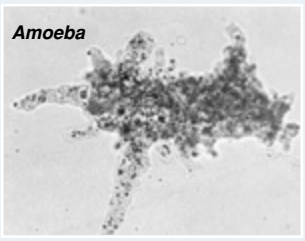
The body fluids of most marine invertebrates, e.g. sea anemones (left), fluctuate with the environment. These animals are **osmoconformers** and cannot regulate salt and water balance. Some intertidal species can tolerate frequent dilutions of normal seawater and some actively take up ions across the gills to compensate for ion loss via the urine.



Animals that regulate their salt and water fluxes, such as fish and marine mammals, are termed **osmoregulators**. Bony fish lose water osmotically and counter the loss by drinking salt water and then excreting the excess salt across the gill surfaces.



Marine sharks and rays generate osmotic concentrations in their body fluids similar to seawater by tolerating high urea. Excess salt from the diet is excreted via a salt gland in the rectum. Marine mammals produce a urine that is high in both salt and urea.



Freshwater animals have body fluids that are osmotically more concentrated than the water they live in and are all osmoregulators. Water tends to enter their tissues by osmosis and must be expelled to avoid flooding the body. Simple protozoans (*Amoeba*, left) use contractile vacuoles to collect the excess water and expel it.



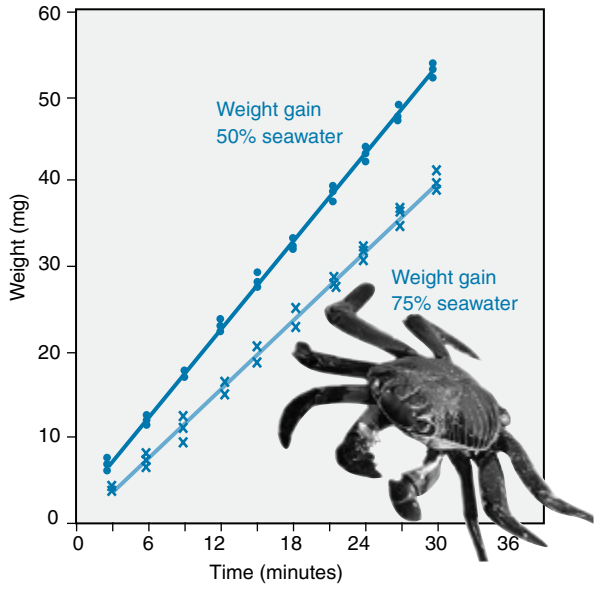
Other invertebrates expel water and nitrogenous wastes using simple nephridial organs. Bony fish and aquatic arthropods produce dilute urine (containing ammonia) and actively take up salts across their gill surfaces.

Responses to Seawater Dilution in Rock Crabs

Species of intertidal crabs vary widely in their ability to regulate their salt and water levels in the face of environmental fluctuations. As shown in the graph below, intertidal crabs face an osmotic influx of water when placed into dilute salinities. The excess water can be excreted in the urine (via the antennal glands), but this is accompanied by a loss of valuable ions. In many species, after a period of adjustment, this loss is met by active ion uptake across the gills.

In an experiment, a student investigated the effect of increasing seawater dilution on the cumulative weight gain of a common rock crab. Six crabs in total were used in the experiment. Three were placed in seawater dilution of 75:25 (75% seawater) and three were placed in a seawater dilution of 50:50 (50% seawater). Cumulative weight gain in each of the six crabs was measured at regular intervals over a period of 30 minutes. The results are plotted below and a line of best fit has been drawn for each set of data.

Weight gain in crabs at two seawater dilutions



1. How can freshwater animals compensate for ions lost during excretion of excess water? _____

_____

2. What is the key difference between an **osmoregulator** and an **osmoconformer**? _____

_____

_____

3. (a) Explain the difference in the two lines plotted on the graph of crab weight gain (above right): _____

_____

_____

(b) What does this experiment suggest about the osmoregulatory ability of this crab species? _____

_____

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211 Water Balances in Desert Mammals

Key Idea: Desert mammals have adaptations to conserve water or reduce water intake requirements.

Water loss is a major problem for most mammals. The adaptations of mammals in arid regions enables them to minimise water losses and reduce the amount of water they need to drink. Arid-adapted species typically produce very concentrated urine, so lose very little water this way. In addition, the metabolic breakdown of food contributes a large proportion of daily water needs. Some, like kangaroo rats, do not drink at all, and obtain most of their water metabolically.

Adaptations of Arid Adapted Rodents

Most desert-dwelling mammals are able to tolerate a low water intake. Arid adapted rodents, such as jerboas and kangaroo rats, conserve water by reducing losses to the environment and obtain the balance of their water needs from the oxidation of dry foods (respiratory metabolism). The table below shows the water balance in a kangaroo rat after eating 100 g of dry pearl barley. Note the high urine to plasma concentration ratio (17) which is more than four times that of a human (4).

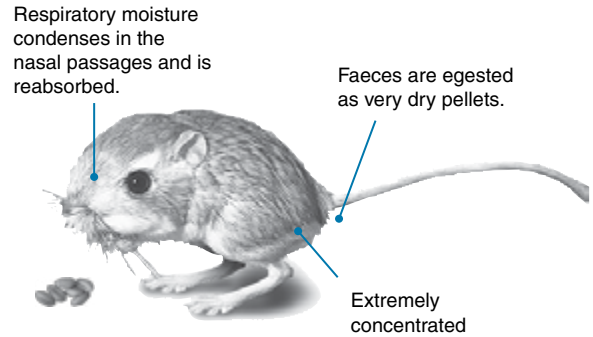
Water balance in a kangaroo rat
(*Dipodomys spectablis*)

Water gains (cm^3)		**Water losses** (cm^3)	
Absorbed from food	6.0	Breathing	43.9
From metabolism	54.0	Urination	13.5
		Defaecation	2.6

Urine/plasma concentration ratio = 17

Adaptations of Kangaroo Rats

Kangaroo rats, and other arid-adapted rodents, tolerate long periods without drinking, meeting their water requirements from the metabolism of dry foods. They dispose of nitrogenous wastes with very little output of water. They do not sweat or pant to keep cool, but are nocturnal and remain underground during the day.



Large Desert Mammals



Camels are well adapted to desert life. Their nasal passages are highly convoluted to trap moisture when exhaling, and they only sweat when the body temperature exceeds 41°C. The urine is highly concentrated and syrupy and the faeces are dry enough to be used as fuel. Metabolism of the fat in the hump also produces water. Camels also tolerate large losses of water without circulatory disturbance because their oval-shaped blood cells can flow even when they are dehydrated.



A suite of adaptations enable kangaroos to exploit the vast arid environment of Australia's semi-deserts. Water is taken in with food but is also derived from metabolism. An elongated large intestine maximises the removal of water from undigested material, producing very dry faeces. The urine is also concentrated, reducing water loss. The hopping mode of locomotion is also very energy efficient, and enables them to cover large expanses of country in search of food and water.

1. Why do most mammals need to drink regularly? _____

_____

2. Describe three physiological adaptations of desert adapted rodents to low water availability:

   (a) _____

   (b) _____

   (c) _____

3. Describe similarities between kangaroos and kangaroo rats in terms of their adaptations for water conservation:

_____

_____

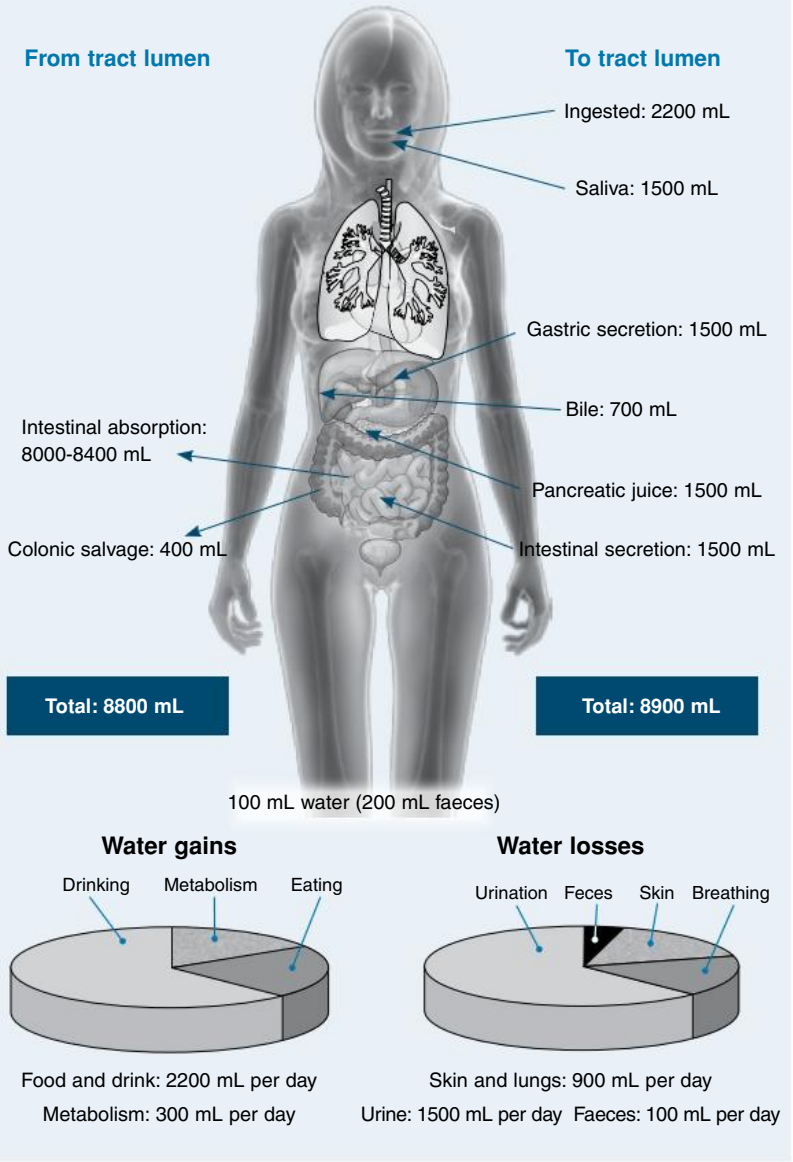
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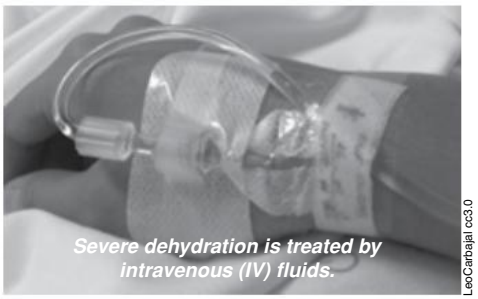
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212 Water Budget in Humans

Key Idea: Water lost from an individual must be replaced by an equal amount to maintain physiological functions. Too much or too little water causes major physiological problems. Water is essential to physiological function and health, we cannot live without water for more than about 100 hours. Any water lost must be replaced by an equal volume, this balance is called the **water budget**. The amount of water required to maintain water balance varies between individuals, and depends on many factors including age, health, gender, level of physical exercise, and the environment (temperature and humidity). Potentially life-threatening health issues arise when the water balance is not maintained either through **dehydration** (excessive water loss) or **overhydration** (excessive water intake).

Daily Water Transfers in an Adult





Severe dehydration is treated by intravenous (IV) fluids.

LeoCarbajal cc3.0

Dehydration occurs when water loss from the body exceeds water intake (e.g. through excessive exercise, fever, or prolonged vomiting or diarrhoea). Many metabolic processes are disrupted, but the physiological effects of dehydration depend upon the extent of water loss.

- 3-4% loss: no obvious problems.
- 5-8% loss: fatigue and dizziness.
- >10% loss: physical and mental deterioration, accompanied by severe thirst.
- >15-25% loss usually fatal.



Kerry Suter

Overhydration (also called hyponatremia from hypo=under, na= salt) occurs when more water is taken into the body than is lost. The excess of water dilutes sodium levels, which can cause a number of problems including digestive problems, behavioural changes, brain damage, seizures, or coma. The condition most often occurs in athletes competing in ultradistance events lasting many hours (above).

1. What is the water budget? _____

2. (a) Distinguish between **dehydration** and **overhydration**: _____

   (b) Describe the physiological consequences of each: _____

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213 Neurone Structure and Function

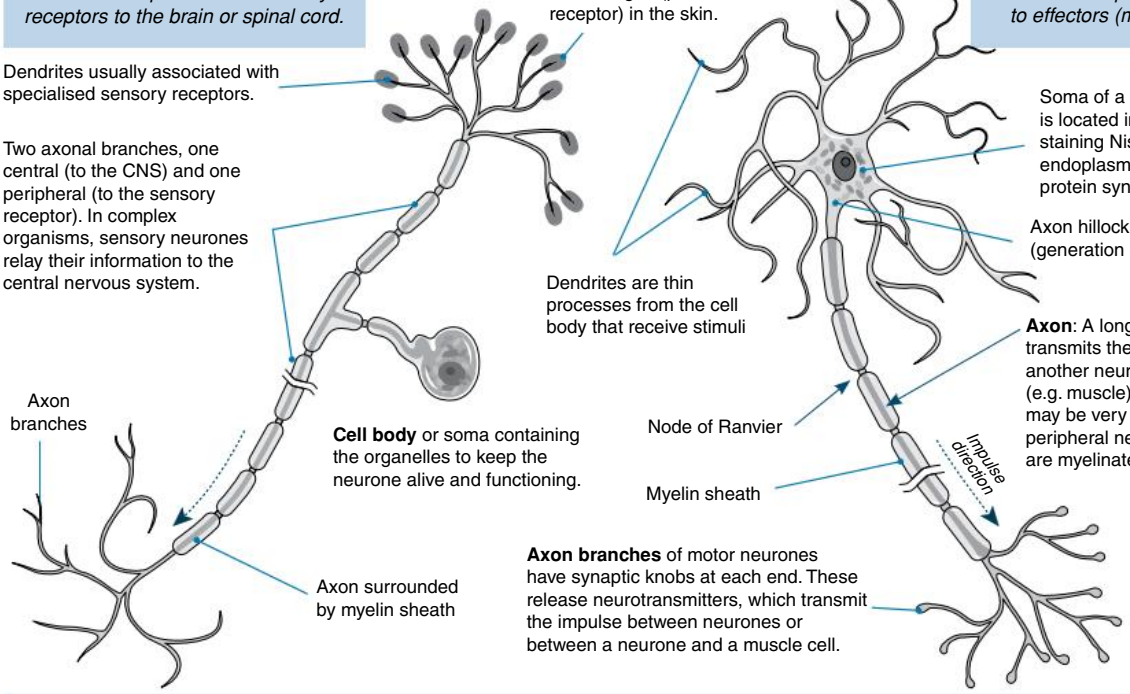
Key Idea: Neurones are electrically excitable cells specialised to process and transmit information via electrical and chemical signals. Increased axon diameter and myelination both increase conduction speed in a neurone.

Neurones transmit information in the form of electrochemical signals from receptors to effectors. Neurones consist of a cell body (soma) and long processes (dendrites and axons). Conduction speed increases with axon diameter and with myelination. Faster conduction speeds enable more rapid responses to stimuli.

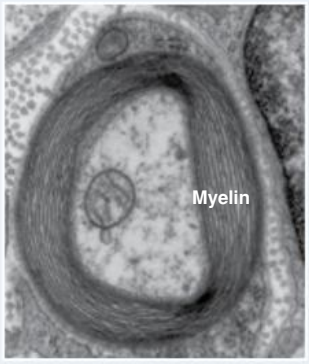
Neurone Structure

Sensory (afferent) neurone
Transmits impulses from sensory receptors to the brain or spinal cord.

Motor (efferent) neurone
Transmits impulses from the CNS to effectors (muscles or glands).

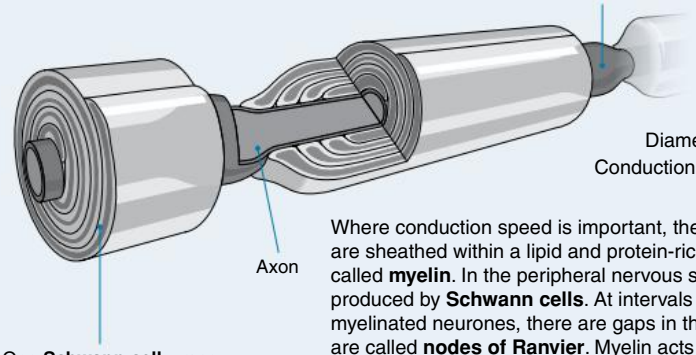


Myelinated Neurones



WIKI

TEM cross section through a myelinated axon



Diameter: 1-25 µm
Conduction speed: 6-120 ms^{-1}

One **Schwann cell** wraps around one axon and produces layers of **myelin** around the axon.

Where conduction speed is important, the axons of neurones are sheathed within a lipid and protein-rich substance called **myelin**. In the peripheral nervous system, myelin is produced by **Schwann cells**. At intervals along the axons of myelinated neurones, there are gaps in the myelin. These are called **nodes of Ranvier**. Myelin acts as an insulator, increasing the speed at which nerve impulses travel because it prevents ion flow across the neurone membrane and forces the current to "jump" along the axon from node to node.

1. Describe the function of each of the following parts of a neurone:

   (a) Dendrites: _____

   (b) Axon: _____

   (c) Cell body: _____

2. (a) What is the function of myelination in neurones? _____

   (b) How does myelination increase the speed of nerve impulse conduction? _____

   _____

   (c) Why do motor neurones in the peripheral nervous system tend to be myelinated? _____

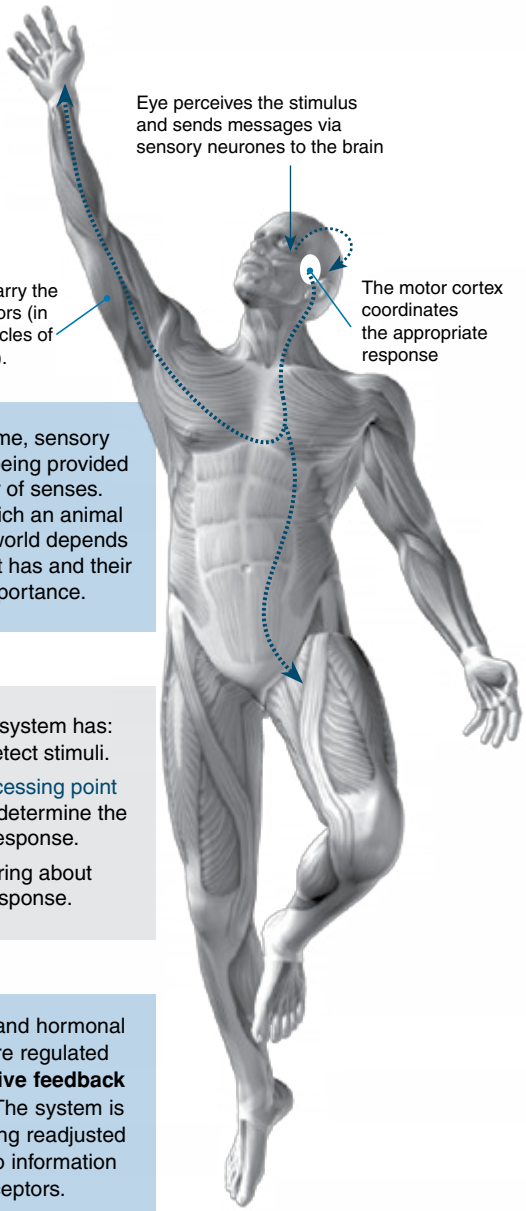
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214 Response and Regulation

Key Idea: The nervous and endocrine systems work together to regulate physiological functions.

Complex multicellular organisms respond to the environment and regulate their physiological functions through the activity of the nervous and the endocrine (hormonal) systems. The nervous system is the body's control and communication centre. It detects stimuli, interprets them, and brings about appropriate responses from muscles and glands. It responds rapidly and its effects are short lived. The endocrine (hormonal) system provides a slower acting but longer lasting means of coordinating physiological activities. The two systems cooperate to respond to environmental stimuli.



At any one time, sensory information is being provided by a number of senses. The way in which an animal perceives the world depends on the senses it has and their relative importance.

The nervous system has:

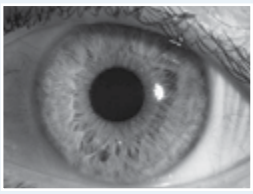
- Sensors to detect stimuli.
- A central processing point (the CNS) to determine the appropriate response.
- Effectors to bring about (effect) the response.

Both nervous and hormonal responses are regulated through **negative feedback** mechanisms. The system is continually being readjusted in response to information from receptors.

The body's activities are coordinated through the central nervous system (CNS). Information relayed to the brain or spinal cord from sensory receptors is interpreted by them and they coordinate a motor response. Peripheral nerves all enter or leave the CNS and relay information to and from the CNS.

Senses and Sense Organs

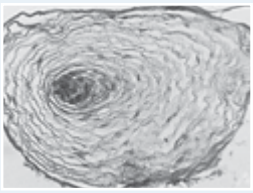
Our senses enable us to perceive and respond appropriately to the external and internal environment. Sensory nerves carry messages (as nerve impulses) from the sensors to the CNS.


Eyes: vision


Ears: hearing


EII Taste buds on tongue: taste

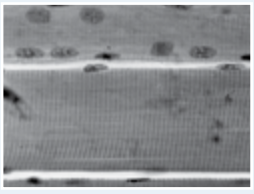

Skin: touch

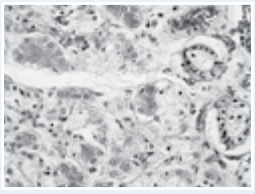

RCN Pacinian corpuscle: pressure

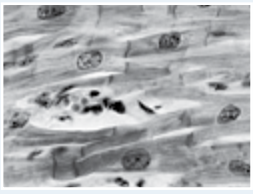

Nose: smell

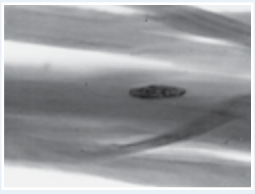
Effectors: Muscle and Glands

Motor nerves carry messages from the CNS to effectors, which bring about appropriate actions (e.g. muscle contraction).


RCN Skeletal muscle: voluntary (conscious) body movement


Salivary gland: involuntary (unconscious) secretion


Cardiac muscle: involuntary (unconscious) contraction


RCN Smooth muscle: involuntary movement (e.g. gut, uterus)

1. (a) What are the basic components of a nervous system? _____

_____

(b) What is the role of each of these components? _____

_____

_____

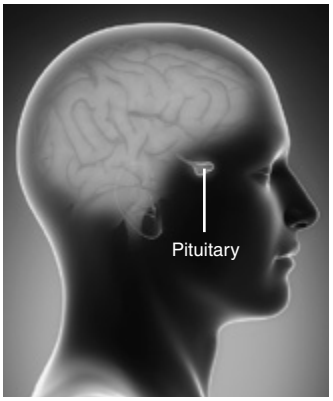
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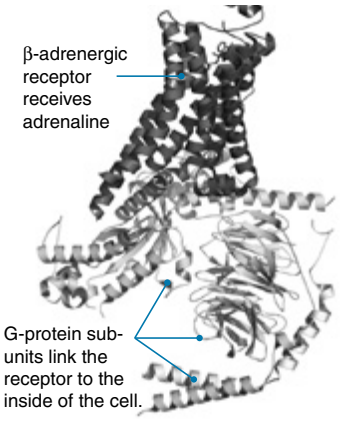
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Comparison of Nervous and Hormonal Control

Hormonal control involves release of the hormone, transport in the blood, interaction with the target cell, and then a response. Thus the time scale and duration of endocrine responses are longer than those of nervous responses. The nervous and hormonal systems do interact. Many endocrine glands secrete hormones in response to nervous stimulation. Some neurotransmitters are also hormones.

	Nervous Control	Hormonal Control
Communication	Impulses across synapses	Hormones in the blood
Speed	Very rapid (within a few milliseconds)	Relatively slow (over minutes, hours, or longer)
Duration	Short term and reversible	Longer lasting effects
Target pathway	Specific (through nerves) to specific cells	Hormones broadcast to target cells everywhere
Action	Causes glands to secrete or muscles to contract	Causes changes in metabolic activity





The endocrine glands secrete hormones, which are carried in the blood and bring about responses in specific target cells. Only target cells have the receptors that enable them to respond to the hormone. The photograph above shows an activated β-adrenergic receptor. Many cells have these receptors, which bind adrenaline. The pituitary gland (above left) is sometimes called the body's master gland because it secretes at least nine hormones which regulate many homeostatic processes.

2. Using the examples pictured on the previous page, discuss how organisms receive stimuli and how they respond:

3. Describe two differences between **nervous control** and **endocrine control** of body systems. For each, explain the significance of the difference:

   (a)

   (b)

4. Explain why nervous and hormonal systems can be regarded as complementary systems that together provide the mechanisms for making appropriate responses to changes in the environment:

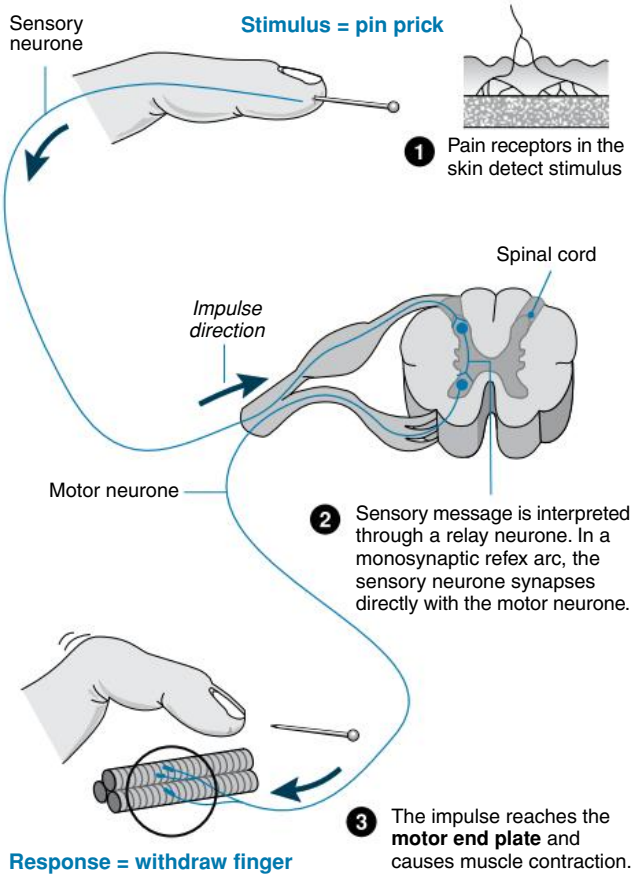
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215 Reflexes

Key Idea: A reflex is an action performed without conscious thought in response to a stimulus.

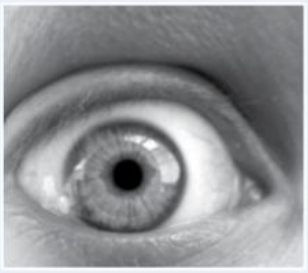
A **reflex** is an automatic response to a stimulus involving a small number of neurones and a central nervous system (CNS) processing point (spinal cord or brain stem). This type of circuit is called a **reflex arc**. Reflexes permit rapid responses to stimuli. Monosynaptic reflexes involve only one CNS synapse (e.g. knee jerk reflex), polysynaptic reflexes involve two or more (e.g. pain withdrawal reflex). Both are spinal reflexes.

Pain Withdrawal: A Polysynaptic Reflex Arc





The patella (knee jerk) reflex is a simple deep tendon reflex used to test the function of the femoral nerve and spinal cord segments L2-L4. It helps to maintain posture and balance when walking.



The pupillary light reflex refers to the rapid expansion or contraction of the pupils in response to t light falling on the retina. It is a polysynaptic cranial reflex and is used to test for brain death.





Normal newborns exhibit a number of primitive reflexes in response to particular stimuli. These reflexes disappear within a few months of birth as the child develops. Primitive reflexes include the grasp reflex (above left) and the startle or Moro reflex (above right) in which a sudden noise will cause the infant to throw out its arms, extend the legs and head, and cry. The rooting and sucking reflexes are other examples of primitive reflexes.

1. Why are reasoning and conscious thought not necessary or desirable features of reflex behaviours?

2. Distinguish between a spinal reflex and a cranial reflex and give an example of each:

3. (a) Distinguish between a monosynaptic and a polysynaptic reflex arc and give an example of each:

   (b) Which would produce the most rapid response, given similar length sensory and motor pathways? Explain:

4. (a) With reference to an example, describe the adaptive value of primitive reflexes in newborns:

   (b) Why are newborns tested for the presence of these reflexes?

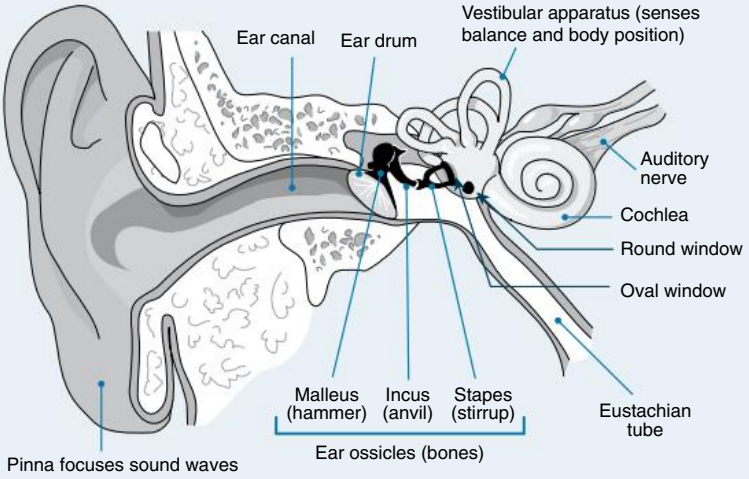
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216 Hearing

Key Idea: Receptors in the ear allow animals to detect sound.

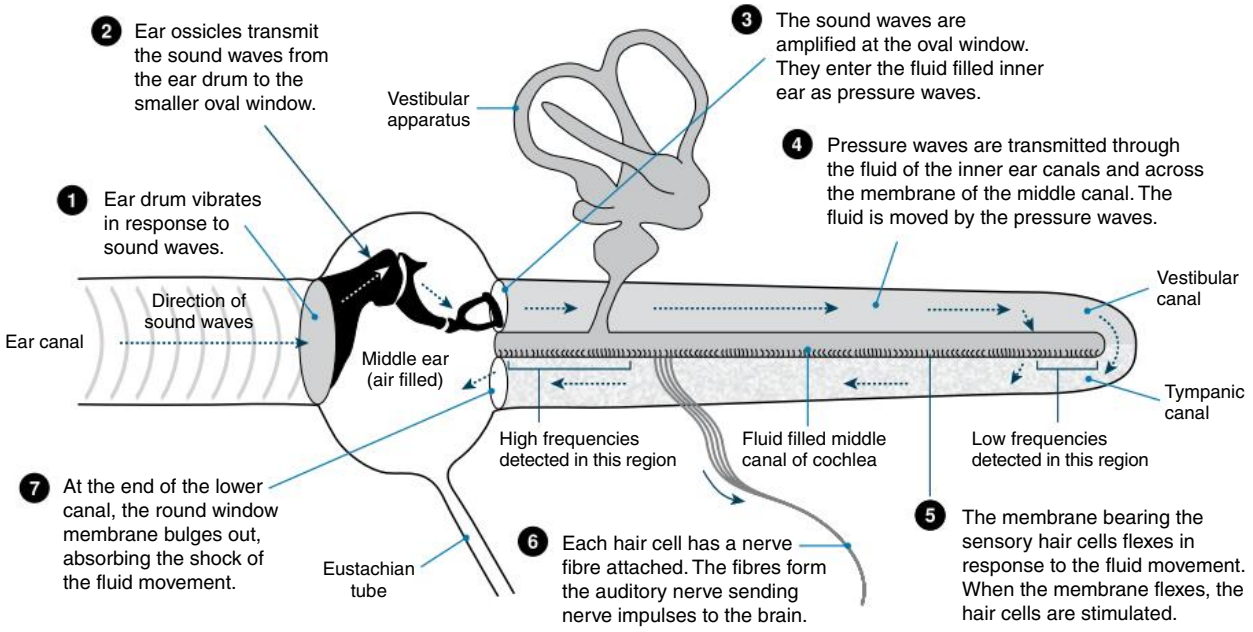
Most animals have receptors for the detection of sound waves. In mammals, these receptors are the ears. Sound is produced by the vibration of particles in a medium and it travels in waves that can pass through solids, liquids, or gases. The distance between wave 'crests' determines the frequency (pitch) of the sound. The absolute size (amplitude) of the waves determines the intensity (loudness) of the sound. Sound reception in mammals is the role of hair cells in the cochlea of the inner ear. The hair cells are easily damaged by prolonged exposure to high intensity sounds, resulting in hearing loss.

The Human Ear



In mammals, sound waves are converted to pressure waves in the inner ear. The ears of mammals use mechanoreceptors (sensory hair cells) to change the pressure waves into nerve impulses. The mammalian ear contains not only the organ of hearing, the cochlea, but all the specialised structures associated with gathering, directing, and amplifying the sound. The cochlea is a tapered, coiled tube, divided lengthwise into three fluid filled canals.

The cochlea is shown below, unrolled to indicate the way in which sound waves are transmitted through the canals to the sensory cells. The mechanisms involved in hearing are outlined in a simplified series of steps. In mammals, the inner ear is also associated with the vestibular apparatus, which detects balance and position.



1. In a short sentence, outline the role of each of the following in the reception and response to sound:

   (a) The ear drum: _____

   (b) The ear ossicles: _____

   (c) The oval window: _____

   (d) The sensory hair cells: _____

   (e) The auditory nerve: _____

2. What is the significance of the inner ear being fluid filled? _____

_____

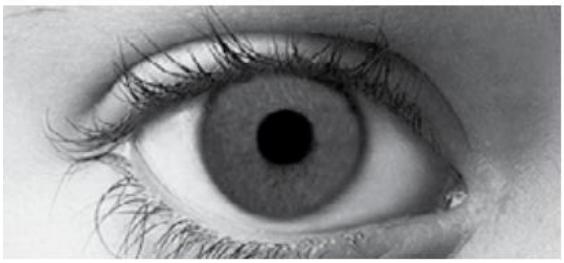
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217 The Structure of the Eye

Key Idea: The eye is a sense organ that responds to light.

The eye is a complex and highly sophisticated sense organ specialised to detect and respond to light. The adult eyeball is about 25 mm in diameter. Only the anterior one-sixth of its total surface area is exposed; the rest lies recessed and protected by the orbit into which it fits. The eyeball is protected and given shape by a fibrous tunic. The posterior part of this structure is the sclera (the white of the eye), while the anterior transparent portion is the cornea, which covers the coloured iris.



The Structure and Function of the Mammalian Eye

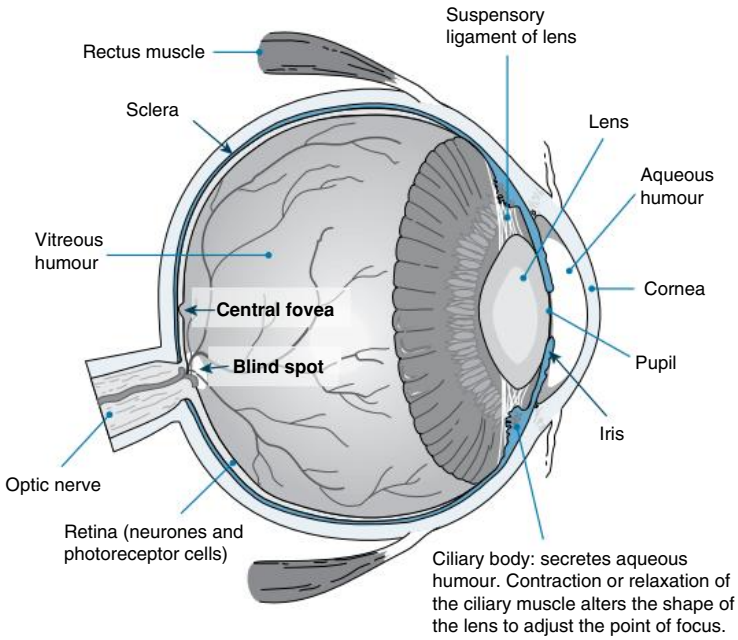
The human eye is essentially a three layered structure comprising an outer fibrous layer (the sclera and cornea), a middle vascular layer (the choroid, ciliary body, and iris), and inner **retina** (neurones and **photoreceptor cells**). The shape of the eye is maintained by the fluid filled cavities (aqueous and vitreous humours), which also assist in light refraction. Eye colour is provided by the pigmented iris. The iris also regulates the entry of light into the eye through the contraction of circular and radial muscles.

Forming a Visual Image

Before light can reach the photoreceptor cells of the retina, it must pass through the cornea, aqueous humour, pupil, lens, and vitreous humour. For vision to occur, light reaching the photoreceptor cells must form an image on the retina. This requires refraction of the incoming light, **accommodation** of the lens, and **constriction** of the pupil.

The anterior of the eye is concerned mainly with refracting (bending) the incoming light rays so that they focus on the retina (below left). Most refraction occurs at the cornea. The lens adjusts the degree of refraction to produce a sharp image. Accommodation adjusts the eye for near or far objects. Constriction of the pupil narrows the diameter of the hole through which light enters the eye, preventing light rays entering from the periphery.

The point at which the nerve fibres leave the eye as the optic nerve, is the **blind spot** (the point at which there are no photoreceptor cells). Nerve impulses travel along the optic nerves to the visual processing areas in the cerebral cortex. Images on the retina are inverted and reversed by the lens but the brain interprets the information it receives to correct for this image reversal.



1. Identify the function of each of the structures of the eye listed below:

   (a) Cornea: _____

   _____

   (b) Ciliary body: _____

   _____

   (c) Iris: _____

   _____

2. (a) The first stage of vision involves forming an image on the retina. What does this involve? _____

   _____

   _____

   (b) How is accommodation achieved? _____

   _____

   _____

   _____

   _____

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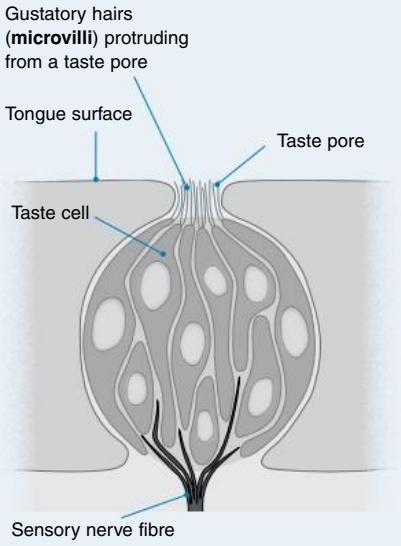
218 Taste and Smell

Key Idea: The receptors for smell and taste respond to chemicals, either carried in the air (smell) or dissolved in a fluid (taste).

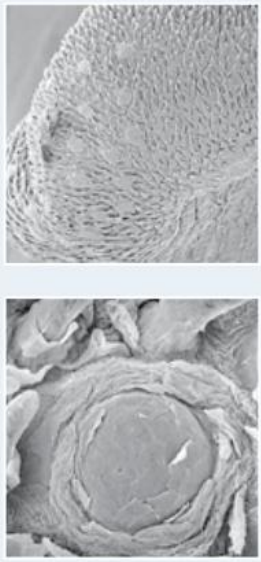
Chemosensory receptors for smell and taste both respond to chemicals, either carried in the air (smell) or dissolved in a fluid (taste). In humans and other mammals, these are located in the nose and tongue respectively. Each receptor type is structurally similar. They are collections of receptor cells equipped with chemosensory microvilli or cilia. When chemicals stimulate their membranes, the cells respond by producing nerve impulses that are transmitted to the cerebral cortex for interpretation.

Taste (Gustation)

The organs of taste are the **taste buds**, which are located on the tongue. Most of the taste buds on the tongue are located on raised protrusions of the tongue surface called **papillae**. Each bud is flask-like in shape, with a pore opening to the surface of the tongue enabling molecules and ions dissolved in saliva to reach the receptor cells inside. Each taste bud is an assembly of 50-150 taste cells. These connect with nerves that send messages to the gustatory region of the brain. There are five basic taste sensations. **Salty** and **sour** operate through ion channels, while **sweet**, **bitter**, and **umami** (savoury) operate through membrane signalling proteins. These taste sensations are found on all areas of the tongue although some regions are more sensitive than others.



Note that taste also relies heavily on smell because odours from food also stimulate olfactory receptors.

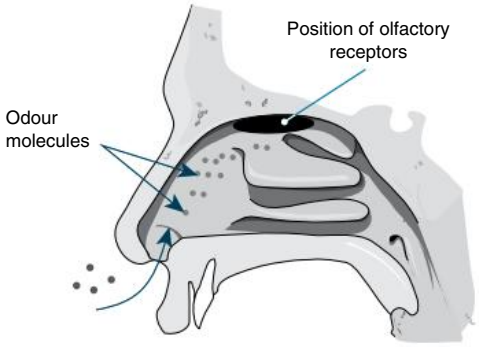


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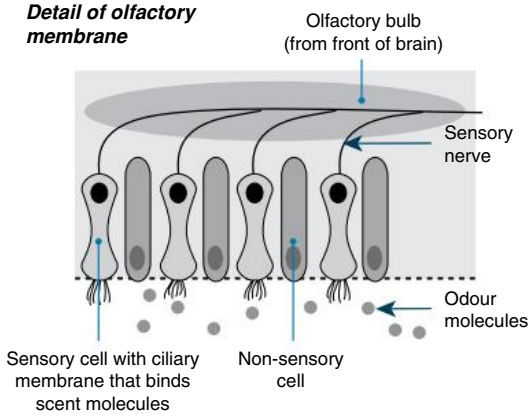
Above: SEMs of the surface of the tongue (top) and close up of one of the papillae (below).

Smell (Olfaction)

In humans, the receptors for smell are located at the top of the nasal cavity. The receptors are specialised hair cells that detect airborne molecules and respond by sending nerve impulses to the olfactory centre of the brain. Unlike taste receptors, olfactory receptors can detect many different odours. However, they quickly adapt to the same smell and will cease to respond to it. This phenomenon is called **sensory adaptation**.



Detail of olfactory membrane



1. Describe the basic mechanism by which chemical sense operates: _____

_____

_____

2. Take a deep breath of a non-toxic, pungent substance such as perfume. Take a sniff of the substance at 10 second intervals for about 1 minute. Make a record of how strongly you perceived the smell to be at each time interval. Use a scale of 1 to 6: **1.** *Very strong;* **2.** *Quite strong;* **3.** *Noticeable;* **4.** *Weak;* **5.** *Very faint;* **6.** *Could not detect.*

Time	Strength	Time	Strength	Time	Strength
10 s	_____	30 s	_____	50 s	_____
20 s	_____	40 s	_____	1 min	_____

3. (a) Explain what happened to your sense of smell over the time period: _____

(b) State the term that describes this phenomenon: _____

(c) What is the adaptive advantage of this phenomenon? _____

_____

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219 Sensory Systems

Key Idea: Animals respond to a range of stimulus modalities to obtain information about their environment.

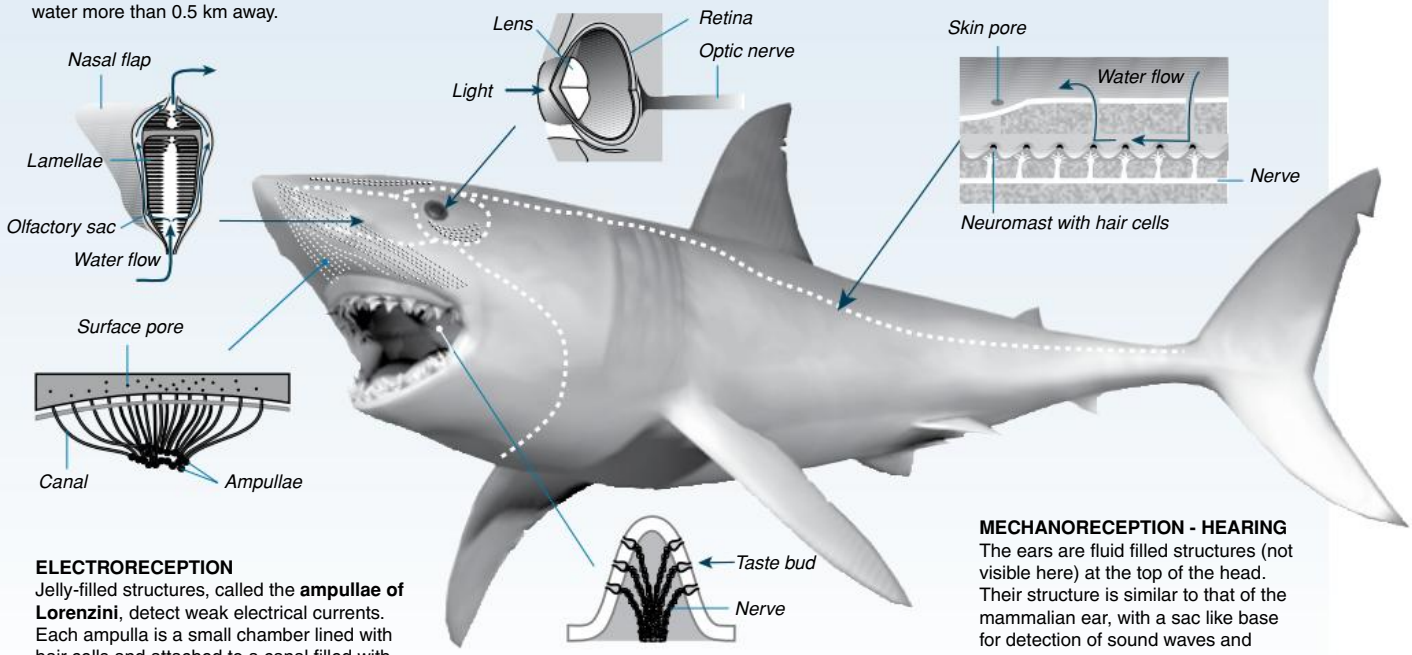
The sensory systems present in any particular species are appropriate to its environment and its needs in terms of feeding, locomotion, reproduction, and predator avoidance. Consequently, many organisms respond to stimulus modalities (e.g. electrical fields) of which humans may be unaware. This activity describes several senses, including various kinds of mechanoreception, a sense that is universal in the animal kingdom and involved in detection of sound and vibration, gravity, touch, pressure, and stretch. In all mechanoreceptors, deformation of the sensory structure by the stimulus (e.g. pressure) leads to a nerve response. The diagram of the senses of the great white shark (*Carcharodon carcharias*), below, shows how senses work together to provide information about the environment.

Senses in the Great White Shark

CHEMICAL SENSE - OLFACTION
Olfaction is a shark's most acute sense. The olfactory sacs lie under the snout. A flap of skin covers each sac and channels water into the chamber and across the sensory lamellae. About 70% of a shark's brain is devoted to sensing 'odours' dissolved in the water. A shark can determine the location of food from the presence of minute particles of flesh or blood in the water more than 0.5 km away.

VISION
Sharks have excellent vision. The retina has both rods and cones, and the presence of a reflective tapetum lucidum improves vision in low light. Seawater has a density almost the same as that of the corneal tissue, so most of the refraction of light is done by the lens.

MECHANORECEPTION - LATERAL LINE
A system of small water-filled canals below the skin surface. Neuromasts in the canal detect the fluid displacement, and are used to assess water current direction and velocity. Together, the lateral line and the inner ear are called the **acoustico-lateralis system**.

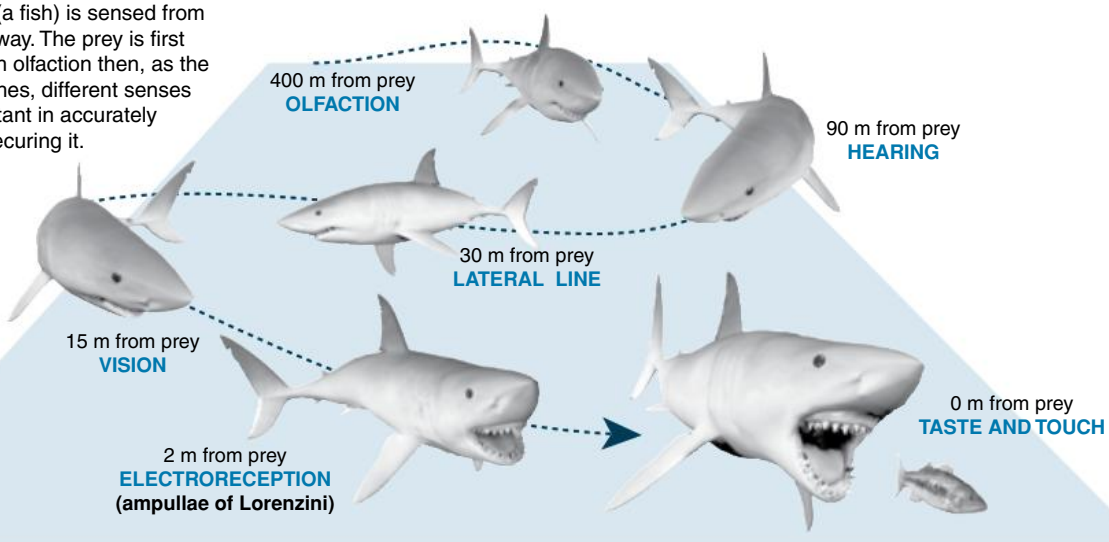


ELECTRORECEPTION
Jelly-filled structures, called the **ampullae of Lorenzini**, detect weak electrical currents. Each ampulla is a small chamber lined with hair cells and attached to a canal filled with conductive jelly. The canals open as pores and are clustered around the eyes and snout. Sharks use the ampullae to sense prey and to navigate using geomagnetic field lines.

CHEMICAL SENSE - TASTE BUDS
Taste receptors cells are on small taste buds in the mouth. They are best stimulated by direct contact, and are used to determine palatability.

MECHANORECEPTION - HEARING
The ears are fluid filled structures (not visible here) at the top of the head. Their structure is similar to that of the mammalian ear, with a sac like base for detection of sound waves and three D-shaped tubes for the detection of acceleration and orientation. Sensitivity to sound is restricted to the low frequency range, particularly less than 375 Hz.

Potential prey (a fish) is sensed from up to 0.5 km away. The prey is first sensed through olfaction then, as the shark approaches, different senses become important in accurately locating and securing it.

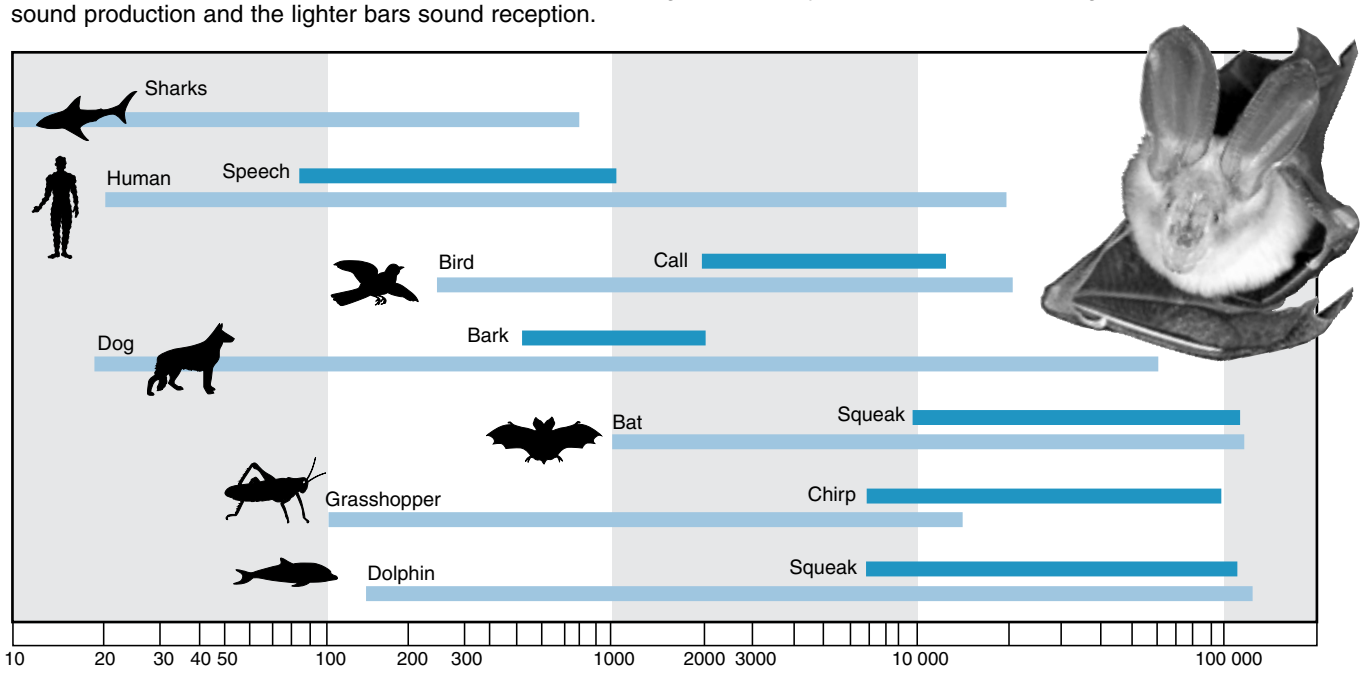


Sensory systems involved in prey detection and capture in great white sharks

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Sound and Hearing

Ears and the auditory organs of insects are also mechanoreceptors. Reception of mechanical stimuli (e.g. sound or vibration) is universal throughout animal phyla. Sound waves travel through various media largely unimpeded and the production and reception of sound allows animals to navigate, communicate, and forage effectively. There is a wide range of frequencies for both sound production and reception amongst animal phyla. The dark bars in the figure below indicate sound production and the lighter bars sound reception.



1. Identify three types of mechanoreceptors and the stimuli to which they respond:

   (a) _____

   (b) _____

   (c) _____

2. What feature indicates that sharks have colour vision? _____

3. (a) In a general way, comment on the range of sound frequencies made by animals relative to what they can hear:

   _____

   _____

   (b) What is the adaptive value of this difference? _____

   _____

4. Why is the lateral line an excellent organ for mechanoreception in water? _____

   _____

   _____

5. (a) Why is sensitivity to sound or vibration so widespread amongst animal phyla? _____

   _____

   (b) Identify three uses animals make of their ability to perceive sound and vibration: _____

   _____

6. Discuss the benefits of using a range of different senses to gather information about the environment:

   _____

   _____

   _____

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220 Animal Communication

Key Idea: Communication is the transmission of (understood) information between individuals of the same species. It is essential to the survival and reproductive success of animals. Effective communication enables animals to avoid predators, coordinate foraging and hunting activity, maintain social behaviours, and attract mates. Messages can be passed between animals using a range of signals that may be visual, chemical, auditory, or tactile. The type of signal used depends on the activity pattern and habitat of the animal, e.g. sound carries well in dense forest.



Sender
The individual who transmits the signal

Channel
The medium in which the signal is transmitted:
visual; chemical/olfactory; tactile or auditory

Code

Rules by which the sender must transmit the signal

Signal
The message conveyed from one individual to another:
aggression, submission, courtship, social bonding

Code

Rules which enable the receiver to decipher the signal



Receiver
The individual who detects the signal



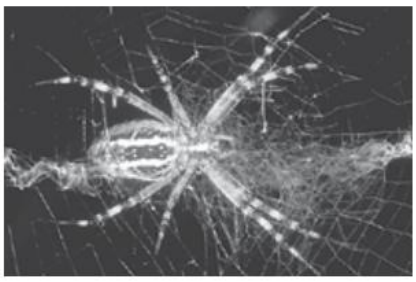
The two male baboons on the right are engaged in a dominance display. Both animals are acting as senders and receivers of a message.

Context
The setting in which the communication occurs: *dominance display; courtship; predator alert; food gathering*



Olfactory Messages

Some animals produce scents that are carried long distances by wind. This may advertise for a mate, or warn neighbouring competitors to avoid a territory. In some cases, mammals use their urine and faeces to mark territorial boundaries. Sniffing genitals is common among mammals.



Tactile Messages

The touching of one animal by another may be a cooperative interaction or an aggressive one. Grooming behaviour between members of a primate group communicates social bonding. Vibrations sent along a web by a male spider communicates to a potential mate not to eat him.



Auditory Messages

Sound can be used to communicate over great distances. Birds keep rivals away and advertise for mates with song. Fin whales can send messages over thousands of kilometres of ocean. Calls made by mammals can be used to attract mates, contact other members of a group, or threaten competitors

Visual Messages

Many animals convey information to other members of the species through their colours and adornments, and through gestures and body language. Visual displays can deliver threats, show submission, attract a mate, and even exert control over a social group.



Warning

Animals may communicate a warning to others through visual displays. Many wasp species (like those above) have brightly coloured black and yellow markings to tell potential predators that they risk being stung if attacked.



Deception

Animals may seek to deceive other animals about their identity. As an alternative to camouflage, animals may use visual markings that startle or deter potential predators. The eye spots on this moth may confuse a predator.



Attraction

Some animals produce a stunning visual display in order to attract a mate. The plumage of some bird species can be extremely colourful and elaborate, such as the peacock (above), the birds of paradise, and the lyrebird.

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LINK 221 LINK 219 KNOW

1. (a) Explain why much of animal communication is ritualised: _____

(b) Discuss the benefits to animals of effective communication over both long and short distances: _____

2. Describe and explain the communication methods best suited to nocturnal animals in a forest habitat: _____

3. Postures provide a very important form of communication between animals. The **ethogram** below illustrates the various postures exhibited by the **purple swamphen** (*Porphyrio porphyrio*), a wetland bird belonging to the rail family. Social behaviours can often be graded from those that display overt aggression to those that are submissive. Swamphens have a **graded range** of displays of increasing aggression or submission. By using the symbols (+, – and 0) at the bottom of the page, indicate the degree of aggressiveness, submissiveness, or neutral body language. Use the spaces provided:

Ethogram for Swamphen Behaviour

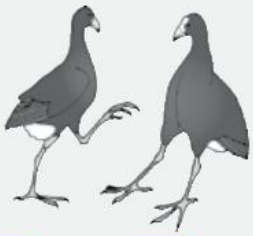


1A

1B



Fighting. One bird jumping with feet ready for clawing and beak open for pecking.



2A 2B

Fighting. One bird in aggressive upright posture with wings and tail raised and feet raised. The other bird is in the aggressive upright but not attacking.



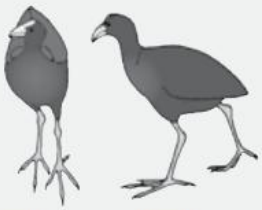
3

Full bow. Submissive wings and tail fully up.



4A 4B

Fighting. Both birds in aggressive uprights and using feet to attack.



5A 5B

Facing away. Submissive display to an aggressive upright bird.



6A 6B

Fighting. Both birds jumping with feet ready for clawing and beak open for pecking.



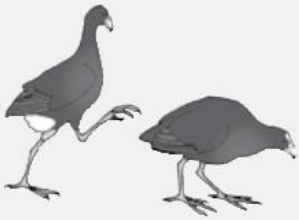
7

Aggressive upright. Wings down. Tail horizontal.



8

Move away. Submissive display. Wings exaggerated. Tail fully up to uncover white feathers.



9A 9B

Crouch. Submissive display to an aggressive upright bird.



10

Horizontal forward. Aggressive display but not as aggressive as an upright.



11A 11B

Head flagging. Submissive display. Head held low and moved from side to side.



12

Head flick. Submissive display. Usually at end of encounter. Wings exaggerated, tail fully up. Beak held too high to peck at other bird.

Range of aggressive/submissive behaviours

+ + very aggressive	+ slightly aggressive	**0** neutral	– slightly submissive	– – very submissive

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221 Behaviour and Species Recognition

Key Idea: Animals exhibit species-specific behaviours that improve their chances of successful reproduction.

Many of the behaviours observed in animals are associated with reproduction, reflecting the importance of this event in an individual's life cycle. Many types of behaviour are aimed at facilitating successful reproduction. These include **courtship behaviours**, which may involve attracting a mate to a particular breeding site. Courtship behaviours are aimed at reducing conflict between the sexes and are often stereotyped or **ritualised**. They rely on sign stimuli to elicit specific responses in potential mates. Other reproductive behaviours are associated with assessing the receptivity of a mate, defending mates against competitors, and rearing the young. Behavioural differences between species are a type of reproductive isolating mechanism to help preserve the uniqueness of a species gene pool.

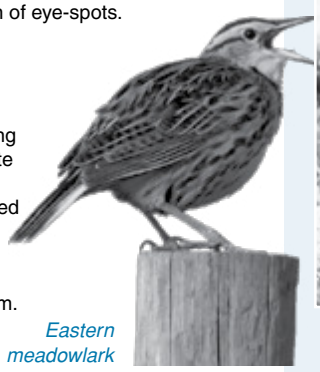
Courtship and Species Recognition

Accurate species recognition when choosing a mate is vital for successful reproduction and species survival. Failure to choose a mate of the same species would result in reproductive failure or hybrid offspring which are infertile or unable to survive. Birds exhibit a wide range of species-specific courtship displays to identify potential mates of the same species who are physiologically ready to reproduce. They may use simple visual or auditory stimuli, or complex stimuli involving several modes of communication specific to the species.



Peacock courtship (left) involves a visually elaborate tail display to attract female attention. The male raises and fans his tail to display the bright colours and eye-spot patterns. Peahens tend to mate with peacocks displaying the best quality tail display which includes the quantity, size and distribution of eye-spots.

Bird song is an important behavioural isolation method for many species including eastern and western meadowlarks. Despite the fact that they look very similar and share the same habitat, they have remained as two separate species. Differences between the songs of the two species enables them to recognise individuals of their own species and mate only with them. This maintains the species isolation.



Eastern meadowlark



Some species use chemical cues as mating signals and to determine mate choice. The crested auklet (left) secretes aldehydes which smell like tangerines. Birds rub their bills in the scented nape of a partner during courtship. This "ruff-sniff" behaviour allows mate evaluation based on chemical potency. A potential partner might be seen as fitter and more attractive if it produces more aldehydes, because the chemical repels ectoparasites.

Courtship Behaviour Aids Successful Mating



Courtship behaviour occurs as a prelude to mating. One of its functions is to synchronise the behaviours of the male and female so that mating can occur, and to override attack or escape behaviour. Here, a male greater frigatebird calls, spreads its wings, and inflates its throat pouch to court a female.



In many bird and arthropod species, the male will provide an offering, such as food, to the female. These **rituals** reduce aggression in the male and promote appeasement behaviour by the female. For some **monogamous** species, e.g. the blue-footed boobies (left), the pairing begins a long term breeding partnership.



Although courtship rituals may be complex, they are very stereotyped and not easily misinterpreted. Males display, usually through exaggerated physical posturing, and the females then select their mates. Courtship displays are species specific and may include ritualised behaviour such as dancing, feeding, and nest-building.

1. (a) Why might courtship behaviour be necessary prior to mating? _____

   _____

   (b) Why is courtship behaviour often ritualised, with stereotyped displays? _____

   _____

   _____

2. What is the role of courtship behaviour in species recognition? _____

   _____

   _____

   _____

   _____

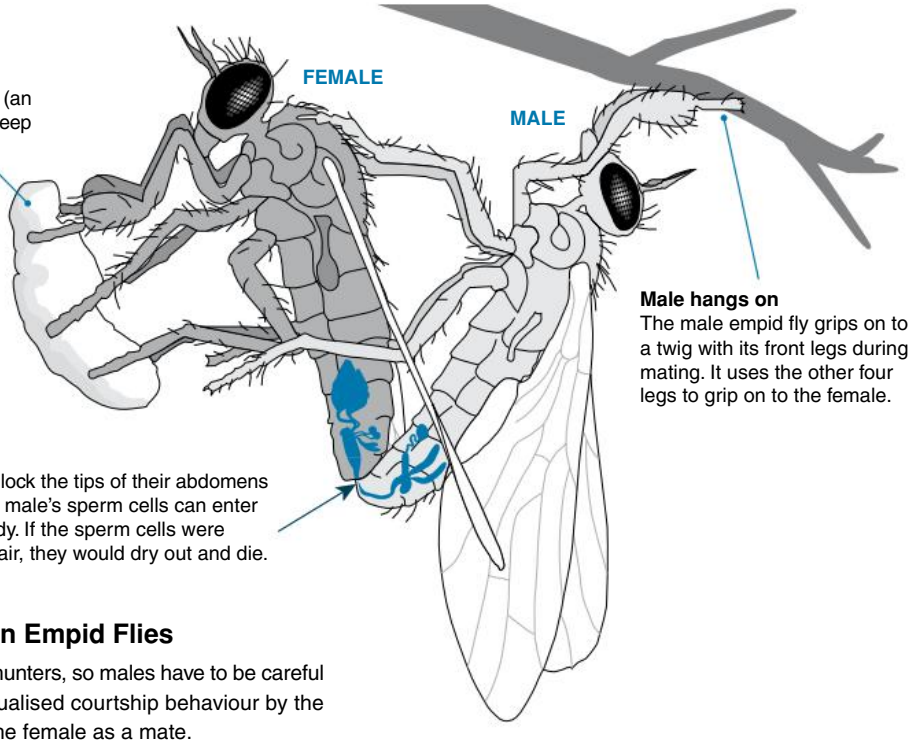
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222 Breeding Behaviour

Key Idea: Breeding behaviours, such as courtship rituals, are adaptations to ensure reproductive success.

Most animals breed annually and show no reproductive behaviour outside the breeding season. During the breeding season, reproductive signals must be given and interpreted correctly, or the chance for successful reproduction may be missed. The short time period that most sexually reproducing animals have in which to breed creates strong selective pressure for behaviour that improves reproductive success. Breeding pairs often establish territories to ensure reliable access to resources. Ritualised courtship behaviours reduce conflict so that mating is achieved without injury.



Courtship gift
The male gives the female a meal (an insect wrapped up in a cocoon) to keep her occupied while he mates.

Male hangs on
The male empid fly grips on to a twig with its front legs during mating. It uses the other four legs to grip on to the female.

Lock and key
The empid flies lock the tips of their abdomens together, so the male's sperm cells can enter the female's body. If the sperm cells were exposed to the air, they would dry out and die.

Mating Between Empid Flies

Female **empid flies** are aggressive hunters, so males have to be careful about how they approach them. Ritualised courtship behaviour by the male helps him to be accepted by the female as a mate.

Territories and Reproductive Behaviour



A territory is any area that is defended against members of the same species. The territory, which usually contains access to valuable resources, is usually defended by acts of aggression or ritualised signals (e.g. vocal, visual or chemical signals).



The availability of resources often determines territory size, and the population becomes spread out accordingly. **Gannet** territories are relatively small, with hens defending only the area they can reach while sitting on their nest (above).



Topi, a lek species

Lek systems involve gatherings of males for highly competitive mating displays. In a lek system, the only area the male defends is the space where mating occurs. Females compete for the highest ranked males, as judged by their position on the lek.

1. Describe two aspects of mating behaviour in empid flies that help to ensure successful mating:

   (a) _____

   (b) _____

2. What is the role of photoperiod in determining the onset of reproductive behaviour in many species? _____

   _____

3. What role might the acquisition of a territory play in an individual's reproductive success (and evolutionary fitness)?

   _____

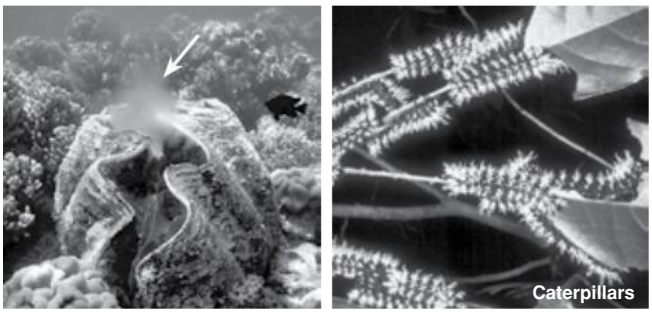
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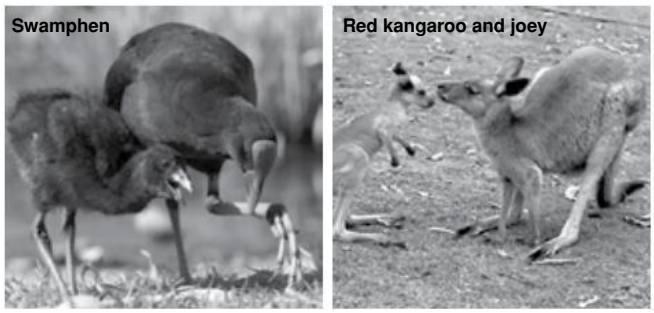
223 Parental Care

Key Idea: Parents may produce large numbers of young but put little effort into their care, or they may produce just a few young and put a lot of effort into their care.

The **reproductive effort** is the amount of energy that animals are prepared to put into reproduction (production and care of young). The amount of care given by parent(s) depends on how much effort is allocated before birth (producing the young) and how much is allocated after the young are born (the parental care period). Species can divide their reproductive effort into many small units (offspring), or into a smaller number of larger units. Reproductive strategies in which more energy is invested in the young are usually associated with a higher degree of parental care before and often after the young are produced.

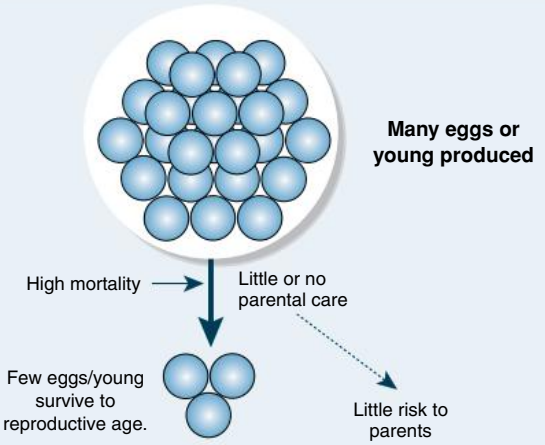


Most invertebrates show no parental care. The giant clam (above left) is releasing millions of eggs into the surrounding water (arrowed). These will be fertilised by sperm released by other clams in the area. The massive numbers of resulting planktonic larvae will be severely reduced by plankton feeding animals. Most insects abandon their eggs after laying. Mortality of the offspring (above right) after hatching (e.g. through predation or starvation) is usually very high.



Scott McDougall

Mammals and birds show high levels of parental care. Amphibians, fish, and reptiles also provide care until the offspring are capable of fending for themselves. Bird parents incubate their eggs in a nest and then feed the chicks until they are independent. Although most mammals give birth to well developed offspring, they are dependent on their mother for nourishment via suckling milk, as well as learning valuable behaviours.



Little or No Parental Care

- Large number of offspring produced.
- The reproductive effort per offspring is low.
- Little or no parental care of the offspring.
- Reproductive effort is directed at producing the offspring and not at parental care after birth.

Parental Care

- Few offspring produced.
- The reproductive effort per offspring is high.
- Moderate/substantial care of young after birth.
- Greater reproductive effort is directed at parental care after birth.

1. Explain how animals with little or no parental care compensate for not caring for their young:

_____

_____

2. Name two quite different animals that exhibit little or no parental care: _____

3. Name two quite different animals that exhibit considerable parental care: _____

4. Describe three specific ways that a young bird may benefit by having a high degree of parental care:

(a) _____

(b) _____

(c) _____

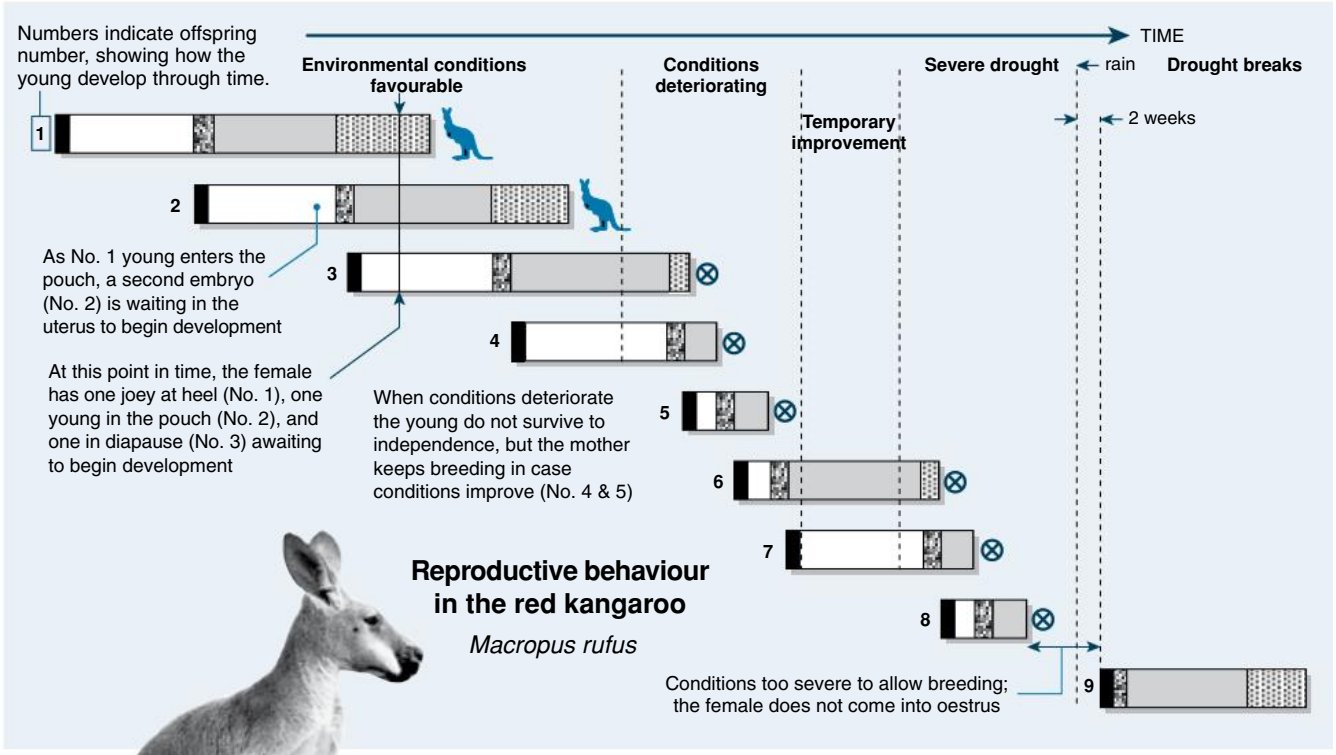
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224 Breeding in a Harsh Climate

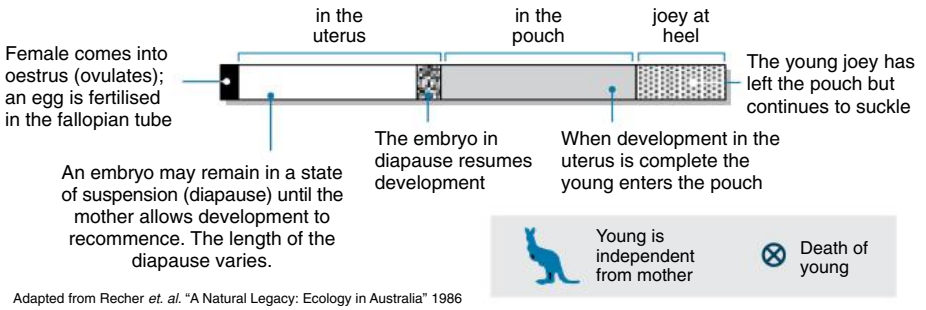
Key Idea: The red kangaroo can adjust its reproductive cycle to suit the prevailing environmental conditions.

The red kangaroo has developed a reproductive strategy that enables it to make the most of good conditions and survive periods of low food availability. In good conditions, it produces young in rapid succession. The female may have a joey at heel, one in the pouch, and a dormant embryo ready to replace the pouch offspring when it leaves (below).





Key to reproductive events



Adapted from Recher *et. al.* "A Natural Legacy: Ecology in Australia" 1986

1. Study the diagrams above and then answer the following questions:

   (a) At what stage of development did offspring number 3 die? _____

   (b) What stage of development did offspring 4 and 5 reach before they died? _____

   (c) How many young were in progress during the period of temporary improvement and what were their stages?

   _____

   (d) Describe the progression of four events occurring during the severe drought: _____

   _____

   (e) What step was missed out after the drought broke? Briefly explain why: _____

   _____

2. When conditions deteriorate, the joey at heel (still suckling) perishes first, then the pouch young, then the diapausing embryo. Why does the mother withdraw nourishment from the young in this order when times are hard?

   _____

   _____

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225 Biological Rhythms

Key Idea: Plants and animals use environmental cues to establish and maintain a pattern of activity.

Environmental cues, such as daylength, timing and the height of tides, temperature, and phase of the moon are often used by plants and animals to establish and maintain a pattern of activity. Regular environmental cues assist survival by synchronising important events in an organism's life cycle; events such as pollination or mating, birth or germination, rearing of offspring, collection and storage of food reserves and body fat, and periods of torpor or inactivity.

1. Define each of the following terms that describe types of biological rhythm:

   (a) **Circadian** rhythm: _____

   Period of cycle: _____

   (b) **Circalunar** rhythm: _____

   Period of cycle: _____

   (c) **Circannual** rhythm: _____

   Period of cycle: _____

   (d) **Circatidal** rhythm: _____

   Period of cycle: _____

2. Define each of the following terms that describe activity patterns linked to **circadian** cycles:

   (a) **Diurnal** activity: _____

   _____

   (b) **Nocturnal** activity: _____

   _____

   (c) **Crepuscular** activity: _____

   _____

3. The photographs below show a plant or animal that uses an **environmental cue** to maintain an activity pattern. For each one, name the **activity pattern** (e.g. annual) and suggest what cue might be used to maintain the pattern:


RA

Echidna Hibernating


RA

Parrot Foraging


DEQ

Bilby Hunting



Synchronised Flowering

   (a) Echidna's 2-4 month hibernation in the snowy mountains of New South Wales: _____

   Environmental cue used: _____

   (b) Rosella parrot's foraging and social behaviour during daylight: _____

   Environmental cue used: _____

   (c) Bilby's activity of hunting for insects, seeds and fruit at night: _____

   Environmental cue used: _____

   (d) Plants coordinated flowering in spring: _____

   Environmental cue used: _____

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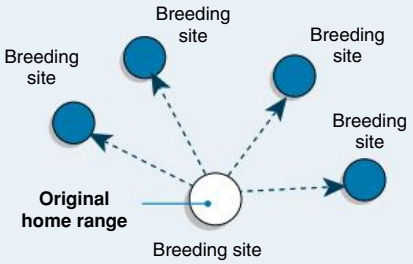
226 Migration Patterns

Key Idea: Migrations often involve very large distances and usually involve a return journey. They are initiated by the activity of internal clocks or timekeepers in response to environmental cues such as change in daylength.

True **migrations** are those where animals travel from one well-defined region to another, for a specific purpose such as overwintering, breeding, or seeking food. Some mass movements of animals are not true migrations in that they do not involve a return journey and they are not governed by an internal biological clock. Such movements are best described as dispersals and are typical of species such as the 'migratory' locusts of north Africa and Australia.

Dispersal: One-way Migration

Some migrations of animals involve a one-way movement. In such cases, the animal does not return to its original home range. This is typical of population dispersal. This often occurs to escape deteriorating habitats and to colonise new ones.



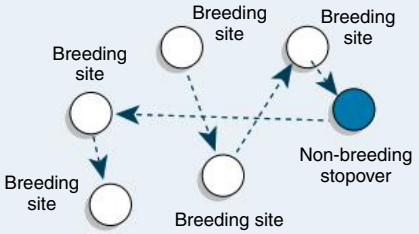
Return Migration

Animals that move to a winter feeding ground are making one leg of a return migration. The same animals return to their home range in the spring which is where they have their breeding sites. Sometimes they follow different routes on the return journey.



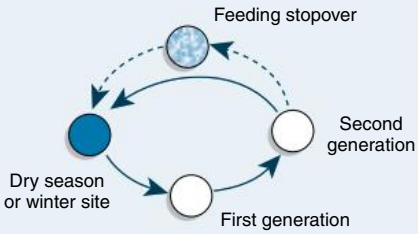
Nomadic Migration

Similar to one-way migration but individuals may breed at several locations during their lifetimes. These migrations are apparently directionless, with no set pattern. Each stopover point is a potential breeding site. There may also be temporary non-breeding stopovers for the winter or dry season.

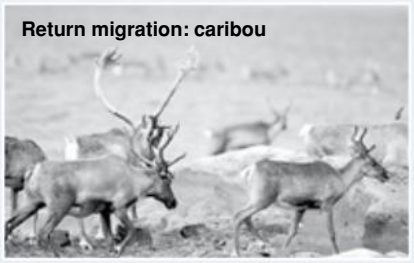


Remigration Circuits

In some populations, the return leg of a migration may have stopovers and may be completed by one or more subsequent generations. In addition to winter or dry season areas, there may be stops at feeding areas by juveniles or adults. Also included are closed circuits where animals die after breeding.













1. Giving an example, describe the conditions under which nomadic migration behaviour might be necessary:

2. Which of the above forms of migration would lead to further dispersal of a population? Explain your answer:

3. Describe an environmental cue important in the regular migratory behaviour of a named species:

4. Discuss the adaptive value of migratory behaviour:

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227 Activity Patterns in Animals

Key Idea: Some animals enter periods of reduced metabolic activity to conserve energy during winter.

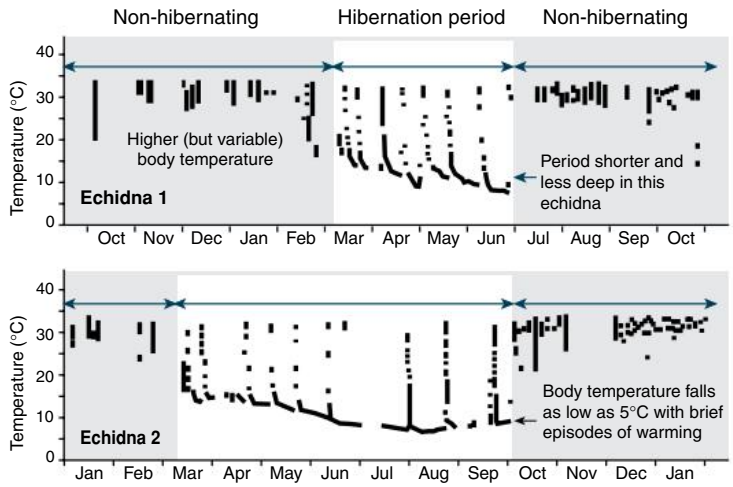
Some animals show seasonal periods of reduced metabolic activity which are triggered by cold weather and conserve energy when food is scarce, or when low temperatures prevent foraging. **Hibernation** is a state of dormancy entered into by some animals during winter. During hibernation, the metabolism is slowed, body temperature falls, and stored fat is metabolised for energy. In temperate regions (such as southern Australia), rises in environmental temperature may cause some animals to come out of hibernation for short periods. Generally hibernation occurs over an extended period (a season or more). **Torpor** is similar to hibernation except that the period of time involved is shorter. Animals in torpor tend to drop their metabolic rate and body temperature for relatively short periods of time (often a daily basis), and rouse themselves at regular intervals. Many of Australia's smaller mammals hibernate or show periods of torpor.

Hibernation in Echidnas

(*Tachyglossus aculeatus*)



Together with platypuses, echidnas have the lowest body temperatures of any mammal. Even when active, their body temperature never rises above 34°C. Their body temperature is also highly variable and depends on environmental temperature and metabolic activity. Inactivity coincides with a drop in body temperature and the heat from muscle activity is needed to maintain body temperatures above 30°C.



Graphs above: The body temperatures of two hibernating echidnas in the Snowy Mountains. During hibernation, echidnas warm themselves briefly every 12 days or so. They hibernate for 6-28 weeks of the year, during which time body temperature falls to as low as 5°C. Brief episodes of warming may occur, possibly related to rises in air temperature. The length of hibernation is related to the time that hibernation begins and the reproductive activity. Hibernation begins earlier and lasts longer in males, whereas nursing females must suckle young into the summer so that the young are well nourished for winter. In addition, mature animals that are going to mate must come out of hibernation earlier than immature animals.

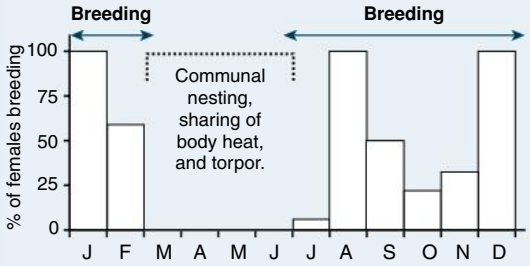
Adapted from Augee and Gooden, 1993. "Echidnas of Australia and New Guinea". NSW Uni. Press.

Torpor in the Fat-tailed Dunnart

(*Sminthopsis crassicaudata*)



The fat tailed dunnart (above) metabolises its tail fat during periods of winter torpor.



The **fat tailed dunnart** is a small carnivorous marsupial, widely distributed in southern Australia in a variety of open habitats. It is entirely nocturnal and its life history is centred around an extended breeding period (above), coinciding with the seasonal abundance of food. During autumn and winter, groups of individuals huddle in communal nests. Like many small Australian marsupials, they enter torpor when food is scarce. During this time, fat stores in the tail act as an energy reserve.

1. Distinguish between **hibernation** and **torpor**: _____

_____

2. What is the main environmental cue for inducing hibernation or torpor in mammals? _____

3. Give one advantage of this activity: _____

4. From the information given, and with reference to the graphs, name the sex of each of the echidnas in the example:

   (a) Echidna 1: _____ (b) Echidna 2: _____

   (c) Give a reason for your answer: _____

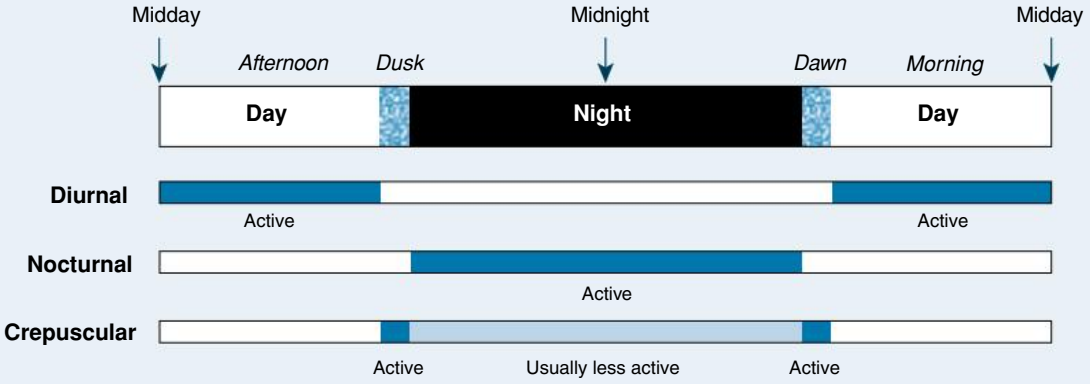
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Activity Patterns Following a Circadian Rhythm

On a day to day basis, the activity patterns of animals follow a **circadian** rhythm based around the approximately 24 h (23 h 57 min) revolution of the Earth on its axis. There are three types of circadian activity patterns: **diurnal**, where activity is confined to the hours of daylight; **nocturnal**, or night activity; and **crepuscular**, where most activity occurs during the dawn and dusk (below).

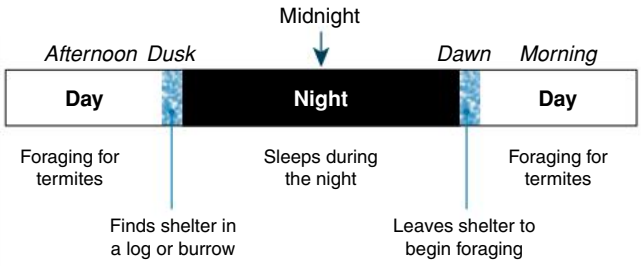


Circadian Activity Patterns in Two Australian Marsupials

Numbat
Myrmecobius fasciatus

The numbat feeds solely on termites. Just as termites are active by day, so are numbats. They occupy their log dens at night, and may shelter in them on the hottest afternoons, but in milder conditions they forage through the daylight hours.

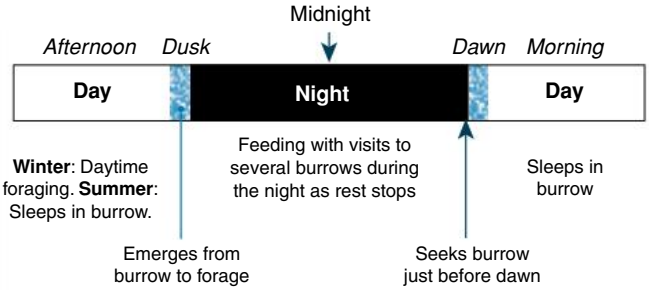




Common Wombat
Vombatus ursinus

Wombats restrict themselves to nocturnal activity in the summer, avoiding high temperatures by spending their days in their deep, humid burrows. In the cooler winter months, they feed in full daylight and bask in the sun near the burrow entrance.





5. What is the adaptive advantage of huddling behaviour in fat tailed dunnarts? _____

6. What factor is likely to determine length of the breeding season in fat tailed dunnarts? _____

7. What type of circadian activity pattern is displayed by each of the following:

   (a) The numbat? _____

   (b) The common wombat? _____

   (c) The fat tailed dunnart? _____

8. What **selection pressures** might have determined these rhythms for the:

   (a) Numbat? _____

   _____

   (b) Common wombat? _____

   _____

9. How do changes in seasonal temperatures influence the circadian activities of the common wombat? _____

   _____

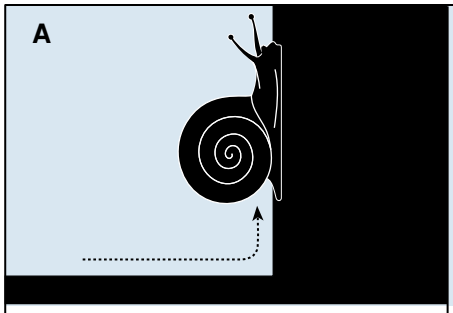
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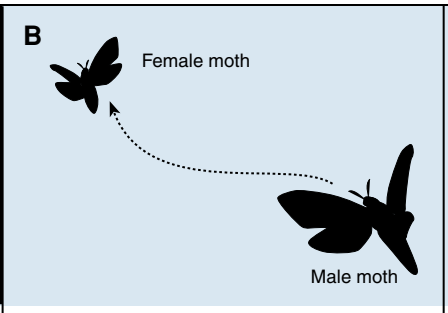
228 Taxes and Kineses

Key Idea: Taxes and kineses are locomotory behaviours involving movements in response to external stimuli.

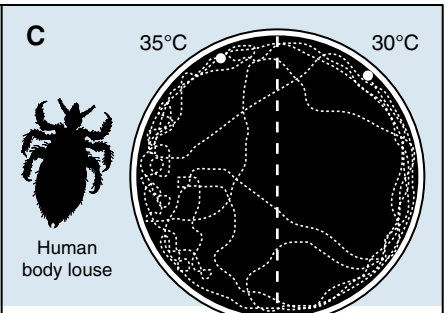
Taxes and kineses are adaptive locomotory behaviours and involve movements in response to external stimuli such as gravity, light, chemicals, and temperature. A **kinesis** (pl. kineses) is a non-directional response to a stimulus in which the speed of movement or the rate of turning is proportional to the stimulus intensity. Kineses do not involve orientation directly to the stimulus and are typical of many invertebrates and protozoa. **Taxes** (sing. taxis) involve orientation and movement in response to a directional stimulus or a gradient in stimulus intensity. Taxes often involve moving the head until the sensory input from both sides is equal (klinotaxis). Many taxes involve a simultaneous response to more than one stimulus, e.g. fish orientate dorsal side up in response to both light and gravity. Orientation responses are always classed according to whether they are towards the stimulus (positive) or away from it (negative).



When confronted with a vertical surface, snails will reorientate themselves so that they climb vertically upwards.



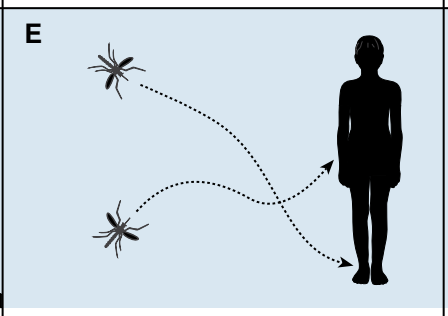
A flying male moth, encountering an odour (pheromone) trail left by a female, will turn and fly upwind until it reaches the female.



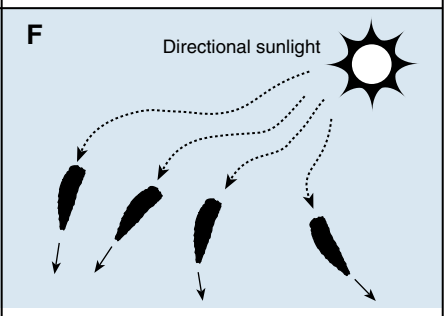
In a circular chamber, lice make relatively few turns at 30°C, but many random turns at 35°C.



Spiny lobsters will back into tight crevices so that their body is touching the crevice sides. The antennae may be extended out.



At close range, mosquitoes use the temperature gradient generated by the body heat of a host to home in on exposed flesh.



Blowfly maggots will turn and move rapidly away from a directional light source.

1. Distinguish between a **kinesis** and a **taxis**, describing examples to illustrate your answer: _____

2. Giving an example, describe the adaptive value of simple orientation behaviours such as kineses: _____

3. Name the physical stimulus for each of the following **prefixes** used in naming orientation responses:

   (a) Gravi- _____ (b) Hydro- _____ (c) Thigmo- _____

   (d) Photo- _____ (e) Chemo- _____ (f) Thermo- _____

4. For each of the above examples (**A**-**F**), describe the orientation response. Indicate whether the response is positive or negative (e.g. positive phototaxis):

   (a) **A:** _____ (b) **B:** _____

   (c) **C:** _____ (d) **D:** _____

   (e) **E:** _____ (f) **F:** _____

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229 Plant Activity Rhythms

Key Idea: Environmental cues act as triggers for plants to begin major life-cycle stages.

Major plant life-cycle stages, e.g. germination, flowering, bud burst, and dormancy occur in response to **environmental cues**, such as daylength, air or soil temperature, and water availability. Some plant movements, including the opening and closing of leaves in response to a light-dark cycle, also occur in response to environmental cues. Synchronising growth and development with strong environmental cues enables plants to complete their life cycles successfully. The timing of these events is critical. Perennial species must withdraw enough nitrogen from their tissues before leaf dieback in order to allow vigorous growth in the next season. Annual species, especially in arid areas where water availability is seasonal, must complete their life cycle while growing conditions are favourable.

Seasonal Activity in Plants

Major seasonal activities in the life cycle of a deciduous tree. Although there is much variation between species, the sequence of events is relatively fixed and some events must occur before others. The exact timing of these depends on the local environmental factors and the genetic programme for development in the individual species.



Events: Plant mobilises food stores to resume shoot growth. Root system increases. Some species flower. **Cue**: Longer days after a period of cold.



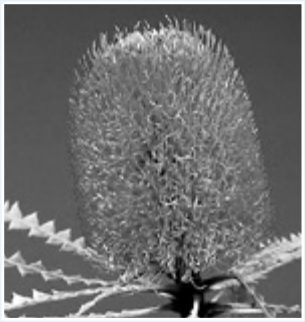
Events: More growth. Flowering, pollination, fruit development and maturation. **Cues**: Warm temperatures and long growing period (long days).



Events: Withdrawal of nutrients from leaves. Leaf fall. Seed dispersal completed. **Cues**: Shorter days and falling air and soil temperatures.



Events: Dormancy of seeds and buds. Slow or no growth. All plant processes slow down. **Cues**: Short days and stable, low air and soil temperatures.



The seeds of some Australian plants, such as *Banksia*, lie dormant inside the fruit until the heat of a bush-fire bursts the fruit and allows their release. This response provides an advantage in fire-prone regions.



Tulip flowers show a circadian rhythm in response to changing ambient air temperature. The flowers are tightly closed in the early morning, reach maximum opening in late morning (above), and close again by nightfall.



Bulb and corm species (crocus, hyacinth) tend to flower together in response to warming. Bulbs, corms, and tubers are food storage organs that provide for winter survival and rapid growth in spring.



The flowering of some desert species is triggered by sudden rain. I theses species, seed germination, growth, flowering, and seed set must happen quickly, as the period suitable for growth is short.

1. Name one important environmental cue for the timing of seasonal activities in plants: _____

2. Plants frequently use the combination of two environmental cues to trigger an event such as the breaking of bud dormancy. What would be the biological advantage of using two cues rather than just one?

   _____

3. Suggest two biological advantages to *Banksia* plants in having seeds whose dormancy is broken by exposure to fire:

   (a) _____

   (b) _____

4. Describe a circadian rhythm in plants (not flower opening) that is related to the day-night cycle: _____

   _____

5. Why are bulbs able to flower so early in spring? _____

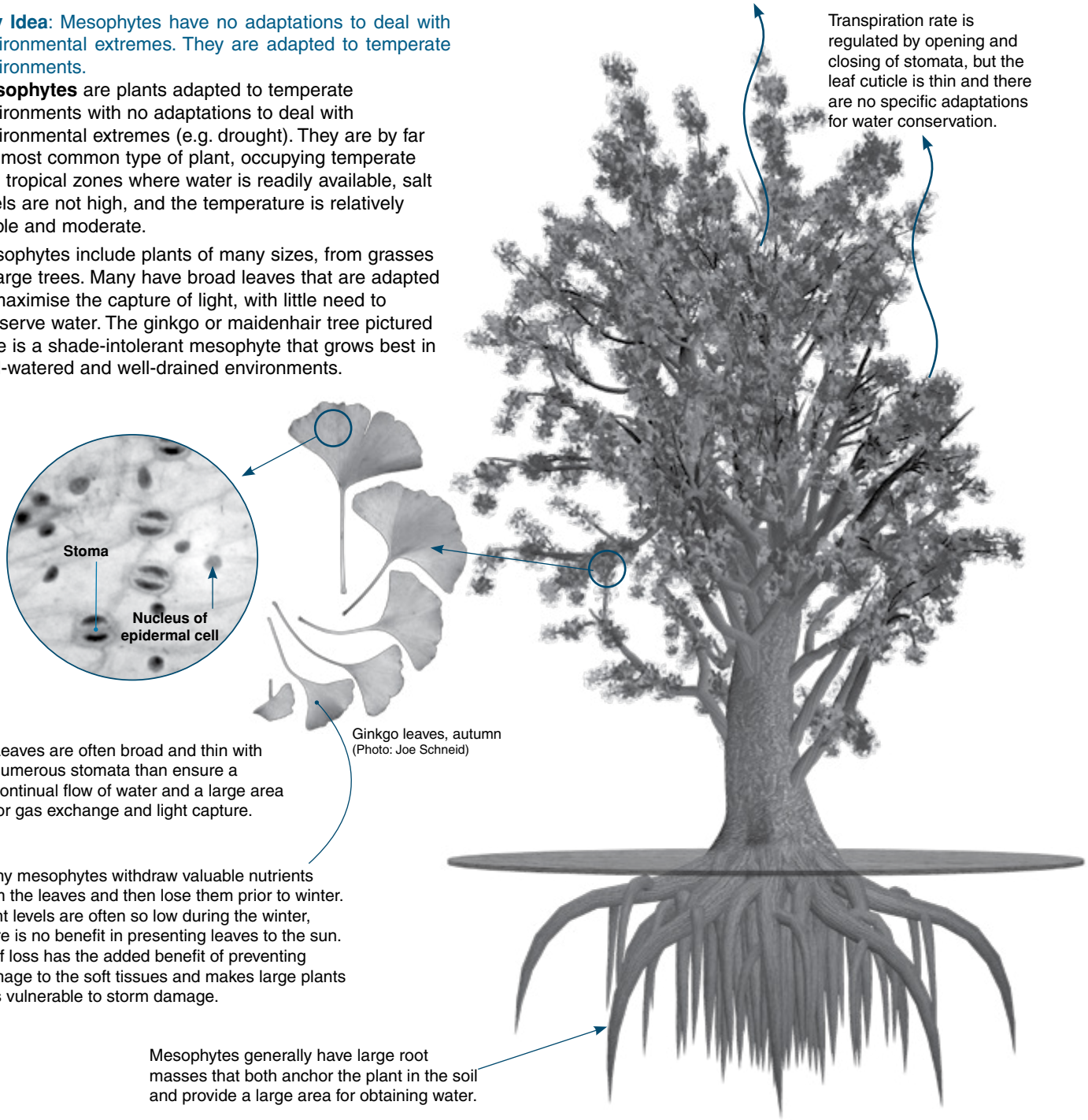
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230 Adaptations of Mesophytes

Key Idea: Mesophytes have no adaptations to deal with environmental extremes. They are adapted to temperate environments.

Mesophytes are plants adapted to temperate environments with no adaptations to deal with environmental extremes (e.g. drought). They are by far the most common type of plant, occupying temperate and tropical zones where water is readily available, salt levels are not high, and the temperature is relatively stable and moderate.

Mesophytes include plants of many sizes, from grasses to large trees. Many have broad leaves that are adapted to maximise the capture of light, with little need to conserve water. The ginkgo or maidenhair tree pictured here is a shade-intolerant mesophyte that grows best in well-watered and well-drained environments.



1. Define the term mesophyte: _____

_____

2. Mesophytes do not have adaptations for extreme environments, but they have adaptations for survival in their own niche. Describe three adaptations of mesophytes, explaining how each is related to survival in an equable environment:

(a) _____

_____

(b) _____

_____

(c) _____

_____

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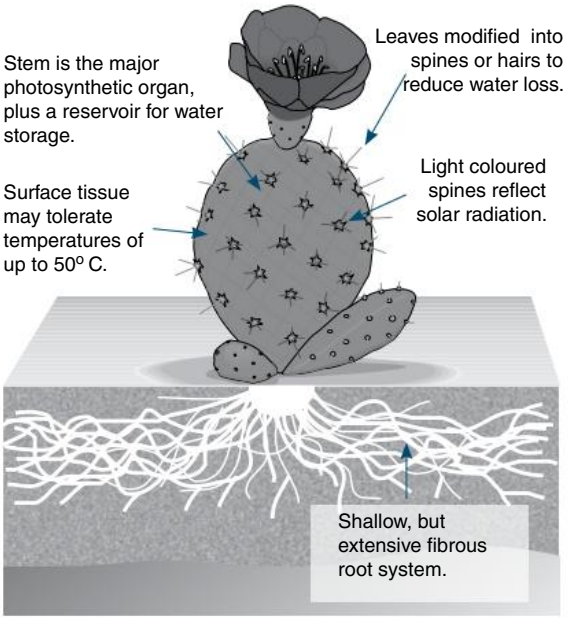
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231 Adaptations of Xerophytes

Key Idea: Xerophytes are plants with adaptations that allow them to survive in dry conditions and conserve water.

Plants adapted to dry conditions are called **xerophytes**. Xerophytes are found in a number of environments, but all show adaptations to conserve water. These adaptations include small, hard leaves, an epidermis with a thick cuticle, sunken stomata, succulence, and permanent or temporary absence of leaves.

- Most xerophytes are found in deserts, but they may be found in humid environments, provided that their roots are in dry micro-environments (e.g. the roots of epiphytic plants that grow on tree trunks or branches).
- Many xerophytes are have a succulent morphology. Their stem are often thickened and retain a large amount of water in the tissues, e.g. *Aloe*.
- Many xerophytes have a low surface area to volume ratio, reducing the amount of water lost through transpiration.
- Salt tolerant plants and alpine species may show xeromorphic features in response to the lack of free water and high transpirational losses in these environments.



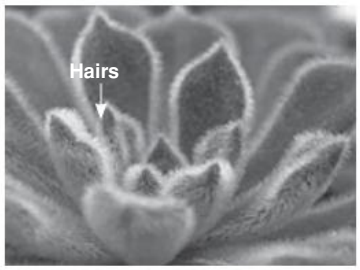
Desert plants, such as cacti, must cope with low or sporadic rainfall and high (potential) transpiration rates. Numerous structural adaptations reduce water losses, and enable them to access and store available water. Adaptations such as waxy leaves also reduce water loss and, in many desert plants, germination is triggered only by a certain quantity of rainfall.



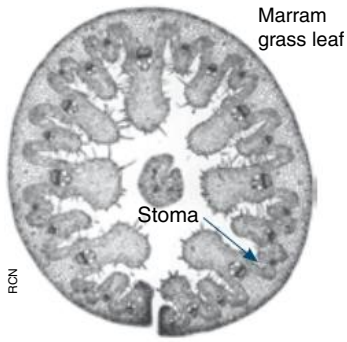
Desert xerophytes in Arizona have a succulent photosynthetic stem



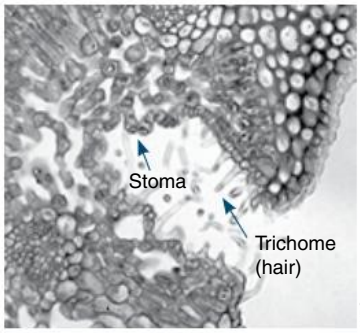
Acacia trees have deep root systems, allowing them to draw water from sources deep underground.



An outer surface coated in fine hairs traps air close to the surface and reduces the transpiration rate.



Grasses on coastal sand dunes curl their leaves. Stomata are sunken in pits, creating a moist microclimate around the pore, which reduces transpiration rate, e.g. marram grass.



Oleander has a thick multi-layered epidermis and the stomata are sunken in trichome-filled pits on the leaf underside which restrict water loss.

1. Define the term xerophyte: _____

_____

2. Describe three xeromorphic adaptations of plants that reduce water loss:

   (a) _____

   (b) _____

   (c) _____

3. How does creating a moist microclimate around the areas of water loss reduce the transpiration rate? _____

_____

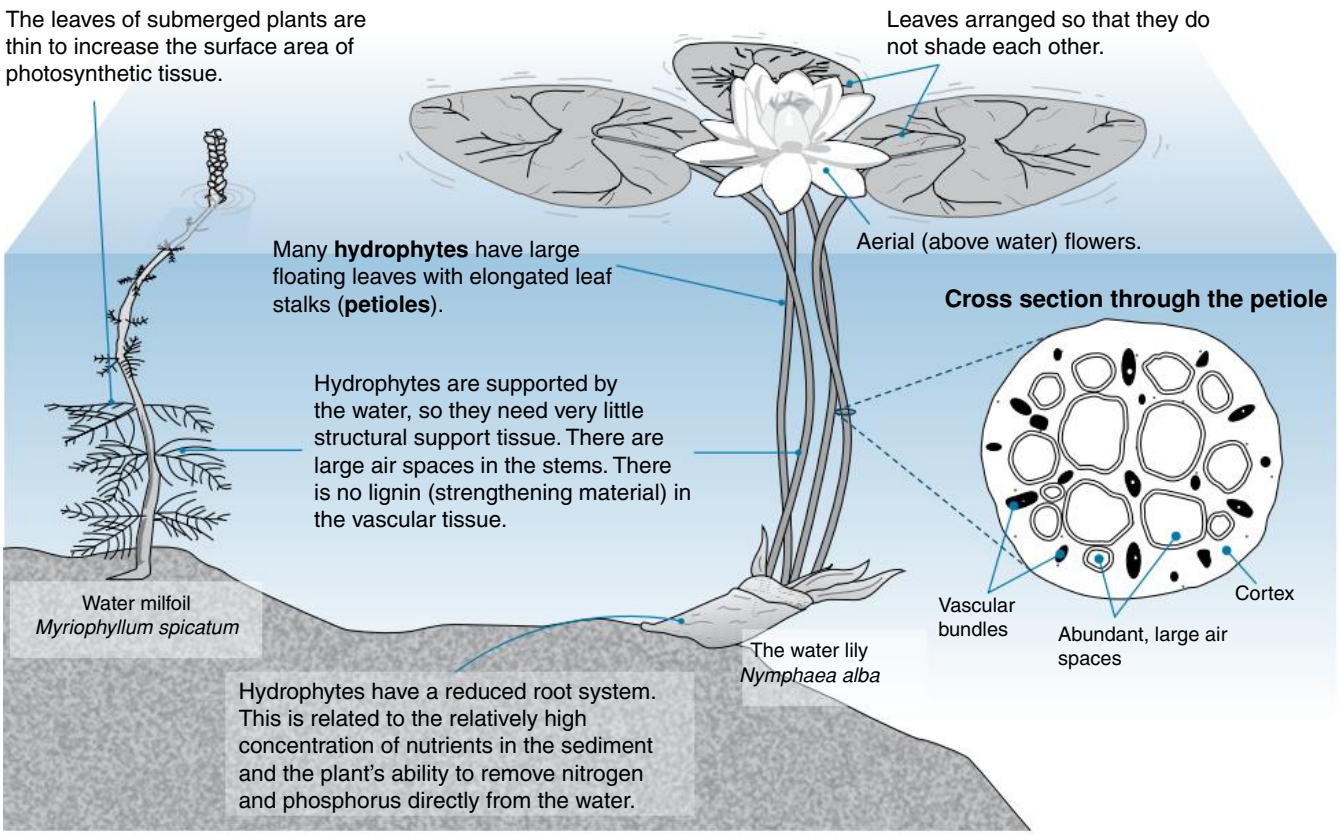
4. How does a low surface area to volume ratio in a plant such as a cactus reduce water loss? _____

_____

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232 Adaptations of Hydrophytes

Key Idea: Hydrophytes are adapted to living in water. They require little structural support tissue and have few adaptations to reduce water loss.



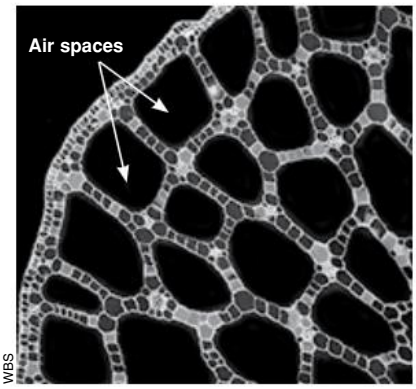


Stephen Moore

Myriophyllum's submerged leaves are well spaced and taper to the surface to help with gas exchange and distribution of sunlight.



The floating leaves of water lilies (*Nymphaea*) have a high density of stomata on the upper leaf surface so they are not blocked by water.



WBS

Cross section through *Potamogeton*, showing large air spaces which assist with flotation and gas exchange.

1. Explain how the following adaptations assist hydrophytes to survive in an aquatic environment:

   (a) Large air spaces within the plants tissues: _____

   _____

   (b) Thin cuticle: _____

   _____

   (c) High stomatal densities on the upper leaf surface: _____

   _____

2. Why do hydrophytic plants retain an aerial (above water) flowering system? _____

   _____

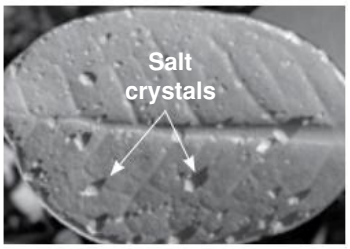
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233 Mangrove Adaptations

Key Idea: Mangroves are halophytes (salt tolerant) and specifically adapted to the high salt, water-logged environments of estuaries, tidal flats, and salt marshes.

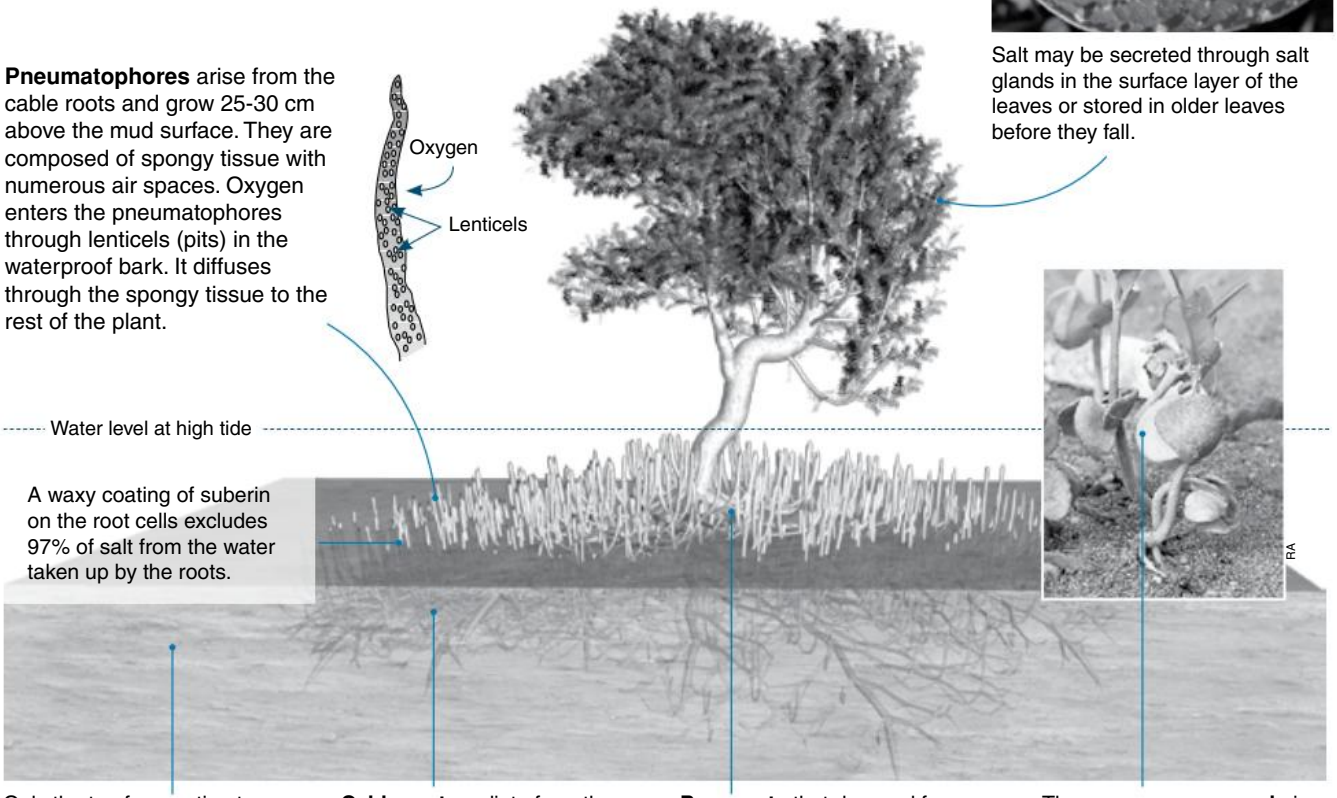
Mangroves are a group of plants with adaptations for growth in seawater and salty, water-logged soil. They grow in the upper part of the intertidal zone, but also extend further inland to form salt marshes and other coastal wetland communities. Australia has 20 genera and 36 species of mangroves.

Mangroves grow from the upper part of the intertidal zone to the high water mark, forming some of the most complex and productive ecosystems on Earth. The high salt environment would kill most other kinds of plants as high salt levels cause water to flow out of the cells. Mangroves overcome this by storing salt in their cell vacuoles and maintaining a high concentration of solutes in the cytoplasm of their cells. This reverses the osmotic gradient and maintains the transpiration stream.



Salt may be secreted through salt glands in the surface layer of the leaves or stored in older leaves before they fall.

Pneumatophores arise from the cable roots and grow 25-30 cm above the mud surface. They are composed of spongy tissue with numerous air spaces. Oxygen enters the pneumatophores through lenticels (pits) in the waterproof bark. It diffuses through the spongy tissue to the rest of the plant.



Only the top few centimetres of the mud is oxygenated. Beneath, the mud is anaerobic (lacking oxygen), black, and foul-smelling. A deep root system is of no use here.

Cable roots radiate from the trunk, about 20-30 cm below the surface. Growing off these radial roots are fine **feeding-roots** (not shown), which create a stable platform.

Prop roots that descend from the trunk act like buttresses, providing additional support for the tree in the soft mud and supplement the oxygen uptake from the pneumatophores.

The mangrove **propagule** is a partially developed seedling adapted for dispersal in water. It is able to quickly take root once it reaches a suitable site.

1. What two physical adaptive features of mangroves provide support for the plant in the soft mud?

   (a) _____

   (b) _____

2. Which adaptive feature enables mangroves to tolerate anaerobic conditions in the substrate?

   _____

3. Describe a physiological problem associated with living in a high-salt substrate: _____

   _____

4. Describe three methods by which various mangrove species solve the problem of a high salt environment:

   (a) _____

   (b) _____

   (c) _____

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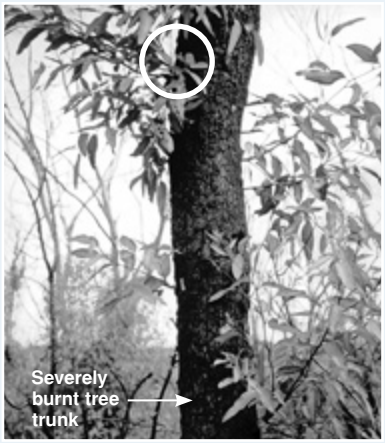
234 Plant Adaptations to Fire

Key Idea: Some Australian plants have adaptations which allow them to survive or benefit from fires.

Some Australian plants have adaptations associated with surviving and even benefiting from fires. Species living in ecosystems prone to fire must be able to survive the fire, or leave offspring that will germinate after the fire. In general, plants cope with fire in two ways. Some re-sprout from protected buds after above-ground parts have been burnt away. Other plants may die completely, relying on the germination of fire resistant seeds to recolonise.

Epicormic Buds

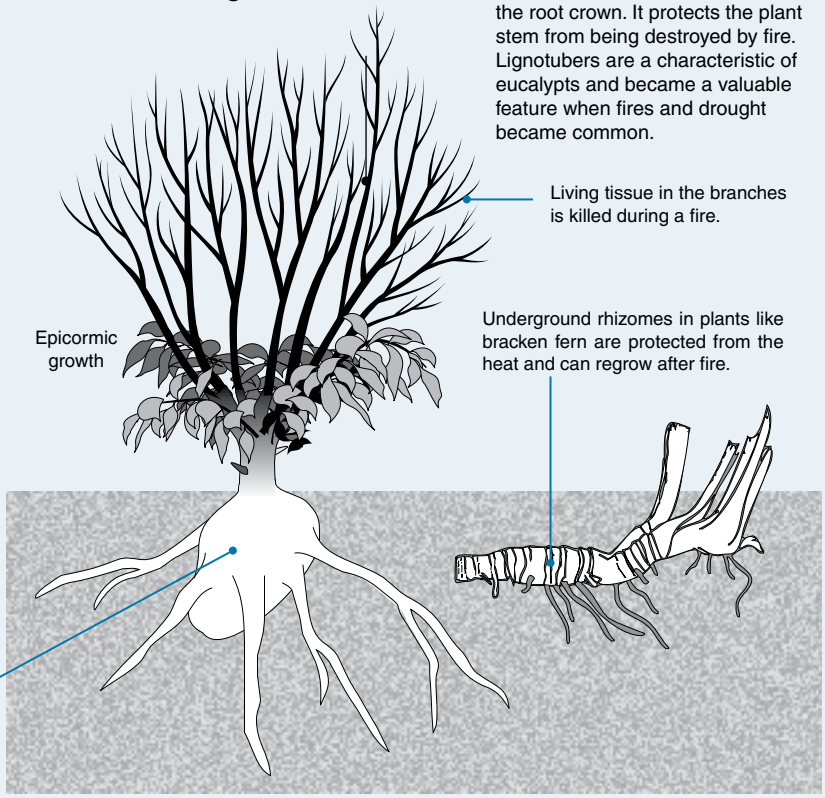
Some eucalypt species have buds under thick bark that grow after a fire. Normally dormant, these buds grow after the leafy tissue is destroyed. The photo below shows a new branch regenerated from such a bud (circled).



Lignotuber: In some species (e.g. the mallee eucalypt) a woody lignotuber is produced. This is safe from the effects of the fire and can store water and reserve food supply to support regrowth. The same lignotuber may survive many fires.

Lignotubers

A **lignotuber** is a woody swelling of the root crown. It protects the plant stem from being destroyed by fire. Lignotubers are a characteristic of eucalypts and became a valuable feature when fires and drought became common.



Fire Tolerant Grasses

Grass species (such as the one in the photograph below) are burnt in bush fires, but quickly regenerate so long as they are not heavily grazed

New growth: After the fire, new growth emerges from the stubble. The growing tips are protected during a fire by soil or the clumped nature of the grass.



All photos RA

Burnt stubble: Old, dry leaves are burnt off easily during the fire, but the intensity of the flame is not great and does not damage the growing tissue.

The Grass Tree (*Xanthorrhoea* spp.)

The grass tree is found in southwestern Australia, and along the ranges of the Great Divide, usually along rocky or gravelly slopes. They have special adaptations to survive bush fires.



Flowering: Grass trees are stimulated into flowering following a fire, producing flower spikes up to two metres long.



New growth: After a fire, new growth emerges from the top of the stem.

Dead leaves: Dead leaves form a skirt at the base of the crown. These burn rapidly and fiercely but do not damage the growing tip in the crown.

Fire-blackened stem: Although it looks damaged, the fibrous stem provides special protection from the fire and the important vascular tissue survives well. The plant sheds its leaves each year, but the bases remain attached to the stem and produce a thick gum that glues the whole lot together into a very effective fire guard.

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Bush fires can range in severity from small, local outbreaks to huge fire storms devastating thousands of hectares. Fire stimulates various plants in four different ways. The heat of the fire causes the sudden release of seeds from eucalyptus trees. The fire also causes the release of vast volumes of ethylene gas which stimulates many surviving plants to flower. The smoke from the fire stimulates the seeds of annual plants that have been dormant for many years in the sand to germinate. The sudden abundance of nutrients released in the ash allows perennials to flourish with flowers. The three photos above show the stages in regeneration from fire, with the last photo being taken several months after the fire.

1. Bush fires are natural events, but humans have increased the frequency of fire occurrence when clearing land. This has meant that species that would usually mature and set seed before the next fire do not have the chance to do so.

   (a) What would happen to these seed-producing species if fire frequency in an area increased markedly?

   _____

   _____

   _____

   (b) What this would do to the diversity of plant species in that area? _____

   _____

   (c) What plants would come to dominate in the area? _____

2. (a) Identify an Australian plant genus that survives fire by reproducing from protected buds or lignotubers:

   _____

   (b) Identify an Australian plant genus that produces resistant seeds which survive after the parent plant has died:

   _____

3. How could fire help the germination of seeds with a very hard seed coat? _____

   _____

   _____

4. Explain two different ways in which regenerating plants could benefit by the aftermath of a fire:

   (a) _____

   _____

   _____

   (b) _____

   _____

   _____

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235 KEY TERMS: Mix and Match

INSTRUCTIONS: Test your vocabulary by matching each term to its definition, as identified by its preceding letter code.

adaptation

annual

circadian rhythm

circatidal rhythm

countercurrent exchange

courtship

crepuscular

diapause

dispersal

diurnal

dormancy

halophyte

hibernation

kinesis

migration

neurone

nocturnal

osmoregulation

perennial

phototropism

reproductive strategy

sensory organ

taxis

thermoregulation

torpor

tropism

xerophyte

A The regulation of body temperature by endogenous or exogenous means.

B A movement by an animal in response to a directional stimulus or a gradient in stimulus intensity.

C A plant growth response to directional light.

D Plant that completes its growth and reproduction cycle over many years, often reproducing every year for many years.

E The movement of a population of animals to a place for over-wintering or reproduction. Classic examples involve the movement to and return from the same locations.

F The suite of reproductive adaptations that together constitute the reproductive pattern of the organism.

G A plant growth response to a directional external stimulus.

H An activity pattern in which most activity occurs during the night.

I Mate-selection rituals that serve to prepare both sexes for reproduction.

J A delay in development in response to regularly occurring periods of adverse environmental conditions. Essentially, it is a physiological state of dormancy with very specific initiating and inhibiting conditions.

K The permanent departure from a location (often of birth) to another in order to find new habitats or nesting sites.

L A plant that naturally grows where it is affected by salinity in the root area or by salt spray.

M A set of random movements in response to a non-directional stimulus that will take the animal away from (or toward) the stimulus.

N A physiological adaptation of some organisms to periods of prolonged cold, marked by a drop in body temperature and metabolic rate.

O A period in an organism's life cycle when growth, development, and (in animals) physical activity is temporarily stopped. The term is most commonly applied to plants.

P A plant with adaptations for survival in an environment with little available water.

Q (Verb) The evolutionary process by which a species becomes better suited to its niche. (Noun) A feature that results from this process.

R A state of decreased physiological activity in an animal, characterised by low body temperature and reduced metabolic rate, that usually occurs on a daily basis.

S An activity pattern in which most activity occurs during the period of daylight.

T The active regulation of the body's ion and water content.

U Exchange between two media moving in opposite directions, such that the system can maintain a nearly constant gradient between the two flows over their entire length. In biological systems, it may apply to transfer of heat, gases or metabolites in the blood.

V A period of activity and rest that repeats around every 24 hours.

W An activity pattern in which most activity occurs during the periods of dawn and dusk.

X A cell specialised to transmit electrical impulses.

Y An event or period of activity that occurs every year, e.g. migration.

Z A period of activity that occurs around every 12 to 13 hours and is related to the rise and fall of sea levels.

AA A specialised organ that is a receptor for a particular type of stimulus.

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236 Adaptations of Organisms Synoptic Question

1. An organism's survival depends on its adaptations to its physical (abiotic) and biotic environment. Describe the environments of hydrophytes, mesophytes, and xerophytes and discuss the adaptations that allow them to survive in their respective environments. You may use extra paper if required.

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QLD As required
VCE Unit 2 (2)
WA ATAR Unit 1
SA Theme O

Communities

Key terms

biomass
carbon cycle
commensalism
community
competition
consumer
decomposer
detritivore
ecological pyramid
energy flow diagram
exploitation
food chain
food web
gross primary production
herbivory
interspecific competition
intraspecific competition
mutualism
net primary production
net primary productivity
nitrogen cycle
parasite
parasitism
population
predation
predator
prey
primary consumer
producer
saprophyte
secondary consumer
ten percent rule
tertiary consumer
trophic efficiency
trophic level



Nutrient cycles

Learning aims and skills

Activity number

- ☐ 1 Describe the role of nutrient cycling in ecosystems (including the hydrologic cycle), explaining how nutrients are exchanged within and between ecosystems, moving between the atmosphere, the Earth's crust, water, and organisms. — 237 238
- ☐ 2 Describe the carbon cycle, using arrows to show the direction of nutrient flow and labels to identify the processes involved. Describe how human activity may intervene in various aspects of the carbon cycle. — 239
- ☐ 3 Describe the nitrogen cycle, using arrows to show the direction of nutrient flow. Describe and explain the processes involved and the role of microorganisms in the cycle. Discuss how humans may intervene in the nitrogen cycle. — 240 289





Energy in ecosystems

Learning aims and skills

Activity number

- ☐ 4 Distinguish between producers, consumers, detritivores, and decomposers. Describe the role of each of these in energy transfer and nutrient cycling. — 241
- ☐ 5 Describe how energy enters ecosystems through the activity of autotrophs. Recall the difference between photoautotrophs and chemoautotrophs in terms of their source of free energy. — 242 257
- ☐ 6 Describe how energy is transferred between trophic levels in food chains and food webs. Construct food chains and food webs for named communities. — 242 244 245 246
- ☐ 7 Explain what is meant by bioaccumulation and explain how it can result in biomagnification of toxic substances in food chains. — 243
- ☐ 8 Draw and interpret an energy flow diagram for a community. Explain trophic efficiency and the 10% rule. — 247
- ☐ 9 Distinguish between gross and net primary production. Compare and contrast the productivity of natural and agricultural ecosystems. — 247 248
- ☐ 10 Describe food chains quantitatively using ecological pyramids based on numbers, biomass, or energy at each trophic level. — 249

Community interactions

Learning aims and skills

Activity number

- ☐ 11 Recall how a community comprises different populations living together. Describe how the species in populations interact in beneficial and harmful ways. Describe interspecific interactions in communities, including commensalism, competition, mutualism, and exploitation (parasitism, predation, herbivory). — 250
- ☐ 12 Describe the role of interspecific competition in constraining niche breadth and in (either) niche differentiation or competitive exclusion. — 251-253
- ☐ 13 Explain the role of inter- and intraspecific competition in limiting population size. — 251 254
- ☐ 14 Describe the characteristics of predator-prey cycles and give examples. Describe structural and physiological adaptations of predators and prey. — 255 256

237 Nutrient Cycles

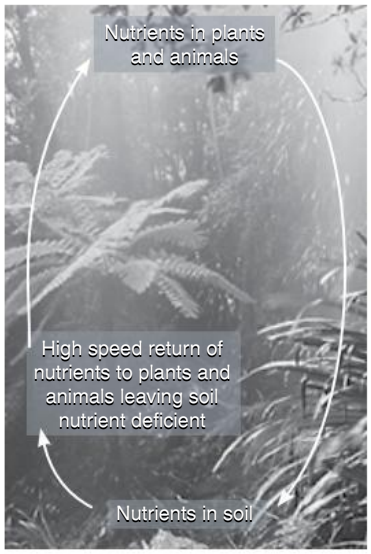
Key Idea: Matter cycles through the biotic and abiotic compartments of Earth's ecosystems in nutrient cycles.

Nutrient cycles move and transfer chemical elements (e.g. carbon, hydrogen, nitrogen, and oxygen) through the abiotic and biotic components of an ecosystem. Commonly, nutrients must be in an ionic (rather than elemental) form in order for plants and animals to have access to them. The supply of nutrients in an ecosystem is finite and limited. Macronutrients are required in large amounts by an organism, whereas micronutrients are need in much smaller quantities.

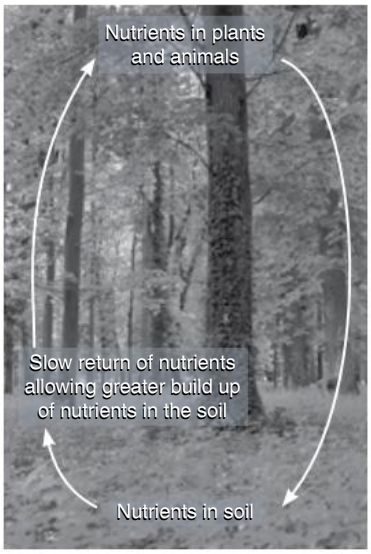
Essential Nutrients

Macronutrient	Common form	Function
Carbon (C)	CO_2	Organic molecules
Oxygen (O)	O_2	Respiration
Hydrogen (H)	H_2O	Cellular hydration
Nitrogen (N)	N_2, NO_3^-, NH_4^+	Proteins, nucleic acids
Potassium (K)	K^+	Principal ion in cells
Phosphorus (P)	$H_2PO_4^-$, HPO_4^{2-}	Nucleic acids, lipids
Calcium (Ca)	Ca^{2+}	Membrane permeability
Magnesium (Mg)	Mg^{2+}	Chlorophyll
Sulfur (S)	SO_4^{2-}	Proteins
Micronutrient	**Common form**	**Function**
Iron (Fe)	Fe^{2+}, Fe^{3+}	Chlorophyll, blood
Manganese (Mn)	Mn^{2+}	Enzyme activation
Molybdenum (Mo)	MoO_4^-	Nitrogen metabolism
Copper (Cu)	Cu^{2+}	Enzyme activation
Sodium (Na)	Na^+	Ion in cells
Silicon (Si)	$Si(OH)_4$	Support tissues

Tropical Rainforest



Temperate Woodland



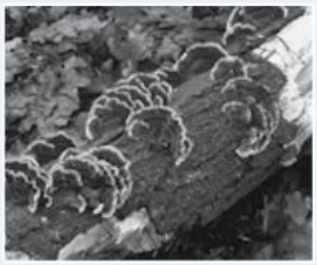
The speed of nutrient cycling can vary markedly. Some nutrients are cycled slowly, others quickly. The environment and diversity of an ecosystem can also have a large effect on the speed at which nutrients are recycled.

The Role of Organisms in Nutrient Cycling



Shirley Owens MSU

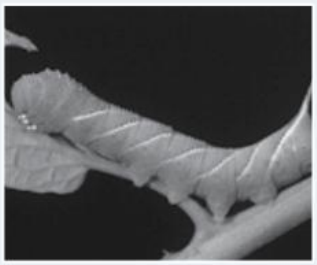
Bacteria
Bacteria play an essential role in nutrient cycles. They act as decomposers, but can also convert nutrients into forms accessible to plants and animals.



Fungi
Fungi are saprophytes and are important decomposers, returning nutrients to the soil or converting them into forms accessible to plants and animals.



Plants
Plants have a role in absorbing nutrients from the soil and making them directly available to browsing animals. They also add their own decaying matter to soils.



Animals
Animals utilise and break down materials from bacteria, plants and fungi and return the nutrients to soils and water via their wastes and when they die.

1. Describe the role of each of the following in nutrient cycling:

   (a) Bacteria: _____

   (b) Fungi: _____

   (c) Plants: _____

   (d) Animals: _____

2. Why are soils in tropical rainforests nutrient deficient relative to soils in temperate woodlands? _____

   _____

   _____

3. Distinguish between macronutrients and micronutrients: _____

   _____

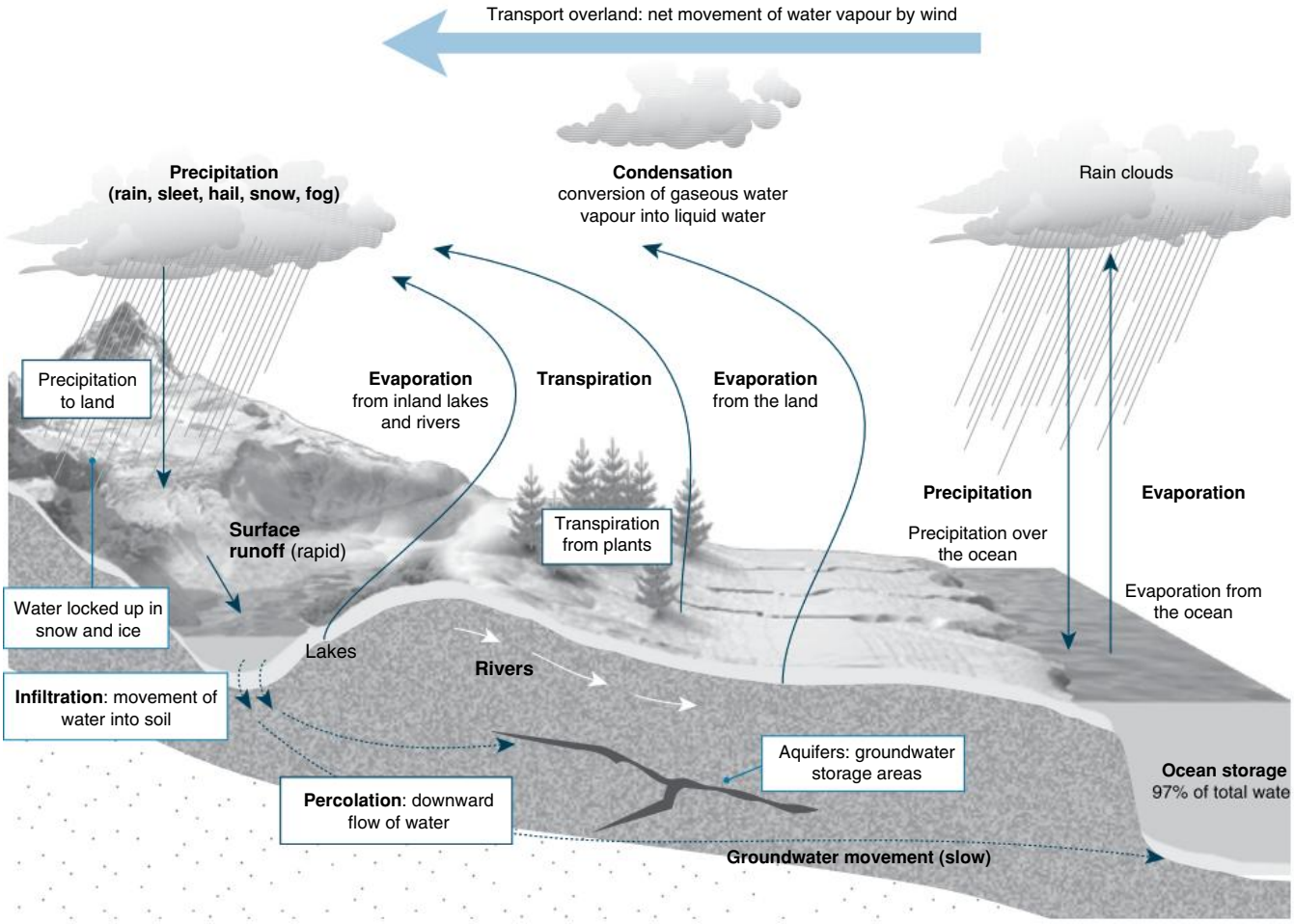
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238 The Hydrologic Cycle

Key Idea: The hydrologic cycle results from the cycling of water from the oceans to the land and back.

The **hydrologic cycle** (water cycle), collects, purifies, and distributes the Earth's fixed supply of water. Besides replenishing inland water supplies, rainwater causes erosion and is a major medium for transporting dissolved nutrients within and among ecosystems. On a global scale, evaporation (conversion of water to gaseous water vapour) exceeds precipitation (rain, snow etc.) over the oceans. This results in a net movement of water vapour (carried by winds) over the land. On land, precipitation exceeds evaporation. Some of this precipitation becomes locked up in snow and ice but most forms surface and groundwater systems that flow back to the sea, completing the major part of the cycle. Over the sea, most of the water vapour is due to evaporation alone. However on land, about 90% of the vapour results from plant transpiration. Animals (particularly humans) intervene in the cycle by utilising the resource for their own needs.



1. Identify two ways in which water returns to the oceans from the land:

   (a) _____ (b) _____

2. Describe three ways in which humans may intervene in the water cycle, and the effects of these interventions:

   (a) _____

   _____

   (b) _____

   _____

   (c) _____

   _____

3. Identify the main reservoir for water on Earth: _____

4. Identify the main reservoirs for **fresh water**: _____

5. Describe the important role of plants in the cycling of water through ecosystems: _____

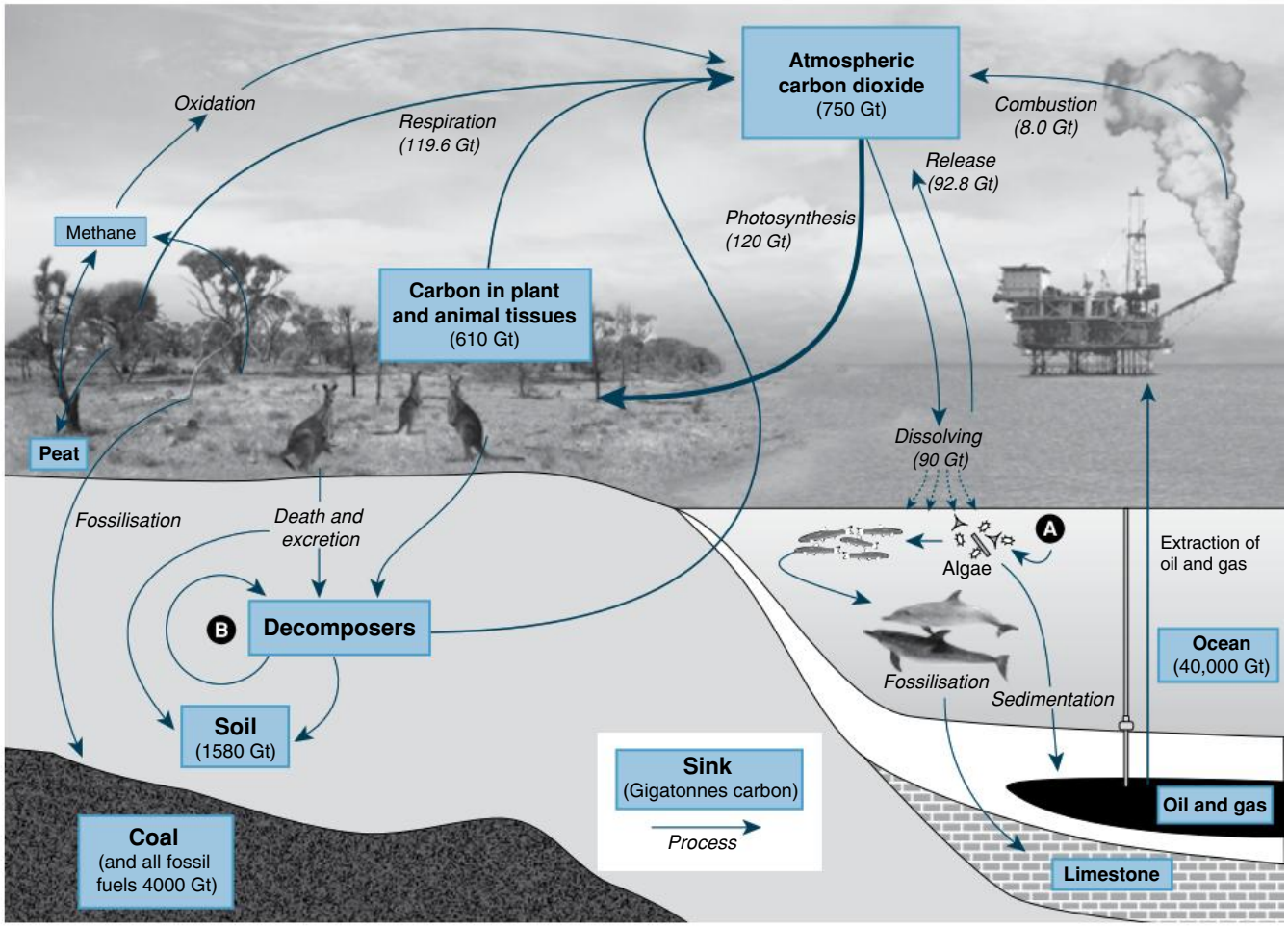
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239 The Carbon Cycle

Key Idea: The continued availability of carbon in ecosystems depends on carbon cycling through the abiotic and biotic components of an ecosystem.

Carbon is an essential element of life and is incorporated into the organic molecules that make up living organisms. Large quantities of carbon are stored in **sinks**, which include the atmosphere as carbon dioxide gas (CO_2), the ocean as carbonate and bicarbonate, and rocks such as coal and limestone. Carbon cycles between the biotic and abiotic environment. Carbon dioxide is converted by autotrophs into carbohydrates via photosynthesis and returned to the atmosphere as CO_2 through respiration (**fluxes**). These fluxes can be measured. Some of the sinks and processes involved in the carbon cycle, together with the carbon fluxes, are shown below. Humans intervene in the carbon cycle through activities such as combustion and deforestation.



1. Add **arrows** and **labels** to the diagram above to show:
   (a) Dissolving of limestone by acid rain
   (b) Release of carbon from the marine food chain
   (c) Mining and burning of coal
   (d) Burning of plant material.

2. (a) Name the processes that release carbon into the atmosphere: _____

   _____

   (b) In what form is the carbon released? _____

3. Name the four geological reservoirs (sinks), in the diagram above, that can act as a source of carbon:
   (a) _____ (c) _____
   (b) _____ (d) _____

4. (a) Identify the process carried out by algae at point [**A**]: _____
   (b) Identify the process carried out by decomposers at [**B**]: _____

5. What would be the effect on carbon cycling if there were no decomposers present in an ecosystem? _____

   _____

   _____

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Termite mound in rainforest

Termites: These insects play an important role in nutrient recycling. With the aid of symbiotic protozoans and bacteria in their guts, they can digest the tough cellulose of woody tissues in trees. Termites fulfil a vital role in breaking down the endless rain of debris in tropical rainforests.


Dung beetle on cow pat

Dung beetles: Beetles play a major role in the decomposition of animal dung. Some beetles merely eat the dung, but true dung beetles, such as the scarabs and *Geotrupes*, bury the dung and lay their eggs in it to provide food for the beetle grubs during their development.


Bracket fungus on tree trunk

Fungi: Together with decomposing bacteria, fungi perform an important role in breaking down dead plant matter in the leaf litter of forests. Some mycorrhizal fungi have been found to link up to the root systems of trees where an exchange of nutrients occurs (a mutualistic relationship).

6. Describe the **biological origin** of the following geological deposits:

   (a) Coal: _____

   (b) Oil: _____

   (c) Limestone: _____

7. Explain the role of each of the following organisms in the carbon cycle:

   (a) Dung beetles: _____

   _____

   (b) Termites: _____

   _____

   (c) Fungi: _____

   _____

8. Bushfires are a common and important part of Australia's ecology. Describe the role of fire in nutrient recycling:

   _____

   _____

9. In natural circumstances, accumulated reserves of carbon such as peat, coal and oil represent a sink or natural diversion from the cycle. Eventually, the carbon in these sinks returns to the cycle through the action of geological processes which return deposits to the surface for oxidation.

   (a) What is the effect of human activity on the amount of carbon stored in sinks? _____

   _____

   (b) Describe two **global effects** resulting from this activity: _____

   _____

   _____

   (c) What could be done to prevent or alleviate these effects? _____

   _____

   _____

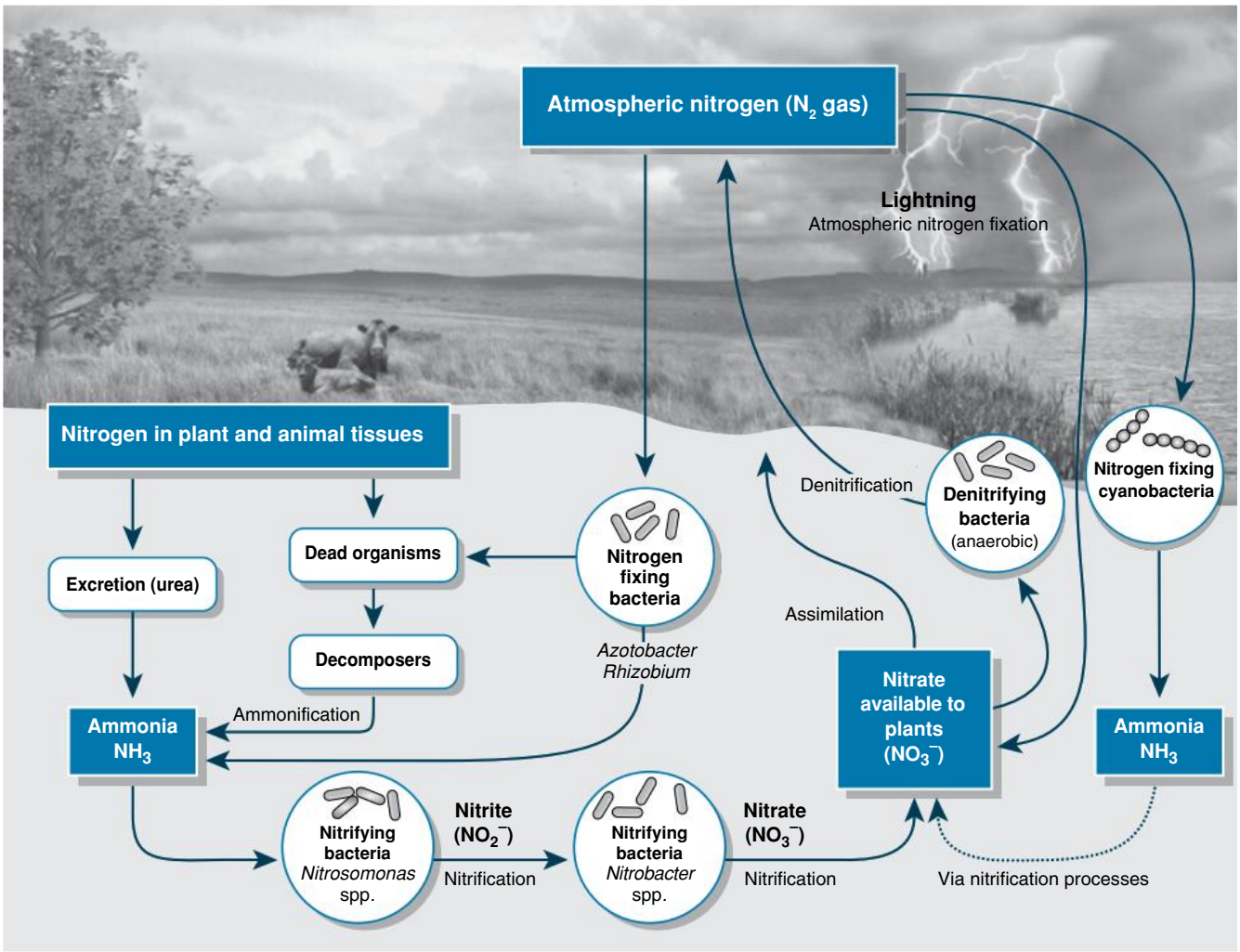
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240 The Nitrogen Cycle

Key Idea: Nitrogen gas is converted to nitrates which are taken up by plants. Heterotrophs obtain their nitrogen by feeding off other organisms.

Nitrogen is an essential component of proteins and nucleic acids and required by all living things. The Earth's atmosphere is about 80% nitrogen gas (N_2), but molecular nitrogen is so stable that it is only rarely available directly to organisms and is often in short supply in biological systems. Bacteria transfer nitrogen between the biotic and abiotic environments. Some bacteria can fix atmospheric nitrogen, while others convert ammonia to nitrate, making it available to plants. Lightning discharges also cause the oxidation of nitrogen gas to nitrate. Nitrogen-fixing bacteria are found free in the soil (*Azotobacter*) and in symbioses with some plants in root nodules (*Rhizobium*). Denitrifying bacteria reverse this activity and return fixed nitrogen to the atmosphere. Humans intervene in the nitrogen cycle by applying nitrogen fertilisers to the land. Overuse of these can pollute water supplies.



1. Describe five instances in the nitrogen cycle where **bacterial** action is important. Include the name of each of the processes and the changes to the form of nitrogen involved:

(a) _____

_____

(b) _____

_____

(c) _____

_____

(d) _____

_____

(e) _____

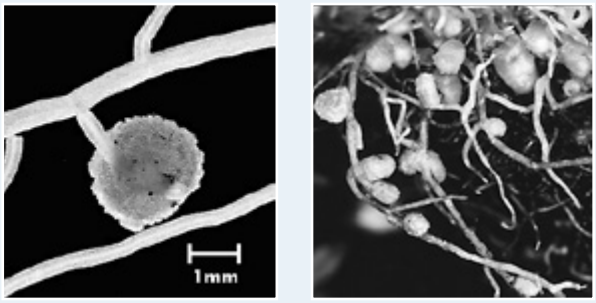
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Nitrogen Fixation in Root Nodules

Root nodules are a root **symbiosis** between a higher plant and a bacterium. The bacteria fix atmospheric nitrogen and are extremely important to the nutrition of many plants, including the economically important legume family. Root nodules are extensions of the root tissue caused by entry of a bacterium. In legumes, this bacterium is *Rhizobium*. Other bacterial genera are involved in the root nodule symbioses in non-legumes.

The bacteria in these symbioses live in the nodule where they fix atmospheric nitrogen and provide the plant with most, or all, of its nitrogen requirements. In return, they have access to a rich supply of carbohydrate. The fixation of atmospheric nitrogen to ammonia occurs within the nodule, using the enzyme **nitrogenase**. Nitrogenase is inhibited by oxygen and the nodule provides a low O_2 environment in which fixation can occur.



WBS

Two examples of legume nodules caused by *Rhizobium*. The images above show the size of a single nodule (left), and the nodules forming clusters around the roots of *Acacia* (right).

Human Intervention in the Nitrogen Cycle

The largest interventions in the nitrogen cycle by humans occur through farming and effluent discharges. Other interventions include burning, which releases nitrogen oxides into the atmosphere, and irrigation and land clearance, which leach nitrate ions from the soil.

Farmers apply organic nitrogen fertilisers to their land in the form of green crops and manures, replacing the nitrogen lost through cropping and harvest. Until the 1950s, atmospheric nitrogen could not be made available to plants except through microbial nitrogen fixation (left). However, during WW II, Fritz Haber developed the **Haber process**, combining nitrogen and hydrogen gas to form gaseous ammonia. The ammonia is converted into ammonium salts and sold as inorganic fertiliser. This process, although energy expensive, made inorganic nitrogen fertilisers readily available and revolutionised farming practices and crop yields.



Two examples of human intervention in the nitrogen cycle. The photographs above show the aerial application of a commercial fertiliser (left), and the harvesting of an agricultural crop (right).

2. Identify three processes that **fix** atmospheric nitrogen:

   (a) _____ (b) _____ (c) _____

3. What process releases nitrogen gas into the atmosphere? _____

4. What is the primary reservoir for nitrogen? _____

5. What form of nitrogen is most readily available to most plants? _____

6. Name one essential organic compound that plants need nitrogen for: _____

7. How do animals acquire the nitrogen they need? _____

   _____

8. Why might farmers plough a crop of legumes into the ground rather than harvest it? _____

   _____

9. Describe five ways in which humans may intervene in the nitrogen cycle and the effects of these interventions:

   (a) _____

   _____

   (b) _____

   _____

   (c) _____

   _____

   (d) _____

   _____

   (e) _____

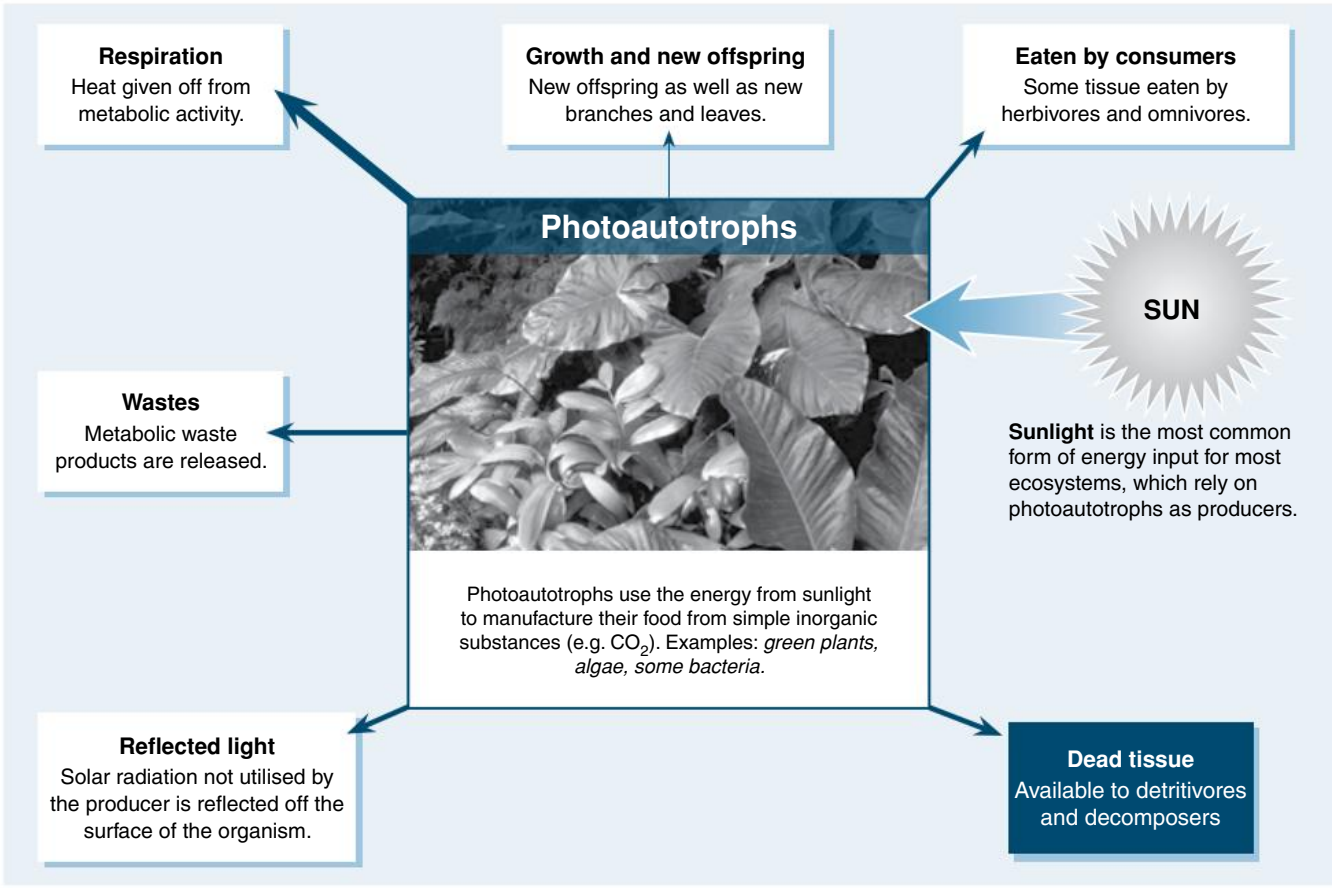
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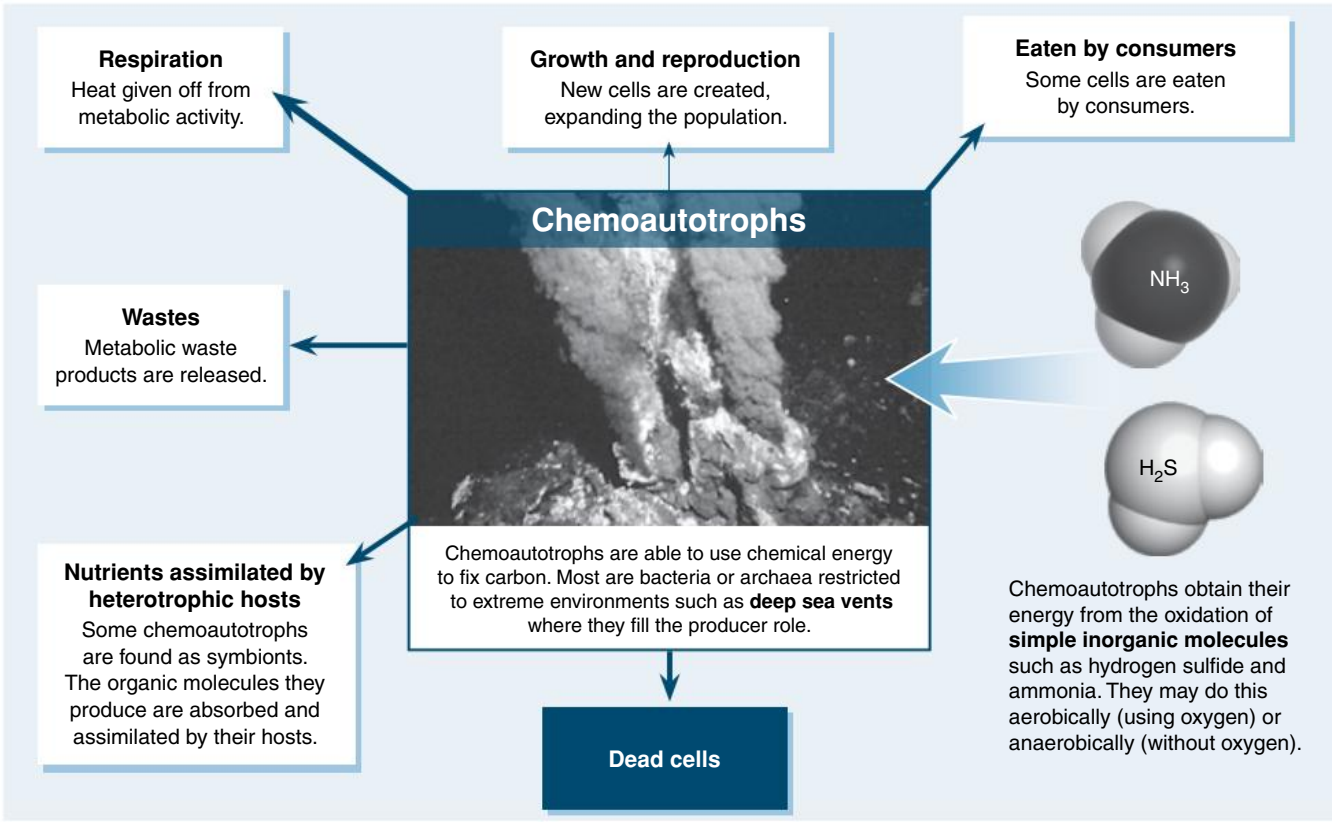
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241 Energy Inputs and Outputs

Key Idea: Autotrophs manufacture their food using the energy from sunlight or chemicals. Heterotrophs consume other organisms to obtain their energy and carbon.

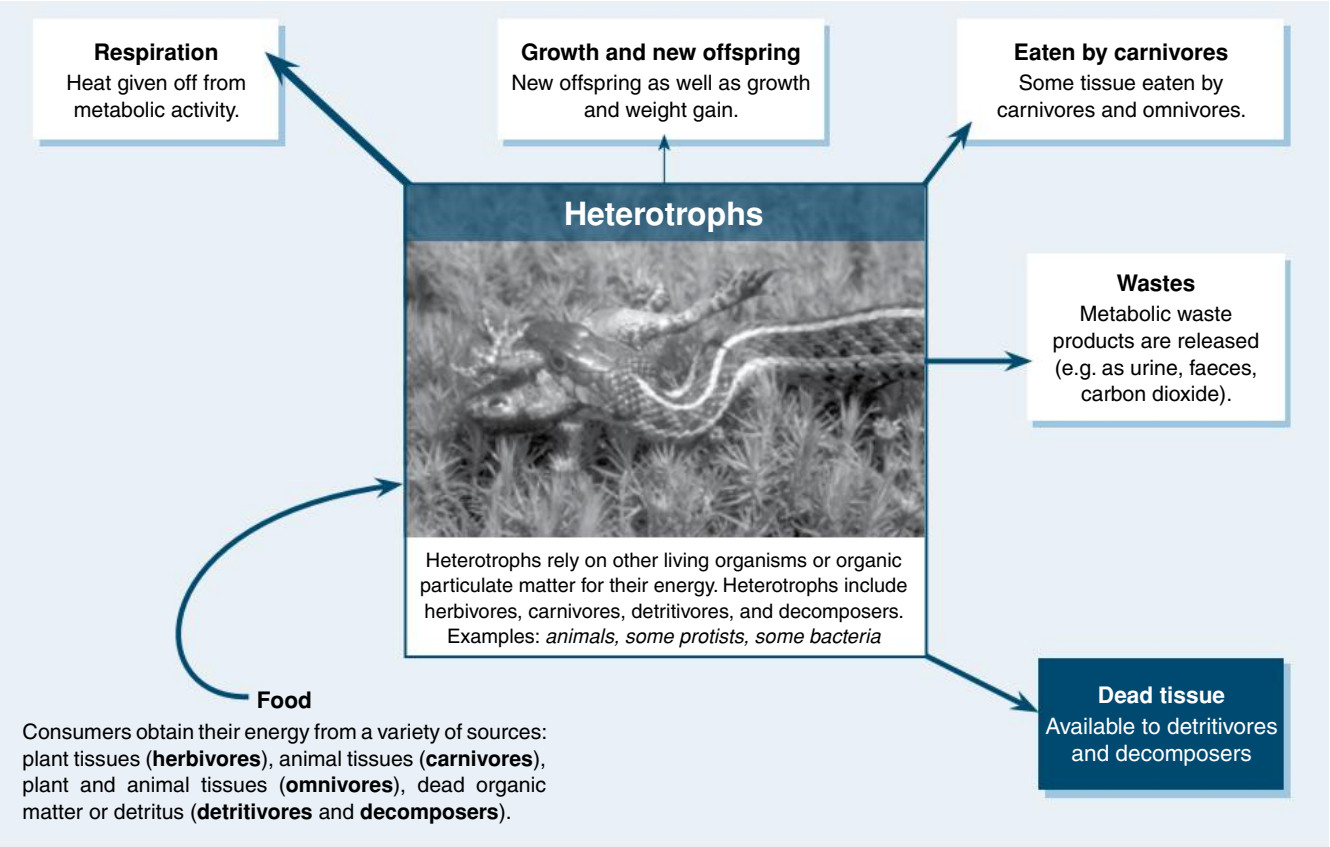
Living things obtain their energy for metabolism in two main ways. **Autotrophs** (producers) use the energy in sunlight or inorganic molecules to make their own food. **Heterotrophs** (consumers) rely on other organisms as a source of energy and carbon. All other organisms depend on producers, even if they do not consume them directly. The energy flow into and out of each trophic (feeding) level can be represented on a diagram using arrows of different sizes to represent relative amounts of energy lost from different trophic levels.





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1. Study the diagrams on energy flow relating to **photoautotrophs**, **chemoautotrophs**, and **heterotrophs**. Describe the differences between these categories of organisms with respect to how they obtain their energy:

2. Describe how energy may be lost from organisms in the form of:

   (a) Wastes: _____

   (b) Respiration: _____

3. Explain why so little energy is available for growth and reproduction, regardless of trophic group: _____

4. Describe the ecological importance of chemoautotrophic organisms in deep sea environments: _____

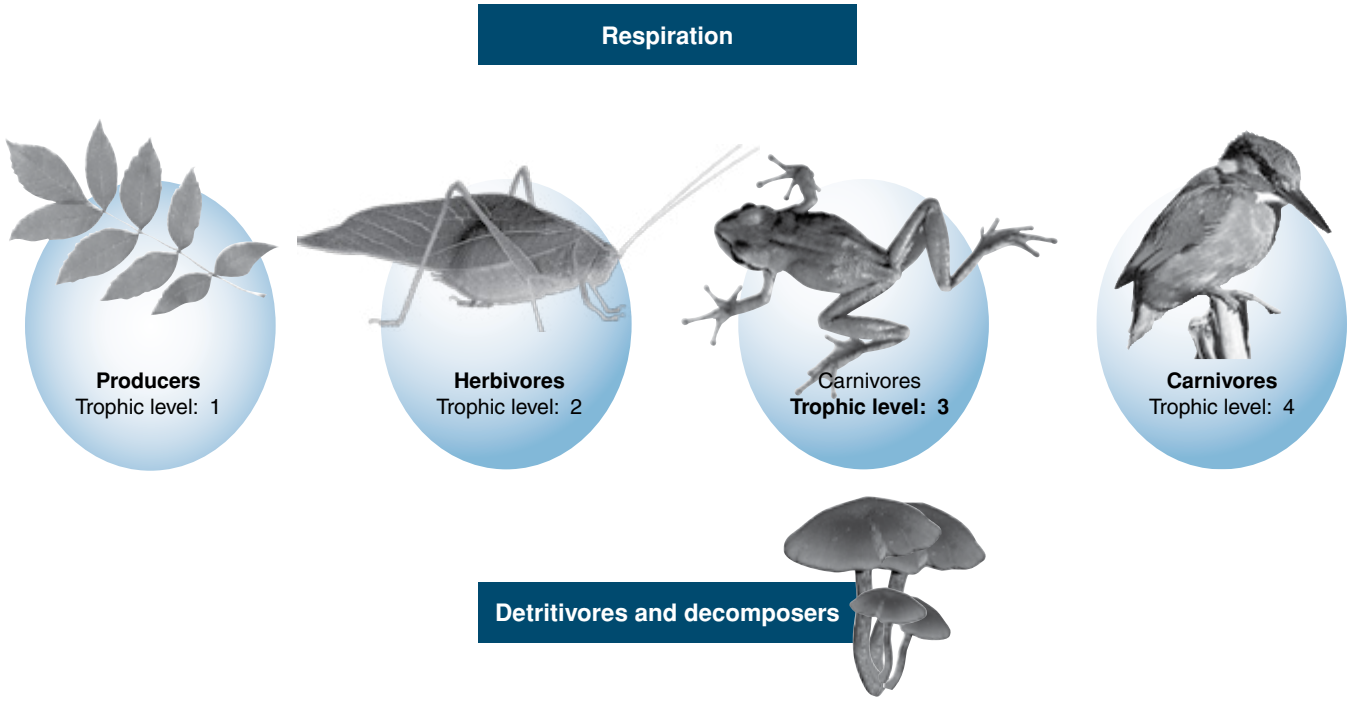
5. In what way is the chemoautotrophic system of the deep sea thermal vent linked to other ecological systems?

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242 Food Chains

Key Idea: A food chain is a model to illustrate the feeding relationships between organisms.

Organisms in ecosystems interact by way of their feeding (trophic) relationships. These interactions can be shown in a **food chain**, which is a simple model to illustrate how energy, in the form of food, passes from one organism to the next. Energy flows through trophic levels rather inefficiently, with only 5-20% of usable energy being transferred to the next level. For this reason, food chains seldom have more than six links. Each organism in the chain is a food source for the next. The levels of a food chain are called **trophic levels**. An organism is assigned to a trophic level based on its position in the food chain. Organisms may occupy different trophic levels in different food chains or during different stages of their life. Arrows link the organisms in a food chain. The direction of the arrow shows the flow of energy through the trophic levels. Most food chains begin with a producer, which is eaten by a primary consumer (**herbivore**). Higher level consumers (**carnivores** and **omnivores**) eat other consumers.



The diagram above represents the basic elements of a food chain. In the questions below, you are asked to add to the diagram the features that indicate the flow of energy through the community of organisms.

1. (a) State the original energy source for this food chain: _____

   (b) Draw arrows on the diagram above to show how the energy flows through the organisms in the food chain.
   (c) Label each of the arrows with the process that carries out this transfer of energy.
   (d) Draw arrows on the diagram to show how the energy is lost by way of respiration.

2. (a) What happens to the **amount** of energy available to each successive trophic level in a food chain?

   _____

   (b) Explain your answer: _____

   _____

3. Discuss the trophic structure of ecosystems, including reference to **food chains** and **trophic** levels:

   _____

   _____

   _____

   _____

   _____

   _____

4. What could you infer about the trophic level(s) of the kingfisher if it was found to eat both katydids and frogs?

   _____

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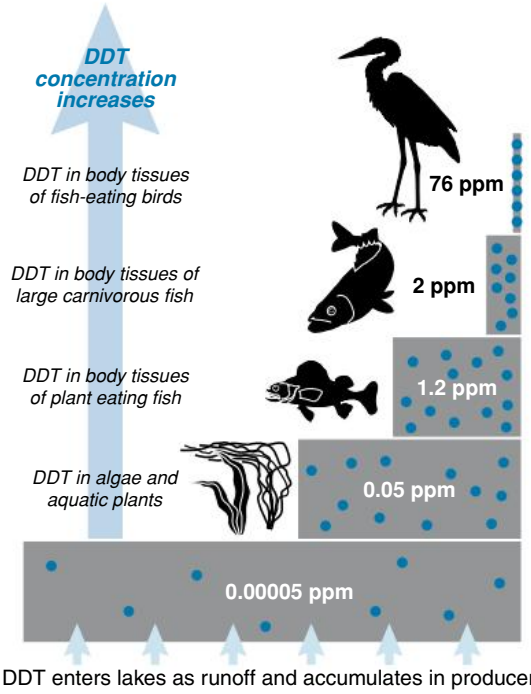
243 Biomagnification of Chemicals

Key Idea: Toxic chemicals can enter a food chain and increase in concentration at each trophic level.

Chemicals, such as pesticides and pharmaceuticals, can be taken up by organisms via their food or be absorbed from the environment. Many chemicals are not readily excreted, but are stored in fatty tissues and show progressive concentration in food chains. This is called **biomagnification** and it puts higher order consumers at risk of accumulating substances in their tissues to lethal levels. The **toxicity** of a chemical is a measure of how poisonous it is. Its **specificity** describes how selective it is in targeting a pest, while its **persistence** describes how long it stays in the environment.

Biomagnification of DDT in Aquatic Ecosystems

DDT is a highly toxic and persistent organochlorine. Its use as a pesticide is now banned in most developed countries because of its detrimental effects in food chains.



DDT enters lakes as runoff and accumulates in producers (**bioaccumulation**). It then concentrates progressively in subsequent trophic levels (**biomagnification**). Higher order consumers may ingest toxic levels because they eat a large number of lower order consumers.

Vultures: A Top Consumer in Crisis



Photo: The white-rumped vulture (*Gyps bengalensis*) was once widespread in India. Today, only one bird remains for every 1000 recorded in 1992.

In the last decade, there has been a dramatic decline in the number of *Gyps* vultures throughout India, Pakistan, and Nepal, where they play an important role in disposing of animal carcasses and human bodies. The cause of the decline was found to be the anti-inflammatory drug Diclofenac, which is widely used to treat illness and injury in livestock. Vultures are highly susceptible to the drug and die from renal failure after feeding at carcass dumps, the traditional method of livestock disposal in South Asia. In 2006, the use of veterinary diclofenac was banned and a vulture-safe alternative is now available.

Image credit for vulture: www.plosbiology.org/article/info:doi/10.1371/journal.pbio.0040061

1. Define the following terms as they relate to the characteristics and use of pesticides:

   (a) Toxicity: _____

   (b) Specificity: _____

   (c) Persistence: _____

   (d) Biomagnification: _____

2. Calculate the increase in DDT concentration between each step in the food chain:

   (a) Between water and algae: 0.05 / 0.00005 = 1000 times

   (b) Between algae and plant-eating fish: _____

   (c) Between plant-eating fish and carnivorous fish: _____

   (d) Between carnivorous fish and fish-eating birds: _____

3. Why are top consumers most at risk from biomagnification? _____

4. What does the case study of the vultures in India tell us about the widespread use of apparently 'safe' drugs?

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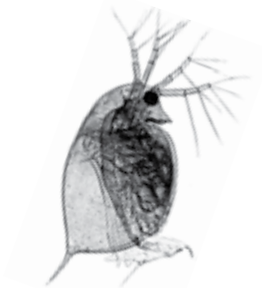
LINK 288 LINK 287 DATA

244 Constructing a Food Web

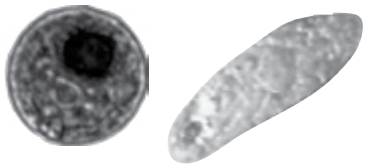
Key Idea: The many food chains in a community can be organised into food webs to show all the feeding interactions.

A **food web** depicts all the interconnected food chains in an ecosystem. Species are assigned to trophic levels on the basis of their sources of nutrition, with the first trophic level (the producers), ultimately supporting all other levels. Consumers are ranked according to the trophic level they occupy, although some may feed at several different trophic levels. The complexity of a food web depends on the number of food chains and trophic levels involved. For the lake community below, assemble the organisms into a food web to illustrate their trophic interactions. The detritus (accumulated dead organic matter) has been omitted in this case, but would normally provide a rich nutrient source for many organisms.

Feeding Requirements of Lake Organisms



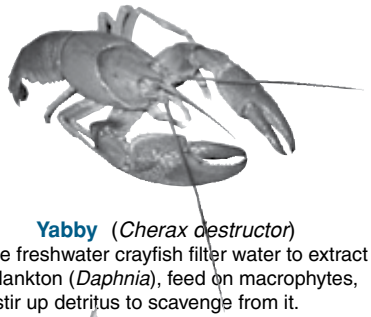
Daphnia (*Daphnia* spp.)
Small freshwater crustacean that forms part of the zooplankton. It feeds on planktonic algae by filtering them from the water with its limbs.



Autotrophic protists
e.g. *Chlamydomonas* (left), *Euglena* (right)
Microscopic, autotrophic protists. Two of many species that form the phytoplankton.



Mallard duck (*Anas platyrhynchos*)
Feed mostly on water plants. Sifts fallen seed, aquatic plants and small animals from the muddy margins of the lake.



Yabby (*Cherax destructor*)
These freshwater crayfish filter water to extract zooplankton (*Daphnia*), feed on macrophytes, and stir up detritus to scavenge from it.



Macrophytes (various species)
A variety of flowering aquatic plants are adapted for being submerged, free-floating, or growing at the lake margin.



Kingfisher (*Alcedo*)
Although not restricted to the lake community, kingfishers feed on small fish, yabbies, and tadpoles.



Diving beetle (*Dytiscus*)
Diving beetles feed on aquatic insect larvae and adult insects blown into the lake community.



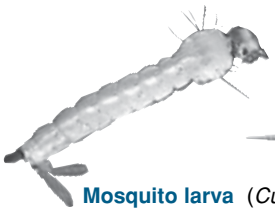
Brown trout (*Salmo trutta*)
Feed on zooplankton, freshwater crayfish, aquatic insect larvae, and insects blown into the water from the surrounding area.



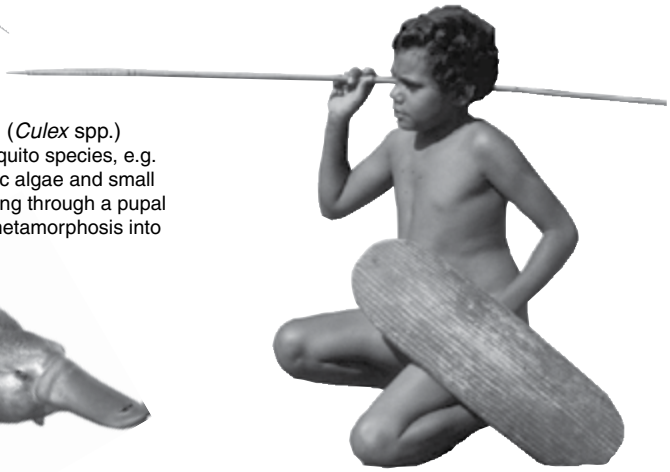
Tadpole (immature frog, *Litoria* spp.)
Feed on algae and very small zooplankton. Adult frogs feed on terrestrial (land dwelling) invertebrates.



Silver perch (*Bidyanus bidyanus*)
Omnivorous, feeding on a range of invertebrates, including crustaceans, aquatic insects, and molluscs, but also some vegetation.



Mosquito larva (*Culex* spp.)
The larvae of most mosquito species, e.g. *Culex*, feed on planktonic algae and small protozoans before passing through a pupal stage and undergoing metamorphosis into adult mosquitoes.



Humans (*Homo sapiens*)
Humans most commonly exploit the lake community food sources by taking trout and yabbies. Traditionally, aboriginal populations have fed on yabbies and fish.



Pelican (*Pelecanus conspicillatus*)
Pelicans feed on fish of varying sizes, including smaller trout and silver perch.



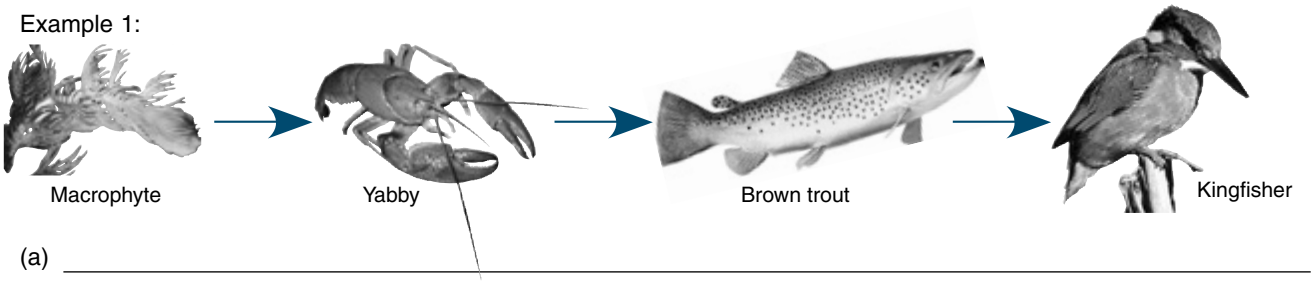
Platypus (*Ornithorhynchus anatinus*)
A unique nocturnal mammal that feeds on insects, molluscs, worms, other invertebrates and small vertebrates.

PRAC WEB 244 LINK 245 LINK 246

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1. From the information provided for the lake food web components on the previous page, construct **ten** different **food chains** (using their names only) to show the feeding relationships between the organisms. Some food chains may be shorter than others and most species will appear in more than one food chain. An example has been completed for you.

Example 1:



(a) _____

(b) _____

(c) _____

(d) _____

(e) _____

(f) _____

(g) _____

(h) _____

(i) _____

(j) _____

2. (a) Use the food chains that you have created above to help you to draw up a complete **food web** for this community. Use only the supplied information to draw arrows showing the flow of **energy** between species. (NOTE: Only energy **from** (not to) the detritus is required)

(b) Label each species with the following codes to indicate its trophic level and status: Indicate:
- Diet type: **P** = Producer, **H** = Herbivore, **C** = Carnivore, **O** = Omnivore (Note: based on the information given).
- Position in the food chain as a consumer (1st, 2nd, 3rd, 4th order consumer): **1–4** (does not include producers).

Example: Mosquito larva is **H1**

Trophic level 5	Kingfisher	Pelican	Humans		Detritus
Trophic level 4	Trout	Silver perch		Platypus	
Trophic level 3	Tadpole	Diving beetle	Yabbie	Duck	
Trophic level 2	*Daphnia*	Mosquito larva			
Trophic level 1	Autotrophic protists			Macrophytes	

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245 Dingo Food Webs

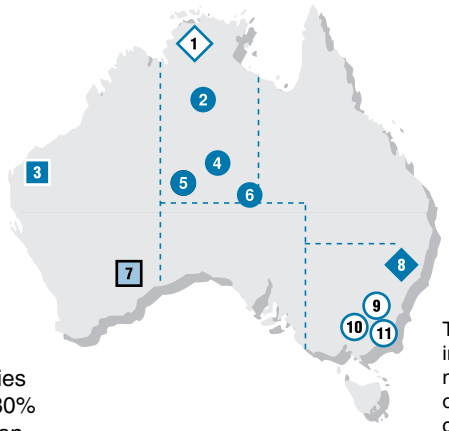
Key Idea: The habitats and trophic interactions of dingoes vary regionally, depending on the community composition.

Dingoes are widespread in Australia as top predators. Dingoes are members of different communities in different parts of Australia, and the food webs they are part of also vary regionally. Samples taken from six different locations (below) show how the prey taken by dingoes varies from one location to another.



RA

Despite the immense range of potential prey species across Australia, only ten species formed almost 80% of a dingo's diet. Dingoes are specialists, rather than generalists, with respect to dietary intake.



Location of sampling sites

1 Kakadu National Park
2 Barkley Tableland
3 Fortesque River
4 Harts Ranges
5 Eldunda
6 Simpson Desert
7 Nullarbor Plain
8 George's Creek Nature Reserve
9 Kosciusko National Park
10 Victorian Highlands
11 Nadgee Nature Reserve

The table below shows the diet of dingoes in six major Australian habitats. The numbers represent the proportion (% occurrence) of stomachs or faeces that contained each prey species. A total of 12 802 stomachs and faeces were sampled over a 20 year period (1966-1986).

◇ **Wet-dry tropics North Australia**	6722 faeces	● **Arid & semi-arid central Australia**	1480 stomachs	□ **Arid south-west Australia**	131 faeces/ stomachs
Dusky rat	33.8	Rabbit	37.9	Rabbit	63.4
Magpie goose	32.5	Cattle	23.3	Red kangaroo	32.1
Agile wallaby	15.1	Long-haired rat	17.6	Cattle	7.6
Northern ringtailed possum	9.7	Red kangaroo	10.2	Red fox	3.8
Grass species	7.1	Central netted dragon	7.8	Little crow	2.3
Feral water buffalo	5.8	Small mammal (undetermined sp.)	3.8	Bobtail skink	1.5
Feral pig	3.5	House mouse	3.6	Feral cat	1.5
Unidentified matter	2.6	Grasshopper	2.7	Centipede/millipede	0.8
Antilopine wallaroo	1.8	Bearded dragon	2.2	Dingo	0.8
Northern brown bandicoot	1.4	Zebra finch	2.1	Grasshopper	0.8
Feral cattle	1.3	Bird (undetermined species)	2.0		
Bird (undetermined species)	0.7	Feral cat	1.8		
Insect (undetermined species)	0.7	Galah	1.8		
Beetle	0.4	Budgerigar	1.5		
■ **Semi-arid north-west Australia**	413 faeces/ stomachs	○ **Cool coastal mountains SE Australia**	2063 faeces/ stomachs	◆ **Humid coastal mountains eastern Australia**	1993 faeces
Red kangaroo/euro	80.6	Swamp wallaby	17.9	Swamp wallaby	30.5
Cattle	11.4	Wallaby (undetermined spp.)	15.8	Bush rat	12.2
Sheep	8.0	Wombat	15.0	Red-necked wallaby	11.1
Bird (undetermined species)	5.6	Animal remains (unidentified)	11.5	Brushtail possums	6.9
Reptile (undetermined species)	3.4	Rabbit	10.5	Bandicoots	
Insects (undetermined species)	2.9	Common ringtail possum	8.0	(long-nosed, Southern brown)	6.8
Echidna	2.2	Waterbird (undetermined sp.)	7.7	Rabbit	6.4
Dingo	1.7	Red-neck wallaby	5.3	Antichinuses (brown, dusky)	5.8
Feral cat	0.5	Possum (undetermined species)	5.1	Parma wallaby	4.6
Bat (undetermined species)	0.2	Rat (undetermined species)	5.0	Common ringtail possum	4.4
Fish (undetermined species)	0.2	Little penguin	4.4	Ring-necked pademelon	3.8
Red fox	0.2	Fish (undetermined species)	3.7	Echidna	3.5
Rothschild's rock wallaby	0.2	Mutton bird	3.6	Long-nosed potoroo	1.7
		Echidna	3.3	Greater glider	1.5

Adapted from: Corbett, L. 1995. The dingo in Australia and Asia, Appendix C: pp. 183-186. University of NSW Press

1. Sites 7 and 3 (above) yielded a small number of prey species in the samples taken. Suggest the likely reason for this:

2. Name **three** prey species that are taken by dingoes in the '*Cool coastal mountains, SE Australia*' (sites 9, 10, and 11), that are restricted to that type of environment (i.e. not represented in the prey taken at other sites):

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3. What evidence is there from the data on the previous page, that dingoes engage in cannibalism? _____

_____

4. Which general kind of prey makes up most of the dingoes' diet? _____

5. At some sample sites, the dingoes' prey included domesticated animals.

   (a) Which prey items represent domesticated animals? _____

   (b) What kind of environmental conditions have encouraged dingoes to make these animals part of their diet?

   _____

6. (a) Which of the sample sites has the least reliable data for indicating the diet of dingoes in its area?

   _____

   (b) Explain your choice: _____

   _____

7. In this study, the diet of dingoes was determined by the sampling methods of examining large numbers of stomach contents and faeces.

   (a) Explain which of these two methods should prove the most reliable for positive identification of prey species:

   _____

   (b) Suggest **two reasons** why the researchers did not simply follow the dingoes and watch what they ate as a way of gathering dietary information on the dingoes:

   Reason 1: _____

   Reason 2: _____

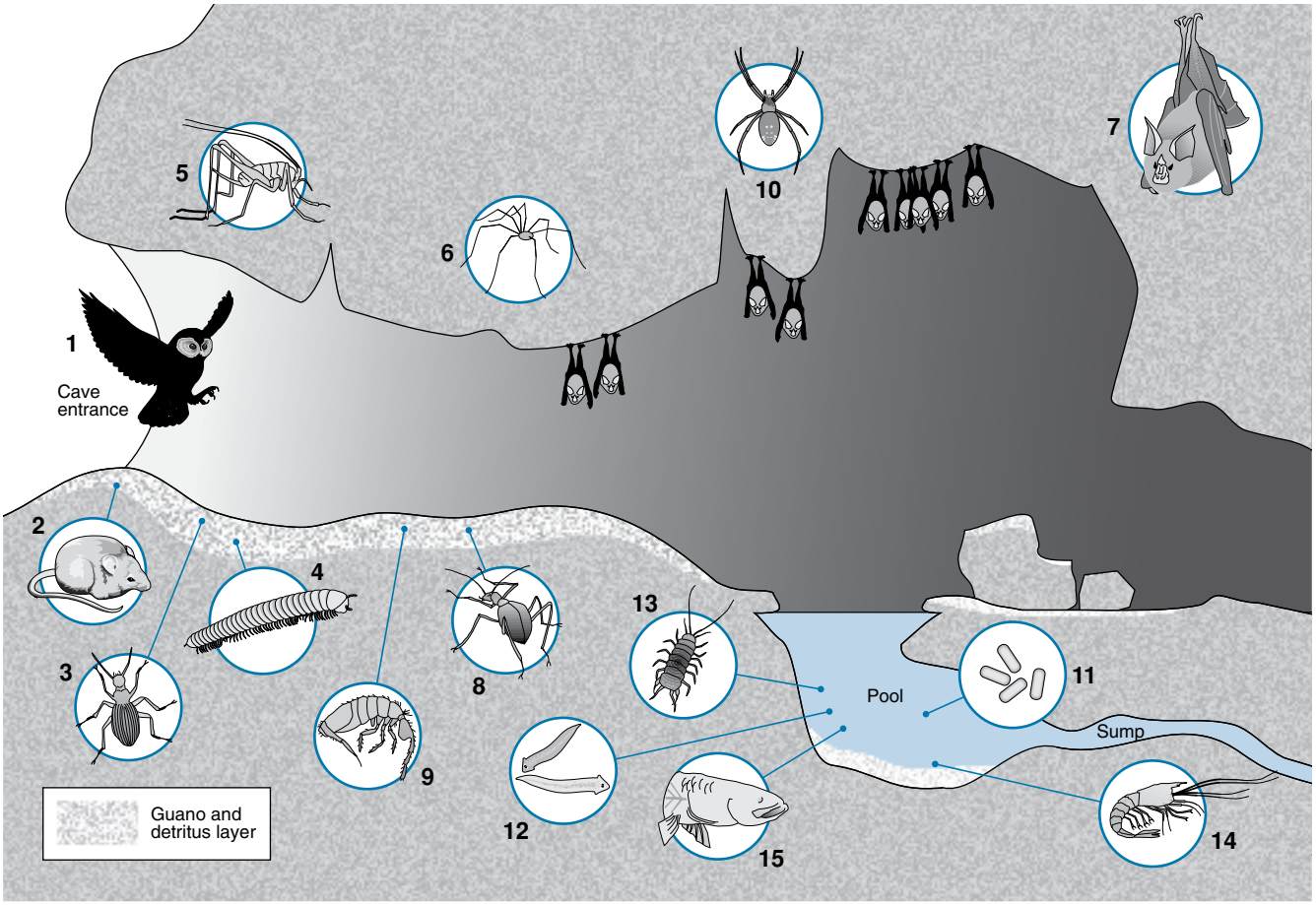
8. Using the data on the previous page, choose one of the 'regional ecotypes' (e.g. wet-dry tropics, north Australia) and produce a food web in the space below. Use only the first **five positively identified** prey species (in most cases, do not include unidentified species). This activity will require you to carry out some research into what the prey species eat.

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246 Cave Food Webs

Key Idea: The food webs of cave ecosystems are fragile and based on only a few resources.

Cave environments lack the light that sustains most ecosystems. Despite this, a wide range of animals are adapted to live there. Some animals, such as bats, are not permanent cave-dwellers, but rest and breed there. Around the entrance of the cave, the owl (1) preys on the mouse (2) which itself feeds on the vegetation outside the cave. The owl and the mouse leave droppings that support the cave dung beetle (3) and millipede (4). The cave cricket (5) scavenges dead birds and mammals near the entrance. The harvestman (6) is a predator of the dung beetle, the millipede, and the cricket. Inside the cave, the horseshoe bat (7) roosts and breeds, leaving the cave to feed on flying insects. The bats produce vast quantities of guano (droppings). The guano is eaten by the blind cave beetle (8), millipede (4) and springtail (9). These invertebrates are hunted by the predatory cave spider (10). In underground pools, the bat guano supports the growth of bacteria (11). Flatworms (12) and isopods (13) feed on the bacteria and are eaten by the blind cave shrimp (14). The blind cave fish (15) is the top predator in this system,feeding on isopods and the blind cave shrimps.



1. Using the lake food web activity as a guide, construct a food web for the cave ecosystem on a separate sheet of paper. For animals that feed outside the cave, do not include this outside source of food. As in the lake food web, label each species with the following codes to indicate its diet type (producer, herbivore, carnivore, omnivore) and its position in the food chain if it is a consumer (1st, 2nd, 3rd, 4th order consumer). Staple your finished web to this page.

2. Which major trophic level is missing from the cave food web? _____

3. How is energy imported into the cave's food web? _____

_____

4. How might energy be removed from the cave ecosystem? _____

_____

_____

5. In many parts of the world, cave-dwelling bat species are endangered, often taken as food by humans or killed as pests. Explain how the cave food web would be affected if bat numbers were to fall substantially:

_____

_____

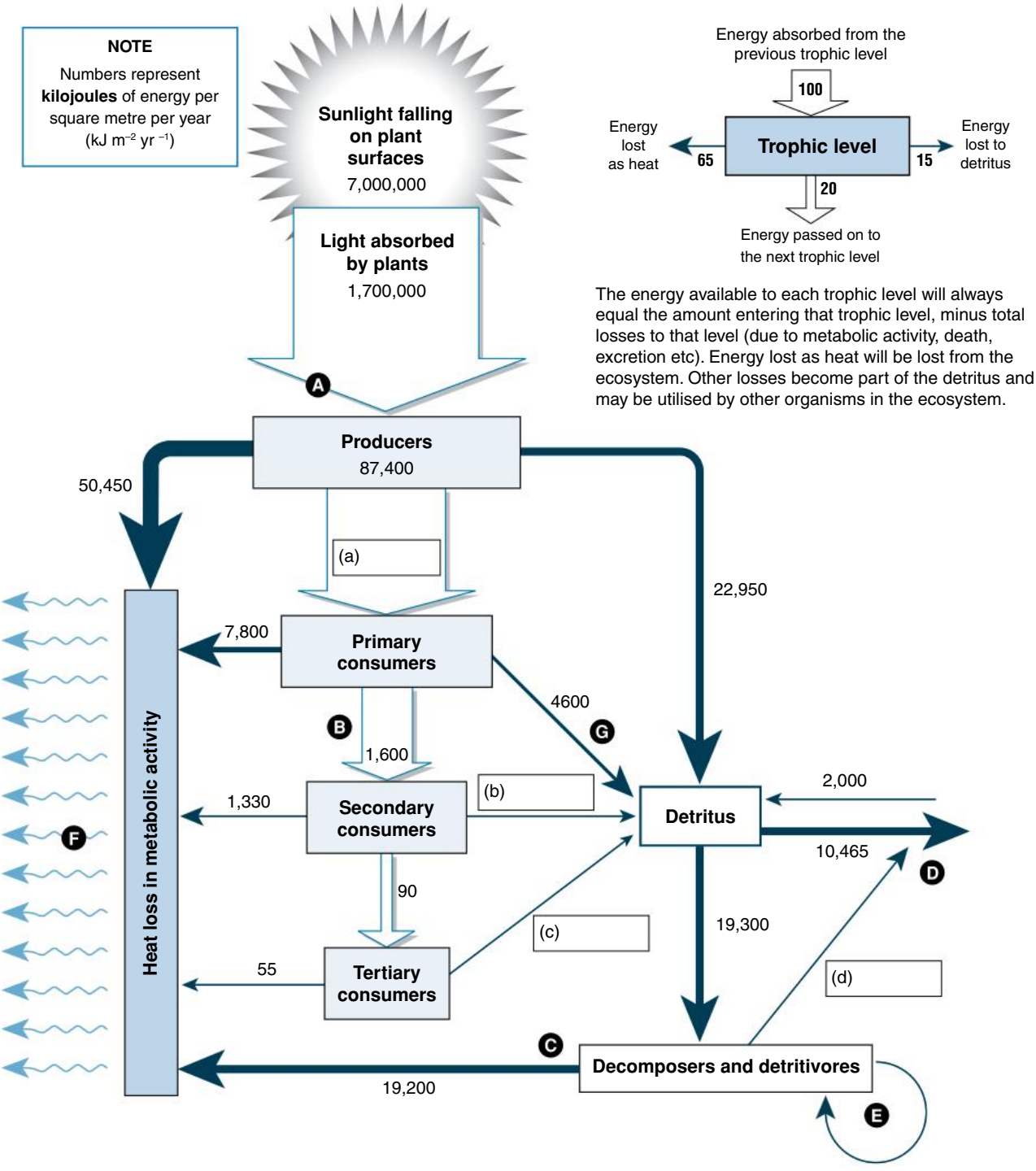
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247 Energy Flow in an Ecosystem

Key Idea: Energy flows through an ecosystem between trophic levels. Only 5-20% of energy is transferred from one trophic level to the next.

Energy cannot be created or destroyed, only transformed from one form (e.g. light energy) to another (e.g. chemical energy in the bonds of molecules). This means that the flow of energy through an ecosystem can be measured. Each time energy is transferred from one trophic level to the next (by eating, defecation, etc.), some energy is given out as heat to the environment, usually during cellular respiration. Living organisms cannot convert heat to other forms of energy, so the amount of energy available to one trophic level is always less than the amount at the previous level. Potentially, we can account for the transfer of energy from its input (as solar radiation) to its release as heat from organisms, because energy is conserved. The percentage of energy transferred from one trophic level to the next is the **trophic efficiency**. It varies between 5% and 20% and measures the efficiency of energy transfer. An average figure of 10% trophic efficiency is often used. This is called the **ten percent rule**.

Energy Flow Through an Ecosystem



The energy available to each trophic level will always equal the amount entering that trophic level, minus total losses to that level (due to metabolic activity, death, excretion etc). Energy lost as heat will be lost from the ecosystem. Other losses become part of the detritus and may be utilised by other organisms in the ecosystem.

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1. Study the diagram on the previous page illustrating energy flow through a hypothetical ecosystem. Use the example at the top of the page as a guide to calculate the missing values (a)–(d) in the diagram. Note that the sum of the energy inputs always equals the sum of the energy outputs. Place your answers in the spaces provided on the diagram.

2. What is the original source of energy for this ecosystem? _____

3. Identify the processes occurring at the points labelled **A – G** on the diagram:

   A. _____ E. _____

   B. _____ F. _____

   C. _____ G. _____

   D. _____

4. (a) Calculate the percentage of light energy falling on the plants that is absorbed at point **A**:

   Light absorbed by plants ÷ sunlight falling on plant surfaces x 100 = _____

   (b) What happens to the light energy that is not absorbed? _____

   _____

5. (a) Calculate the percentage of light energy absorbed that is actually converted (fixed) into producer energy:

   Producers ÷ light absorbed by plants x 100 = _____

   (b) How much light energy is absorbed but not fixed: _____

   (c) Account for the difference between the amount of energy absorbed and the amount actually fixed by producers:

   _____

   _____

6. Of the total amount of energy **fixed** by producers in this ecosystem (at point **A**) calculate:

   (a) The total amount that ended up as metabolic waste heat (in kJ): _____

   (b) The percentage of the energy fixed that ended up as waste heat: _____

7. (a) State the groups for which detritus is an energy source: _____

   (b) How could detritus be removed or added to an ecosystem? _____

   _____

8. Under certain conditions, decomposition rates can be very low or even zero, allowing detritus to accumulate:

   (a) From your knowledge of biological processes, what conditions might slow decomposition rates?

   _____

   (b) What are the consequences of this lack of decomposer activity to the energy flow? _____

   _____

   (c) Add an additional arrow to the diagram on the previous page to illustrate your answer. _____

   (d) Describe three examples of materials that have resulted from a lack of decomposer activity on detrital material:

   _____

   _____

9. The **ten percent rule** states that the total energy content of a trophic level in an ecosystem is only about one-tenth (or 10%) that of the preceding level. For each of the trophic levels in the diagram on the preceding page, determine the amount of energy passed on to the next trophic level as a percentage:

   (a) Producer to primary consumer: _____

   (b) Primary consumer to secondary consumer: _____

   (c) Secondary consumer to tertiary consumer: _____



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248 Primary Productivity

Key Idea: Only a portion of the total energy fixed by a plant in photosynthesis is available to consumers.

The energy entering ecosystems is fixed by producers at a rate that is dependent on limiting factors such as temperature and the availability of light, water, and nutrients. The total energy fixed as biomass by a plant in photosynthesis is the gross primary production (GPP) and it is expressed as J m^{-2} or as g m^{-2}. A portion of this energy is required by the plant for respiration. Subtracting respiration from GPP gives the **net primary production**. The rate of biomass production, or **net primary productivity**, is the biomass produced per area per unit time. Trophic efficiencies vary widely, and can be very high in natural systems where a large amount of the producer biomass is consumed and assimilated. Humans intervene in natural energy flows by simplifying the system and reducing the number of transfers occurring between trophic levels.

The Productivity of Natural Grassland Ecosystems

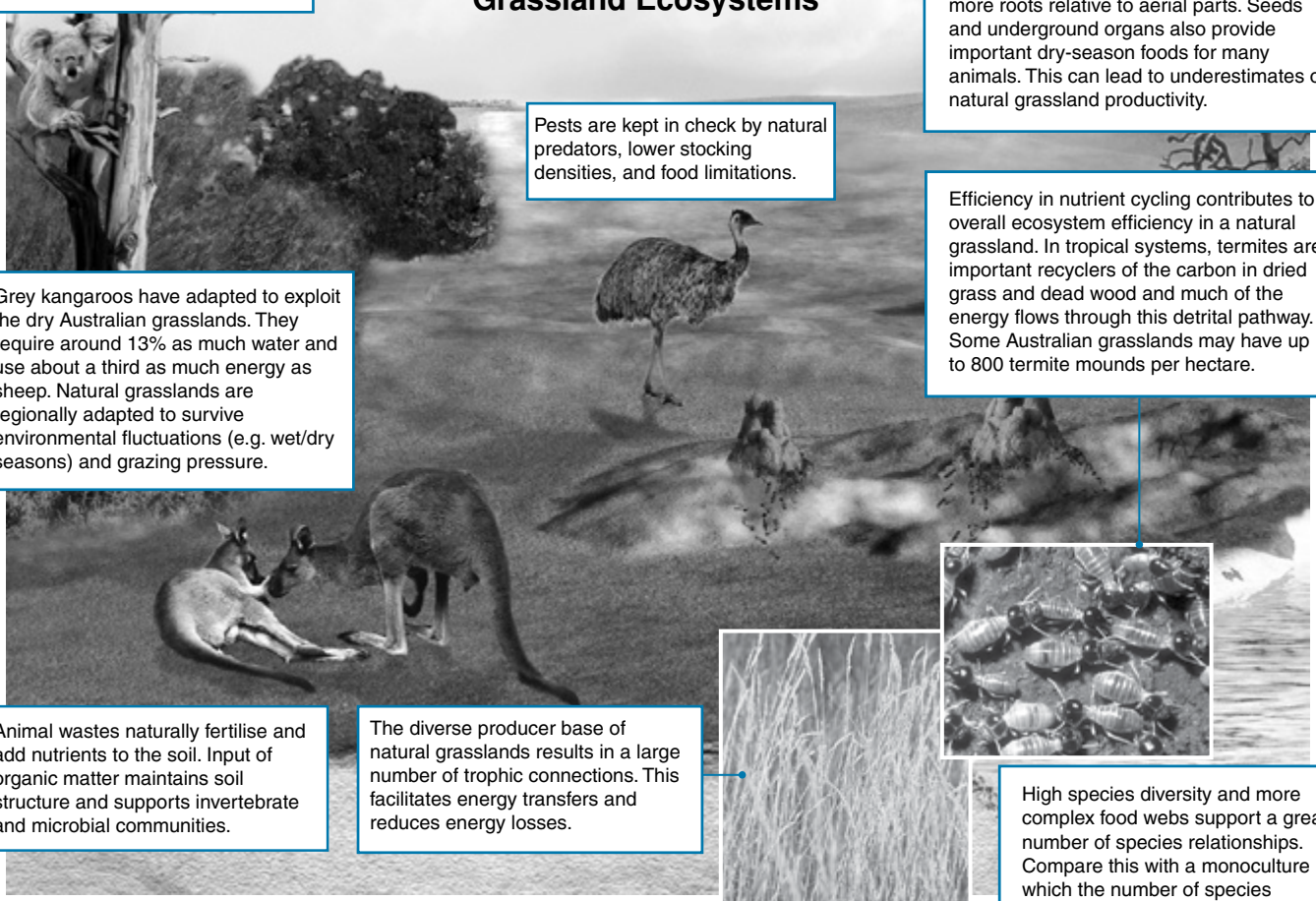
Trees and shrubs have leaves that are eaten by browsing mammals as well as invertebrates.

Root production is an important part of primary productivity and, compared with trees, herbaceous species tend to produce more roots relative to aerial parts. Seeds and underground organs also provide important dry-season foods for many animals. This can lead to underestimates of natural grassland productivity.

Pests are kept in check by natural predators, lower stocking densities, and food limitations.

Efficiency in nutrient cycling contributes to overall ecosystem efficiency in a natural grassland. In tropical systems, termites are important recyclers of the carbon in dried grass and dead wood and much of the energy flows through this detrital pathway. Some Australian grasslands may have up to 800 termite mounds per hectare.

Grey kangaroos have adapted to exploit the dry Australian grasslands. They require around 13% as much water and use about a third as much energy as sheep. Natural grasslands are regionally adapted to survive environmental fluctuations (e.g. wet/dry seasons) and grazing pressure.



Animal wastes naturally fertilise and add nutrients to the soil. Input of organic matter maintains soil structure and supports invertebrate and microbial communities.

The diverse producer base of natural grasslands results in a large number of trophic connections. This facilitates energy transfers and reduces energy losses.

High species diversity and more complex food webs support a greater number of species relationships. Compare this with a monoculture in which the number of species interactions is reduced, food webs are simplified, and the opportunity for pest explosions increases.

*The **trophic efficiencies** of natural ecosystems (efficiency of energy transfer between trophic levels) vary widely and depend on the proportion of producer biomass consumed and then assimilated by herbivores. In natural grasslands, high palatability and turnover contribute to high secondary productivity (rate of production of consumer biomass).*

1. Explain the difference between net primary production and net primary productivity: _____

_____

2. Briefly describe three factors that may affect the primary productivity of an ecosystem:

   (a) _____

   (b) _____

   (c) _____

3. Describe three reasons for the relatively high net primary productivity and high trophic efficiencies of natural grasslands:

   (a) _____

   (b) _____

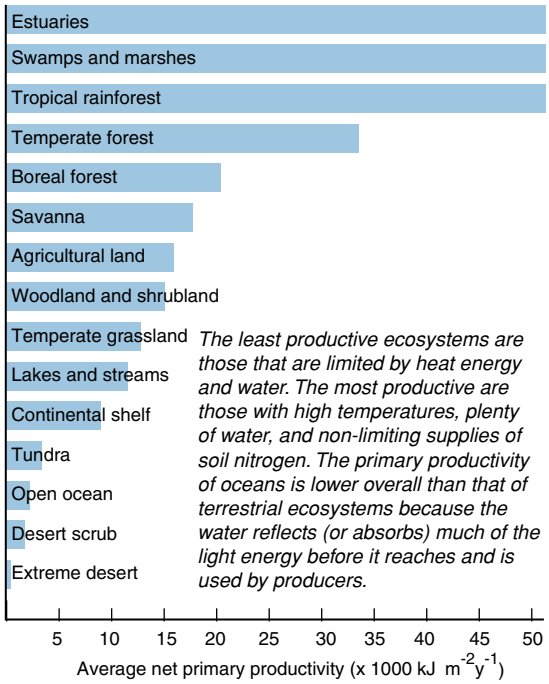
   (c) _____

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Measuring Productivity

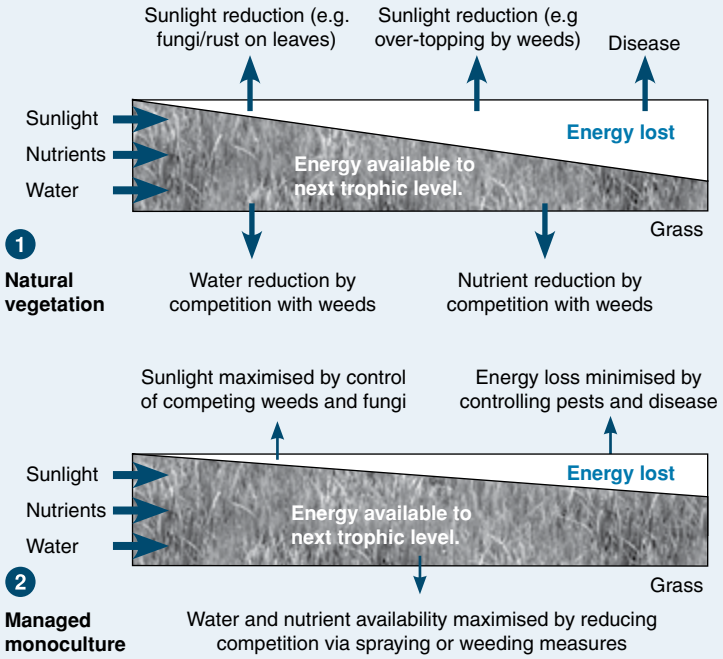
The gross primary productivity of an ecosystem will depend on the capacity of the producers to capture and fix carbon in organic compounds. In most ecosystems, this is limited by constraints on photosynthesis (availability of light, nutrients, or water for example). The net primary productivity is then determined by how much of this goes into plant biomass per unit time, after respiratory needs are met. This will be the amount available to the next trophic level. It is difficult to measure productivity, but it is often estimated from the harvestable dry biomass or standing crop (the net primary production).



The least productive ecosystems are those that are limited by heat energy and water. The most productive are those with high temperatures, plenty of water, and non-limiting supplies of soil nitrogen. The primary productivity of oceans is lower overall than that of terrestrial ecosystems because the water reflects (or absorbs) much of the light energy before it reaches and is used by producers.

Agriculture and Productivity

Increasing net productivity in agriculture (increasing yield) is a matter of manipulating and maximising energy flow through a reduced number of trophic levels. On a farm, the simplest way to increase the net primary productivity is to produce a monoculture. Monocultures reduce competition between the desirable crop and weed species, allowing crops to put more energy into biomass. Other agricultural practices designed to increase productivity in crops include pest (herbivore) control and spraying to reduce disease. Higher productivity in feed-crops also allows greater secondary productivity (e.g. in livestock). Here, similar agricultural practices make sure the energy from feed-crops is efficiently assimilated by livestock.



4. Estimating the NPP is relatively simple: all the plant material (including root material) from a measured area (e.g. 1 m^2) is collected and dried (at 105°C) until it reaches a constant mass. This mass, called the **standing crop**, is recorded (in kg m^{-2}). The procedure is repeated after some set time period (e.g. 1 month). The difference between the two calculated masses represents the estimated NPP:

   (a) Suggest why this procedure only provides an estimate of NPP: _____

   _____

   (b) State what extra information would be required in order to express the standing crop value in kJ m^{-2}: _____

   _____

   (c) Suggest what information would be required in order to calculate the GPP: _____

   _____

5. (a) How could a farmer maximise the net primary productivity of a particular crop? _____

   _____

   _____

   (b) How could a farmer maximise the productivity of their livestock? _____

   _____

   _____

6. Explain the contrasting net primary productivities of intensive horticultural land and desert: _____

   _____

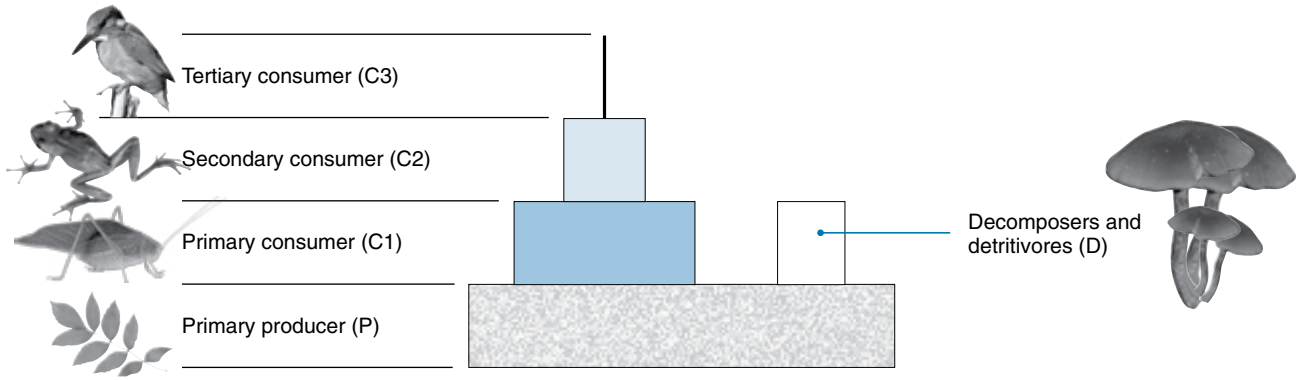
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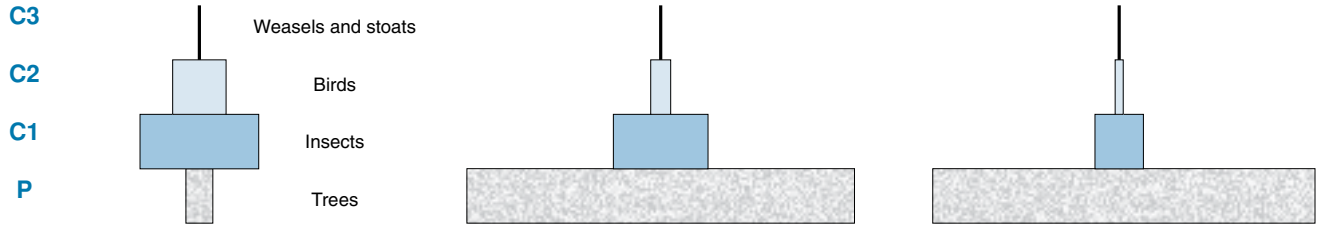
249 Ecological Pyramids

Key Idea: Ecological pyramids are used to illustrate the number of organisms, amount of energy, or amount of biomass at each trophic level in an ecosystem.

The energy, biomass, or numbers of organisms at each trophic level in any ecosystem can be represented by an ecological pyramid. The first trophic level is placed at the bottom of the pyramid and subsequent trophic levels are stacked on top in their 'feeding sequence'. Ecological pyramids provide a convenient model to illustrate the relationship between different trophic levels in an ecosystem.



The generalised ecological pyramid pictured above shows a conventional pyramid shape, with a large number (or biomass) of producers forming the base for an increasingly small number (or biomass) of consumers. Decomposers are placed at the level of the primary consumers and off to the side. They may obtain energy from many different trophic levels and so do not fit into the conventional pyramid structure. For any particular ecosystem at any one time (e.g. the forest ecosystem below), the shape of this typical pyramid can vary greatly depending on whether the trophic relationships are expressed as numbers, biomass or energy



Numbers in a forest community

Pyramids of numbers display the number of individual organisms at each trophic level. The pyramid above has few producers, but they may be of a very large size (e.g. trees). This gives an 'inverted pyramid', although not all pyramids of numbers are like this.

Biomass in a forest community

Biomass pyramids measure the 'weight' of biological material at each trophic level. Water content of organisms varies, so 'dry weight' is often used. Organism size is taken into account, allowing meaningful comparisons of different trophic levels.

Energy in a forest community

Pyramids of energy are often very similar to biomass pyramids. The energy content at each trophic level is generally comparable to the biomass (i.e. similar amounts of dry biomass tend to have about the same energy content).

1. What do each of the following types of ecological pyramids measure?

   (a) Number pyramid: _____

   (b) Biomass pyramid: _____

   (c) Energy pyramid: _____

2. What is the advantage of using a biomass or energy pyramid rather than a pyramid of numbers to express the relationship between different trophic levels?

   _____

   _____

   _____

   _____

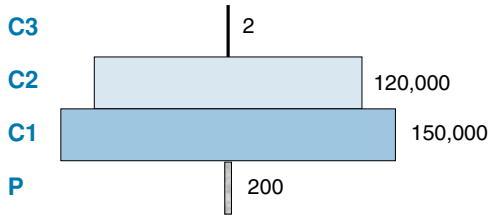
3. How can a forest community with relatively few producers (see next page) support a large number of consumers?

   _____

   _____

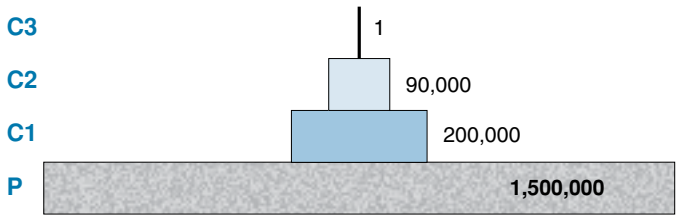
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Pyramid of numbers: forest community

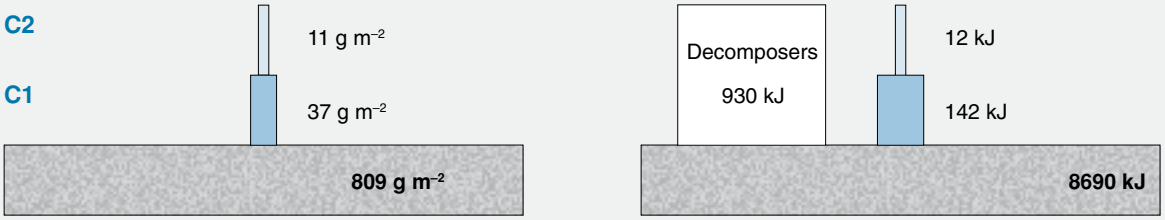
In a forest community, a few producers may support a large number of consumers. This is due to the large size of the producers; large trees can support many individual consumer organisms. The example above shows the numbers at each trophic level for an oak forest in England, in an area of 10 m^2.



Pyramid of numbers: grassland community

In a grassland community, a large number of (small) producers support a much smaller number of consumers. Grass plants can support only a few individual consumer organisms and take time to recover from grazing pressure. The example above shows the numbers at each trophic level for a derelict grassland area (10 m^2) in Michigan, United States.

Pyramids for a Plankton Community



Biomass

The pyramids of biomass and energy are virtually identical. The two pyramids illustrated here relate to the same hypothetical plankton community. A large biomass of producers supports a smaller biomass of consumers. The energy at each trophic level

Energy

is reduced with each progressive stage in the food chain. As a general rule, a maximum of 10% of the energy is passed on to the next level in the food chain. The remaining energy is lost due to respiration, waste, and heat.

4. Determine the **energy transfer** between trophic levels in the plankton community example in the above diagram:

   (a) Between producers and the primary consumers: _____

   (b) Between the primary consumers and the secondary consumers: _____

   (c) Why is the amount of energy transferred from the producer level to primary consumers considerably less than the expected 10% that occurs in many other communities?

   _____

   _____

   (d) After the producers, which trophic group has the greatest energy content? _____

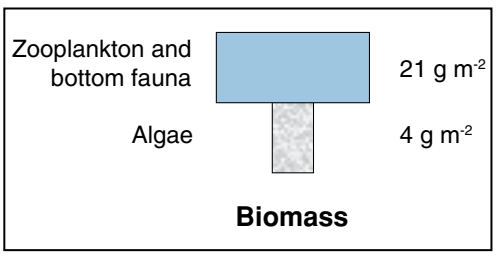
   (e) Give a likely explanation why this is the case: _____

   _____

   _____

An unusual biomass pyramid

The biomass pyramids of some ecosystems appear rather unusual with an inverted shape. The first trophic level has a lower biomass than the second level. What this pyramid does not show is the rate at which the producers (algae) are reproducing in order to support the larger biomass of consumers.



5. Give a possible explanation of how a small biomass of producers (algae) can support a larger biomass of consumers (zooplankton):

   _____

   _____

   _____

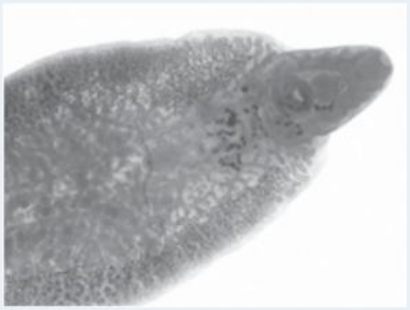
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250 Species Interactions

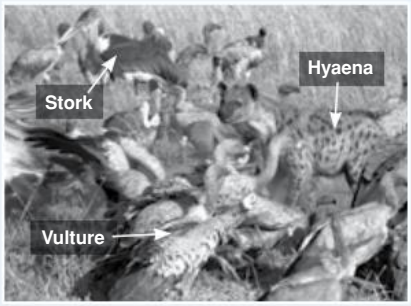
Key Idea: A community of organisms interacts in ways that can be beneficial, neutral, or harmful to one or both parties.

No organism exists in isolation. The particular characteristics of ecosystems and their communities arise as a result of the physical environment, the species that live there, and the complex interactions occurring between those species. Species interactions may involve only occasional or indirect contact (predation or competition) or they may involve close association or symbiosis. Symbiosis is a term that encompasses a variety of interactions involving close species contact. There are three types of symbiosis: parasitism (a form of exploitation), mutualism, and commensalism.

Examples of Species Interactions



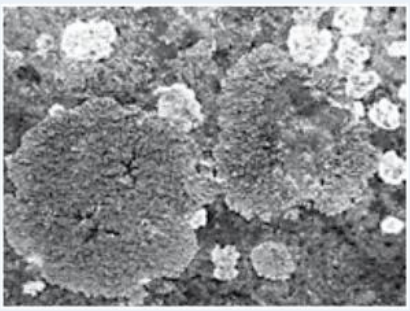
Parasites exploit a host's resources for their own benefit. The host is harmed, but rarely killed. Endoparasites, such as flukes (above), live inside their hosts. Ectoparasites, such as ticks, live attached to the outside of the host.



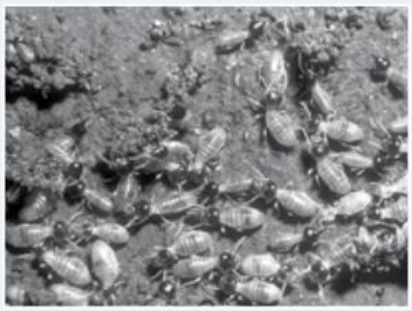
Interactions involving **competition** for the same food resources are dominated by the largest, most aggressive species. Here, hyaenas compete for a carcass with vultures and maribou storks.



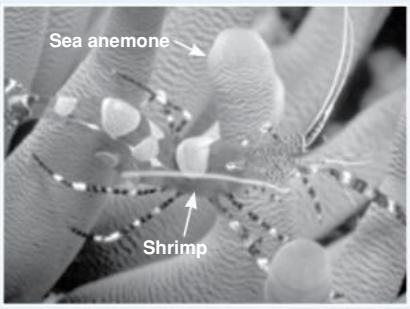
Predation is an easily identified relationship, as one species kills and eats another (above). Herbivory is similar type of exploitation, except that the plant is usually not killed by the herbivore and may even benefit from cropping.



Mutualism involves a close association between two species that offers both an advantage. **Lichens** (above) are the result of a mutualism between a fungus and an alga or a cyanobacterium.



Termites have a mutualistic relationship with the cellulose digesting microbes (primarily protozoa) in their guts. A similar mutualistic relationship exists between ruminants and their gut microflora of bacteria and ciliates.



Many species of decapod crustaceans, such as this anemone shrimp, are commensal with sea anemones. The shrimp gains an advantage by being protected from predators by the anemone's tentacles.

1. Using an example, discuss how a mutualistic relationship provides for the nutrition of two or more types of organism:

2. Identify the relationship between each of the following organisms:

   (a) A tapeworm and its host: _____

   (b) A cat and a flea: _____

   (c) A hyaena and a vulture: _____

   (d) A snake and a rat: _____

   (e) A shrimp and an anemone: _____

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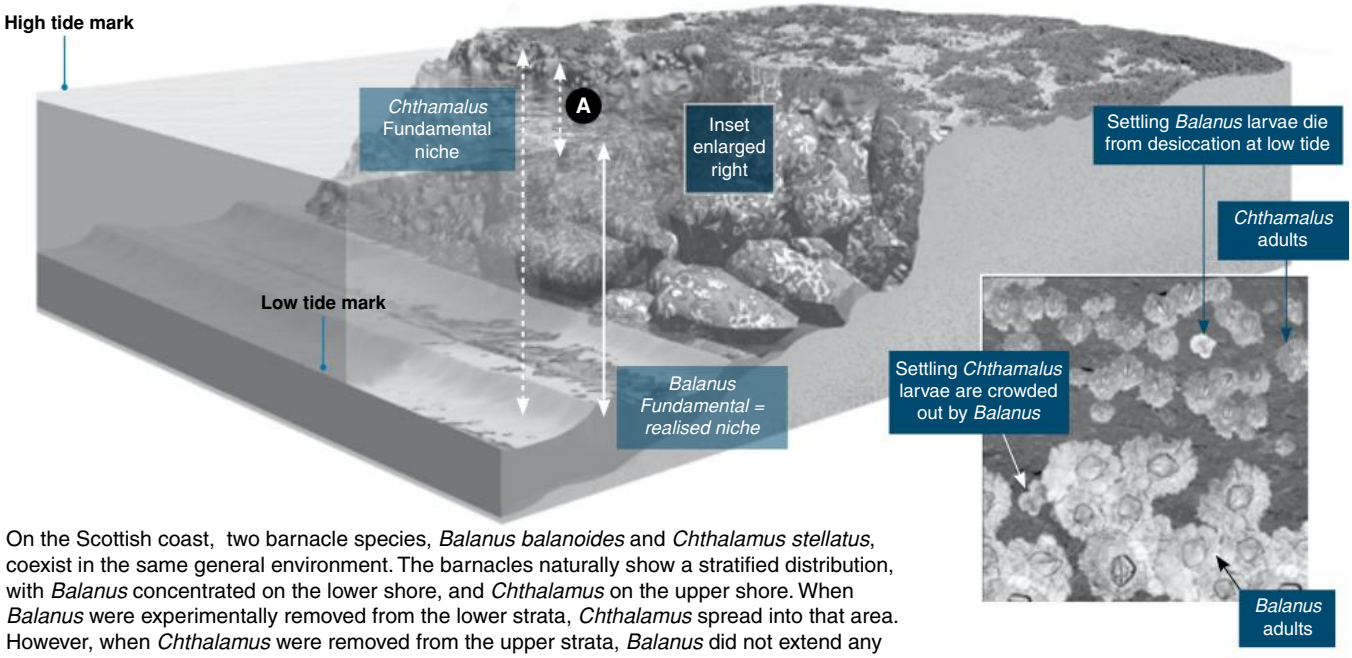
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251 Interspecific Competition

Key Idea: Interspecific competition is competition between individuals of different species for resources. It can affect the distribution of species sharing the same general environment.

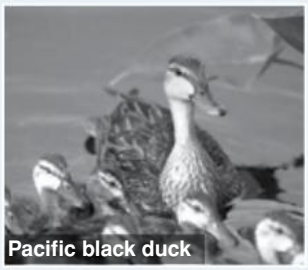
Interspecific competition (competition between different species) is usually less intense than intraspecific (same species) competition because coexisting species have evolved slight differences in their realised niches. However, when two species with very similar niche requirements are brought into direct competition through the introduction of a foreign species, one usually benefits at the expense of the other, which is excluded (the **competitive exclusion principle**). The introduction of alien species is implicated in the competitive displacement and decline of many native species. Displacement of native species by introduced ones is more likely if the introduced competitor is adaptable and hardy, with high fertility.

Competitive Exclusion in Barnacles



On the Scottish coast, two barnacle species, *Balanus balanoides* and *Chthalamus stellatus*, coexist in the same general environment. The barnacles naturally show a stratified distribution, with *Balanus* concentrated on the lower shore, and *Chthalamus* on the upper shore. When *Balanus* were experimentally removed from the lower strata, *Chthalamus* spread into that area. However, when *Chthalamus* were removed from the upper strata, *Balanus* did not extend any further up the shore than usual.





In Australia, the mallard duck, *Anas platyrhynchos* (left) is at least partly responsible for the decline in native Pacific black ducks (*Anas superciliosa*). Mallards are bigger than the native ducks and can physically bully them in competing for food. They are also more fertile, with an average clutch size of 11 eggs (compared with 8 in blacks). Mallard males are also very sexually aggressive and will interbreed with blacks to form fertile hybrids so that the pool of "pure bred" blacks is diminished.





RCN

Throughout the world, the introduction of mosquito fish, *Gambusia affinis* (left) is implicated in the decline of endemic fish and amphibian species. *Gambusia* is an aggressive, opportunistic species, with a strong competitive advantage. In Australia, evidence suggests that the presence of *Gambusia* results in a decline in native fish and frog populations (e.g. the green and golden bell frog). *Gambusia* are prolific breeders, compete for food and habitat, and prey on the immature stages of native species.

1. (a) In the example of the barnacles (above), describe what is represented by the zone labelled with the arrow **A**:

   _____

   (b) Explain the evidence for the barnacle distribution being the result of competitive exclusion: _____

   _____

2. Describe two aspects of the biology of a named introduced species that have helped its success as an invading competitor:

   (a) _____

   (b) _____

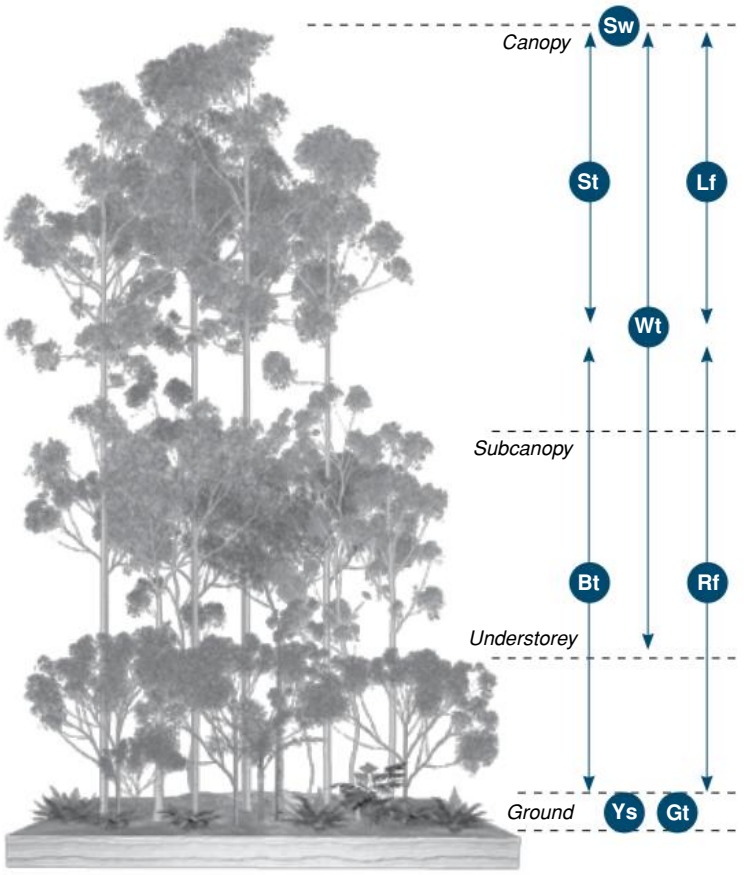
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252 Niche Differentiation

Key Idea: Interspecific competition is reduced when different species exploit slightly different resources.

Competition is most intense between members of the same species because their habitat and resource requirements are identical. Interspecific competition is usually less intense, although many species exploit at least some of the same resources. Different species with similar ecological requirements may reduce direct competition by exploiting the resources within different microhabitats or by exploiting the same resources at different times of the day or year.



Reducing Competition in a Eucalypt Forest

The diagram on the left shows the foraging heights of birds in an eastern Australian eucalypt forest. A wide variety of food resources are offered by the structure of the forest. Different layers of the forest allow birds to specialise in foraging at different heights. The ground-dwelling yellow-throated scrubwren and ground thrush have robust legs and feet, while the white-throated treecreeper has long toes and large curved claws and the swifts are extremely agile fliers capable of catching insects on the wing.

Key to bird species

Ys	Yellow-throated scrubwren	Lf	Leaden flycatcher
Bt	Brown thornbill	Gt	Ground thrush
Sw	Spine-tailed swift	Rf	Rufous fantail
St	Striated thornbill	Wt	White-throated treecreeper

Adapted from: Recher et al., 1986. A Natural Legacy: Ecology in Australia. Maxwell Macmillan Publishing Australia.

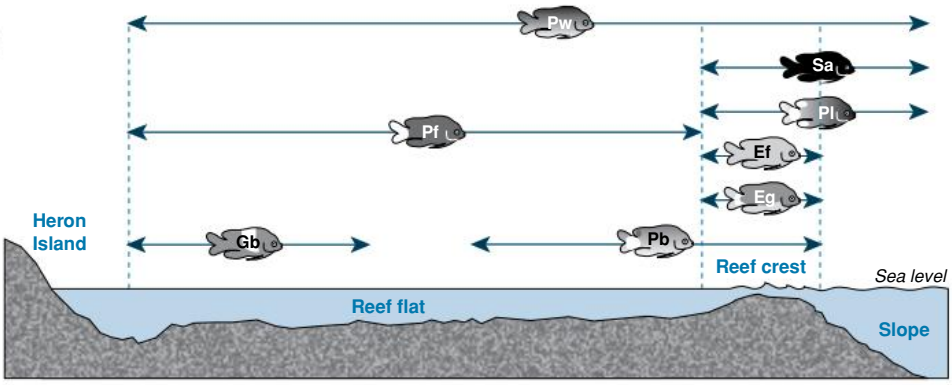
Distribution of Ecologically Similar Fish

The diagram below shows the distribution of ecologically similar damselfish over a coral reef at Heron Island, Queensland, Australia. The habitat and resource requirements of these species overlap considerably.



Key to damselfish species

Pw	*Pomacentrus wardi*
Pf	*Pomacentrus flavicauda*
Pb	*Pomacentrus bankanensis*
Sa	*Stegastes apicalis*
Pl	*Plectroglyphidodon lacrymatus*
Ef	*Eupomacentrus fasciolatus*
Eg	*Eupomacentrus gascoynei*
Gb	*Glyphidodontops biocellatus*



1. Describe two ways in which species can avoid directly competing for the same resources in their habitat:

   (a) _____

   (b) _____

2. Why is intraspecific competition generally more intense than interspecific competition? _____

   _____

3. How might the damselfish on the reef at Heron Island (above) reduce competition? _____

   _____

   _____

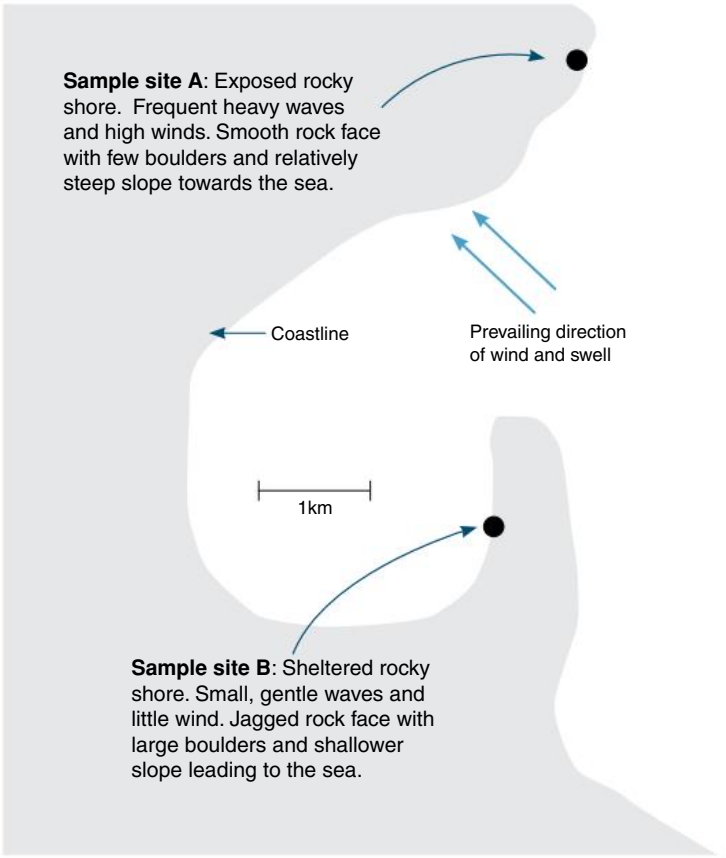
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253 Field Study of a Rocky Shore

Key Idea: Field studies collect physical and biological data that measure aspects of community structure or function.

Many biological investigations require the collection of data from natural communities. Biotic data may include the density or distribution of organisms at a site. Recording physical (abiotic) data of the site allows the site to be compared with others. The investigation below looks at the populations of animals found on an exposed and a sheltered rocky shore.



The Aim

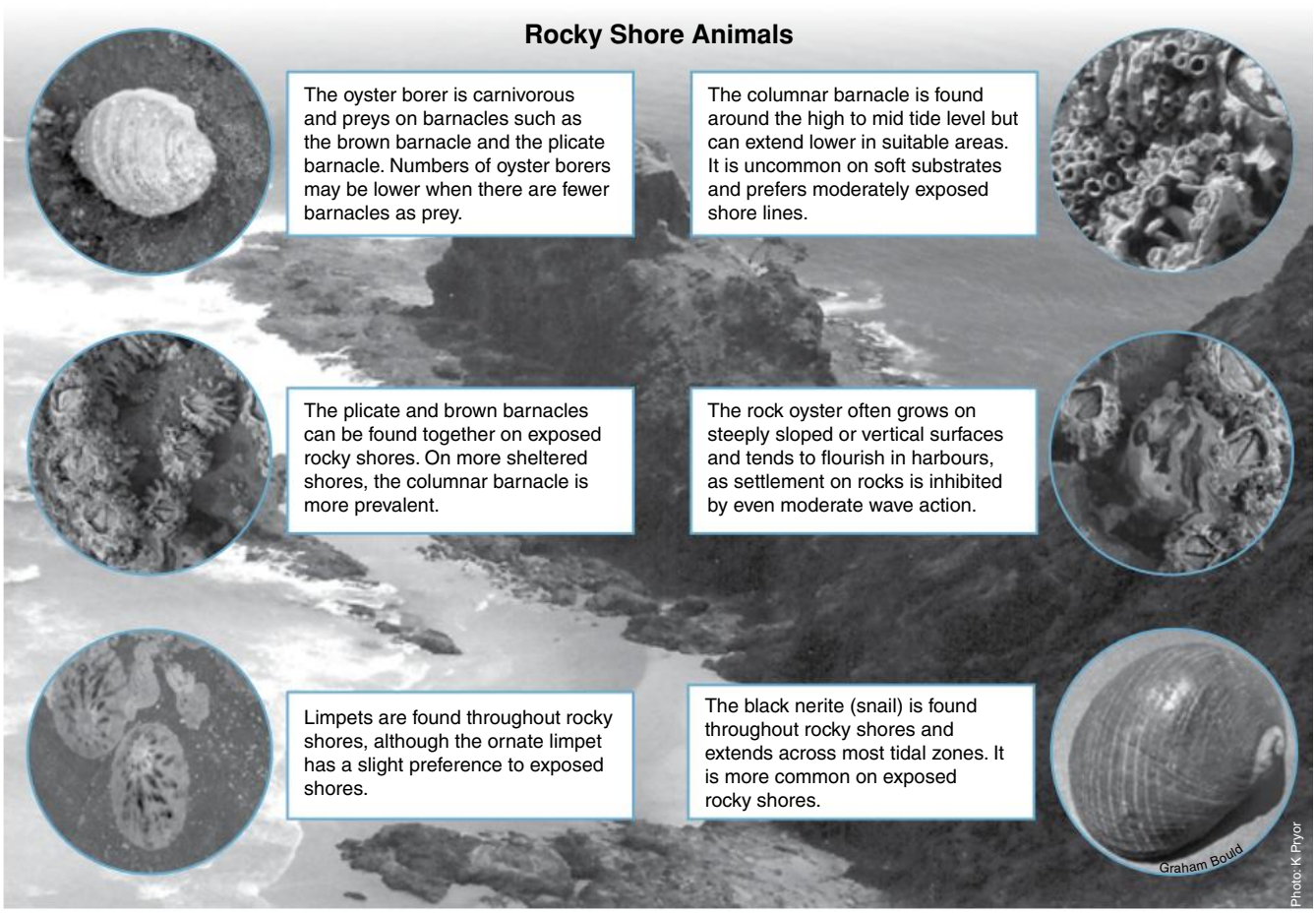
To investigate the differences in the abundance of intertidal animals on an exposed rocky shore and a sheltered rocky shore.

Background

The composition of rocky shore communities is strongly influenced by the shore's physical environment. Animals that cling to rocks must keep their hold on the substrate while being subjected to intense wave action and currents. However, the constant wave action brings high levels of nutrients and oxygen. Communities on sheltered rocky shores, although encountering less physical stress, may face lower nutrient and oxygen levels.

To investigate differences in the abundance of intertidal animals, students laid out 1 m^2 quadrats at regular intervals along one tidal zone at two separate but nearby sites: a rocky shore exposed to wind and heavy wave action and a rocky shore with very little heavy wave action. The animals were counted and their numbers in each quadrat recorded.

Rocky Shore Animals



All photos: C. Pilditch except where indicated

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1. Underline an appropriate hypothesis for this field study from the possible hypotheses below:

   (a) Wave action causes differences in communities on rocky shores.

   (b) The topography of the coastline affects rocky shore communities.

   (c) The communities of intertidal animals differ between exposed rocky shores and sheltered rocky shores.

   (d) Water temperature affects rocky shore communities.

2. During the field study, students counted the number of animals in each quadrat and recorded them in a note book. In the space below, tabulate the data to show the total number of each species and the mean number of animals per quadrat:

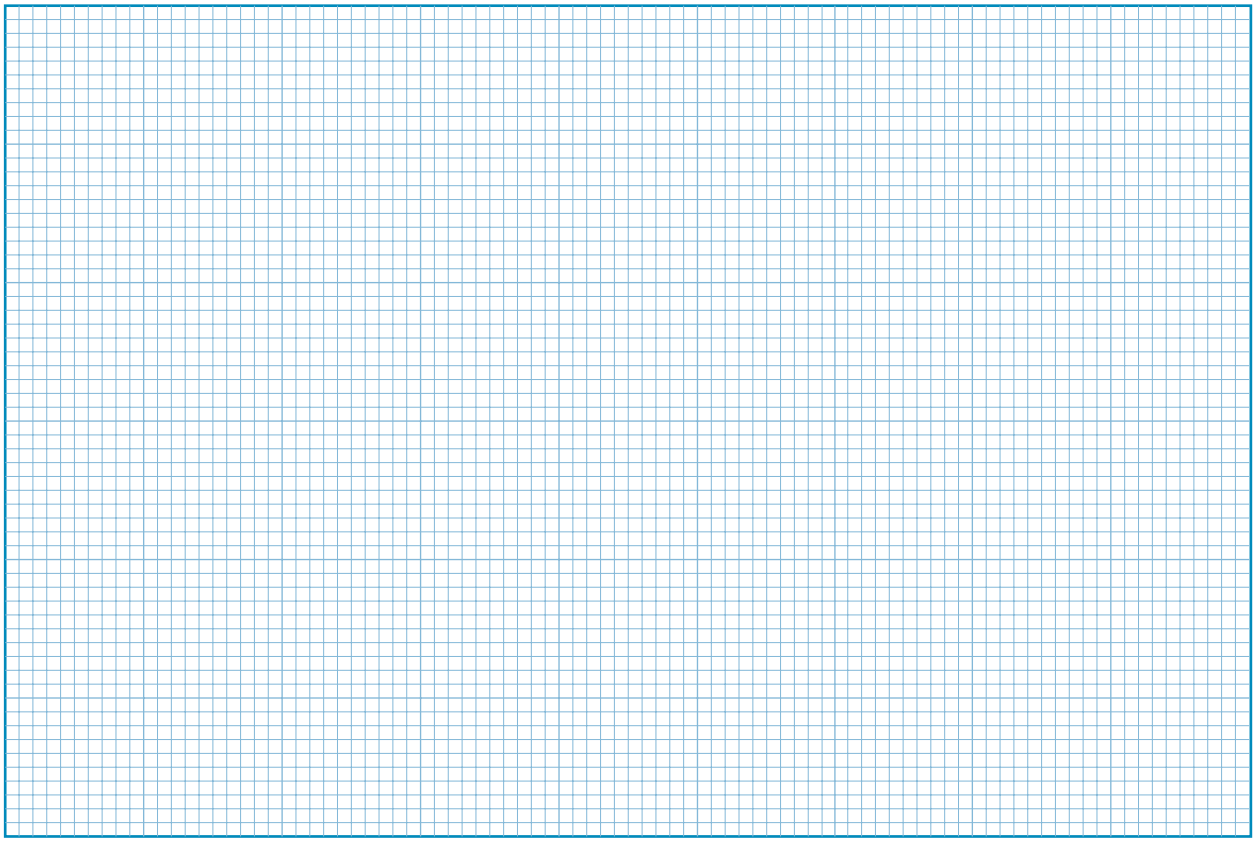
Field data notebook

Count per quadrat. Quadrats 1 m^2

Site A	1	2	3	4	5	6	7	8
Brown barnacle	39	38	37	21	40	56	36	41
Oyster borer	6	7	4	3	7	8	9	2
Columnar barnacle	6	8	14	10	9	12	8	11
Plicate barnacle	50	52	46	45	56	15	68	54
Ornate limpet	9	7	8	10	6	7	6	10
Radiate limpet	5	6	4	8	6	7	5	6
Black nerite	7	7	6	8	4	6	8	9
Site B								
Brown barnacle	7	6	7	5	8	5	7	7
Oyster borer	2	3	1	3	2	2	1	1
Columnar barnacle	56	57	58	55	60	47	58	36
Plicate barnacle	11	11	13	10	14	9	9	8
Rock oyster	7	8	8	6	2	4	8	6
Ornate limpet	7	8	5	6	5	7	9	3
Radiate limpet	13	14	11	10	14	12	9	13
Black nerite	6	5	3	1	4	5	2	3

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3. Use the grid below to draw a column graph of the mean number of species per 1 m^2 at each sample site. Remember to include a title, correctly labelled axes, and a key.



4. Which species was entirely absent from site A? _____

5. (a) Explain why more brown barnacles and plicate barnacles were found at site A: _____

_____

(b) Explain why more oyster borers were found at site A: _____

_____

6. A student wrote the following discussion of the field study. If you read it carefully, you can see that it restates the results of the study, but falls short of discussing them. Revise it to include explanatory detail that might account for the results:

We investigated the difference in communities between an exposed and a sheltered rocky shore. Sample site A was more exposed than the second sample site with bigger waves and stronger winds. The animals we sampled were those that attach themselves to the rock. Quadrats were used to count the numbers of animals present. We found the brown barnacle and the plicate barnacles were the most common animal on the exposed rocky shore. Their numbers were reduced on the sheltered shore, but the columnar barnacle was more prevalent. Rock oysters were found only at site B. The abundance of the other animals varied only slightly except the oyster borer which was more abundant at site A.

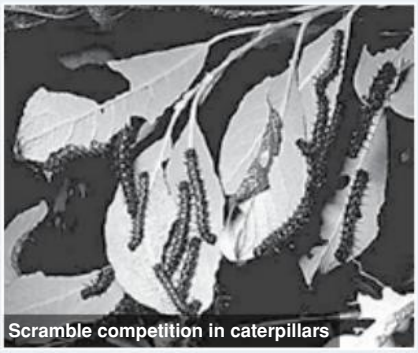
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254 Intraspecific Competition

Key Idea: Intraspecific competition is usually intense as individuals are competing for exactly the same resources.

As a population grows, the resources available to each individual become fewer and **intraspecific competition** (competition between members of the same species) increases. When the demand for a resource (e.g. light) exceeds supply, that resource becomes a limiting factor to the number of individuals the environment can support (the **carrying capacity**). Populations respond to resource limitation by reducing growth rate (e.g. lower birth rates or higher mortality). The response of individuals to limited resources varies. In many invertebrates and some vertebrates, individuals reduce their growth rate and mature at a smaller size. In many vertebrates, territories space individuals apart according to resource availability and only those individuals able to secure a territory will be abld to breed.

Intraspecific Competition



Scramble competition in caterpillars

Direct competition for food between members of the same species is called **scramble competition.** Where scramble competition is intense, none of the competitors gets enough food to survive.



Contest competition in wolves

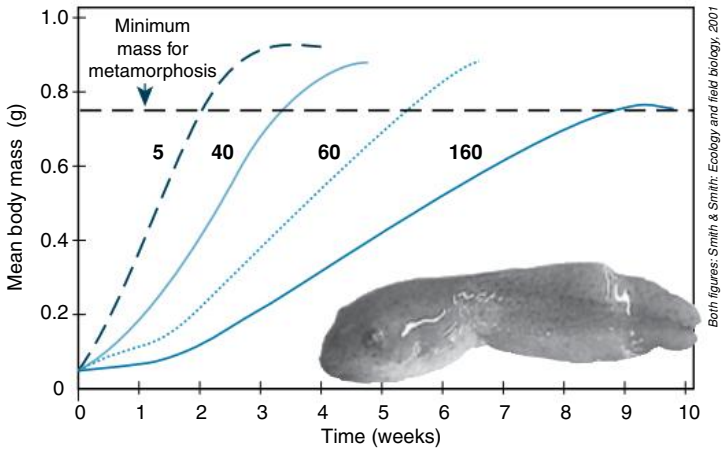
In some cases, competition is limited by hierarchies within a social group. Dominant individuals receive enough food, but individuals low in the hierarchy must **contest** what is left and may miss out.



Display of a male anole

Individuals may compete for breeding sites, mates, or food. In anole lizards (above), males have a bright red throat pouch and use much of their energy displaying to compete with other males for mates.

Competition Between Tadpoles of *Rana tigrina*



Food shortage reduces both individual growth rate and survival, and population growth. In some organisms, where there is a metamorphosis or a series of moults before adulthood (e.g. frogs, crustacean zooplankton, and butterflies), individuals may die before they mature.

The graph (left) shows how the growth rate of tadpoles (*Rana tigrina*) declines as the density increases from 5 to 160 individuals (in the same sized space).

- At high densities, tadpoles grow more slowly, take longer to reach the minimum size for metamorphosis (0.75 g), and have less chance of metamorphosing into frogs.
- Tadpoles held at lower densities grow faster to a larger size, metamorphosing at an average size of 0.889 g.
- In some species, such as frogs and butterflies, the adults and juveniles reduce the intensity of intraspecific competition by exploiting different food resources.

1. Using an example, predict the likely effects of **intraspecific competition** on each of the following:

   (a) Individual growth rate: _____

   (b) Population growth rate: _____

   (c) Final population size: _____

2. In the tank experiment with *Rana* (above), the tadpoles were contained in a fixed volume with a set amount of food:

   (a) How did *Rana* tadpoles respond to resource limitation? _____

   _____

   (b) Categorise the effect on the tadpoles as density-dependent / density-independent (delete one).

   (c) Do you think the results of this experiment are representative of what happens in a natural population? Explain:

   _____

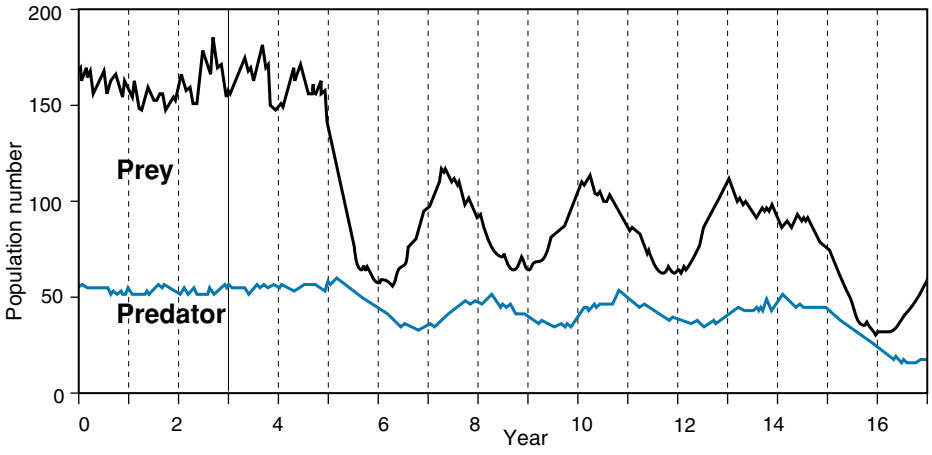
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255 Predator-Prey Interactions

Key Idea: Predator and prey populations frequently show regular population cycles. The predator cycle is usually based on the intrinsic population cycle of the prey species.

It was once thought that predators regulated the population numbers of their prey. However, we now know that this is not usually the case. Prey species are more likely to be regulated by other factors such as the availability of food. However, predator population cycles are often regulated by the availability of prey, especially when there is little opportunity for switching to alternative prey species.

Fluctuations in hypothetical prey and predator populations





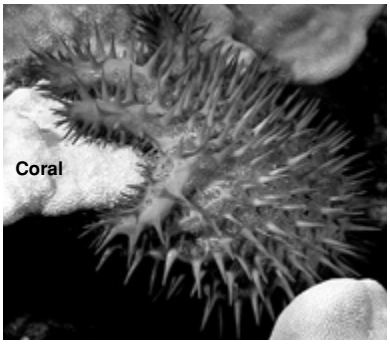
Predators capture and eat their prey, but do they control their population numbers?



Crown-of-thorns starfish

Population cycles in crown-of-thorns starfish

The crown-of-thorns starfish (right) is a voracious predator of coral on the Great Barrier Reef. A single starfish can destroy 5 m^2 of coral in a year. There have been two major starfish population explosions in recent times. One lasted from the early 1960s until the mid 1970s. The other began in the late 1970s and receded in the early 1990s. The reason for these cyclic outbreaks is not yet known. A favourite explanation is that shell collecting has led to a decline in the numbers of triton shells; one of the crown-of-thorn's few predators. However, tritons have a varied diet and feed on other organisms and they have never been common.



1. The graph above shows cycles in hypothetical predator and prey populations over 17 years. Answer the following:

   (a) State which population shows the greatest variation in population numbers: _____

   (b) Give the year at which a change occurred in the stability of the two population levels: _____

   (c) Describe the nature of the pattern of population numbers after the change: _____

   (d) Determine the period (duration) of the cycle exhibited by the two populations: _____

   (e) Determine how much the peaks of the two populations are out of phase (time lag between peaks): _____

2. The **crown-of-thorns starfish** on the Great Barrier Reef have undergone huge population increases in recent times.

   (a) Describe a favourite suggested cause for this population increase: _____

   _____

   _____

   (b) Why is this unlikely to be the major reason for the increase in starfish numbers? _____

   _____

   _____

3. At various times, a number of exotic species (such as rabbits and prickly pear cactus) were released into Australia's natural ecosystems. Why did many of these introduced species become uncontrollable pests?

   _____

   _____

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256 Predator-Prey Strategies

Key Idea: Predators have numerous adaptations for locating, identifying, and subduing prey. Prey can avoid being eaten by using passive defences, such as hiding, or active ones, such as escaping or defending themselves against predators.

Predator Avoidance Strategies



Mimicry
Harmless prey gain immunity from attack by mimicking harmful animals. This is called Batesian mimicry.



Poisonous
Poisonous animals often advertise their unpalatability by using brightly coloured and gaudy markings.



Visual deception
Deceptive markings such as large, fake eyes may deceive predators, allowing the prey to escape.



Chemical defence
Some animals can produce offensive smelling chemicals. American skunks squirt a nauseous fluid at attackers.



Offensive weapons
Offensive weapons such as antlers, claws, and horns are essential if prey are to fend off a predator's attack.

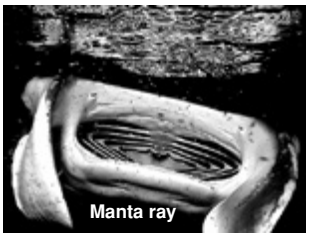


Camouflage
Cryptic shape and colouration allows some animals to blend into their background, like this insect above.

Prey Capturing Strategies



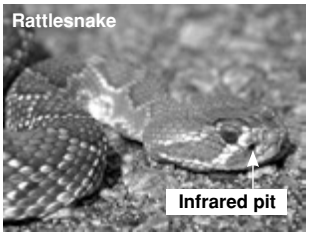
Concealment
Some animals camouflage themselves in their habitat, and strike when the prey comes within reach.



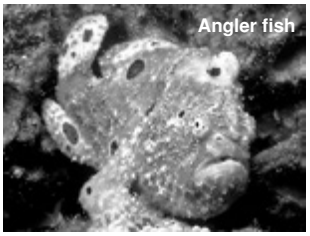
Filter feeding
Many marine species (e.g. barnacles, baleen whales, manta rays, sponges) filter the water to extract tiny plankton.



Tool use
Some animals are gifted tool users. Chimpanzees use prepared twigs to extract termites from mounds.



Stealth
The night hunting ability of some poisonous snakes is greatly helped by the presence of infrared senses.



Lures
This angler fish, glow worms, and a type of spider all use lures to attract prey within striking range.



Traps
Spiders have developed a unique method of trapping their prey. Strong, sticky silk threads trap flying insects.

1. Describe a behaviour of prey that is actively defensive: _____

2. Describe the behaviour of a named predator that facilitates prey capture: _____

3. Why are poisonous (unpalatable) animals are often brightly coloured? _____

4. What is the purpose of large, fake eyes on some butterflies and fish? _____

5. How does Batesian mimicry benefit the mimic (the one that is actually edible)? _____

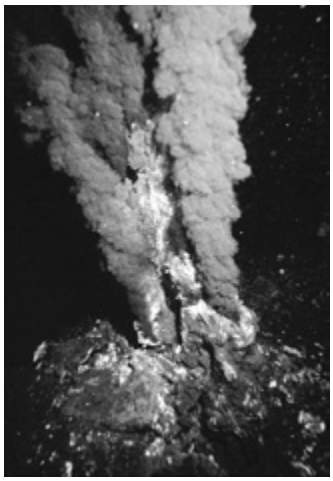
6. Describe a behaviour typical of a (named) prey species that makes them difficult to detect by a predator:

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LINK 250 LINK 182 KNOW

257 The Darkest Depths

Key Idea: The unique communities surrounding hydrothermal vents are reliant on the nutrients and heat provided by the vents for their survival.



Deep sea hydrothermal vents occur at around 2000 m depth and where tectonic plates meet. Buckling in the plates causes fault lines to form where water can move down into the crust before being heated and ejected at temperatures of up to 350°C. Temperatures this high are possible because the pressure of the ocean prevents the water from boiling into steam. The high water temperature dissolves minerals from crustal rocks and, when they reach the surface, they precipitate into formations called **black smokers** - chimneys of minerals that may reach 60m high.

Hydrothermal vents are the site of unique communities. At this depth, no light penetrates and the amount of organic debris falling from above is minimal because much of it has been used up by the time it reaches the bottom. The organisms living here are restricted in their movement; tens of metres from the mouth of the vent, the water temperature plummets to barely above freezing. The degree of isolation has resulted in the evolution of unique fauna.

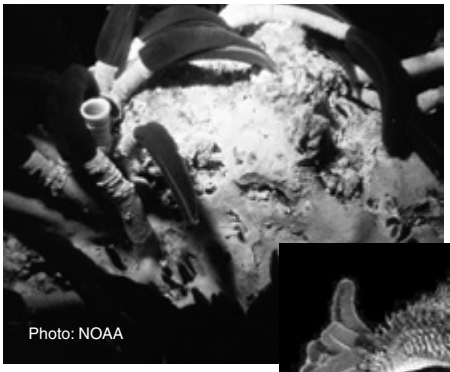


Photo: NOAA

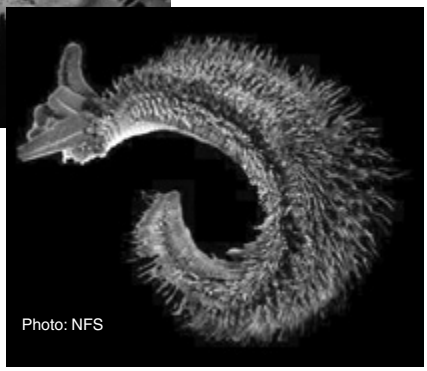


Photo: NFS

The water from the hydrothermal vents is rich in minerals and the bacteria living there have evolved to use these to manufacture food. These chemosynthetic bacteria use oxygen and hydrogen sulfide (highly toxic to most organisms) to build organic molecules. They are the producers on which the vent community is based. They form thick mats around the vents or float in aggregations resembling snow storms.

Tube worms, one of the larger organisms in these communities, provide shelter for the bacteria and benefit from the products of bacterial **chemosynthesis**. Vent mussels also have bacteria living within them and have abandoned a filter-feeding lifestyle to form a mutualistic relationship with bacteria in their tissues. Blind shrimps and crabs scavenge on decaying material and the bacterial mats. Octopi and fish also make up part of the food web, preying on smaller animals. Of most interest to scientists is the Pompeii worm. It can withstand temperatures of 80°C; higher than any other complex organism. The hairy coat that covers it is, in fact, mats of bacteria on which the worm feeds.

1. Describe the environmental conditions found around deep sea hydrothermal vents: _____

2. Explain reasons for the uniqueness of the vent communities: _____

3. Discuss the relationships between the organisms of the vent community and use the information to construct a basic food web in the space provided:

LINK 241

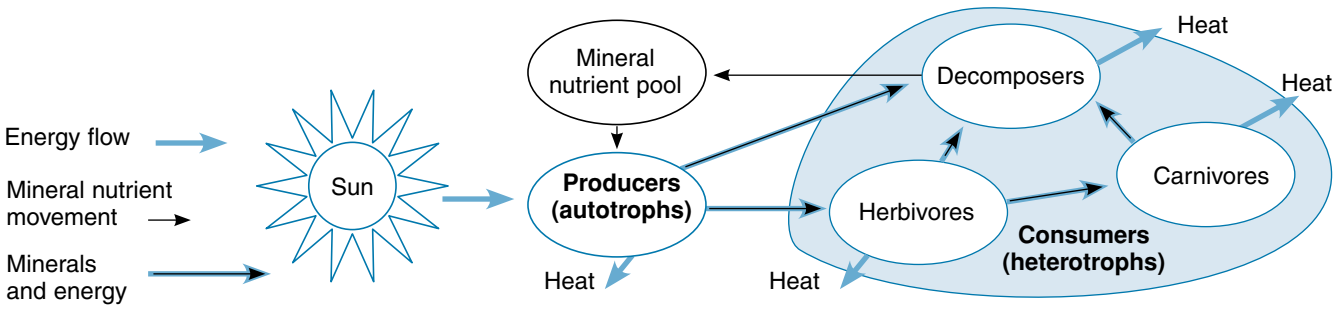
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258 KEY TERMS: Did You Get It?

1. Test your vocabulary by matching each term to its definition, as identified by its preceding letter code.

biomagnification	**A** A graphical representation of the numbers, energy, or biomass at each trophic level in an ecosystem. Often pyramidal in shape.
carbon cycle	**B** A law describing the approximate amount of energy passing from one trophic level to another.
consumer	**C** Organism that is capable of making its own food, e.g. green plants.
ecological pyramid	**D** The processes by which nitrogen circulates between the atmosphere and the biosphere. Ammonification, denitrification, nitrogen fixation and nitrification are all part of this cycle..
food chain	**E** Biogeochemical cycle by which carbon is exchanged among the biotic and abiotic components of the Earth.
food web	**F** The efficiency of energy transfer from one trophic level to the one above.
gross primary production	**G** Competition for resources between members of the same species.
hydrologic cycle	**H** Any of the feeding levels that energy passes through in an ecosystem.
interspecific	**I** The difference between the amount of energy fixed as biomass by plants and the amount that is used up in respiration. It is the amount of energy available to first order consumers.
intraspecific	**J** The cycling of water through the environment, from lakes, seas and oceans to clouds, rain, through organisms, to ground water and rivers and back.
net primary production	**K** A complex series of interactions showing the feeding relationships between organisms in an ecosystem.
net primary productivity	**L** The progressive concentration of a chemical in a food chain.
nitrogen cycle	**M** Competition for resources between individuals of different species.
producer	**N** The total amount of energy fixed as biomass by a plant in photosynthesis.
ten percent law	**O** An organism that obtains its carbon and energy from other organisms.
trophic efficiency	**P** A sequence of steps describing how an organism derives energy from the ones before it.
trophic level	**Q** The rate of biomass production by plants less the amount that is used in respiration.

2. The schematic below shows the movement of energy and minerals from producers to consumers.



(a) How are the movements of minerals and energy different? _____

_____

(b) What process is responsible for losses of energy from the system? _____

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QLD As required
VCE Unit 2 (2)
WA ATAR Unit 1
SA Theme E

Population Dynamics

Key terms

abundance
age structure
carrying capacity
community
demography
density
density dependent factor
density independent factor
distribution
environmental resistance
exponential growth
life tables
limiting factor
logistic growth
mark and recapture
migration rate
mortality
natality
population
population growth
population sampling
population size
r selection
survivorship curve

Features of populations

Learning aims and skills

Activity number

- ☐ 1 Explain the difference between a population and a community. Understand that populations exhibit attributes not shown by individuals themselves. Describe population-specific characteristics including age structure, natality, mortality, and distribution. Distinguish population density and population size. — 259
- ☐ 2 Describe how the attributes of populations can be assessed quantitatively using population sampling. Describe methods for population sampling (e.g. quadrats and mark and recapture). — 260 266
- ☐ 3 Describe the distribution patterns of organisms within their range: uniform, random, and clumped. Describe factors governing each type of distribution. — 261
- ☐ 4 Explain how some behaviours (e.g. hierarchies and territoriality) reduce intraspecific competition and promote more equitable access to resources. — 262





Population dynamics

Learning aims and skills

Activity number

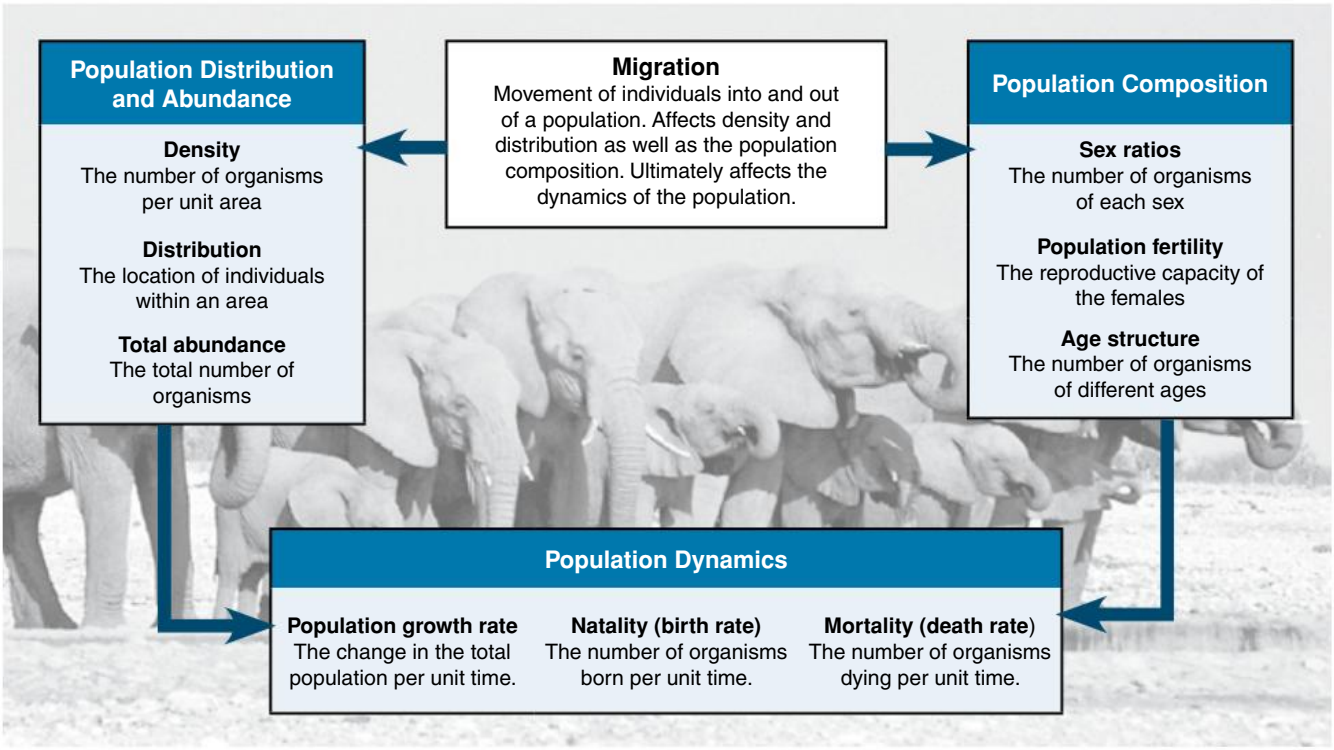
- ☐ 5 Describe factors regulating population size. Include reference to carrying capacity, environmental resistance, density dependent factors, and density independent factors. — 263
- ☐ 6 Describe the role of life tables in providing information of patterns of population natality and mortality. Explain how survivorship curves are used to analyse age specific mortality. Describe and explain the features of different types of survivorship curves (early loss, late loss, constant loss) and give examples. — 264
- ☐ 7 Explain how the age structure of a population influences its capacity for growth. — 265
- ☐ 8 Recall the characteristics of population cycles in interacting species in which the fluctuations in population growth in one species lag behind those of the other, usually in a predictable way. — 255
- ☐ 9 Explain how population size can be affected by births, deaths, and migration and express the relationship in an equation. — 267
- ☐ 10 Describe how the trends in population change can be shown in a population growth curve of population numbers (Y axis) against time (X axis). Describe exponential and logistic growth. Explain patterns of population growth in colonising, stable, and declining populations. — 268
- ☐ 11 Describe and explain past or present demographic trends in human populations. — 269



259 Features of Populations

Key Idea: Populations exhibit attributes, such as density, age structure, and mortality, that are not shown by individuals.

A **population** refers to all the organisms of the same species in a particular area. Biologists are often interested in population size (abundance) and density, both of which reflect the carrying capacity of the environment, i.e. how many organisms the environment can support. Populations have structure, with particular ratios of different ages and sexes. Analysis of age structure can show if the population is declining or increasing in size. We can also look at the distribution of organisms in their environment and so determine what aspects of the habitat are favoured over others. One way to retrieve information about populations is to sample them. Sampling involves collecting data, directly or indirectly, about features of the population from samples (since populations are usually too large to examine in total).



1. Describe one example of a population attribute that would be a good indicator of each of the following:

   (a) Whether the population is increasing or decreasing: _____

   _____

   (b) The ability of the environment to support the population: _____

   _____

2. (a) Which population attributes can be measured directly from the population? _____

   _____

   (b) Which population attributes must be calculated from collected data? _____

   _____

3. Describe the value of population sampling for each of the following situations:

   (a) Conservation of a population of an endangered species: _____

   _____

   _____

   (b) Management of a fisheries resource: _____

   _____

   _____

   _____

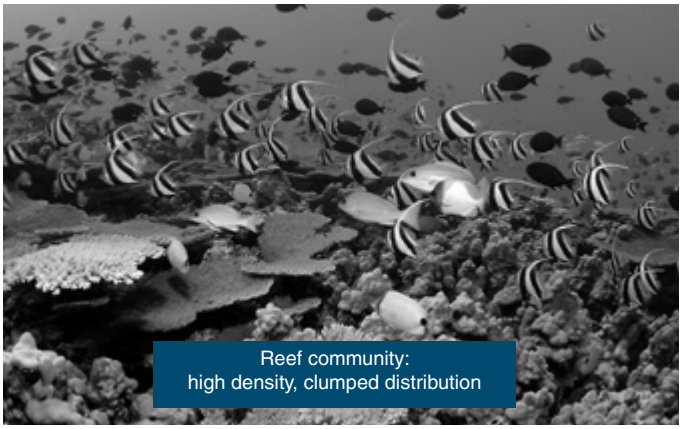
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260 Sampling Populations

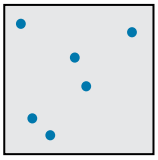
Key Idea: The method used to sample a population must be appropriate to the type of organism being sampled, its distribution, and the environment.

In most field studies, it is not possible to measure or count every member of a population. Instead, the population is sampled in a way that provides a fair (unbiased) representation of the organisms present and their distribution. This is achieved through **random sampling**, a technique in which every possible sample of a given size has the same chance of selection. Sampling techniques must be appropriate to the community being studied and the information you wish to obtain. Any field study must also consider the time and equipment available, the organisms involved, and the impact of the sampling method on the environment. Indicator species and species diversity indices are used as a way of quantifying biodiversity and monitor ecosystem change.

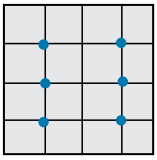
Quantifying the Diversity of Ecosystems



The methods we use to sample communities and their constituent populations must be appropriate to the ecosystem being investigated. Communities in which the populations are at low density and have a random or clumped distribution will require a different sampling strategy to those where the populations are uniformly distributed and at higher density. Each sampling option has advantages and drawbacks for particular communities. How would you assess aspects (e.g. species richness, abundance, or distribution) of the reef community above?



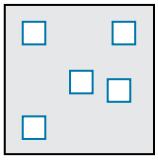
Random point sampling



Point sampling: systematic grid



Line and belt transects
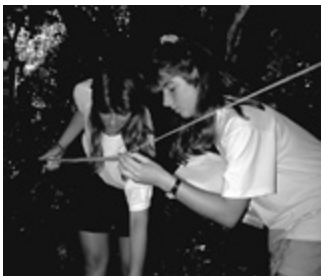


Random quadrats



Photo: www.coastal planning.net

Marine ecologists use quadrat sampling to estimate biodiversity prior to works such as dredging.



RA

Line transects are appropriate to estimate biodiversity along an environmental gradient.





Tagging has been used for more than 30 years to follow the migration of monarch butterflies. The photo here depicts an older tagging method, which has largely been replaced by a tag on the underside of the hindwing (inset). The newer method results in better survival and recapture rates and interferes less with flight.

Which Sampling Method?

Field biologists take a number of factors into consideration when deciding on a sampling method for a chosen population or community. The benefits and drawbacks of some common methods are outlined below:

Point sampling is time efficient and good for determining species abundance and community composition. However, organisms in low abundance may be missed.

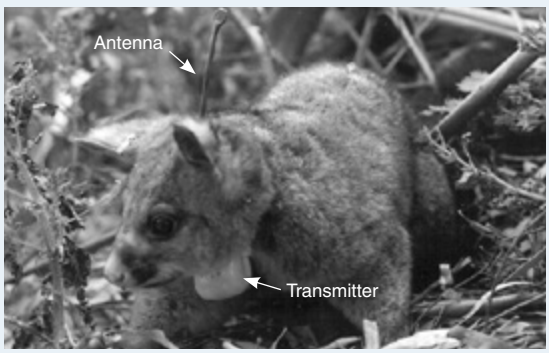
Transects are well suited to determining changes in community composition along an environmental gradient but can be time consuming to do well.

Quadrats are also good for assessments of community diversity and compostion but are largely restricted to plants and immobile animals. Quadrat size must also be appropriate for the organisms being sampled.

Mark and recapture is useful for highly mobile species which are otherwise difficult to record. However, it is time consuming to do well. **Radiotracking** (below) offers an alternative to mark and recapture and is now widely used in conservation to study the movements of both threatened species and pests.



Radio-tracking technology is now widely used in many aspects of conservation work. Radio-tracking has been used to study the movements and habitat use of a range of animal species. The information allows conservation organisations to develop better strategies for managing these species in the wild or follow the progress of reintroduced captive-bred animals.



PH

Australian brush-tailed possums are a major pest in New Zealand where they damage native forests, and prey on native birds. Radio-tracking is used on possums in critical conservation areas in New Zealand to determine dispersal rates, distribution, and habitat use, so that pest control can be implemented more effectively.

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Using Dataloggers in Field Studies

Usually, when information about populations is collected, we also collect information about the physical environment. This provides information about the local habitat and can be useful in assessing habitat preference. Using **dataloggers,** collecting this information is straightforward.

Dataloggers are electronic instruments that record measurements over time. They are equipped with a microprocessor, data storage facility, and sensor. Different sensors are used to measure a range of variables in water or air. The datalogger is connected to a computer, and software is used to set the limits of operation (e.g. the sampling interval) and initiate the logger. The logger is then disconnected and used remotely to record and store data. When reconnected to the computer, the data are downloaded, viewed, and plotted. Dataloggers make data collection quick and accurate, and they enable prompt data analysis.





Datalogger photos courtesy of PASCO

Dataloggers fitted with sensors are easy to use in a wide range of aquatic and terrestrial environments. Different variables can be measured by changing the sensor attached to the logger.

1. Why do we **sample** populations? _____

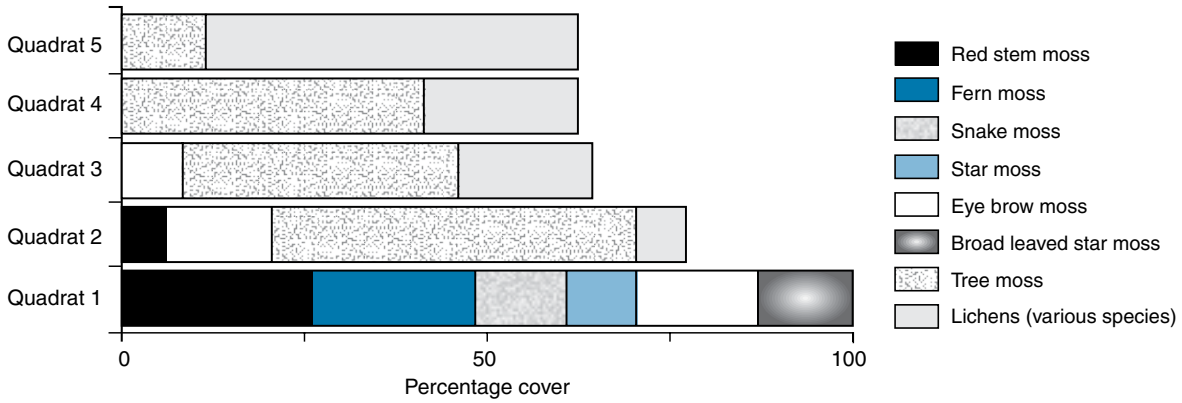
2. Describe a sampling technique that would be appropriate for determining each of the following:

   (a) The percentage cover of a plant species in pasture: _____

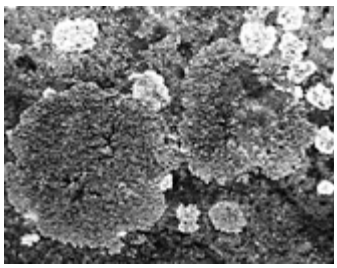
   (b) The density and age structure of a plankton population: _____

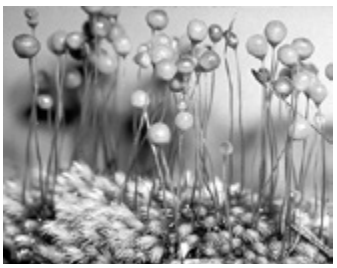
   (c) Change in community composition from low to high altitude on a mountain: _____

3. Why is it common practice to also collect information about the physical environment when sampling populations?



QUADRAT	1	2	3	4	5
Height / m	0.4	0.8	1.2	1.6	2.0
Light / arbitrary units	40	56	68	72	72
Humidity / percent	99	88	80	76	78
Temperature / °C	12.1	12.2	13	14.3	14.2





4. The figure (above) shows the changes in vegetation cover along a 2 m vertical transect up the trunk of an oak tree (*Quercus*). Changes in the physical factors light, humidity, and temperature along the same transect were also recorded. From what you know about the ecology of mosses and lichens, account for the observed vegetation distribution:

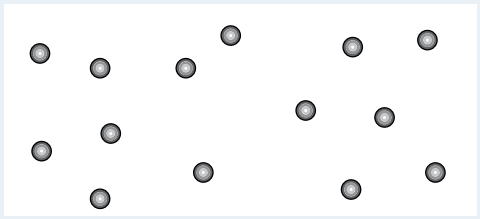
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261 Density and Distribution

Key Idea: Population density is the number of organisms of one species in a specified area. Distribution describes how the organisms are distributed relative to each other.

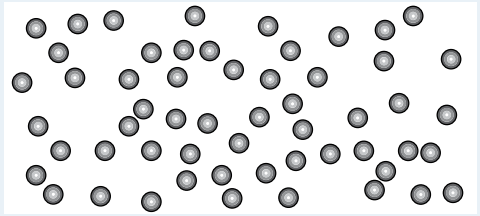
Population density is the number of individuals per unit area or volume. The three basic distribution patterns are: random, clumped, and uniform. In the diagram below, the circles represent individuals of the same species. It can also represent populations of different species.

Low Density



In low density populations, individuals are spaced well apart. There are only a few individuals per unit area or volume (e.g. highly territorial, solitary mammal species).

High Density



In high density populations, individuals are crowded together. There are many individuals per unit area or volume (e.g. colonial organisms, such as many corals).

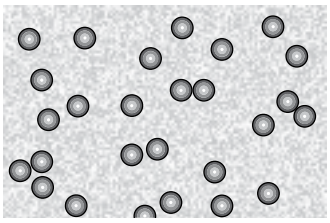


Tigers are solitary animals, found at low densities.



Termites form well organised, high density colonies.

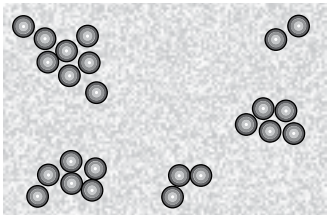
Random Distribution





Random distributions occur when the spacing between individuals is irregular. The presence of one individual does not directly affect the location of any other individual. Random distributions are uncommon in animals but are often seen in plants.

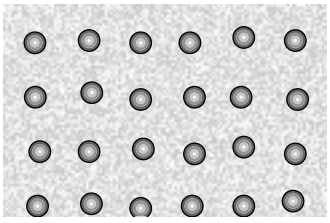
Clumped Distribution





Clumped distributions occur when individuals are grouped in patches (sometimes around a resource). The presence of one individual increases the probability of finding another close by. Such distributions occur in herding and highly social species.

Uniform Distribution





Regular distribution patterns occur when individuals are evenly spaced within the area. The presence of one individual decreases the probability of finding another individual very close by. The penguins illustrated above are also at a high density.

1. (a) How could the distribution of resources lead to organisms having a clumped distribution pattern? _____

   _____

   _____

   (b) How could a group social behaviour lead to organisms having a clumped distribution pattern? _____

   _____

   _____

2. What type of behaviour might encourage a uniform distribution of an animal species? _____

   _____

3. What type of environment would encourage uniform distribution? _____

4. Describe an example of each of the following types of distribution pattern:

   (a) Clumped: _____

   (b) Random (more or less): _____

   (c) Uniform (more or less): _____

KNOW WEB 261 LINK 259

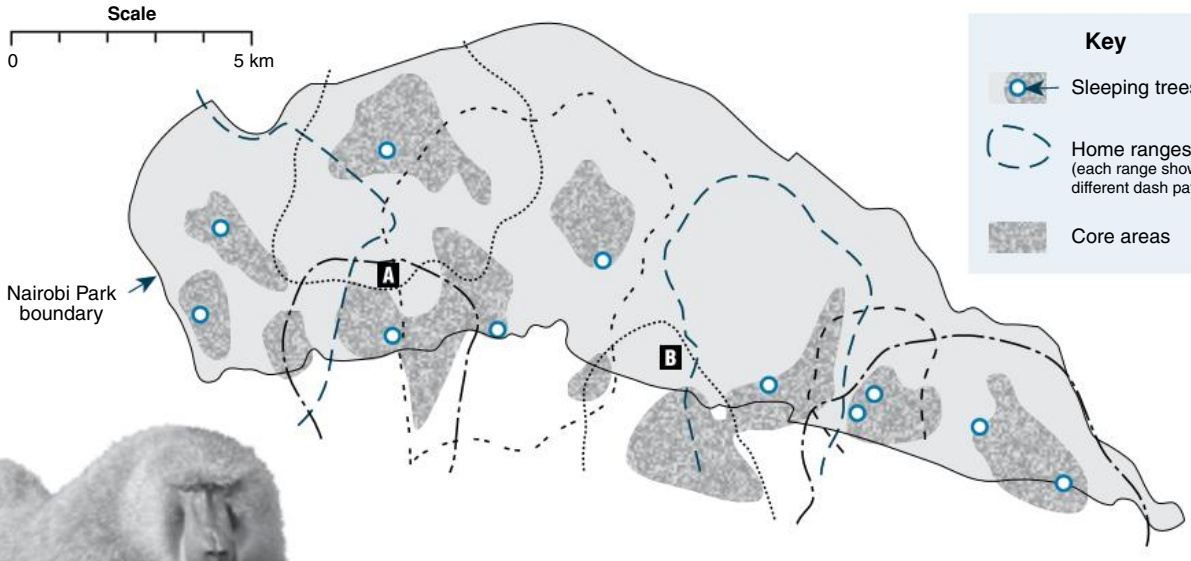
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262 Resources and Distribution

Key Idea: Social species with strong dominance hierarchies may occupy overlapping home ranges, which are larger than their defended territories.

Many social mammals carry out most of their activities within well defined areas. These areas may be **territories**, which are defended, or home ranges, which are generally not defended exclusively. Olive baboons in Africa are social animals with a highly developed dominance hierarchy, which regulates access to resources and reduces conflict. These social groups, or troops occupy a distinct **home range**. This is the area regularly used by the troop, which provides it with the resources it needs for survival.

Baboon Home Ranges in Nairobi Park





The map above shows the home ranges for baboon troops in Nairobi Park, Kenya. The size of each home range depends on the resources available in the area and the number of baboons in the troop (each troop can number from 20-80 baboons). Savannah-dwelling baboons spend more time on the ground than do most other primates and have one of the largest home ranges, averaging 20 km^2. They may travel up to 4 km a day in search of food. Most of the troop's activity is concentrated in the core area (which is like a territory). This area contains the best food sources, and more importantly, water holes and trees for sleeping in at night. Although olive baboons spend nearly all the day on the ground, they always return to the safety of the trees before dusk to sleep.

1. What factors are likely to influence the size of the home range in any given area? _____

2. Describe some of the advantages of social hierarchies: _____

3. Why would baboons defend the core areas aggressively? _____

4. (a) How many home ranges are represented on the map? _____

   (b) How many home ranges overlap at the following points on the map? Point **A**: _____ Point **B**: _____

   (c) Contrast the distribution of **home ranges** and **core areas** of neighbouring troops: _____

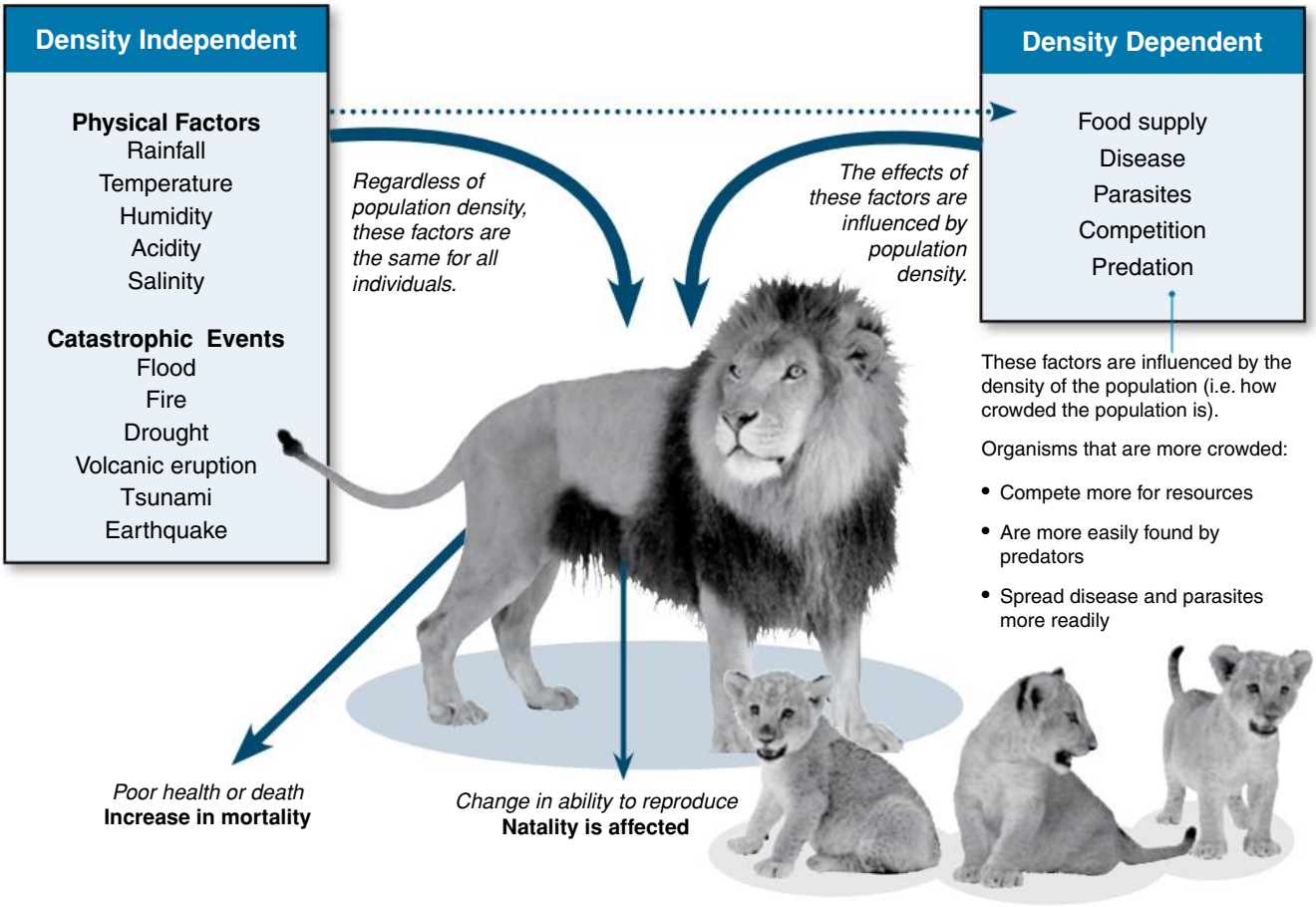
5. Provide an example of a territorial Australian animal, and suggest a purpose for the territoriality: _____

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LINK 254 KNOW

263 Population Regulation

Key Idea: A population's size is regulated by factors that affect population growth by changing birth or death rates. Population size is regulated by factors that limit population growth. The diagram below illustrates how population size can be regulated by environmental factors. **Density independent** factors are those that act independently of population density and affect all individuals more or less equally. **Density dependent** factors have a greater effect when the population density is higher. They become less important when the population density is low.



1. Discuss the role of **density dependent factors** and **density independent factors** in population regulation. In your discussion, make it clear that you understand the meaning of each of these terms:

2. Why does disease have a greater influence in regulating population size when population density is higher?

3. In cooler climates, aphids go through a huge population increase during the summer months. In autumn, population numbers decline steeply. Describe a density dependent and a density independent factor regulating the population:

   (a) Density dependent: _____

   (b) Density independent: _____

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264 Survivorship Curves

Key Idea: Survivorship curves depict age-specific mortality. The shape of a survivorship curve shows at which life stages the highest mortality occurs. There are three main types.

The survivorship curve depicts age-specific mortality and shows graphically at which life stages the highest mortality occurs. It is obtained by plotting the number of individuals of a particular cohort against time. Survivorship curves are standardised to start at 1000 (or 1) and, as the population ages, the number of survivors declines. Wherever the curve becomes steep, there is an increase in mortality. The type I curve is typical of populations whose individuals tend to live out their physiological life span, produce fewer young, and show parental care. The type II curve shows constant loss at all life stages. Organisms that suffer high losses of the early life stages (type III curve) produce vast numbers of offspring to compensate. Many species exhibit a mix of the three basic types (e.g. some birds have a high chick mortality (type III) and a constant adult mortality (type II).

Hypothetical Survivorship Curves

Type I: Late Loss

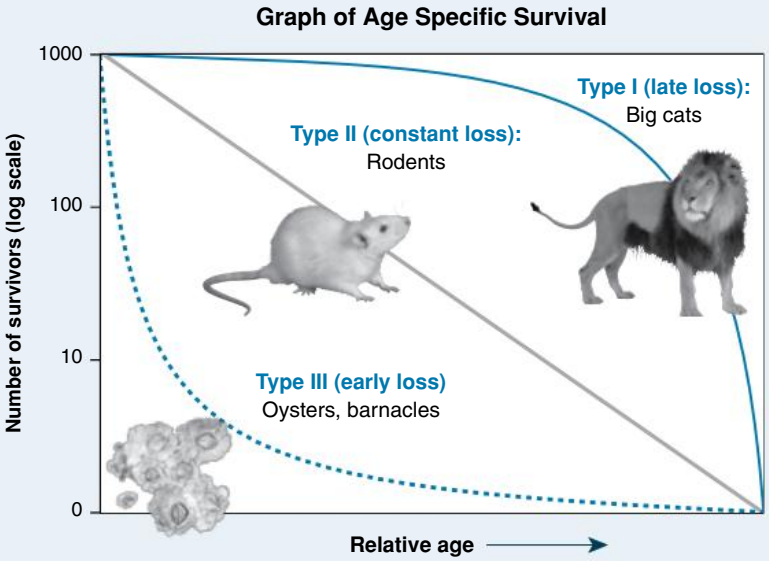
Mortality (death rate) is very low in the infant and juvenile years, and throughout most of adult life. Mortality increases rapidly in old age. Examples: Humans (in developed countries) and many other large mammals (e.g. big cats, elephants, antelope).

Type II: Constant Loss

Mortality is relatively constant through all life stages (no one age is more susceptible than another). Examples: Some invertebrates such as *Hydra*, some birds, some annual plants, some lizards, and many rodents.

Type III: Early Loss

Mortality is very high during early life stages, followed by a very low death rate for the few individuals reaching adulthood. Examples: Many fish (not mouth brooders) and most marine invertebrates (e.g. oysters, barnacles).



Three basic types of survivorship curves and representative organisms for each type. The vertical axis may be scaled arithmetically or logarithmically.



Elephants have a close matriarchal society and a long period of parental care. Elephants are long-lived and females usually produce just one calf.



Rodents are well known for their large litters and prolific breeding capacity. Individuals are lost from the population at a more or less constant rate.



Despite vigilant parental care, many birds suffer high juvenile losses (Type III). For those surviving to adulthood, deaths occur at a constant rate.

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1. Why might human populations not necessarily show a type I curve? _____

2. How do organisms with a type III survivorship compensate for high mortality during early life stages?

3. Describe the features of a species with a type I survivorship that aid in high juvenile survival: _____

4. Discuss the following statement: "There is no standard survivorship curve for a given species; the curve depicts the nature of a population at a particular time and place and under certain environmental conditions.":

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LINK 297 LINK 265 KNOW

Cemeteries are an excellent place to study changes in human demographics. Data collected from headstones can be used to calculate death rates and produce survivorship curves. It is also possible to compare survivorship curves over different periods and see how certain factors (e.g. war, medical advances) have altered survivorship.

The data (right) represents age of death data for males and females collected over two different time periods; pre-1950 and post 1950. The pre-1950s was characterised by two world wars, and the prevalence of diseases such as polio and tuberculosis. The post 1950s have also seen global conflict, but to a lesser degree than the pre-1950 period. Many advances in medicine (e.g. vaccines) and technology have been made during this time.

The data used in this exercise has been collected from the online records of several cemeteries across five different states in the United States to provide representative data.

Pre-1950				Post 1950			
Males age at death		Females age at death		Males age at death		Females age at death	
81	5	9	4	80	31	92	76
40	0	76	18	81	78	46	92
54	24	0	71	79	56	44	96
70	70	78	2	81	86	70	65
75	39	69	63	8	80	80	54
64	71	6	1	30	64	71	87
45	27	46	84	88	41	88	82
22	64	60	68	90	76	65	80
71	0	84	58	84	17	51	90
62	41	75	19	64	40	80	85
89	77	43	24	60	79	87	63
31	21	64	62	71	74	76	58
10	1	67	52	62	46	63	89
42	75	42	29	63	71	33	56
1	50	39	8	83	90	99	86

Data source: http://www.interment.net/us/index.htm

5. Complete the following table using the cemetery data provided. The males Pre-1950 data have been completed for you.

(a) In the number of deaths column, record the number of deaths for each age category.

(b) **Calculate the survivorship** for each age category. For each column, enter the total number of individuals in the study (30) in the 0-9 age survivorship cell. This is the survivorship for the 0-9 age group. Subtract the number of deaths at age 0-9 from the survivorship value at age 0-9. This is the survivorship at the 10-19 age category. To calculate the survivorship for age 20-29, subtract the number of deaths at the age 10-19 age category from the survivorship value for age 10-19. Continue until you have completed the column.

	Males Pre-1950		Females Pre-1950		Males Post 1950		Females Post 1950	
Age	**No. of deaths**	**Survivorship**	**No. of deaths**	**Survivorship**	**No. of deaths**	**Survivorship**	**No. of deaths**	**Survivorship**
0-9	5	30						
10-19	1	25						
20-29	4	24						
30-39	2	20						
40-49	4	18						
50-59	2	14						
60-69	3	12						
70-79	7	9						
80-89	2	2						
90-99	0	0						
Total	30							

6. (a) On a separate piece of graph paper, construct a graph to compare the survivorship curves for each category. Staple the graph into this workbook once you have completed the activity.

(b) What conclusions can you make about survivorship before 1950 and after 1950? _____

_____

_____

(c) What factors might cause these differences? _____

_____

_____

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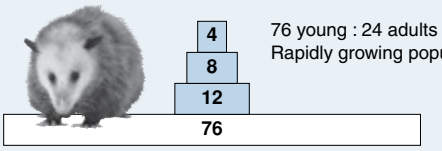
265 Population Age Structure

Key Idea: Population age structure can be represented as pyramids with the youngest individuals forming the base.

The **age structure** of a population refers to the relative proportion of individuals in each age group in the population. The age structure of populations can be categorised according to specific age catergories (e.g. years), or by other measures such as life stage (egg, larvae, pupae), or size class (height or diameter in plants). Population growth is strongly influenced by age structure. Population age structures are represented as pyramids, in which the proportions of individuals in each age/size class are plotted with the youngest individuals at the pyramid's base. The number of individuals moving from one age class to the next influences the age structure of the population from year to year. The loss of an age class (e.g. through over-harvesting) can profoundly affect a population's ability to sustain itself.

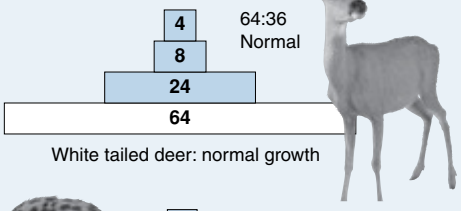
Age Structures in Animal Populations

Population growth is strongly influenced by age structure. A population with a high proportion of reproductive and pre-reproductive aged individuals has a much greater potential for population growth than one that is dominated by older individuals. These theoretical age pyramids show how growing populations are characterised by a high ratio of young (white bar) to adult age classes (blue bars). Ageing populations with poor production are typically dominated by older individuals.



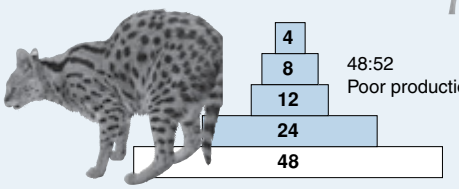
76 young : 24 adults
Rapidly growing population

Virginia opposum: growing population



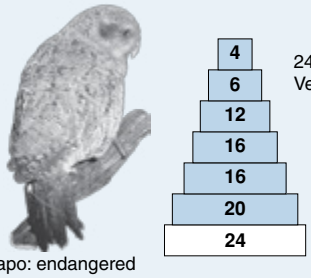
64:36
Normal

White tailed deer: normal growth



48:52
Poor production (ageing)

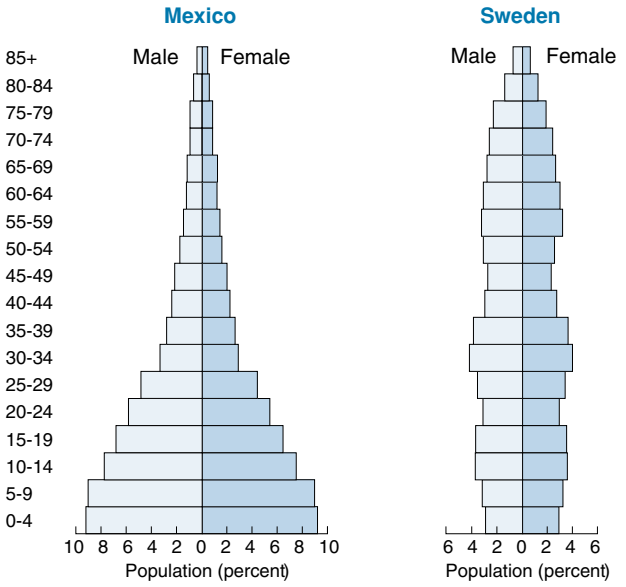
Serval: locally at risk



24:76
Very poor production

Kakapo: endangered

Age Structures in Human Populations





Most of the growth in human populations in recent years has occurred in the developing countries in Africa, Asia, and Central and South America. This is reflected in their age structure; a large proportion of the population comprises individuals younger than 15 years (age pyramid above, left). Even if each has fewer children, the population will continue to increase for many years. The stable age structure of Sweden is shown for comparison

1. For the theoretical age pyramids above left:

   (a) Determine the approximate ratio of young to adults in a rapidly increasing population: _____

   (b) Why are changes in population age structure alone not necessarily a reliable predictor of population trends?

   _____

   _____

2. Why is the population of Mexico likely to continue to increase rapidly even if the rate of population growth slows?

   _____

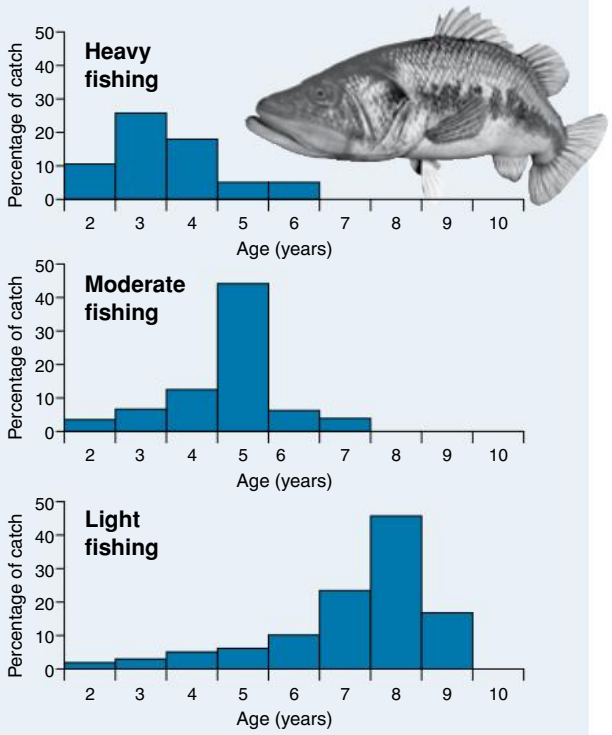
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LINK 259 KNOW

Managed Fisheries

Analysis of a population's age structure can help in its management because it can indicate where most of the mortality occurs and whether or not reproductive individuals are being replaced. The age structure of plant and animal populations can be assessed through an analysis of size which is often related to age in a predictable way. The graphs below show the age structure of a hypothetical fish population under different fishing pressures. The age structure of the population is determined by analysing the fish catch to determine the frequency of fish in each size (age) class.

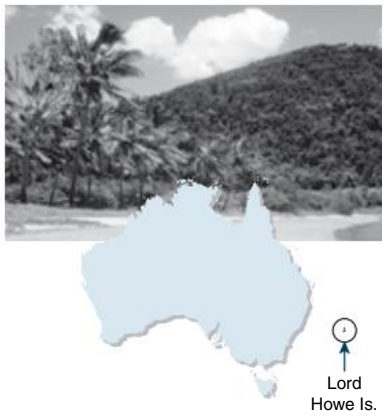


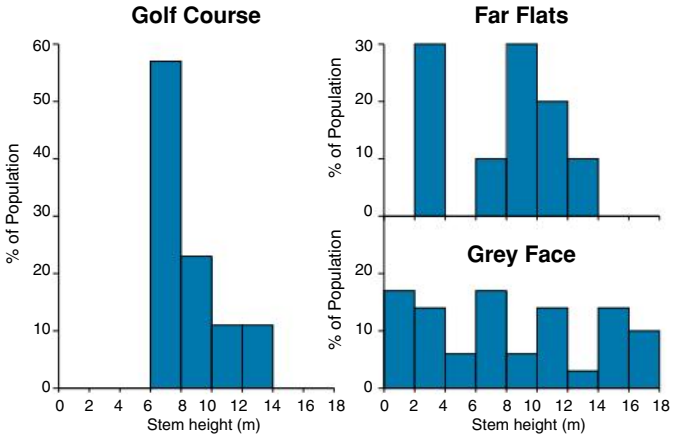
Thatch Palm Populations on Lord Howe Island

Lord Howe Island is a narrow sliver of land approximately 770 km northeast of Sydney. The age structure of populations of the thatch palm *Howea forsteriana* was determined at three locations on the island: the golf course, Grey Face and Far Flats. The height of the stem was used as an indication of age. The differences in age structure between the three sites are mainly due to the extent of grazing at each site.



Height or thickness of stem can be used as an indicator of age in plants.





3. For the managed fish populations above left:

   (a) What general factor changes the population age structure? _____

   (b) How does the age structure change when the fishing pressure increases from light to heavy?

   _____

4. Determine the most common age class for each of the above fish populations under the following fishing pressures:

   (a) Heavy: _____ (b) Moderate: _____ (c) Light: _____

5. Determine which of the three sites sampled on Lord Howe Island (above, right), best reflects the age structure of:

   (a) An ungrazed population: _____

   Reason for your answer: _____

   (b) A heavily grazed and mown population: _____

   Reason for your answer: _____

6. What are the likely long term prospects for the population at the golf course? _____

   _____

7. Describe a potential problem with using size to estimate age: _____

   _____

8. Why is it important to know the age structure of a harvested population? _____

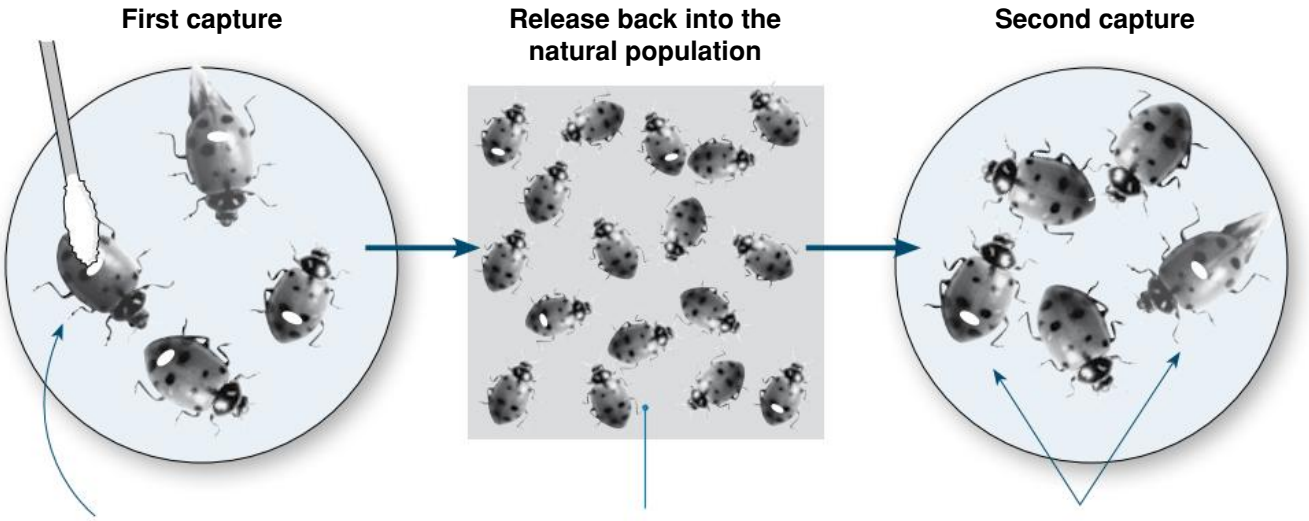
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266 Mark and Recapture

Key Idea: Mark and recapture sampling allows the population size of highly mobile organisms to be estimated.

The mark and recapture method of estimating population size is used in the study of animal populations in which the individuals are highly mobile. It is of no value where animals do not move or move very little. The number of animals caught in each sample must be large enough to be valid. The technique is outlined in the diagram below.



The Lincoln Index

$$\text{Total population} = \frac{\text{No. of animals in 1st sample (all marked)} \times \text{Total no. of animals in 2nd sample}}{\text{Number of marked animals in the second sample (recaptured)}}$$

The mark and recapture technique comprises a number of simple steps:

1. The population is sampled by capturing as many of the individuals as possible and practical.
2. Each animal is marked in a way to distinguish it from unmarked animals (unique mark for each individual not required).
3. Return the animals to their habitat and leave them for a long enough period for complete mixing with the rest of the population to take place
4. Take another sample of the population (this does not need to be the same sample size as the first sample, but it does have to be large enough to be valid).
5. Determine the numbers of marked to unmarked animals in this second sample. Use the equation above to estimate the size of the overall population.

1. For this exercise you will need several boxes of matches and a pen. Work in a group of 2-3 students to 'sample' the population of matches in the full box by using the mark and recapture method. Each match will represent one animal.

   (a) Take out 10 matches from the box and mark them on 4 sides with a pen so that you will be able to recognise them from the other unmarked matches later.
   (b) Return the marked matches to the box and shake the box to mix the matches.
   (c) Take a sample of 20 matches from the same box and record the number of marked matches and unmarked matches.
   (d) Determine the total population size by using the equation above.
   (e) Repeat the sampling 4 more times (steps b–d above) and record your results:

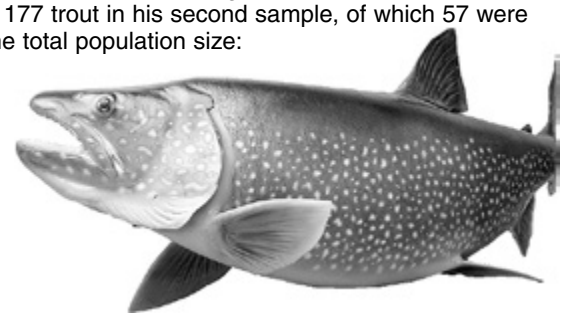
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Estimated population					

   (f) Count the actual number of matches in the matchbox : _____

   (g) Compare the actual number to your estimates and state by how much it differs: _____

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2. In 1919 a researcher by the name of Dahl wanted to estimate the number of trout in a Norwegian lake. The trout were subject to fishing so it was important to know how big the population was in order to manage the fish stock. He captured and marked 109 trout in his first sample. A few days later, he caught 177 trout in his second sample, of which 57 were marked. Use the **Lincoln index** (on the previous page) to estimate the total population size:



Size of 1st sample: _____

Size of 2nd sample: _____

No. marked in 2nd sample: _____

Estimated total population: _____

3. Describe some of the problems with the mark and recapture method if the second sampling is:

   (a) Left too long a time before being repeated: _____

   _____

   (b) Too soon after the first sampling: _____

   _____

4. Describe two important assumptions in this method of sampling that would cause the method to fail if they were not true:

   (a) _____

   _____

   _____

   (b) _____

   _____

   _____

5. Some types of animal would be unsuitable for this method of population estimation (i.e. would not work).

   (a) Name an animal for which this method of sampling would not be effective: _____

   (b) Explain your answer above: _____

   _____

   _____

6. Describe three methods for marking animals for mark and recapture sampling. Take into account the possibility of animals shedding their skin, or being difficult to get close to again:

   (a) _____

   (b) _____

   (c) _____

7. CSIRO scientists are involved in a computerised tagging programme for southern bluefin tuna. Describe the type of information that the scientists hope to obtain through such a tagging programme:

   _____

   _____

   _____

   _____

   _____

   _____

   _____

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267 Population Growth

Key Idea: Population size increases through births or immigration and decreases through deaths and emigration.

Populations are dynamic and the number of individuals in a population may fluctuate considerably over time. Populations gain individuals through births or immigration, and lose individuals through deaths and emigration. For a population in equilibrium, these factors balance out and there is no net change in the population abundance. When losses exceed gains, the population declines. When gains exceed losses, the population increases.

Births, deaths, immigrations (movements into the population) and emigrations (movements out of the population) are events that determine the numbers of individuals in a population. Population growth depends on the number of individuals added to the population from births and immigration, minus the number lost through deaths and emigration. This is expressed as:

Population growth =

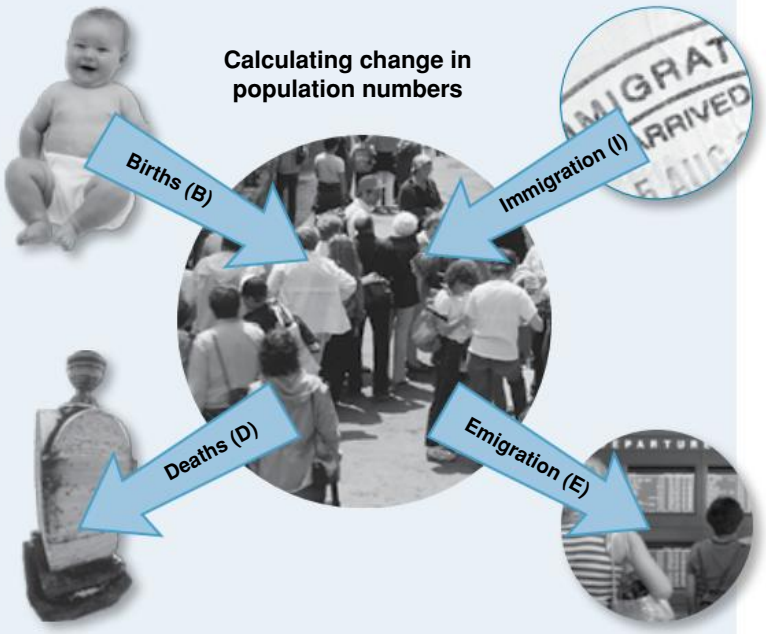
Births – Deaths + Immigration – Emigration
(B) (D) (I) (E)

The difference between immigration and emigration gives net migration. Ecologists usually measure the **rate** of these events. These rates are influenced by environmental factors (see below) and by the characteristics of the organisms themselves. Rates in population studies are commonly expressed in one of two ways:

- Numbers per unit time, e.g. 20,150 live births per year.
- Per capita rate (number per head of population), e.g. 122 live births per 1000 individuals per year (12.2%).

Limiting Factors

Population size is also affected by limiting factors; factors or resources that control a process such as organism growth, or population growth or distribution. Examples include availability of food, predation pressure, or available habitat.



Human populations often appear exempt from limiting factors as technology and efficiency solve many food and shelter problems. However, as the last arable land is used and agriculture reaches its limits of efficiency, it is estimated that the human population may peak at around 10 billion by 2050.

1. Define the following terms used to describe changes in population numbers:

   (a) Death rate (mortality): _____

   (b) Birth rate (natality): _____

   (c) Net migration rate: _____

2. Explain how the concept of limiting factors applies to population biology: _____

   _____

3. Using the terms, B, D, I, and E (above), construct equations to express the following (the first is completed for you):

   (a) A population in equilibrium: B + I = D + E

   (b) A declining population: _____

   (c) An increasing population: _____

4. A population started with a total number of 100 individuals. Over the following year, population data were collected. Calculate birth rates, death rates, net migration rate, and rate of population change for the data below (as percentages):

   (a) Births = 14: Birth rate = _____ (b) Net migration = +2: Net migration rate = _____

   (c) Deaths = 20: Death rate = _____ (d) Rate of population change = _____

   (e) State whether the population is increasing or declining: _____

5. The human population is around 6.7 billion. Describe and explain two limiting factors for population growth in humans:

   _____

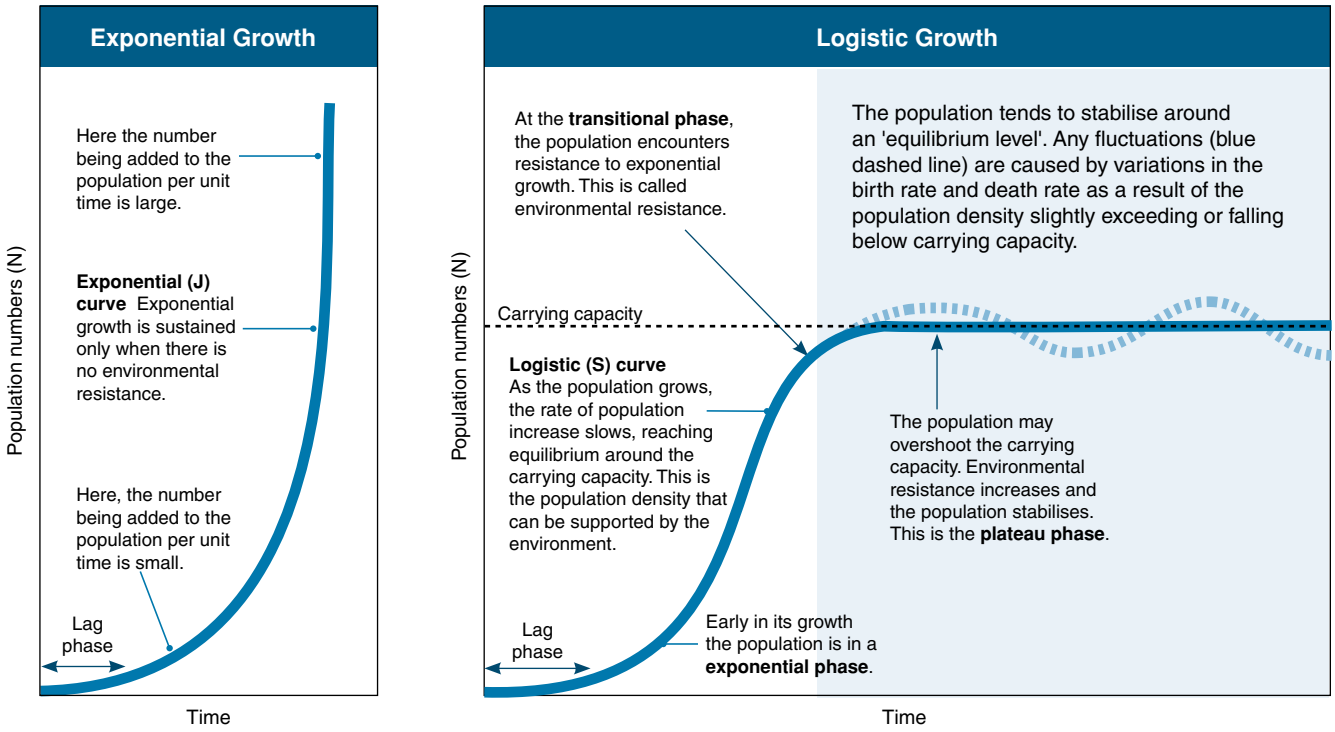
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268 Population Growth Curves

Key Idea: Population growth can be exponential or logistic. The maximum sustainable population size is limited by the environment's carrying capacity.

Population growth is the change in a population over time. It is regulated by the **carrying capacity** (the maximum number the environment can sustain). Population growth falls into two main types: exponential or logistic (sigmoidal). **Exponential** (J-shaped) growth is rapid but not sustainable and occurs when resources are essentially unlimited. **Logistic** (S-shaped) growth begins exponentially, but slows as the population approaches the carrying capacity of the environment. Established populations may fluctuate about the carrying capacity in a regular way as they respond (with a slight lag) to the constraints imposed by limited resources.



1. Why don't populations continue to increase exponentially in an environment? _____

2. What is meant by environmental resistance? _____

3. (a) What is meant by **carrying capacity**? _____

   (b) Explain the importance of carrying capacity to the growth and maintenance of population numbers: _____

4. (a) Describe and explain the phases of the logistic growth curve: _____

   (b) Explain why a population might overshoot carrying capacity before stabilising around carrying capacity:

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269 The Rise and Fall of Human Populations

Key Idea: Human populations are subject to rises and collapses in the same way as natural animal populations.

Throughout history there have been a number of peaks of human civilisation followed by collapse. These collapses have been triggered by various events but can generally be attributed either to the spread of disease or to the collapse of a food source (normally agriculture). Examples can be traced right back to the origins of humans.



Mitochondrial DNA analyses show that the human population may have been on the brink of extinction with only around 10,000 individuals alive 150,000 years ago. The population remained low for virtually the whole of human prehistory. When the first towns and cities were being built, around 10,000 years ago, the human population had reached barely 5 million. By around 700 AD, the human population had reached over 150 million, and first very large cities were developing. One such city was the Mayan city of Tikal.

TIKAL: At its peak around 800 AD, Tikal and the surrounding area, was inhabited by over 400,000 people. Extensive fields were used to cultivate crops and the total area of the city and its satellite towns and fields may have reached over 250 km^2. Eventually the carrying capacity of the tropical, nutrient-poor land was overextended and people began to starve. By 900 AD the city had been deserted and the surrounding area abandoned.



EASTER ISLAND: Similar events happened elsewhere. Easter Island is located 3,000 km from South America and 2,000 km from the nearest occupied land (the tiny, isolated Pitcairn Island). Easter Island has a mild climate and fertile volcanic soil, but when Europeans discovered it in the 1700s, it was covered in dry grassland, lacking trees or any vegetation above 1m high. Around 2,000 people survived on the island by subsistence farming, yet all around stood huge stone statues, some 30 m tall and weighing over 200 tonnes. Clearly a much larger more advanced society had been living on the island at some time in the past. Archaeological studies have found that populations reached 20,000 people prior to 1500AD. Exhaustion of the island's resources by the population was followed by war and civil unrest and the population fell to the subsistence levels found in the 1700s.

EUROPE: Despite isolated events, the world population continued to grow so that by 1350 AD it had reached around 450 million. As a result of the continued rise of urban populations, often living in squalid conditions, disease spread rapidly. The bubonic plague, which swept through Europe at this time, reduced its population almost by half, and reduced the world's population to 350 million. Despite further outbreaks of plague and the huge death tolls of various wars, the human population had reached 2.5 billion by 1950. By 1990 it was 5 billion and today it is around 7 billion. In slightly less than 60 years the human population has grown almost twice as much as it did in the whole of human history up until 1950. Much of this growth can be attributed to major advances in agriculture and medicine. However, signs are appearing that the human population is approaching maximum sustainable levels. Annual crop yields have ceased increasing and many common illnesses are becoming more difficult to treat. The rapid spread of modern pandemics, such as H1N1 influenza, illustrates the vulnerability of modern human populations. Could it be, perhaps, that another great reduction in the human population is imminent?

1. Describe the general trend of human population growth over the last 100,000 years: _____

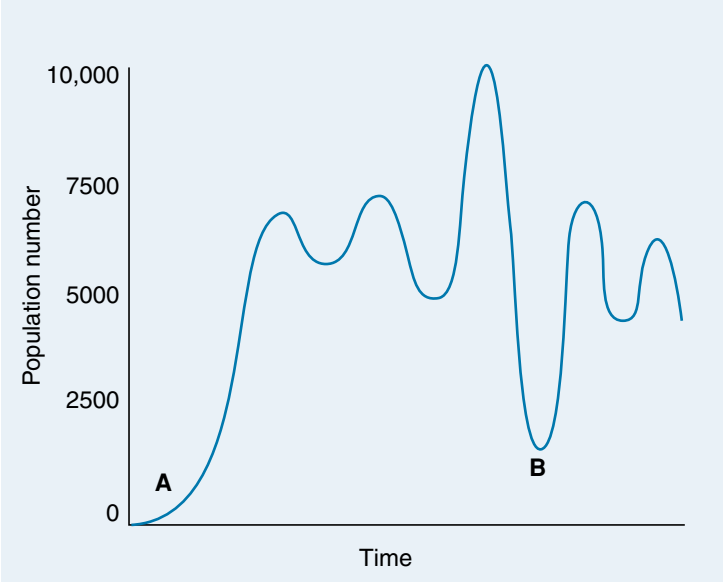
2. Explain why the human population has grown at such a increased rate in the last 60 years: _____

3. Discuss similarities between the events at Tikal and on the Easter Islands and how they can help us plan for the future:

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270 KEY TERMS: Did You Get It?

1. Study the graph of population growth for a hypothetical population below and answer the following questions:



(a) Estimate the carrying capacity of the environment:

_____

(b) What happened at point **A** on the diagram?

_____

_____

_____

_____

(c) What happened at point **B** on the diagram?

_____

_____

_____

(d) What factors might have caused this? _____

_____

_____

2. (a) Life tables present information about the age-specific survival of organisms. Plot a survivorship curve for elk hinds (below) based on the lx column of the life table below. X denotes the age in years and lx the number surviving at the start of each age. The life table also has columns for proportion dying at each age (dx) and mortality (qx).

(b) Describe the survivorship curve for these large mammals: _____

_____

_____

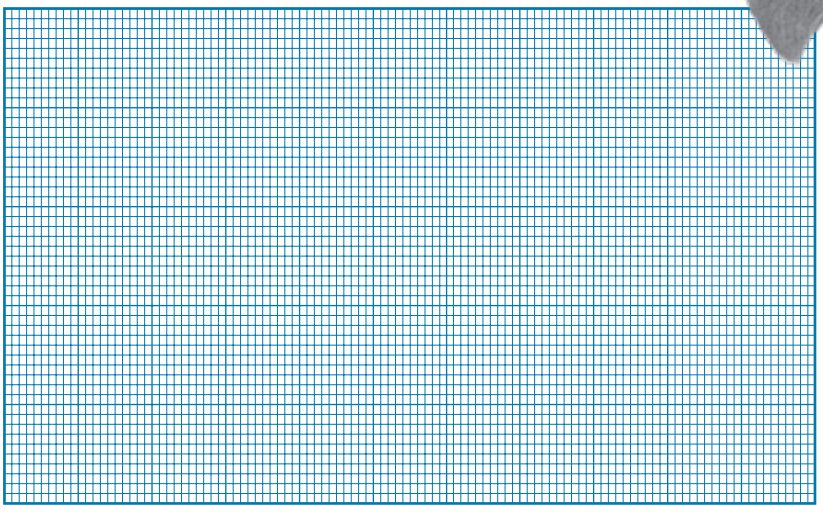
(c) Identify the survivorship curve that best fits the curve described in (b): _____

Life Table for Female Elk, Northern Yellowstone

x	l_x	d_x	q_x
0	1000	323	0.323
1	677	13	0.019
2	664	2	0.003
3	662	2	0.003
4	660	4	0.006
5	656	4	0.006
6	652	9	0.014
7	643	3	0.005
8	640	3	0.005
9	637	9	0.014
10	628	7	0.001
11	621	12	0.019
12	609	13	0.021
13	596	41	0.069
14	555	34	0.061
15	521	20	0.038
16	501	59	0.118
17	442	75	0.170
18	367	93	0.253
19	274	82	0.299
20	192	57	0.297
21+	135	135	1.000

Survivorship Curve for Female Elk of Northern Yellowstone National Park





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QLD As required
VCE Unit 2 (2)
WA ATAR Unit 1
SA Theme E

Changes in Ecosystems

Key terms

agriculture
acacias (Acacia)
biodiversity
climax community
conservation
deforestation
desertification
ecological succession
ecosystem stability
environmental change
eucalypts (Eucalyptus)
eutrophication
glacial
global warming
Gondwana
greenhouse effect
greenhouse gas
indicator species
interglacial
Pangaea
pollution
primary succession
sclerophyll
secondary succession
soil degradation
stratospheric ozone depletion
sustainability
urbanisation

Australia's history

Learning aims and skills

Activity number

- ☐ 1 Briefly describe Australia's geological and biological past including: 272-275
  - (a) Australia's continental drift away from Gondwana. 272
  - (b) The effect of glacial and interglacial periods on Australia's climate, physical environment, fauna, and vegetative patterns. 273
  - (c) The features of Australia's flora, with emphasis on the eucalypts, and acacias, and the probable cause of the evolution of the sclerophylls. 274
  - (d) A brief outline Australia's biological history including reference to the kinds of plants and animals that are Gondwana remnants. 275





Ecosystem change

Learning aims and skills

Activity number

- ☐ 2 Describe the biodiversity of the Earth's natural ecosystems. Describe threats to global and local (Australian) biodiversity and describe measures to counteract the loss or decline of species. 177 276-279
- ☐ 3 Recognise ecological succession as a community pattern over time. Describe an example of primary succession and secondary succession. 280-282
- ☐ 4 Describe how our knowledge of past environmental change is gained from various lines of biological, geochemical, and physical evidence. 283
- ☐ 5 Explain the relationship between ecosystem stability and diversity. Describe the applications of diversity indices in natural and modified ecosystems. 284
- ☐ 6 Explain that impact of human activity on ecosystems is the result of resource use, urbanisation, rapid population growth, and large population size. 292
- ☐ 7 Describe how humans alter natural ecosystems for agriculture. Compare natural and agricultural ecosystems in terms of productivity, stability, and sustainability. 285 286
- ☐ 8 Describe the causes and consequences of pollution. Include reference to water pollution, nitrogen pollution, and atmospheric (air) pollutants. 288 289 293
- ☐ 9 Describe the environmental impact of human activity (including soil degradation, salinisation, over-fishing, and deforestation). 285 287 290
- ☐ 10 Describe the causes of stratospheric ozone depletion and explain its biological consequences. 291
- ☐ 11 Explain what is meant by the greenhouse effect. Describe and explain the causes and biological and economic consequences of global warming. Discuss measures of reducing global warming or its impact. 294 295



271 The Modern Atlantis?

Key Idea: Sea level rise as a result of climate change will have an adverse effect on many low lying islands.

Computer models of accelerated global warming show that the mean sea level may rise by between 100 and 900 mm over the next century. This is mainly due to the thermal expansion of the oceans as they increase in temperature, but also includes the melting of ice sheets. This rise in sea level will have a significant effect on low lying islands and coral atolls as many are presently only a few metres above sea level.

Vanishing Lands

The newspaper, and author name of the following article are fictitious, but the text is based on real events and information.

The Tribune
By Michael Anton: Saturday 7 June 2008

After many years of unanswered appeals for action on climate change, the tiny South Pacific nation of Kiribati has concluded that it is doomed. On Thursday its President, Anote Tong, used World Environment Day to request international help to evacuate his country before it disappears.

Kiribati consists of just 33 coral atolls scattered across 5 million square kilometres of the Pacific Ocean and it has limited scope for coping with impending global climate changes with most of the land being barely 2 metres above sea level.

Speaking from New Zealand, Mr Tong said his fellow countrymen, i-Kiribati, as they are known, had no alternative but to leave. "We may be beyond redemption," he said. "We may be at the point of no return, where the emissions in the atmosphere will carry on contributing to climate change, to produce a sea level change. So in time our small, low-lying islands will be submerged."

A London economics graduate, Mr Tong said the emigration of his people needed to start immediately. "We don't want to believe this, and our people don't want to believe this. It gives us a deep sense of frustration. What do we do?"

Kiribati is home to 97,000 people most of them living on the main atoll of Tarawa, a ring of islets surrounding a central lagoon. It is regarded as one of the places most vulnerable to climate change along with Vanauta, Tuvalu and the Marshall Islands.

Currently, the most serious problem Kiribati faces is erosion caused by flooding and storms. "We have to find the next highest spot," said Mr Tong. "At the moment there's only the coconut trees." But even the coconut trees are dying, caused by drought and a rising level of salt in ground water, which is also not being replaced due to the fact there has little rain at all for the last three years.

Mr Tong was in New Zealand – which, after committing itself to becoming carbon neutral, was chosen to host the UN's World Environment Day – for talks with Prime Minister, Helen Clark, whom he hopes to persuade to help resettle his people. But he also appealed to other countries for help relocating the i-Kiribati.

However, New Zealand, already with a large population of Pacific Islanders, would have immense trouble absorbing the 97,000 immigrants which would strain its generosity to the limit and total almost 2.5% of its current national population.

And that is just Kiribati. Talks have not yet begun with many of the other island nations which soon may also be submerged. In 2006, the Australian government issued a warning of a flood of environmental refugees across the Asian-Pacific region.

President Tong said he had heard many national leaders argue that measures to combat climate change could negatively affect their economic development, but pointed out that for the i-Kiribati it was not a matter of economics, it was a matter of survival. He said that while international scientists argue about the causes of climate change, the effects were already beginning to show on his nation. "I am not a scientist, but what I know is that things are happening we did not experience in the past... Every second week, when we get the high tides, there are always reports of erosion."

Villages, after occupying the same site for centuries, are having to be relocated due to the encroaching water. "We're doing it now... it's that urgent," he said. "Where they have been living over the past few decades is no longer there. It is being eroded."

Worse case scenarios suggest the i-Kiribati could be uninhabitable within 60 years, Mr Tong said. "I've appealed to the international community that we need to address this challenge. It's a challenge for the whole global community."

Leading industrialised nations last month pledged to cut their carbon emissions in half by 2050. But they stopped short of setting firm targets for 2020, which many scientists argue is crucial if the planet is to be saved. But for Kiribati, its saviour may have come too late.

1. From the information provided in the article, explain why Kiribati is vulnerable to the effects of global warming:

2. The article states that global warming is already adversely affecting the island nation of Kiribati. What are the physical effects it refers to, and what will be their impact on the inhabitants of Kiribati in the short term?

3. The inhabitants of Kiribati may be forced to relocate to other countries. What could this mean for the identity of the i-Kiribati and their culture and language?

4. Using other research tools, such as the library or internet, find and read other articles relating to sea level change in the Pacific. Do they all agree that there will be a rise in sea level if carbon emissions are not reduced? Explain why you think some articles take different viewpoints:

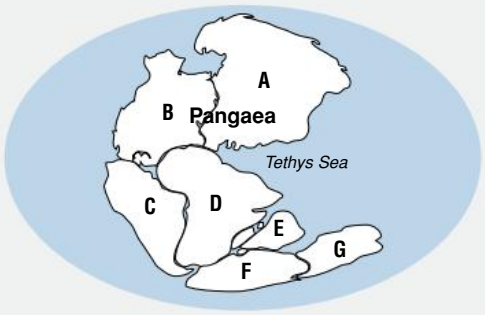
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272 Australia's Geological Past

Key Idea: Australia was once part of the super-continent Gondwana before separating to form its own continent.

Australia began its existence as part of the super-continent Gondwana. Gondwana began to break up during the Cretaceous, but Australia remained attached to Antarctica until about 60 million years ago (mya). It then began to drift north, leaving Antarctica. Australia remained isolated for more than 20 million years. Although it continues to drift north at the rate of 6 cm per year, it still has no direct connection with Asia and only in the last 15 million years has it been close enough to Asia to allow a major exchange of organisms. It is not surprising then that much of Australia's characteristic biota is Gondwanan in origin (e.g. marsupials, ratites, eucalypts, acacia, *Protea*, and *Nothofagus*).

1 Permian: 250 million years ago



All of the continents at this time are combined into a single supercontinent called Pangaea.

South America has already broken away from Antarctica. This occurred mid-Cretaceous (about 100-90 mya).

3 Late Cretaceous: 65 million years ago



Australia is still attached to Antarctica, but is soon to separate (some 60 million years ago) and become an island continent.

2 Late Jurassic: 150 million years ago



Gondwana separates from Laurasia and drifts south towards the South Pole.

Pangaea splits into two supercontinents: Laurasia and Gondwana.

Australia still attached to Antarctica, South America and Africa, allowing plants and animals to exchange between them.

4 Eocene: 45-38 million years ago



After separating from Antarctica, Australia spent more than 20 my moving northward. During this time it was relatively isolated from other major landmasses and received little in the way of terrestrial biota.

1. Identify the continental landmasses labelled **A** to **G** in the diagram above (top, left: Permian, 250 mya):

   A. _____ B. _____ C. _____ D. _____

   E. _____ F. _____ G. _____

2. What mechanism powers continental drift? _____

3. What has been the role of continental drift in shaping Australia's biota? _____

   _____

   _____

4. When did the following continents separate from each other (period, or years if known)?

   (a) South America from Antarctica: _____ (b) Australia from Antarctica: _____

5. Gondwana contained the ancestral populations of much of Australia's modern biota.

   (a) Name an example of an Australian plant group that has a Gondwanan origin: _____

   (b) Name an example of an Australian animal group that has a Gondwanan origin: _____

6. Where might the plants and animals, not of Gondwana origin, have come from? _____

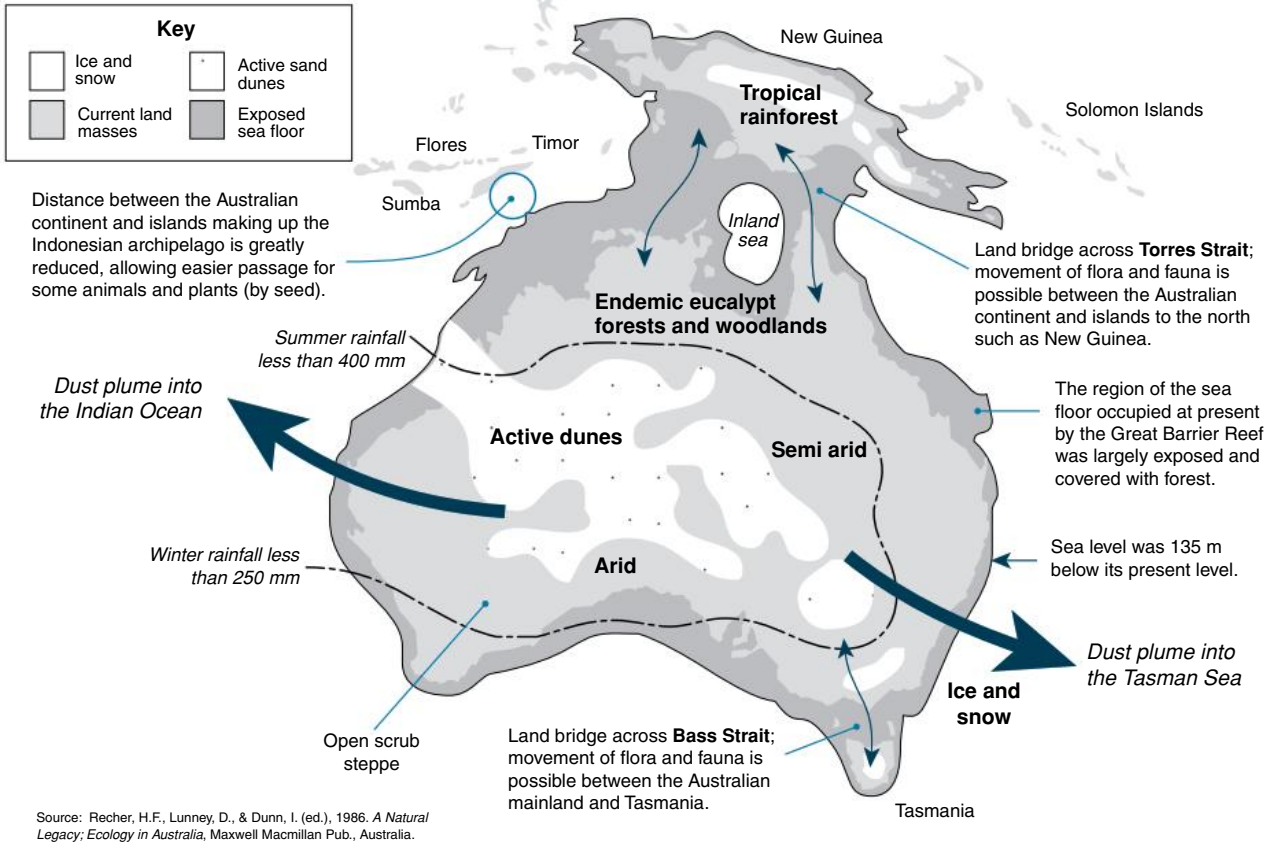
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273 Australia During the Glacial Periods

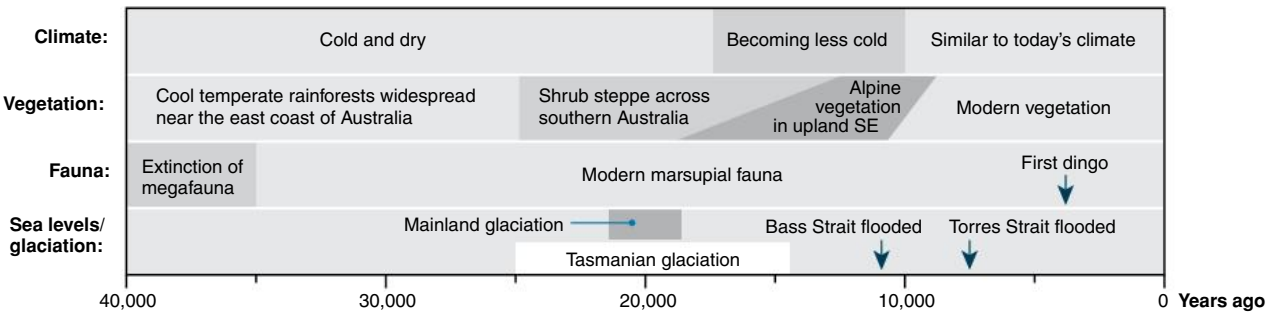
Key Idea: The alternation of glacial periods with interglacials contributed to the current characteristics of Australia's biota.

At the start of the Pleistocene (~2 mya), the world entered the current ice age and has since undergone a number of severe glacials (colloquially and confusingly also called ice ages). There have been five cycles with the last finishing about 10,000 years ago. The diagram below depicts Australia during the coldest interval of the most recent glacial, about 18,000 years ago. Glaciers were formed in the mountains of Tasmania, south-east Australia and New Guinea. The alternation of dry, cold, glacial periods with moist, mild, interglacials had a profound impact on Australian ecosystems. In most areas, modern vegetation only became established about 8000 years ago.



Source: Recher, H.F., Lunney, D., & Dunn, I. (ed.), 1986. *A Natural Legacy; Ecology in Australia*, Maxwell Macmillan Pub., Australia.

Australia during the last 40,000 years



1. What were the consequences of the last glacial to the movement of biota between Australia and islands to the north?

2. Specifically, describe the effect of the glacials on the accessibility of the Australian mainland to:

   (a) Tasmania and New Guinea: _____

   (b) The island of Timor: _____

3. Even during glacials, a water barrier of at least 50 km existed between Australia and its nearest Asian neighbours. This prevented many Asian species from making the crossing. How would the first humans have crossed this barrier?

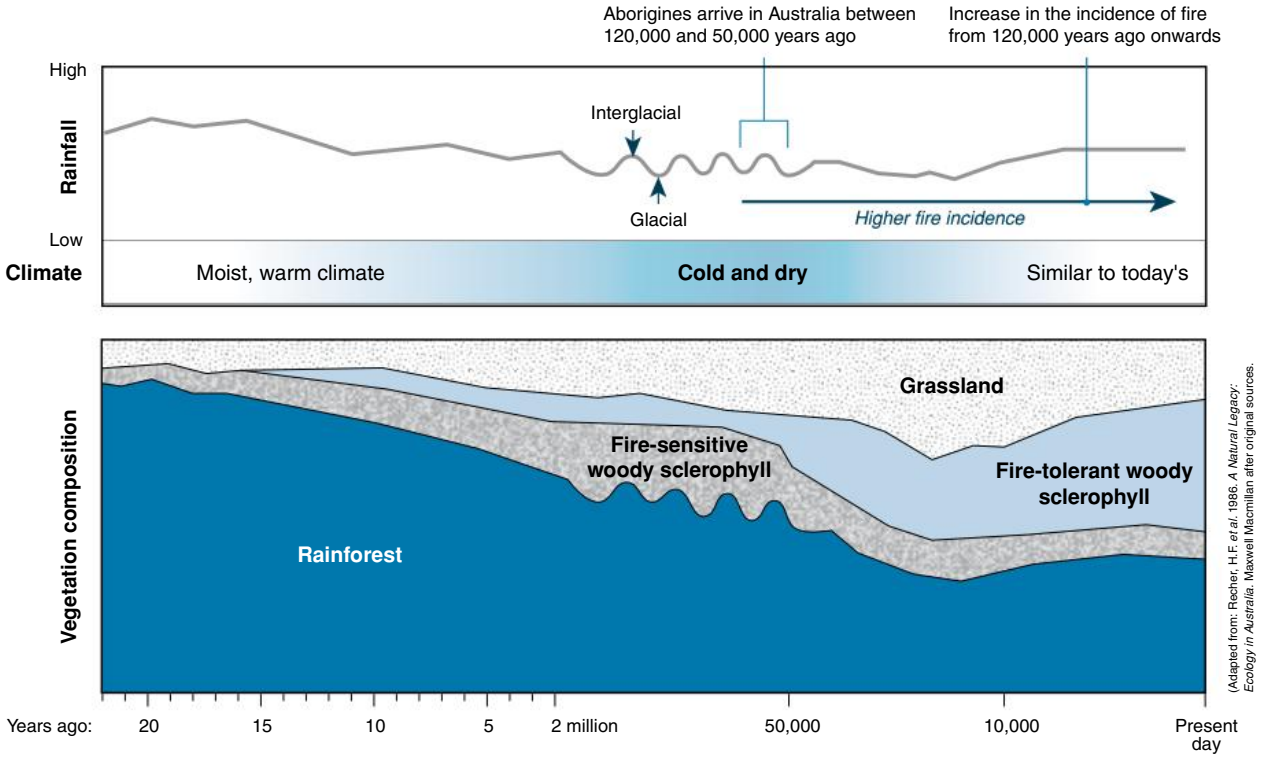
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274 Australia's Vegetation Changes

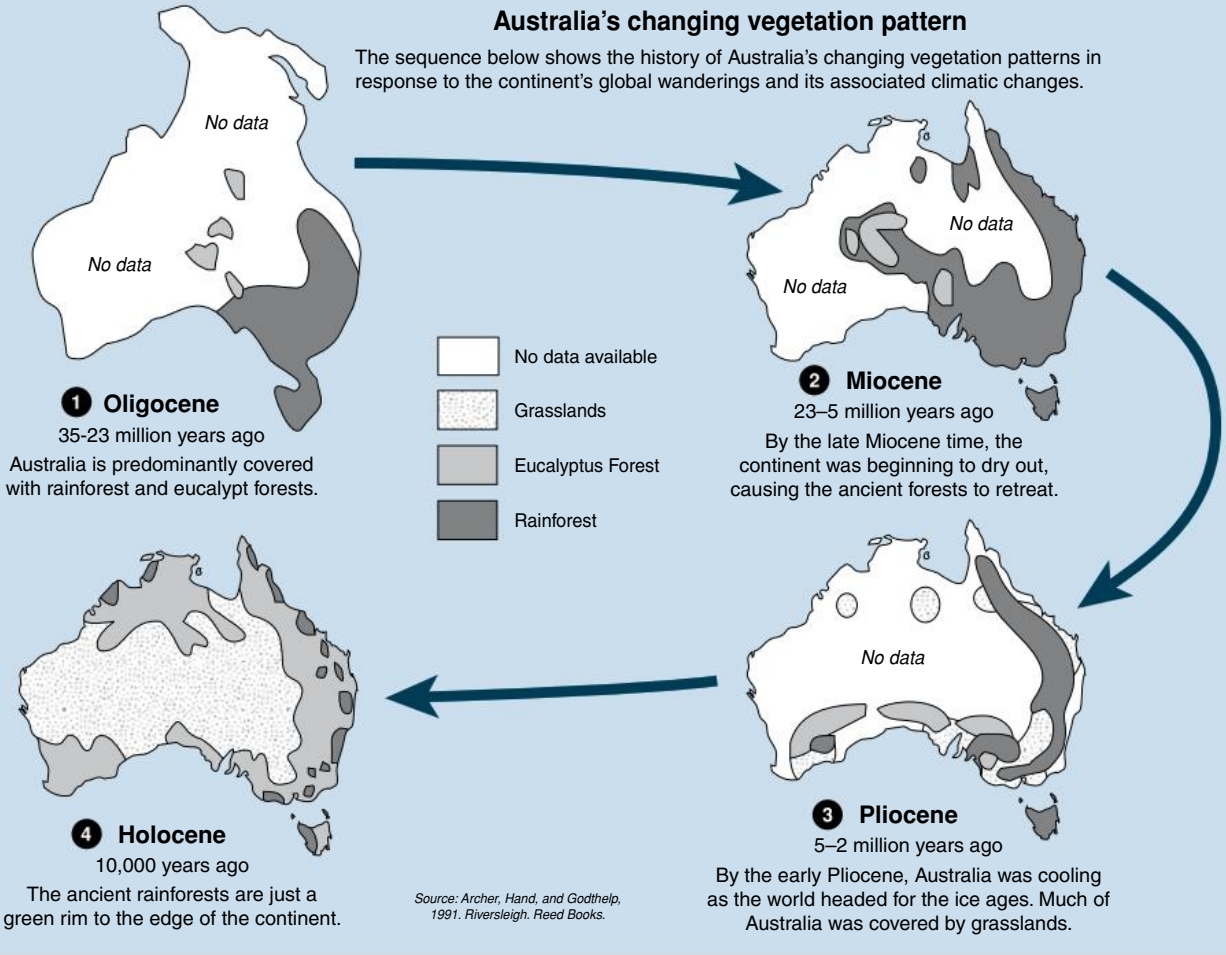
Key Idea: Australia's unique vegetation has evolved as a result of Australia's isolation from other land masses.

Australia separated from Gondwana about 60 mya and has remained isolated apart from links with New Guinea during glacial periods. Many of Australia's plant species are unique: 80% of the flowering plants occur nowhere else in the world. The eucalypts and the acacias dominate the flora over much of Australia. Many Australian flowering plants are **sclerophylls**, plants with hard and often small leaves. This is thought to be a response to the nutrient-poor, ancient soils. With the increase in the incidence of fire, woody, fire adapted sclerophyll species became more common.



Australia's changing vegetation pattern

The sequence below shows the history of Australia's changing vegetation patterns in response to the continent's global wanderings and its associated climatic changes.



1 Oligocene
35-23 million years ago
Australia is predominantly covered with rainforest and eucalypt forests.

2 Miocene
23–5 million years ago
By the late Miocene time, the continent was beginning to dry out, causing the ancient forests to retreat.

3 Pliocene
5–2 million years ago
By the early Pliocene, Australia was cooling as the world headed for the ice ages. Much of Australia was covered by grasslands.

4 Holocene
10,000 years ago
The ancient rainforests are just a green rim to the edge of the continent.

Source: Archer, Hand, and Godthelp, 1991. Riversleigh. Reed Books.

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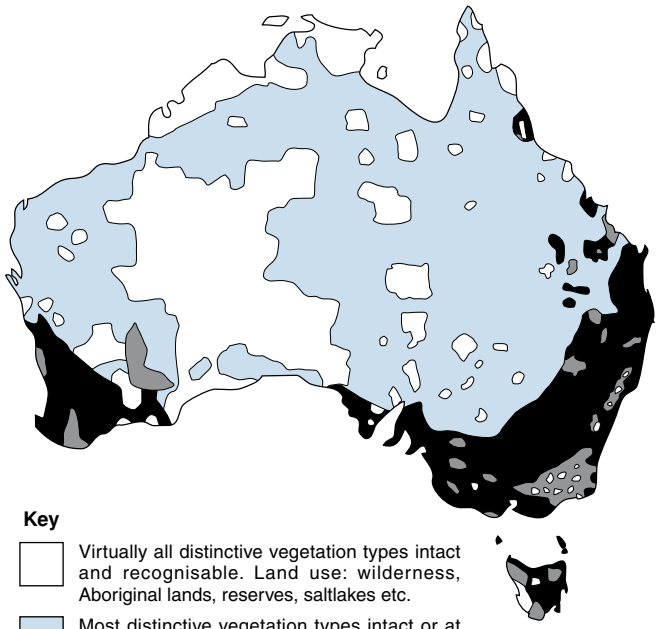
European settlement has had severe effects on the communities of Australian plants. Some vegetation types remain largely unaltered, but many have been radically changed, even destroyed, by human activities such as heavy industry, mining, and urban settlement. At least 15% of Australia's flora is now exotic. For some ecosystems, recovery is unlikely. The table below is a summary of the effects of European settlement on natural ecosystems in Australia.

Major land use	Effects and changes to vegetation
Urban settlement, industrial activity and mining activity	• Natural vegetation virtually removed • Exotic vegetation planted • Soils altered • Pollutants added to the environment • Flooding and altered stream features • Scarification by mining, waste dumps
Forestry activities	• Structure of natural vegetation altered • Destruction by woodchipping • Exotic vegetation planted • Altered fire regimes • Weed invasion and increased fire risks • Pollution and an increase in disease
Cropping and pastoral activity (intensive grazing and dairying)	• Natural vegetation virtually removed • Exotic vegetation planted • Exotic animals and weeds introduced • Pollutants added to the environment • Altered fire regimes • Soils altered • Ground cover altered (more erosion) • Increased disease
Rangeland activities (grazing of sheep and cattle)	• Natural vegetation partially removed • Exotic animals introduced • Ground cover altered (more erosion) • Altered fire regimes • Pollutants added to the environment
Unused areas including wilderness areas	• Minor invasion of exotic plants • Invasions by exotic animals • Areas radioactive after nuclear tests • Vegetation cleared by mining surveys

Information source: Read, I.G. 1994. The Bush: A guide to the vegetated landscapes of Australia. UNSW Press. ISBN: 0-86840-238-9

Disturbance to Australia's Natural Vegetation

The map below provides a visual guide to the degree of disturbance caused by various types of land use in different regions of Australia.



1. Describe the conditions during the glacials and interglacials, 2 million to 10,000 years ago:

   (a) Rainfall: _____

   (b) Climate: _____

2. During this time, the extent of the rainforests varies (oscillates), as well as generally declining.

   (a) What caused the **oscillation** in rainforest abundance? _____

   (b) Why was there a general decline in rainforest abundance? _____

3. The grasslands have gradually expanded their range and become more abundant.

   (a) Approximately when did this expansion begin? _____

   (b) What was the likely cause? _____

4. The abundance of **fire-tolerant** woody sclerophyll forest increased towards the end of the glacial periods.

   (a) What physical factor was probably responsible for this increase? _____

   (b) Why are early humans also implicated? _____

5. Summarise the main impacts of European land use on the vegetation and ecosystems of Australia with respect to:

   (a) Vegetation clearance: _____

   (b) Invasion of pests and weeds: _____

   (c) Removal of ground cover: _____

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275 Australia's Biological History

Key Idea: Australia's biota is diverse in origin, but much of it is unique, the species having undergone adaptive radiation at a time when Australia was isolated from other land masses.

Some Australian biota is Gondwanan in origin, and close relatives of these species can be found on other continents originating from Gondwana. Other species arrived during recent glacial periods when the sea level dropped and land-bridges formed between Australia and Asia. Australia's unique biota is a result of species undergoing adaptive radiation at a time when Australia was geographically isolated.

Pangean	Gondwanan	Asian Tertiary	Modern	Introduced
> 150 mya	150 – 60 mya	40 mya – latter Tertiary	15 mya – present	100,000 ya – present
Peripatus, cockroaches, ancient insects, some spiders and earthworms.	Marsupial mammals, ratite birds, chelid turtles, some geckos, some land molluscs, some spiders, some insects, some groups of scorpions.	Most families of lizards and snakes, tree rats, many birds, some spiders, many insects.	Ranid frog, pig-nosed turtle, native rats, bats, rainbow bee eater, various spiders and insects.	Dingo, trout, cane toad, mallard duck, common pheasant, house sparrow, blackbird, starling, thrush, dog, cat, fox, house mouse, deer, sheep, pigs, Arabian camel, goat, rabbit, hare, rats, horses.
Ferns, confers, cycads, gingkos, lycopods, horsetails.	Species of *Nothofagus* (beech), Myrtaceae family (myrtle) Proteaceae, banksia, podocarp.	Diversification of acacia and eucalyptus. Some grasses, she-oaks, ginger.	Grasses	Bananas, clover, alligator weed, corn, rice, wheat, water hyacinth, rubber vine.

Origin of Australia's Biota

The origin of monotremes (right) is unknown. The only surviving monotremes are indigenous to Australia and New Guinea. The oldest monotreme fossils are dated at 120 mya.

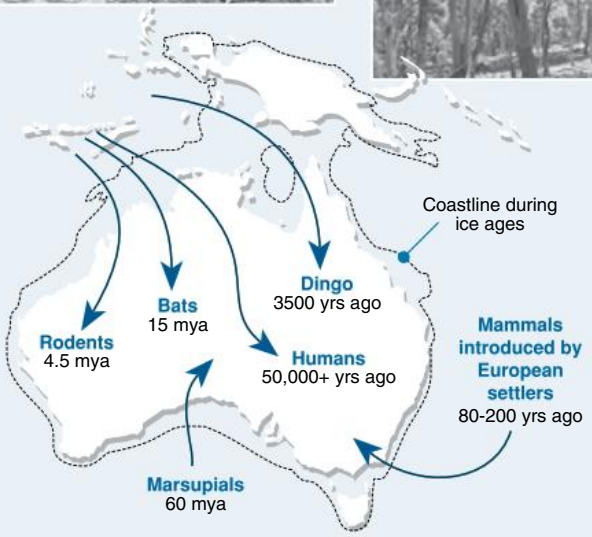




Eucalyptus pollen first appeared in Australia about 34 mya, but the Myrtaceae family to which it belongs was present about 64 mya. Today, eucalypts (left) are a predominant Australian plant.



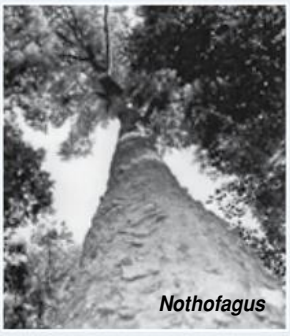
Australia has about 117 species of endemic marsupials (above). Marsupials are also found in New Guinea and South and Central America. Ancestral marsupials probably originated about 60 mya in South America.



Dispersal of some mammalian fauna



The emu (above) evolved from an ancestral Gondwanan ratite population into its current form when Australia was isolated from other land masses.



The Southern (or Antarctic) beeches (*Nothofagus* species) evolved when Australia was still part of Gondwana. While once widespread through ancient Australia, *Nothofagus* is now limited to the south-east. They are also found in temperate regions of New Zealand, New Guinea, New Caledonia, and southern South America.



Bats and rodents are relatively recent arrivals to Australia. Most Australian bats (both fruit bats and micro-bats) are related to Asian groups. Their ancestors almost certainly flew to Australia across narrowing marine straits.

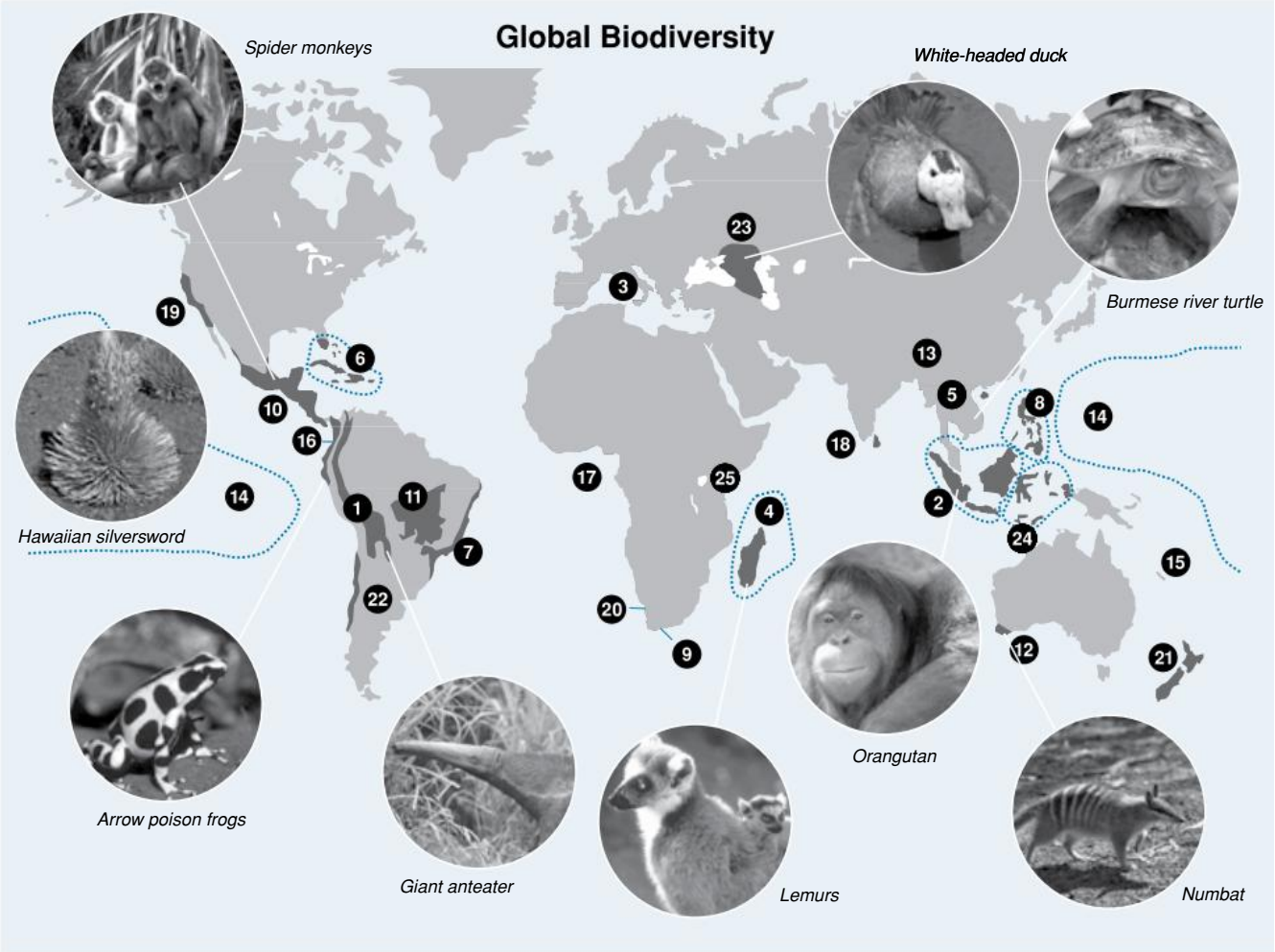
1. What role did the landbridge between Australia and Asia have on Australia's biota? _____

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276 Global Biodiversity

Key Idea: Biodiversity is the sum of all biotic variation from the level of genes to ecosystems. Some regions have higher biodiversity than others.

The species is the basic unit by which we measure biodiversity. **Biodiversity** is defined as the sum of all biotic variation from the level of genes to ecosystems. **Species diversity** describes species richness (the number of species), **genetic diversity** is the diversity of genes within a species, and **ecosystem diversity** refers to the diversity at the ecosystem level of organisation. Total biodiversity can be threatened by the loss of just one of these components. Biodiversity is not distributed evenly on Earth, it is richer in the tropics and concentrated more in some areas than in others. Twenty five biodiversity hotspots are recognised. Hotspots are biologically diverse and ecologically distinct regions under the greatest threat of destruction. They are identified on the basis of the number of species present, the amount of endemism, and the extent to which the species are threatened.



1. Distinguish between species diversity and genetic diversity and explain the importance of both of these to our definition of total biological diversity:

2. Explain the importance of considering ecosystem (habitat) diversity when targeting regions for conservation purposes:

3. Use your research tools (including the *Weblinks* identified below) to identify each of the 25 biodiversity hotspots illustrated in the diagram above. For each region, summarise the characteristics that have resulted in it being identified as a biodiversity hotspot. Present your summary as a short report and attach it to this page of your workbook.

KNOW LINK 277 LINK 278

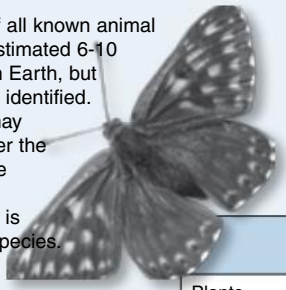
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277 Loss of Biodiversity

Key Idea: Loss of biodiversity reduces the stability and resilience of natural ecosystems.

More than a third of the planet's terrestrial plant and animal species are found within biodiversity hotspot regions, which cover only 1.4% of the Earth's land area. Unfortunately, these hotspots often occur near areas of dense human habitation and rapid human population growth. Human pressure on the biota of these regions is driving up extinction rates, which are estimated at 100-1000 times the natural background extinction rate of 10-100 species a year. Over 41,000 species are now on the International Union for Conservation's (IUCN) red list, and 16,000 are threatened with extinction. Loss of biodiversity reduces the stability and resilience of natural ecosystems (their ability to resist and recover from change).

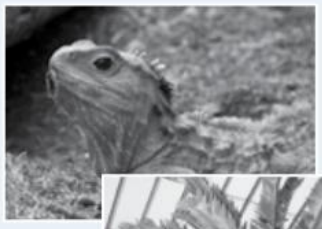
Insects make up 80% of all known animal species. There are an estimated 6-10 million insect species on Earth, but only 900,000 have been identified. Some 44,000 species may have become extinct over the last 600 years. The Duke of Burgundy butterfly (*Hamearis lucina*), right, is an endangered British species.





The giant panda (above), is one of many critically endangered terrestrial mammals, with fewer than 2000 surviving in the wild. Amongst the 120 species of marine mammals, approximately 25% (including the humpback whale and Hector's dolphin) are on the ICUN's red list.

About 5% of the 8225 reptile species are at risk. These include the two tuatara species (right) from New Zealand, which are the only living members of the order Sphenodontia, and the critically endangered blue iguana. Only about 200 blue iguanas remain, all in the Grand Caymans.



	Total number of species*	Number of IUCN listed species
Plants	310,000 - 422,000	8474
Insects	6 -10 million	622
Fish	28,000	126
Amphibians	5743	1809
Reptiles	8225	423
Birds	10,000	1133
Mammals	5400	1027

* Estimated numbers

Prior to the impact of human activity on the environment, one bird species became extinct every 100 years. Today, the rate is one every year, and may increase to 10 species every year by the end of the century. Some at risk birds, such as the Hawaiian crow (right), are now found only in captivity.





Current estimates suggest as many as 47% of plant species may be endangered. Some, such as the South African cycad *Encephalartos woodii* (above), is one of the rarest plants in the world. It is extinct in the wild and all remaining specimens are clones.

Threats to Biodiversity



Rainforests in some of the most species-rich regions of the world are being destroyed at an alarming rate as world demand for tropical hardwoods increases and land is cleared for the establishment of agriculture.



Illegal trade in species (for food, body parts, or for the exotic pet trade) is pushing some species to the brink of extinction. Despite international bans on trade, illegal trade in primates, parrots, reptiles, and big cats (among others) continues.



Pollution and the pressure of human populations on natural habitats threatens biodiversity in many regions. Environmental pollutants may accumulate through food chains or cause harm directly, as with this bird trapped in oil.

1. Discuss, in general terms, the effects of loss of biodiversity on an ecosystem: _____

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LINK 295 LINK 284 LINK 279 LINK 278 KNOW

278 Biodiversity and Conservation

Key Idea: Conservation measures, both *in-situ* or *ex-situ*, aim to maintain or increase biodiversity.

In 1992, the Convention on Biological Diversity was adopted in Rio de Janeiro. Its aims are to conserve biodiversity, use biodiversity in a sustainable way, and ensure that the benefits of genetic resources are shared equitably. Conservationists have a number of strategies to protect at-risk species and help threatened species to return to sustainable population sizes. ***Ex-situ*** methods operate away from the natural environment and are useful where species are critically endangered. ***In-situ*** conservation methods manage ecosystems to protect diversity within the natural environment.

Ex-Situ Conservation Methods



Jessica Bonsell cc 3.0

Captive Breeding and Relocation

Individuals are captured and bred under protected conditions. If breeding is successful and there is suitable habitat available, captive individuals may be relocated to the wild where they can establish natural populations.

Left: Taronga Zoo runs a captive breeding programme for the Regent honeyeater.

The Role of Zoos

Many zoos specialise in captive breeding programmes for endangered species and participate in global programmes to retain the genetic diversity of captive bred species. *Right: Several zoos and sanctuaries, including Taronga and Healesville are involved in recovery programmes for the Tasmanian devil.*



Ian Smith



The Role of Botanic Gardens

Botanic gardens play a critical role in plant conservation. They maintain seed banks, nuture rare species, maintain a living collection of plants, and help to conserve indigenous plant knowledge. They also have an important role in both research and education.

Photo left: The palm house at Kew Botanic Gardens.

Seed and Gene Banks

Seed and gene banks have a role in preserving genetic diversity. A seed bank (right) stores seeds as a source for future planting if seed reserves elsewhere are lost. The seeds may be from rare species whose genetic diversity is at risk, or they may be the seeds of crop plants, in some cases of ancient varieties no longer used in commercial production.



In-Situ Conservation Methods



Habitat corridor restoration (Australia)

Habitat Protection and Restoration

Parks and reserves focus on **whole ecosystem conservation**. These areas aim to preserve habitats with special importance and they may be intensively managed through pest and weed control programmes, revegetation, and reintroduction of threatened species. A "research by management" approach is associated with careful population monitoring and management to return threatened species to viable levels.



Martin Pot

Numbat (vulnerable species)

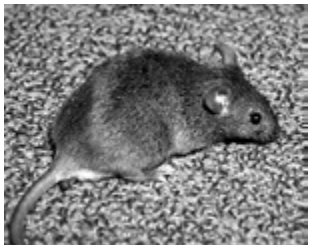
Ban on Trade in Endangered Species

The Convention on International Trade in Endangered Species (**CITES**) is an international agreement between governments which aims to ensure that international trade in species of wild animals and plants does not threaten their survival. Unfortunately, even under CITES, species are not guaranteed safety from illegal trade.



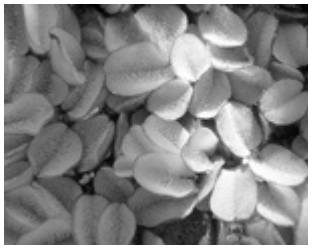
DoC-RM

Feral cats prey on birds and reptiles



IS

Introduced rats compete with natives



Salvinia weed invades waterways



LC

Wasps: competitors and killers

At least 18 exotic mammals, including cats, dogs, foxes, water buffalo, pigs, and goats, have established feral populations in Australia. Some species, e.g. trout and sparrows, were introduced deliberately, while others, such as black rats and house mice were accidental introductions. Cats and foxes are predators of native animals and have been implicated in many species declines. Introduced rodents compete with native species with similar niches.

The activities of introduced invertebrates and plants have also contributed to the decline in Australia's native species. German wasps arrived in timber shipments in 1978 and have since spread widely, preying on native insects and attacking soft fruits. Introduced plants are also a problem. About 25% of introduced plants are considered actual or potential serious environmental weeds. Salvinia is an aggressive invader despite control measures.

LINK KNOW 279

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St Helens wax flower

A species is presumed extinct if it has not been located during the preceding 50 years (or 10 years after thorough searching). Endangered species, such the St Helens wax flower, are in danger of extinction. Their survival in the wild is unlikely if the factors causing their decline continue. Vulnerable species are those that will become endangered in the next 25 years if the factors causing their decline continue.



Luis A de la Parra

Palm cockatoo (*Probosciger aterrimus*): This spectacular bird has a very restricted natural distribution, found at the very tip of Cape York in Queensland. Their large size, magnificent head crest, and red face patch make them much sought after by illegal bird traffickers and collectors. Palm cockatoos are currently not listed as threatened but could move into that category if habitat loss in the area continues.



IS

Dainty green tree frog

Amphibians: Globally, amphibians are in serious decline as a result of habitat losses and disease (e.g. amphibian chytrid disease). Australia's amphibian fauna includes a large number of endemic species. More than 30 species are endangered or critically endangered and many more are threatened or at risk. In general, too little is known about their true diversity and their biology to identify risks and arrest their decline.

1. Explain the impact of each of the following on Australian native species:

   (a) Habitat destruction: _____

   _____

   (b) Pests, predators and weeds: _____

   _____

   (c) Hunting and collection: _____

   _____

2. There are a number of strategies for the management of native species. For each of those listed below, briefly describe its role in enhancing species survival in the wild:

   (a) Protection of habitat: _____

   _____

   (b) Habitat restoration: _____

   _____

   (c) Pest control: _____

   _____

   (d) Captive breeding and relocation: _____

   _____

   (e) Public education: _____

3. Suggest why species should be preserved from extinction: _____

   _____

   _____

   _____

4. Although they are not endangered, the plight of vulnerable species also concerns conservationists. Suggest why:

   _____

   _____

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279 Species Action Plans

Key Idea: Specific conservation plans aim to assist the recovery of species identified as at risk of extinction.

The Endangered Species Programme aims to prevent further species extinctions and assist species recovery. Priority is given to species according to their conservation status and the existing threats to survival in the wild. Species Action Plans are developed for at-risk species and set priorities for current and future conservation. Action plans are developed from information on past and present distribution, population trends, general ecology, and threats to survival. They are reviewed regularly to ensure that their aims remain relevant. Modern endangered species management takes an ecosystem based approach, recognising that species cannot recover unless their natural community is also preserved. This approach aims to restore entire ecosystems or areas of habitat, through pest control, habitat restoration, and species reintroductions. It offers greater long term survival of threatened species in the wild.

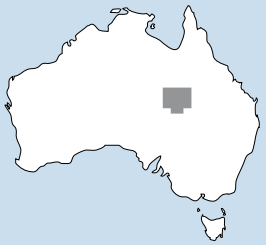


IS

Kowari *(Dasycercus byrnei)*

Status: Vulnerable: Now confined to the Lake Eyre Basin outside the Simpson Desert, occupying Mitchell grass plains. Locally extinct in much of its former range. Reasons for decline include introduced predators, cattle grazing, and increased vehicular traffic have all been implicated.

Action plan: To establish and implement a long-term monitoring programme at selected sites throughout their range. Existing populations will be studied carefully, with a view to better protection and management. Emphasis has been placed on examining the impact of cattle grazing and developing habitat models, as suitable habitat richness appears important to kowari success. Further actions will depend on the outcomes of current research.



Lake Eyre Basin outside the Simpson Desert bioregion. Recent reports suggest a distribution to the east of the Simpson Desert in Queensland.

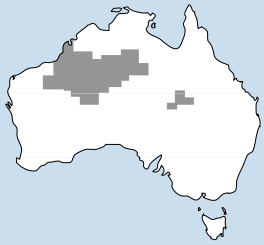


DEQ

Greater Bilby *(Macrotis lagotis)*

Status: Vulnerable: Formerly occurred over 70% of mainland Australia, but populations have declined up to 90% since European settlement. Threats are related to competition and predation from foxes and cats, habitat destruction from introduced herbivores, and the absence of a suitable fire regime for maintaining their spinifex habitat

Action plan: To move the species from 'vulnerable' to 'lower risk' in the next decade, protect the species in its current range (e.g. through predator control), and increase the population by reintroduction into its former range (SA, NSW, and WA). Species distribution, census, and habitat use have been determined. Procedures for captive breeding and reintroducing captive-bred animals have been established.



Wild bilby populations are now restricted mainly to the Tanami Desert, Great Sandy and Gibson Deserts, and a small region in SW Queensland.

1. The implementation of action plans relies on both scientific expertise and the assistance of the public. Explain how each of these has a part in a recovery operation:

   (a) Scientific expertise: _____

   _____

   _____

   (b) Assistance and cooperation of the public: _____

   _____

   _____

2. Recovery plans emphasise proper knowledge of the biology of the species in question. Explain the importance of having a sound knowledge of a species' biology when implementing an action plan:

   _____

   _____

   _____

3. Based on the information above, what do you regard as the two main general causes of the decline in the numbers of some of Australia's native species:

   (a) _____

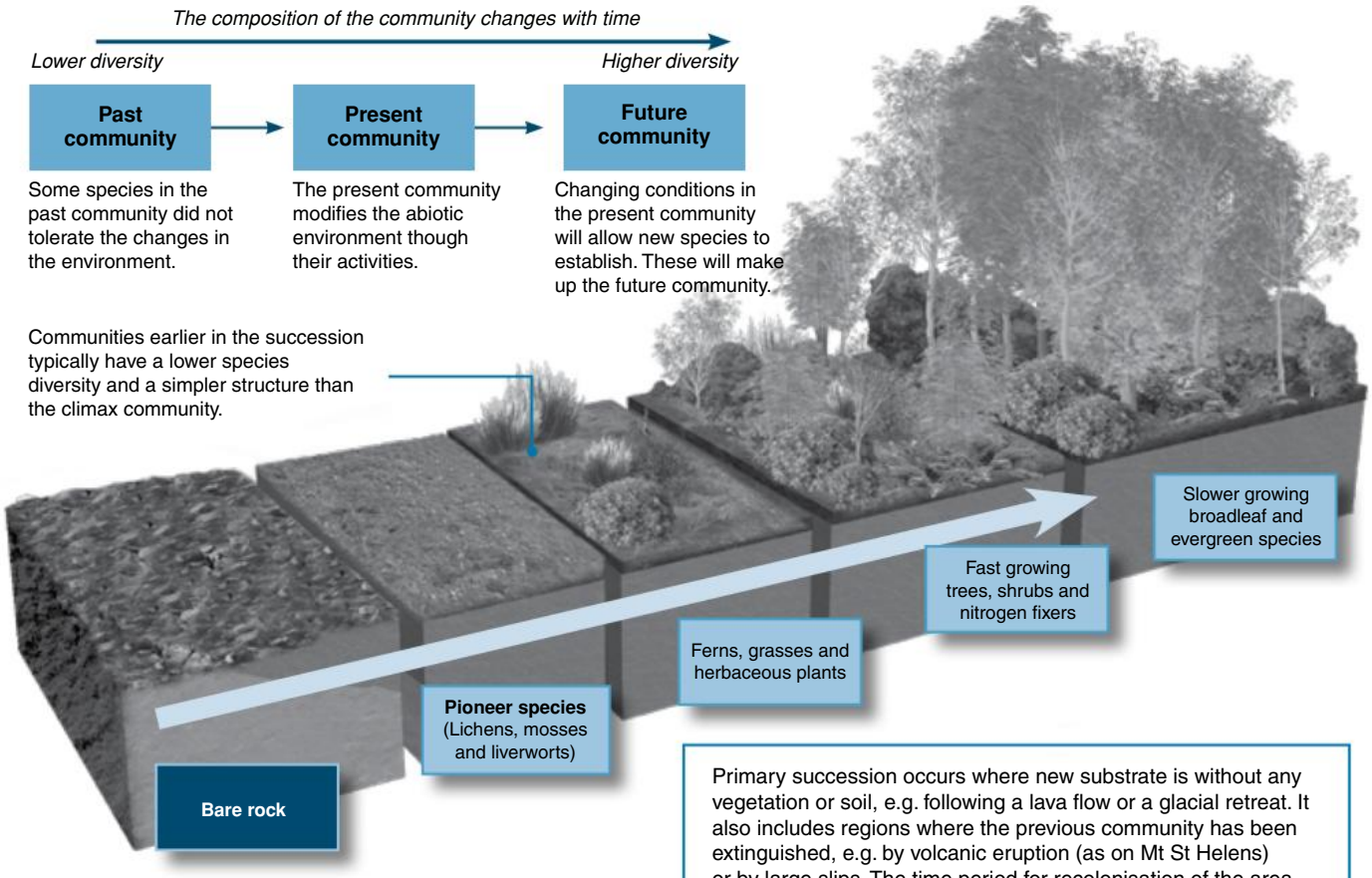
   (b) _____

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280 Primary Succession

Key Idea: Primary succession is a type of ecological succession occurring in a region where there is no pre-existing vegetation or soil.

Ecological succession is the process by which communities change over time. Succession occurs as a result of the interactions between biotic and abiotic factors. Earlier communities modify the physical environment, making it more favourable for species that make up the later communities. Over time, a succession results in a stable climax community. P**rimary succession** is a type of ecological succession describing the colonisation of a region where there is no pre-existing vegetation or soil.



Primary succession occurs where new substrate is without any vegetation or soil, e.g. following a lava flow or a glacial retreat. It also includes regions where the previous community has been extinguished, e.g. by volcanic eruption (as on Mt St Helens) or by large slips. The time period for recolonisation of the area and the composition of the final community depend on the local environment. Recovery is quicker where vegetation is close.

1. Describe situations in which a primary succession is likely to occur: _____

2. (a) Identify some early colonisers during the establishment phase of a community on bare rock: _____

   (b) Describe two important roles of the species that are early colonisers of bare slopes: _____

3. Explain why climax communities are more stable and resistant to disturbance than early successional communities:

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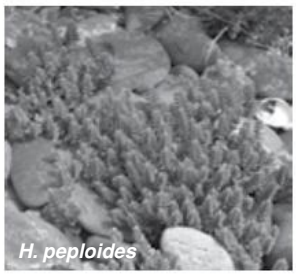
281 Succession on Surtsey Island

Key Idea: The successional events occurring on the island of Surtsey confirm that primary succession occurs in stages.

Surtsey Island is a volcanic island, 33 km off Iceland. The island was formed over four years from 1963 to 1967 when a submerged volcano built up an island. The island is 150 m above sea level and 1.4 km^2. As an entirely new island, Surtsey provided researchers with an ideal environment to study primary succession. Its colonisation by plants and animals has been recorded since its formation. The first vascular plant was discovered in 1965, two years before the eruptions ended. Since then, 69 plant species have colonised the island and there are several established seabird colonies.

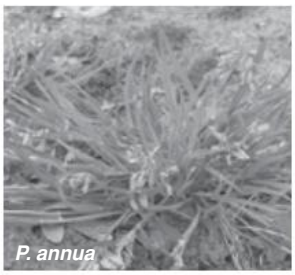


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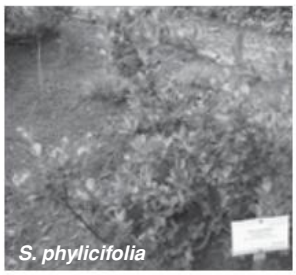


Mikrolit

The first stage of colonisation of Surtsey (1965-1974) was dominated by shore plants colonising the northern shores of the island. The most successful coloniser was *Honckenya peploides* which established on tephra sand and gravel flats. It first set seed in 1971 and then spread across the island. Carbon and nitrogen levels in the soil were very low during this time. This initial colonisation by shore plants was followed by a lag phase (from 1975-1984). There was further establishment of shore plants but few new colonisers, which slowed the rate of succession.

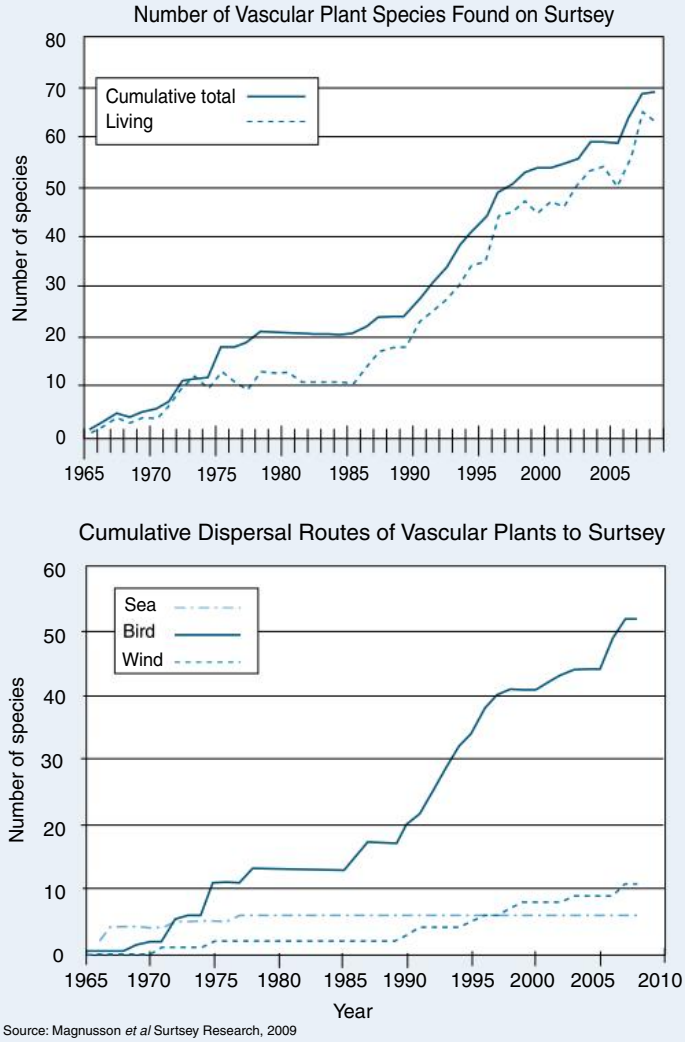


Rasbak



Daderot

Following the lag phase and the establishment of a gull colony on the southern end of the island, a number of new plant species arrived (1985-1994). Populations of plants inside or near the gull colony expanded rapidly covering about 3 ha, while populations outside the colony remained low but stable. Grasses such as *Poa annua* formed extensive patches of vegetation. After this rapid increase in plant species, the arrival of new colonisers again slowed (1995-2008). A second wave of colonisers began to establish following this slower phase and soil organic matter increased markedly. The first bushy plants established in 1998, with the arrival of the willow *Salix phylicifolia*. The area of vegetation cover near the gull colony expanded to about 10 ha.



Source: Magnusson *et al* Surtsey Research, 2009

1. Explain why Surtsey provided ideal conditions for studying primary succession: _____

2. Explain why the first colonising plants established in the north of the island, while later colonisers established in the south.

3. Use the graphs to identify the following:

   (a) The year the gull colony established: _____

   (b) The most common method for new plant species to arrive on the island: _____

   (c) The year of the arrival of the second wave of plant colonisers. Suggest a reason for this second wave of colonisers:

LINK
KNOW 283

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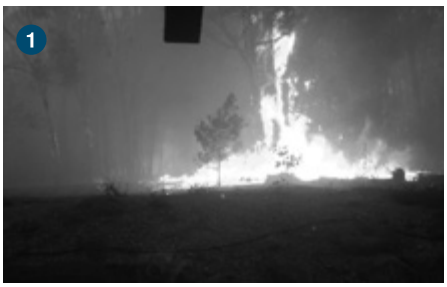
282 Secondary Succession

Key Idea: Secondary succession occurs when a previously vegetated area is cleared, leaving behind soil and seeds.

Secondary succession occurs when land is cleared of vegetation (e.g. after a fire). Soil and seed stocks are not lost and root stocks are often undamaged. As a result, secondary succession tends to be more rapid than primary succession, although the time scale depends on the species involved, soil composition, and climate. Secondary succession may occur over a wide area (as after a forest fire), or in smaller areas where single trees have fallen or abandoned farmland has been left to regenerate. Tree falls result in a type of secondary succession called gap regeneration.

The number and diversity of fire adapted species present after a fire will influence secondary succession growth patterns. Regeneration may come from vegetative reproduction or seed growth.

A succession sequence in a eucalypt forest may include the appearance of low herbs and bryophytes for the first 12 months. The following seedling stage is dominated mainly by eucalypt and acacia seedlings, but other shrubs, bracken, and tree ferns may also be present.



Daniel Cleaveley cc3.0

1. Bush fires (above) are more common in some types of forest (e.g. dry sclerophyll forests) than cool, temperate forests.



RA

2. **Bush fires** are a common occurrence in Australia. Some occur naturally (e.g. start from a lightning storm) while others are set by humans either intentionally or unintentionally. Many plant species have evolved to survive the effects of bush fires (e.g. the grass tree), while others, such as Australian mountain ash (*Eucalyptus regnans*), need fires in order to survive and reproduce. Several months after a fire, trees can be seen regenerating from the base (above).

Many factors affect forest regeneration after a fire including the composition of the forest, the type and duration of the fire, and whether large trees are destroyed leaving gaps in the canopy.

3. During regeneration, competition between species is intense. Eucalypts, such as *Eucalyptus regnans*, begin to dominate the forest (below). Their rapid growth (up to 1 m per year), gives them a distinct advantage over other species.



Fir0002 cc3.0

1. Distinguish between **primary** succession and **secondary** succession: _____

2. Why is secondary succession usually a more rapid process than primary succession? _____

3. Describe an event commonly resulting in a secondary succession in Australian ecosystems: _____

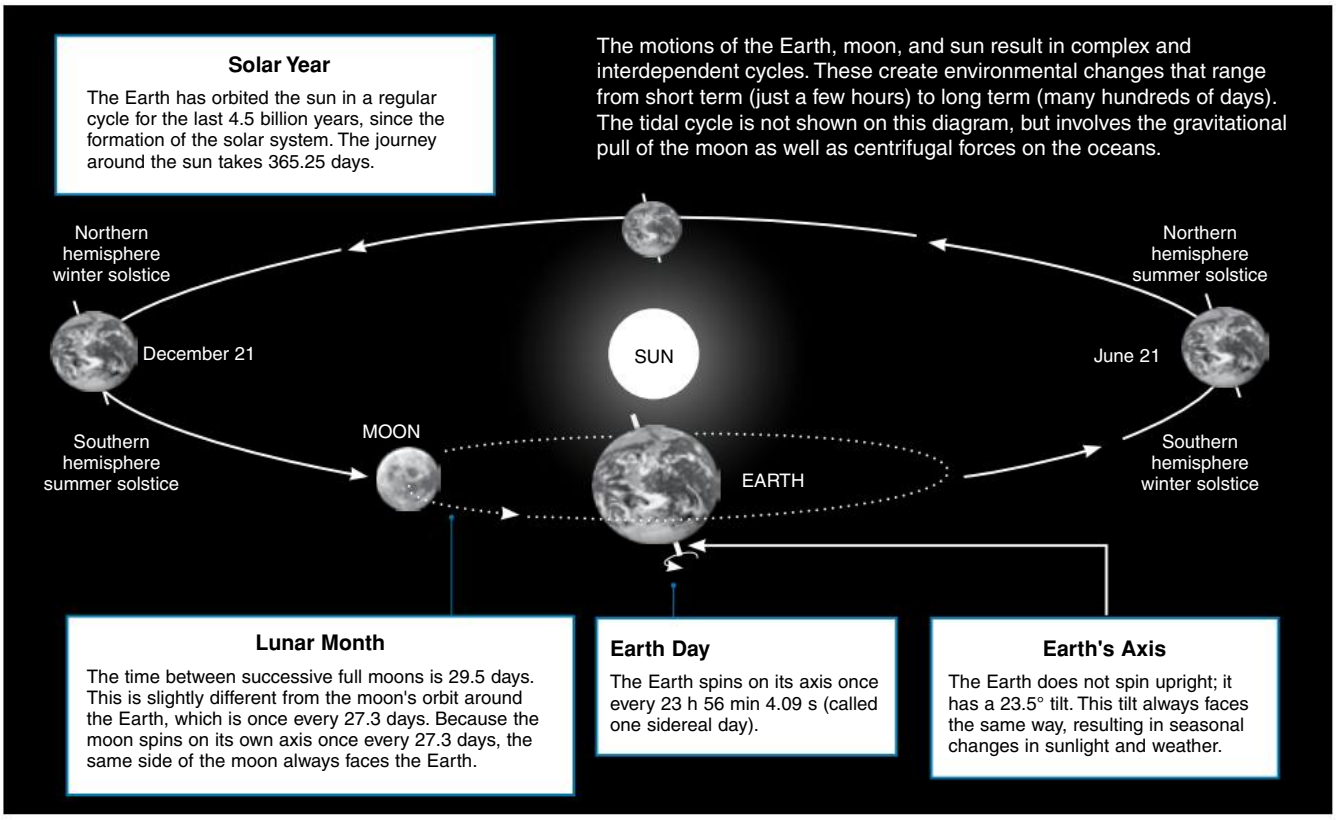
4. Explain why a succession from cleared agricultural land follows a different course than succession after a forest fire:

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283 Environmental Change

Key Idea: Changes in the biosphere, geological forces, and cosmic forces can bring about environmental change.

Environmental changes come from three sources: the biosphere itself, geological forces (crustal movements and plate tectonics), and cosmic forces (the movement of the moon around the Earth, and the Earth and planets around the sun). All three forces can cause cycles, steady states, and trends (directional changes) in the environment. Environmental trends (e.g. climate cooling) cause long term changes in communities. Short term, predictable cycles provide the cues that enable organisms to time important events in their life cycles.



Evidence for Past Changes in the Environment

Geochemical evidence		Physical evidence		Biological evidence	
Type of evidence	**Factor indicated**	**Type of evidence**	**Factor indicated**	**Type of evidence**	**Factor indicated**
Minerals & mineral ratios	Temperature, acidity, precipitation, salinity/ seawater composition	Erosional landforms	Ice movement (drumlins, fjords, hanging valleys), frigid climate, water presence	Macrofossil plants	Flora, habitats, rainfall, temperature
Coal	Abundant vegetation, moisture	Terrestrial soils palaeosols (buried soil profiles)	Vegetation type, climate,& atmospheric composition	Microfossil plants (pollen grains, spores)	Plant communities, temperature, rainfall
Duricrusts	Rainfall	Lake & marine rainfall,sediments	Lake levels, runoff, surface and deep water temperature, salinity	Tree growth rings	Water availability, frosts, growing season
Substitution elements	(in marine shells) temperature	Glaciers & ice sheets	*Advances and retreats*: Temperature, duration of melting season, sunshine and cloudiness, snowfall *Annual layers* (ice cores): Temperature, CO_2 content, aerosol content, nitrates	Animal fossils:	
Trace elements	Salinity			*Mammals*	Climate, habitat
Isotopes:				*Amphibians*	Warmth, watery habitat
Oxygen ($^{18}O/^{16}O$)	Temperature			*Insects*	Temperature, rainfall
Carbon ($^{13}C/^{12}C$)	Vegetation density			*Molluscs*	Climate, salinity for freshwater species
Strontium ($^{87}Sr/^{86}Sr$)	Continental runoff			*Cladocerans* and *ostracods*	Climate, productivity in lakes, water conditions
				Corals	Temperature, salinity
				Foraminifera	Temperature, salinity

Source: Modified from Huggett, R.J., 1997. Environmental Change – The Evolving Biosphere

1. Identify an **environmental cue** that might be used by an organism to time a life cycle event and name that event:

_____

2. For each of the following categories, provide an example of a type of evidence for environmental change:

(a) Geochemical: _____

(b) Physical: _____

(c) Biological: _____

KNOW LINK 272 LINK 273 LINK 274

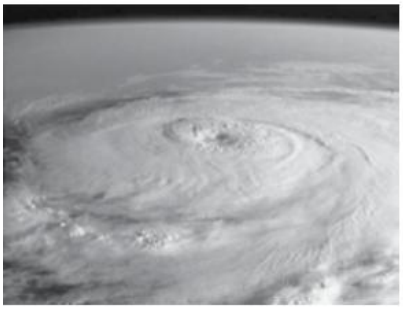
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Climatic change during the last 2-3 million years has involved cycles of glacial and interglacial conditions. These cycles are largely the result of an interplay between astronomical cycles and atmospheric CO_2 concentrations.



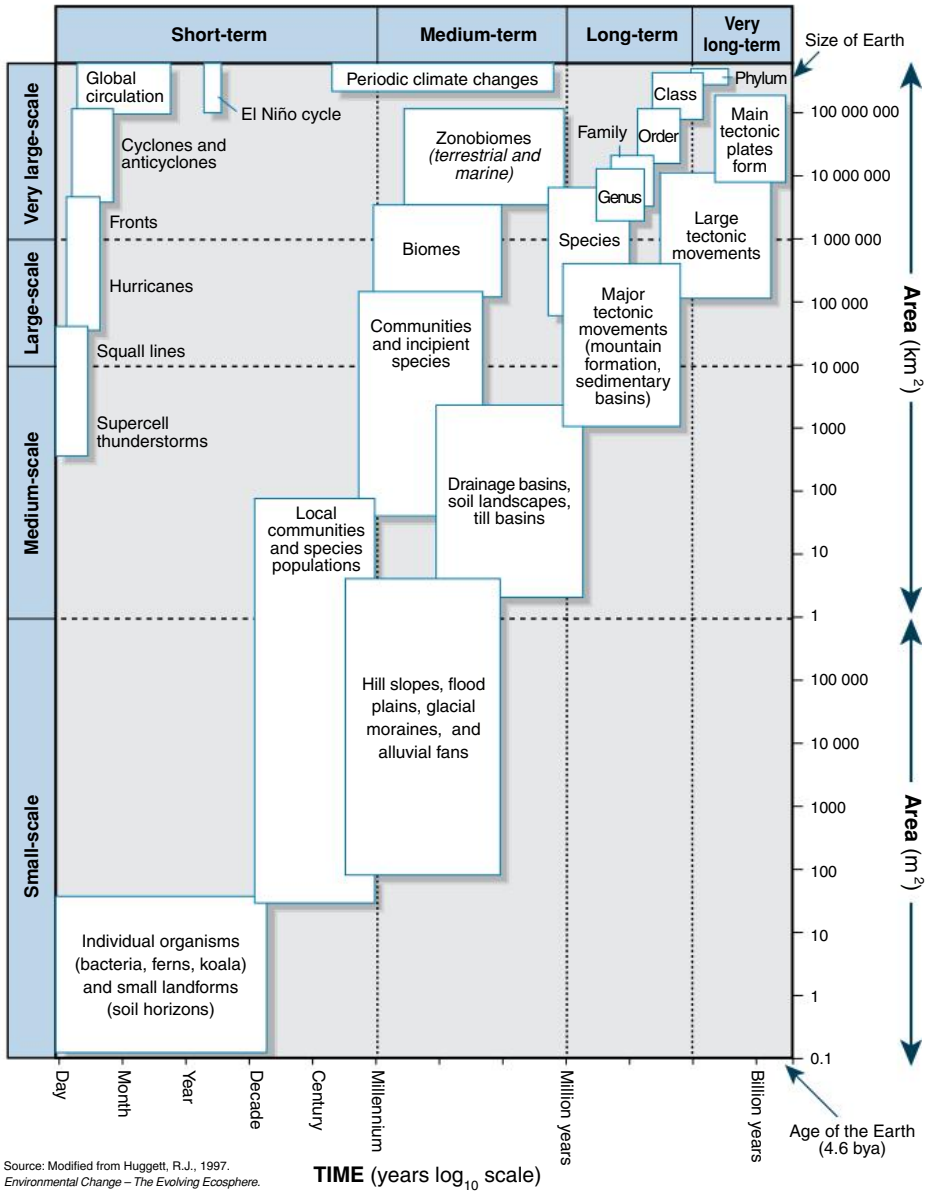
Volcanic eruptions may have a large effect on local biological communities. They may also cause prolonged changes to regional and global weather (e.g. Mount Pinatubo eruption, 1989).



Some weather patterns are responsible for subtle changes to ecosystems, such as the gradual onset of a drought. They may also provide large scale and forceful changes, such as those caused by hurricanes or cyclones.

Time scale and geographic extent of environmental change

(Time scale: horizontal axis / geographic extent: vertical axis)



Source: Modified from Huggett, R.J., 1997. *Environmental Change – The Evolving Ecosphere.*

3. Explain how the study of past changes in the environment (see the table on the previous page) may be used to understand current regional and global climates and to be able to predict future changes:

4. Periodic long term changes in the Earth's orbit, a change in the sun's heat output, and continental drift may have been the cause of cycles of climate change in the distant past. These climate changes involved a cooling of the Earth:

   (a) Name these periods of climate cooling: _____

   (b) Describe two changes to the landscape that occurred during this period: _____

5. (a) On the diagram above, colour-code each of the rectangles to indicate the four themes of environmental change:

   Climatic: ☐ Ecological: ☐ Tectonic: ☐ Evolutionary: ☐

   (b) To what extent are these four types of environmental change interlinked? _____

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284 Ecosystem Stability

Key Idea: An ecosystem's ability to resist and recover from change is called stability. Species diversity influences stability.

Ecological theory suggests that all species in an ecosystem contribute to its function. Therefore, species loss past a certain point is likely to have a detrimental effect on the functioning of the ecosystem and on its ability to resist change and recover from disturbances (its stability). The loss of keystone species can be particularly detrimental.





Rainforests (above left) represent the highest diversity systems on Earth. Whilst they are generally resistant to disturbance, once degraded, (above) they have little ability to recover. The diversity of ecosystems at low latitudes is generally higher than that at high latitudes, where climates are harsher, niches are broader, and systems may be dependent on a small number of key species.

The Concept of Ecosystem Stability

The stability of an ecosystem refers to its apparently unchanging nature over time. Ecosystem stability has various components, including **inertia** (the ability to resist disturbance) and **resilience** (the ability to recover from external disturbances).

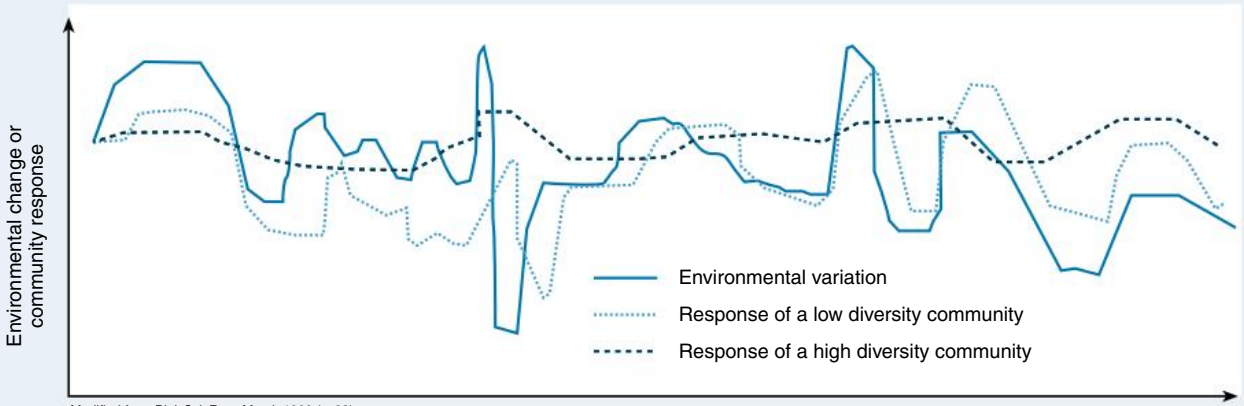
Evidence from both experimental and natural systems indicates that the most diverse ecosystems are also the most stable. This correlation is presumed to be a consequence of the large number of biotic interactions operating to buffer diverse systems against change. However, there is uncertainty over what level of diversity provides insurance against catastrophe. Ecosystems are very complex and stability probably relies more on the differential responses of all its species to variable conditions. Current thinking emphasises the role of multiple factors, including diversity, in dictating stability.





Single species crops (far left), represent low diversity systems that can be vulnerable to disease, pests, and disturbance. In contrast, natural grasslands (left) may appear on the surface to be homogeneous, but contain many species which vary in their predominance seasonally. Although they may be easily disturbed (e.g. by burning) they are very resilient and usually recover quickly.

Community Response to Environmental Change



Modified from Biol. Sci. Rev., March 1999 (p. 22)

In models of ecosystem function, higher species diversity increases the stability of ecosystem functions such as productivity and nutrient cycling. In the graph above, note how the low diversity system varies more consistently with the environmental variation, whereas the high diversity system is buffered against major fluctuations. In any one ecosystem, some species may be more influential than others in the stability of the system. Such **keystone** (key) **species** have a disproportionate effect on ecosystem function due to their pivotal role in some ecosystem function such as nutrient recycling or production of plant biomass.



Elephants can change the entire vegetation structure of areas into which they migrate. Their pattern of grazing on taller plant species promotes a predominance of lower growing grasses with small leaves.



Termites are among the few larger soil organisms able (through a symbiosis with microbes) to break down plant cellulose. They have a profound effect on the rates of nutrient processing in tropical environments.



The starfish *Pisaster* occurs along the coasts of North America where it feeds on mussels. If it is removed, the mussels dominate, crowding out most algae and leading to a decrease in the number of herbivore species.

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Keystone Species in Australia and Threats to Ecosystem Stability



The endangered southern cassowary is a key species in Australia's wet tropics. They are obligate frugivores, and their digestive system passes seeds, unharmed, into a pile of rich manure. Some 70-100 plant species depend on the cassowary to disperse their seeds.

istockphotos.com



Mistletoes are aerial parasitic plants and are a keystone species in Australia, being used by mammals, birds and insects as a source of food (leaves, fruits, or nectar). For some butterfly species (genus *Ogyris*), the mistletoe is an obligatory food plant for their larvae.

Photo: thebegavalley.com plant database



Cane toads are a significant pest in Australia, expanding their range each year and poisoning and competing with native species. Like many invaders, cane toads disturb the natural web of interactions in an ecosystem, contributing to reduction in stability and resilience.

1. What do you understand by the term **ecosystem stability**? _____

2. Give one probable reason why high biodiversity provides greater ecosystem stability: _____

3. Why are **keystone species** so important to ecosystem function? _____

4. Discuss features of the biology of the following organisms that contribute to their position as keystone species:

   (a) Southern cassowary: _____

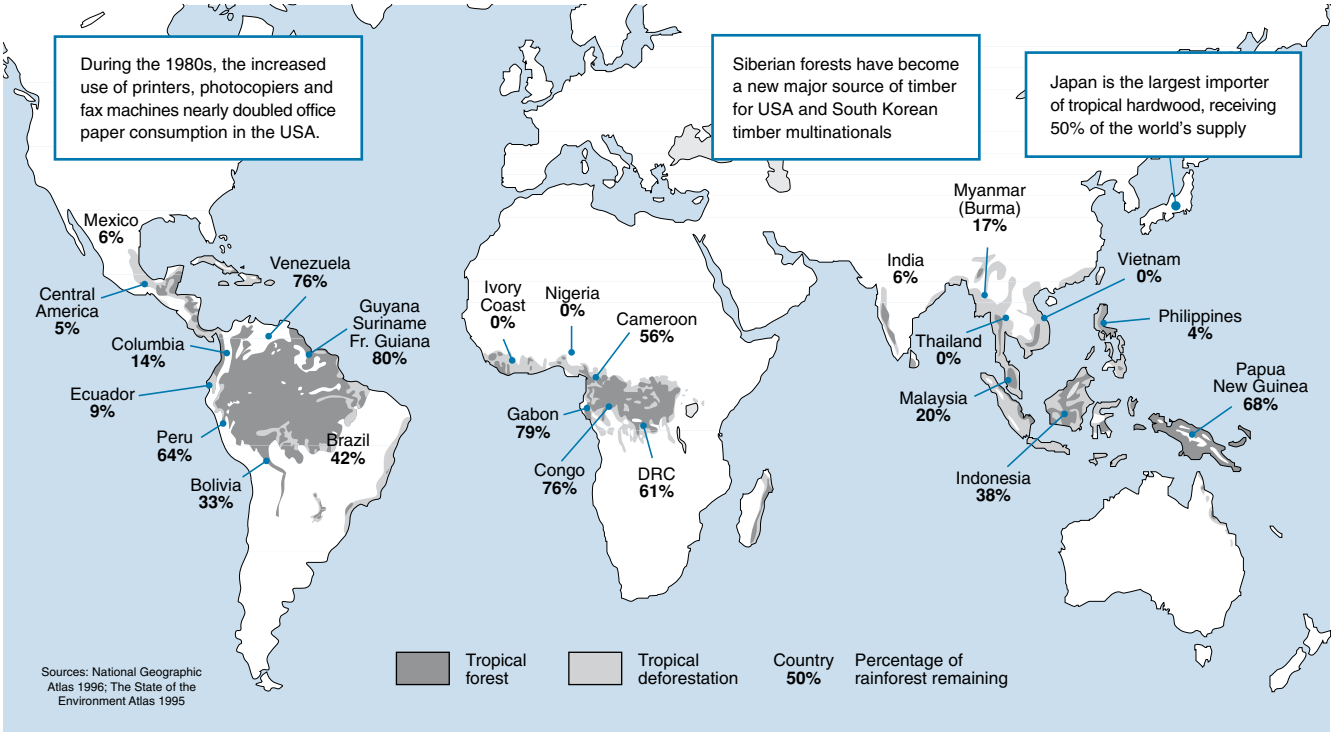
   (b) Mistletoes, (e.g. melaleuca mistletoe, wattle mistletoe): _____

5. With respect to ecosystem diversity, discuss the impact of cane toads in Australia, explaining how they might contribute to instability and ecosystem deterioration:

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285 Tropical Deforestation

Key Idea: Deforestation is the permanent removal of forest from an area. Deforestation has significant negative impacts. Tropical rainforests occur in places where the climate is very moist throughout the year (200-450 cm of rainfall per year). Tropical deforestation contributes towards global warming through a reduction in photosynthesis. Its destruction prevents local people farming sustainable crops (e.g. rubber, nuts, fruit, and oils). Tropical deforestation results in the loss of many species, including species that may be potential new sources of foods or medicines.





Rainforest is being removed at an alarming rate as world demand for tropical hardwoods increases and land is cleared for agriculture. The resulting farms and plantations often have short-lived productivity.



Huge forest fires devastated large amounts of tropical rainforest in Indonesia and Brazil in 1997/98. The fires in Indonesia were started by people attempting to clear the forest areas for farming in a year of particularly low rainfall.



The building of new road networks into regions with tropical rainforests destroys valuable habitat for animal species and increases erosion. In the Amazon, 75% of deforestation has occurred within 50 km of Brazil's roads.

All photos DigitalVision

1. Describe three reasons why tropical rainforests should be conserved:

   (a) _____

   (b) _____

   (c) _____

2. Identify the three main human activities that cause tropical deforestation and briefly describe their detrimental effects:

   (a) _____

   (b) _____

   (c) _____

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286 Agricultural vs Natural Ecosystems

Key Idea: Agricultural systems generally have lower biodiversity than natural ecosystems. Their stability can be maintained by continued input of energy.

Agriculture reduces biodiversity. After the native vegetation has been cleared, soil tillage and burning reduces microbial biomass in the soil, affecting soil structure and processes such as decomposition and nutrient cycling. When habitats shrink, populations decline and small isolated populations may not be viable. Habitat fragmentation also disrupts the activity patterns of mobile species, especially those that will not move over open agricultural land. Vegetation clearance has also caused major changes to the hydrological balance of natural ecosystems in Australia, raising water tables and, in some areas, causing saline groundwater to rise. Australia's legacy of land clearance, species introductions, and farming of marginal land has left the continent impoverished relative to its state 200 years ago. A National Strategy for Ecologically Sustainable Development (ESD) is now in place with the aim to enable development while protecting biological diversity and ecological processes and systems.

Agricultural Ecosystems in Australia

Agriculture is the largest land use in Australia, with the greatest area supporting grazing of cattle and sheep. Most grazing occurs in the rangelands in central and northern Australia, while cropping is concentrated on the coastal fringe. Australian soils have low nutrient content and much of Australia's agriculture is dependent on heavy use of fertilisers. Cultivation practices often result in land degradation, e.g. erosion, soil compaction, and loss of soil structure. Most land practices also modify the hydrology of the area, and can result in erosion, raised water tables, and salinisation.



Features of Agricultural Systems in Australia

- Pastoralism increases the number of large herbivores on the land, increases the number of watering points, decreases the natural fire frequency, and increases the risk of soil erosion.
- Cropping involves heavy use of pesticides and fertilisers, although land practices such as crop rotation and retention of stubble improves the sustainability of some crops (e.g. wheat).
- Native plants keep water tables low. In farmed areas, raised water tables and changes to water flow results in salinisation.
- Agricultural systems are, by their very nature, low diversity systems, typically dominated by only a few species. Their stability is maintained by a constant input of energy.
- Ecosystems are dependent on having a set of species to carry out the cycles of production, consumption, and decomposition. Agricultural systems may lack the diversity necessary for this.

Natural Ecosystems in Australia

Natural ecosystems are heterogeneous. Their features are the result of the long term interactions between the physical and biotic environments. In Australia, the characteristic biota is superbly adapted to survival in one of the most arid and nutrient poor environments on Earth. In the absence of disturbance, Australian ecosystems are diverse and resilient. Australia's vegetation, characterised by sclerophylls, enriches and retains the soil, prevents the rise of salt-rich groundwater, and supports a wide diversity of fauna, even in the arid zones.



Features of Australia's Natural Ecosystems

- Characterised by aridity and generally poor soils over much of the continent. Australia has very few sizeable rivers.
- Most inland lakes are dry for long periods and many are brackish or salty. There is very little permanent fresh water.
- Australia is the world's most fire-prone continent. Much of the vegetation relies on frequent exposure to fire.
- Natural vegetation zones are determined by climate. Forests are found in humid regions and woodland in drier areas.
- Australian lands have a naturally low carrying capacity (a measure of the biomass the land resources can support).
- The low carrying capacity of Australian ecosystems makes them vulnerable to disturbance. Once disturbed, recovery is difficult, e.g. it is difficult to revegetate saline lands.

1. Why are natural ecosystems in Australia particularly vulnerable to poor land management practices? _____

2. Describe an example of an ecosystem in Australia that has been altered by agricultural use. Explain how the ecosystem has been changed and categorise the farming practice as sustainable or non-sustainable:

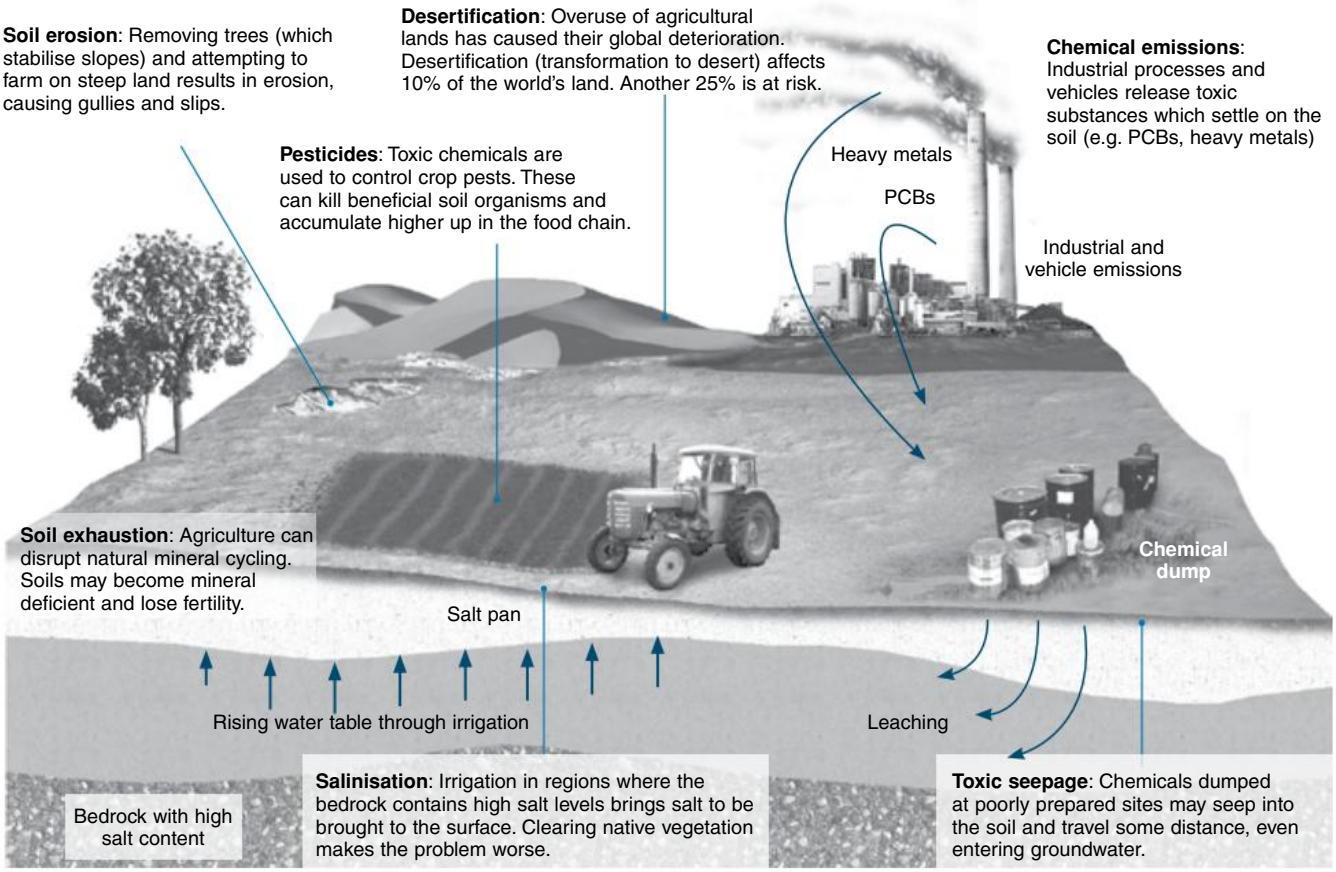
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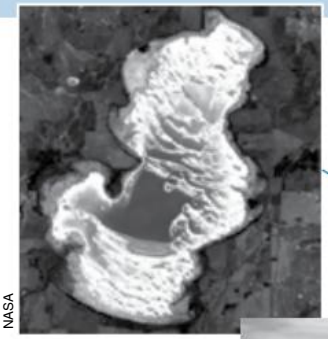
287 Soil Degradation

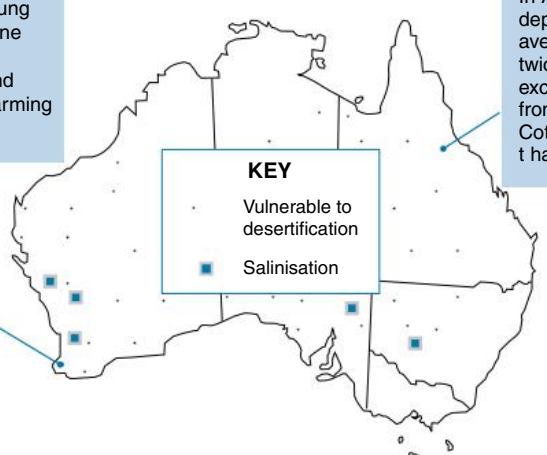
Key Idea: Soil degradation refers to the loss of a soil's equilibrium (structure, composition, and function). Poor land management practices contribute to soil degradation.

Soil is a fragile resource and can be damaged or lost through deforestation and overgrazing. Some soils, such as those under rainforest, are vulnerable to human interference because they are very thin and nutrient poor. If cleared for agriculture, they often become unproductive after only a few years farming. Chemically intensive agricultural practices, may produce reasonable crop yields for a time but are unsustainable because the soil loses its structure, organic matter, and living organisms. With time, poorly managed soils deteriorate, become unproductive, and are at greater risk of loss through erosion (removal of soil).



Land surrounding the salt water Dumbleyung Lake (below), has become increasing saline (white patches) and is now unsuitable for grazing. An estimated 2.5 million ha of land have become salinised since European farming methods were introduced to Australia.


NASA

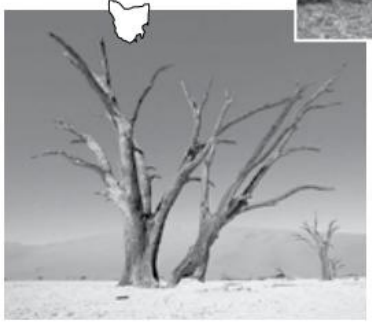


In Australia, soil is replaced by organic deposition at a rate of 0.5 t $ha^{-1}yr^{-1}$, The average rate of soil loss is estimated to be twice that, but some agricultural practices exceed even this rate. The rate of soil loss from sugar cane production is 37 t $ha^{-1}yr^{-1}$. Cotton production depletes soil at a rate of 7 t $ha^{-1}yr^{-1}$.


Sugarcane harvest

Agricultural pesticides and fertilisers, and mining and mineral processing emissions are the biggest land pollutants in Australia. The five biggest chemical land emissions are ammonia, chlorine, chromium (III) compounds, copper compounds and nickel compounds.


Mining



Desertification (left) affects around 42% of Australia's arid and semi-arid lands, with the majority of the country at future risk (see map). Periods of drought make the situation worse as grazing pressures further reduce ground cover and expose land to erosion by wind and water.

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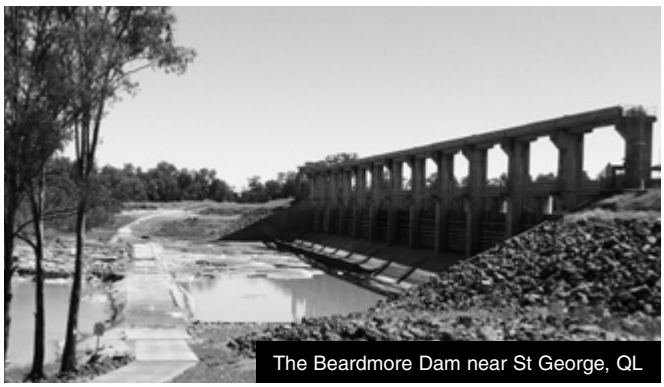
The Murray-Darling Basin, named for the Murray and Darling Rivers, extends over 4 states and supports three quarters of Australia's irrigated land.

Agricultural irrigation, including for rice and cotton, accounts for most of the water extracted from the Murray-Darling system. Clearance of the natural vegetation and irrigation of farmland raises the groundwater level and brings (naturally present) salts to the surface. Once the soil is salty, the native vegetation cannot be replanted.



Irrigation channel for cotton (Balonne River, QL)

Hullwarren CC 3.0



The Beardmore Dam near St George, QL

Hullwarren CC 3.0

The regulation of the river's flow has reduced the frequency and duration of natural floods. There is not more salt than before, but the salt is mobilised by regulation of water levels. Plants cannot grow in salty soil because the soil has a higher solute concentration than the root and the plants are no longer able to get the water they need.

1. How does human induced salinisation develop? _____

2. (a) Describe a biological consequence of salinisation on the natural ecosystems of the Murray-Darling:

   (b) Name two factors responsible for salinisation in the Murray-Darling: _____

3. (a) Describe a human-induced cause of soil erosion, explaining how it results in soil loss: _____

   (b) Suggest how humans could assist in preventing erosion: _____

4. Discuss the features of **desertification**, outlining its causes and the ways in which it might be averted or reversed:

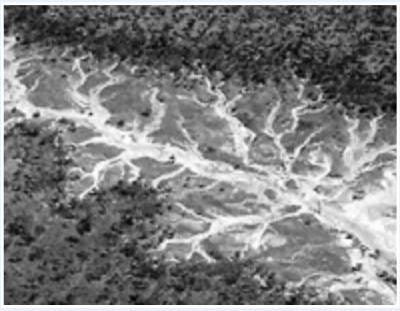
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288 Water Pollution

Key Idea: Water pollution is the contamination of water.

Water pollution occurs when pollutants enter water bodies and contaminate them. Pollutants may enter directly from point sources or via groundwater. Pollutants can alter the physical state of a water body (e.g. temperature or pH) or introduce toxic substances, such as herbicides or oils. Pollutants that increase the nutrient load of a water body create problems by promoting excessive weed and algal growth. Organic effluent also reduces the oxygen concentration in the water because oxygen is used for the microbial decomposition of the extra organic matter. An indicator of the polluting capacity of an effluent is the biochemical (or biological) oxygen demand (BOD). In an arid land such as Australia, conservation of freshwater resources is an important environmental issue.

Sources of Water Pollution



Sediment pollution: Soil erosion causes soil particles to be carried into waterways. Increased sediment loads cause choking of waterways, buildup behind dams, and the destruction of aquatic habitats.



Sewage: Water containing human wastes, soaps and detergents is discharged into waterways such as rivers, lakes and the sea. Most communities apply some treatment.



Pathogens: Disease-causing microbes from infected animals and humans can be discharged into waterways. This is a particular problem during floods when sewage may mix with drinking water.



Inorganic plant nutrients: Fertiliser runoff from farmland adds large quantities of nitrogen and phosphorus to waterways. The nutrient enrichment speeds up **eutrophication** (which naturally occurs very slowly) causing algal blooms and prolific weed growth.



Organic compounds: Synthetic, often toxic, compounds, may be released into waterways from oil spills (above), the application of agrichemicals, and as the waste products of manufacturing (e.g. dioxin, PCBs, dieldrin, phenols).



RA

Thermal pollution: Many industrial processes, including thermal power generation (above), release heated water into river systems. The increase in water temperature reduces oxygen levels and may harm the survival of river species.



Kurchatov Institute

Radioactive substances: Mining and refinement of radioactive metals may discharge radioactive materials. Accidental spills from nuclear power stations, such as the Chernobyl nuclear disaster of 1986, (above) and the recent Fukushima Daiichi nuclear disaster in Japan may contaminate waterways.



Inorganic chemicals: Acid drainage from mines and acid rain can severely alter the pH of waterways. The runoff from open-caste mining operations can be loaded with poisonous heavy metals such as mercury, cadmium, and arsenic.

Detecting Pollution

Water pollution can be monitored in several ways. The nutrient loading can be assessed by measuring the BOD. Electronic probes and chemical tests can identify the absolute levels of various inorganic pollutants (e.g. nitrates, phosphates, and heavy metals). The presence of **indicator species** can give an indication of the pollution status for a waterway. This method relies on an understanding of the tolerance levels to pollution of different species that should be living in the waterway (e.g. worms, insect larvae, snails, and crustaceans).

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Biological Indicators

One of the best ways to determine the health of an ecosystem is to measure the variety of organisms living in it. Certain species, called **indicator species**, are typical of ecosystems in a particular state of health (e.g. polluted or pristine). Evaluating an ecosystem's biodiversity can provide information about its health, particularly if the species assemblages have changed as a result of disturbance.

Diversity can also be quantified using a **diversity index**. Such indices are widely used in ecological work, particularly for monitoring ecosystem change or pollution.



Stephen Moore

A high diversity of stream invertebrates (right) indicates high water quality. It includes indicator species, such as stoneflies, which are only found where oxygen levels are high.

1. What is the main cause of **accelerated eutrophication**? _____

2. Describe three uses of water for each of the following areas of human activity:

   (a) Domestic use: _____

   (b) Industrial use: _____

   (c) Agricultural use: _____

3. (a) What is the **biochemical oxygen demand** (BOD)? How is it related to water pollution? _____

   (b) How could human activity contribute to a very high BOD in a lake or river? _____

   (c) What is the likely effect of a very high BOD on the invertebrates and fish living in a small lake?

   (d) Why is the sample kept in darkness when measuring BOD? _____

4. Sewage effluent may be sprayed onto agricultural land to irrigate crops and plantations of trees:

   (a) What is the advantage of utilising sewage in this way? _____

   (b) Describe a major drawback of using sewage effluent in this way: _____

   (c) Suggest an alternative treatment or use of the effluent: _____

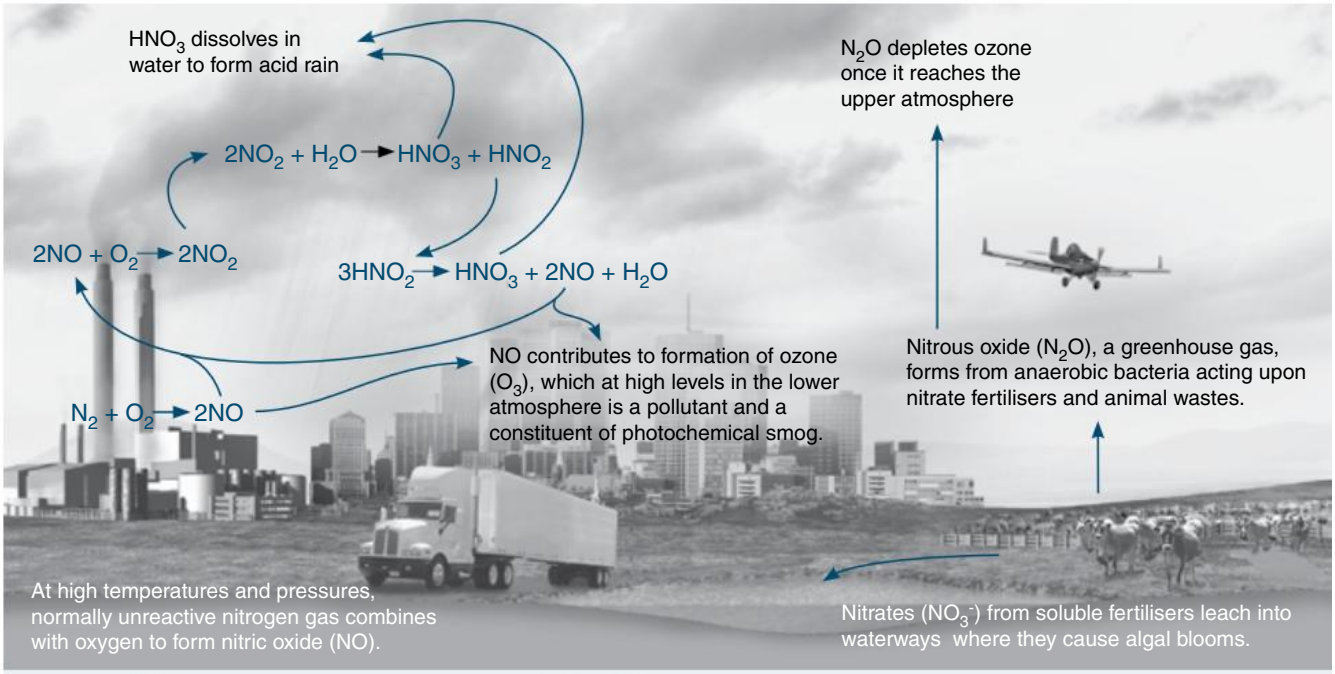
5. At the CSIRO's *Wagga Wagga Effluent Plantation Project*, researchers are experimenting with sewage effluent to irrigate plantations of trees. Why do they regard sewage effluent as a resource, not a waste disposal problem?

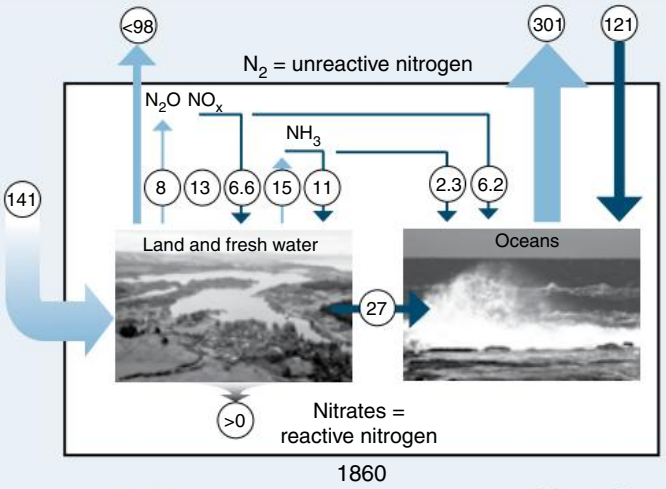
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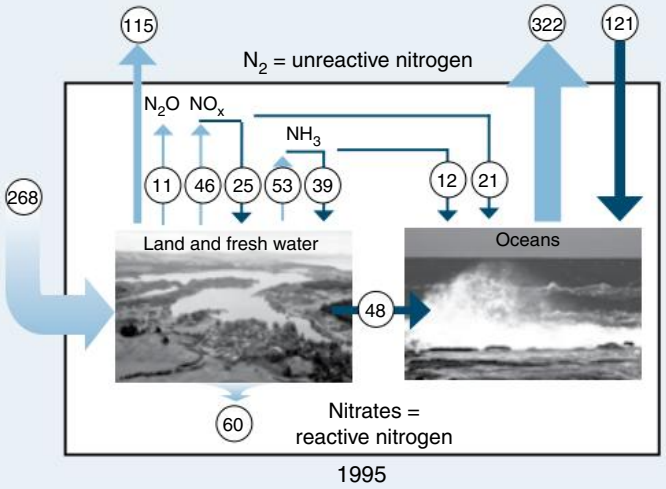
289 Nitrogen Pollution

Key Idea: Excessive nitrogen in the environment can cause groundwater contamination and eutrophication of waterways.

Excess nitrogen in the environment (**nitrogen pollution**) has several effects depending on the compound formed. Nitrogen gas (N_2) makes up almost 80% of the atmosphere but is unreactive at normal pressure and temperature. However, at the high pressures and temperatures of factory processes and combustion engines, N_2 forms nitrogen oxides, which contribute to air pollution. Nitrates in fertilisers are washed into groundwater and slowly make their way to lakes and rivers and eventually out to sea. This process can take time to become noticeable because groundwater may take decades to reach a waterway. Likewise, once nitrate loads are reduced, it may take years for a recovery to occur.

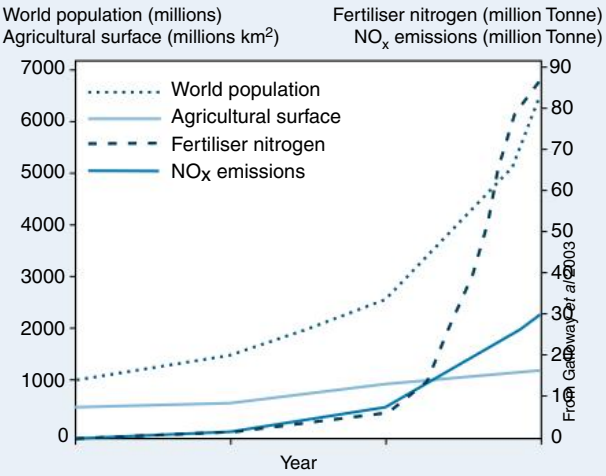






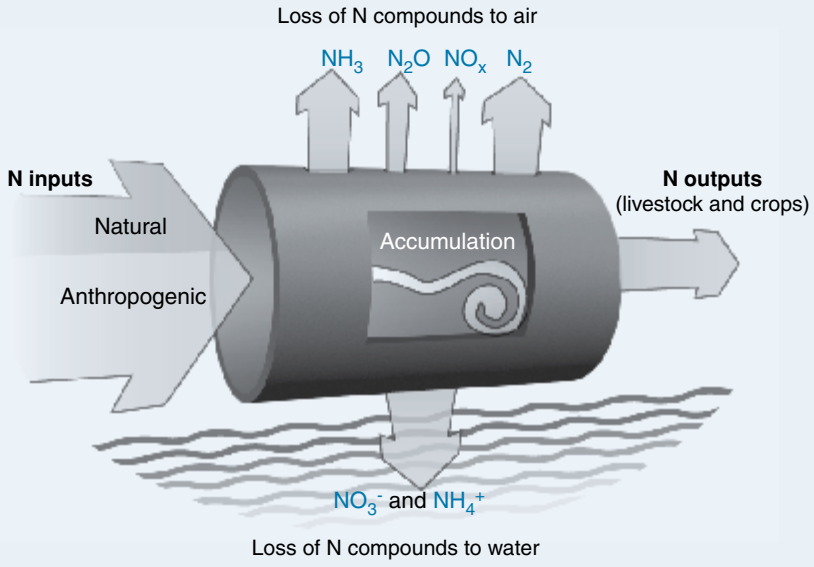
Changes in nitrogen inputs and outputs between 1860 and 1995 in million Tonne (modified from Galloway *et al* 2004)

Early last century, the Haber-Bosch process made nitrate fertilisers readily available for the first time. Since then, the use of nitrogen fertilisers has increased at an almost exponential rate. Importantly, this has led to an increase in the levels of nitrogen in land and water by up to 60 times those of 100 years ago. This extra nitrogen load is one of the causes of human-induced accelerated enrichment (**cultural eutrophication**) of lakes and coastal waters. An increase in algal production also results in higher decomposer activity and, consequently, oxygen depletion, fish deaths, and depletion of aquatic biodiversity. Many aquatic microorganisms also produce toxins, which may accumulate in the water, fish, and shellfish. The diagrams (left) show the increase in nitrates in water sources from 1860 to 1995. The rate at which nitrates are added has increased faster than the rate at which nitrates are returned to the atmosphere as unreactive N_2 gas. This has led to the widespread accumulation of nitrogen.



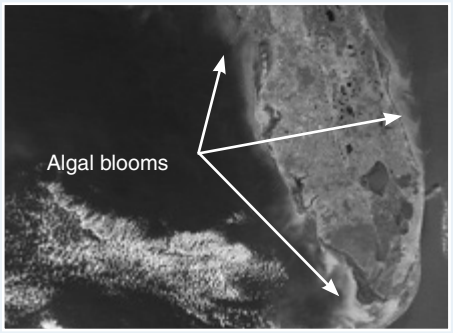
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From O. Oenema *et al* 2007

The "hole in the pipe" model (left) demonstrates inefficiencies in nitrogen fertiliser use. Nitrogen that is added to the soil and not immediately taken up by plants is washed into waterways or released into the air by bacterial action. These losses can be minimised to an extent by using slow release fertilisers during periods of wet weather and by careful irrigation practices.



Satellite photo of algal blooms around Florida. Excessive nitrogen contributes to algal blooms in both coastal and inlands waters. *Image: NASA*

1. Describe the effect each of the following nitrogen compounds have on air and water quality:

   (a) NO: _____

   _____

   (b) N_2O: _____

   _____

   (c) NO_2: _____

   _____

   (d) NO_3^-: _____

   _____

2. Explain why the formation of NO can cause large scale and long term environmental problems: _____

   _____

   _____

3. Why would an immediate halt in the use of nitrogen fertilisers not cause an immediate stop in their effects?

   _____

   _____

   _____

4. (a) Calculate the increase in nitrogen deposition in the oceans from 1860 to 1995 and compare this to the increase in release of nitrogen from the oceans.

   _____

   (b) What is the effect of this increase on the oceans? _____

   _____

5. (a) Why do nitrogen inputs tend to be so much more than outputs in crops and from livestock? _____

   _____

   (b) Suggest how the nitrogen losses could be minimised: _____

   _____

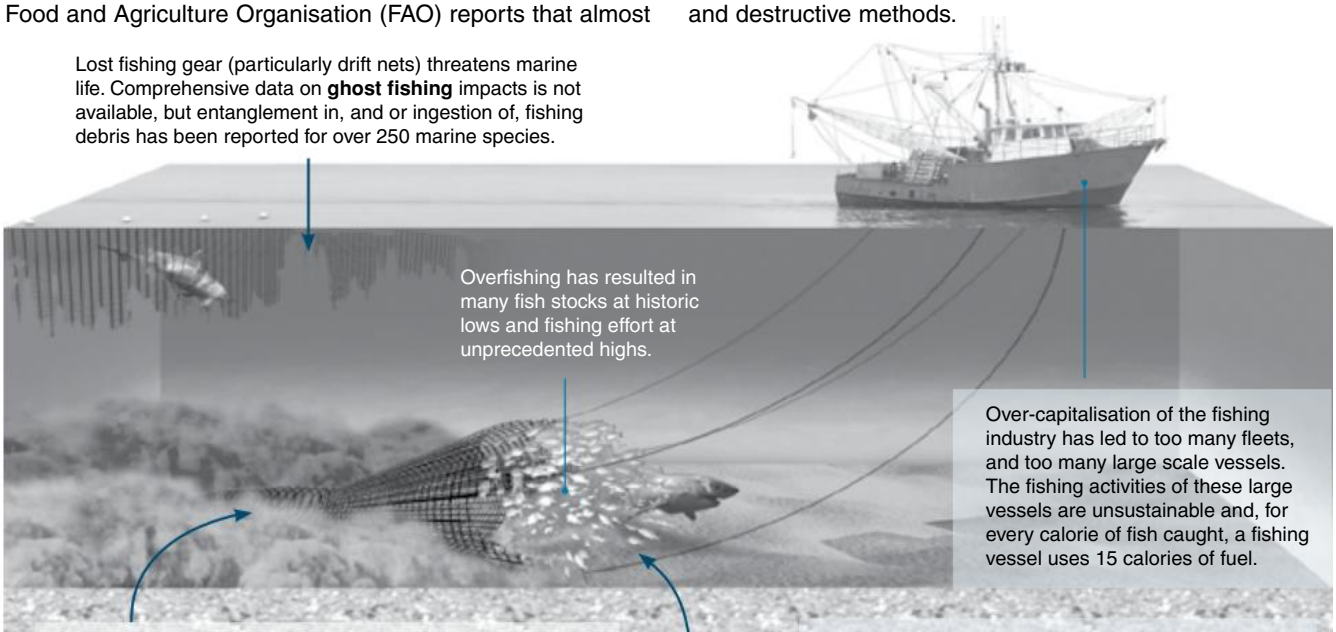
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290 Ecological Impacts of Fishing

Key Idea: Fisheries must be managed to ensure they are sustainable. Overfishing can severely deplete fish stocks.

Commercial fishing is a worldwide resource extraction industry. Decades of over-fishing has pushed commercially important species (such as cod) into steep decline. The UN's Food and Agriculture Organisation (FAO) reports that almost seven out of ten of the ocean's commercially targeted marine fish stocks are either fully or heavily exploited (44%), over-exploited (16%), depleted (6%), or in recovery (3%). The maximum sustainable yield has been exceeded by too many fishing vessels catching too many fish, often using wasteful and destructive methods.



Lost fishing gear (particularly drift nets) threatens marine life. Comprehensive data on **ghost fishing** impacts is not available, but entanglement in, and or ingestion of, fishing debris has been reported for over 250 marine species.

Overfishing has resulted in many fish stocks at historic lows and fishing effort at unprecedented highs.

Over-capitalisation of the fishing industry has led to too many fleets, and too many large scale vessels. The fishing activities of these large vessels are unsustainable and, for every calorie of fish caught, a fishing vessel uses 15 calories of fuel.

Bottom trawls and dredges cause large scale physical damage to the seafloor. Non-commercial, bottom-dwelling species in the path of the net can be uprooted, damaged, or killed, turning the seafloor into a barren, unproductive wasteland unable to sustain marine life. An area equal to half the world's continental shelves is now trawled every year. In other words, the world's seabed is being scraped 150 times faster than the world's forests are being clear-cut.

The limited selectivity of fishing gear results in millions of marine organisms being discarded for economic, legal, or personal reasons. These organisms are defined as **by-catch** and include fish, invertebrates, protected marine mammals, sea turtles, and sea birds. Depending on the gear and handling techniques, some or all of the discarded organisms die. A recent estimation of the worldwide by-catch is approximately 30 million tons per year, which is about one third of the estimated 85 million tons of catch that is retained each year.



Photo: Jane Ussher

Longline fishing (mainly for tuna) results in the death of 100,000 albatrosses and petrels every year in the southern Pacific alone. Six of the world's twenty albatross species are in serious decline and longline fishing is implicated in each case.



NOAA

Over-harvesting of abundant species, or removal of too many reproductive individuals from a population, can have far reaching ecological effects. Modern boats, with their sophisticated fish-finding equipment, have the ability to catch entire schools of fish.



Fish farming, once thought to be the solution to the world's overfishing problems, actually accelerates the decline of wild fish stocks. Many farmed fish are fed meal made from wild fish, but it takes about 1 kg of wild fish to grow 300 g of farmed fish. Some forms of fish farming destroy natural fish habitat and produce large scale effluent flows.

1. What does **over-exploitation** mean in relation to commercial fisheries management? _____

_____

2. What is **by-catch**? _____

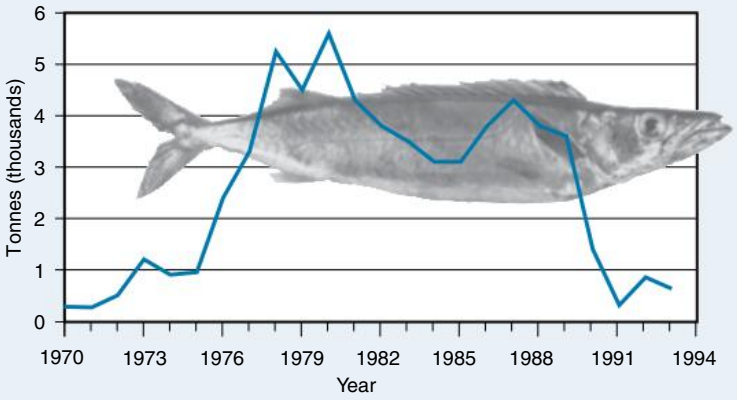
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Gemfish (*Rexia solandri*)

The graph below shows the commercial gemfish catch, 1970-1993. There is agreement that, in the last decade, the species has been in general decline.



Gemfish are distributed throughout southern Australian waters, living in deep water from 100-700 m. Mature gemfish form large migrating schools of the coast of NSW, where they are easily targeted by trawlers. The decline in the gemfish catch has been well documented and it represents a classic case of fisheries over-exploitation. Although the total allowable catch (TAC) was set at zero in 1993, there is still a considerable bycatch and the fishery has not recovered, and may never do so. Suggested measures for the protection of this fish stock include:

- Protection of pre-spawning and spawning aggregations with exclusion of trawlers in particular from these areas.
- Action to increase mesh sizes to minimise death of juvenile fish caught as by-catch.
- The establishment of a more extensive system of marine protected areas to act as refuges.

Stocks of commercially fished species must be managed carefully to ensure that the catch does not undermine the sustainability of the fishery. In Australia, about 50 species make up 85% of the commercial catch. The most important species are either fully exploited and are being managed to achieve a sustainable yield, or have been overexploited and are now being managed to allow recovery.

Total allowable catch (TAC): The amount of the fish stock that can legally be caught.

Maximum sustainable yield: The maximum amount that can be routinely caught without long-term depletion.

Source: CSIRO marine research

3. Using an example, explain why a catch over the **maximum sustainable yield** will result in the collapse of a fishery:

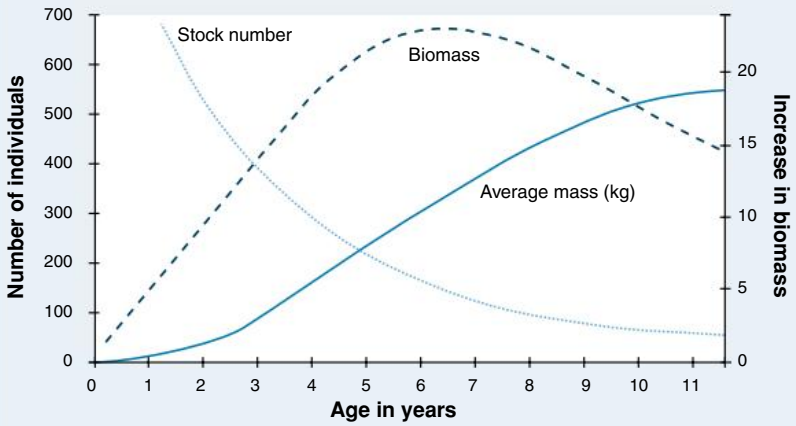
4. Use the graph showing the relationship between age, biomass, and stock numbers in a hypothetical commercially harvested fish population (below, right) to answer the following questions:

   (a) What is the optimum age for harvest?

   (b) During which age range does the greatest increase in biomass occur?

   (c) What other life history data would be required by fisheries scientists when deciding on the management plan for this population?

The relationship between age, biomass, and stock numbers in a commercially harvested fish population



5. Using the gemfish as an example:

   (a) Discuss the current state of the fishery (including stock status, catch rates, and TAC):

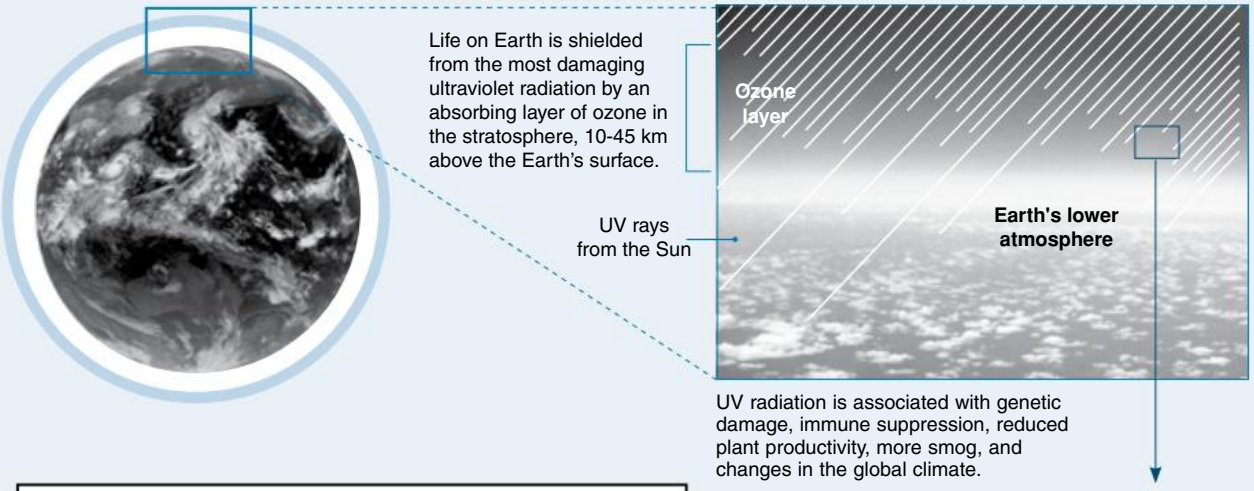
   (b) Describe some management options for conserving the fishery:

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291 Stratospheric Ozone Depletion

Key Idea: The ozone layer absorbs the majority of the Sun's UV light, preventing it from reaching the Earth's surface. Human activity has reduced the ozone layer.

The **ozone** (O_3) layer in the upper stratosphere, 17-26 km above the Earth's surface, absorbs about 99% of the harmful UV radiation from the sun and prevents it from reaching the Earth's surface. The ozone layer is being depleted by human-produced chemicals (ozone depleting compounds). Researchers discovered that ozone in the upper stratosphere over Antarctica is destroyed during the Antarctic spring and early summer (September–December). This destruction takes the form of a thinning, where ozone levels decrease by 50%-100%. Severe ozone loss has also been observed over the Arctic. During the winter of 1999-2000, Arctic ozone levels were depleted by 60% at an altitude of 18 km, up from around 45% in the previous winter. The main cause of ozone depletion are chemicals such as chloro-fluoro-carbons (CFCs) which release reactive free chlorine. The use of ozone-depleting substances has been cut by 70% since 1987. Ozone loss is projected to diminish gradually until around 2050 when the polar ozone holes will return to 1975 levels. It will take another 100-200 years for full recovery.



Sources of ozone depleting chemicals

The chemicals listed below drift up to the stratosphere, where ultraviolet radiation causes release of free chlorine, a highly reactive chemical.

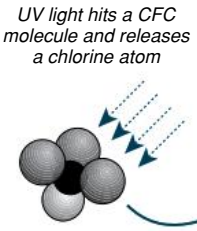
Chloro-fluoro-carbons (CFCs)
- Propellants for aerosol cans
- Coolants in air-conditioners
- Coolants (freon) in refrigerators
- Styrofoam insulation/packaging
- Medical sterilisers

Halons
- Used in many fire extinguishers

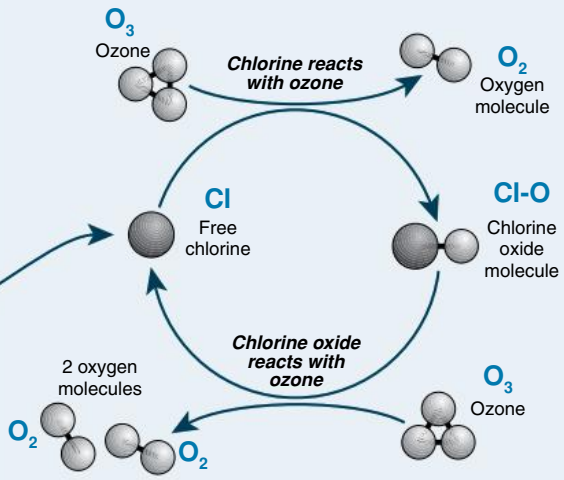
Methyl bromide
- Used as a fumigant in agriculture

Methyl chloroform
- Used to degrease metals

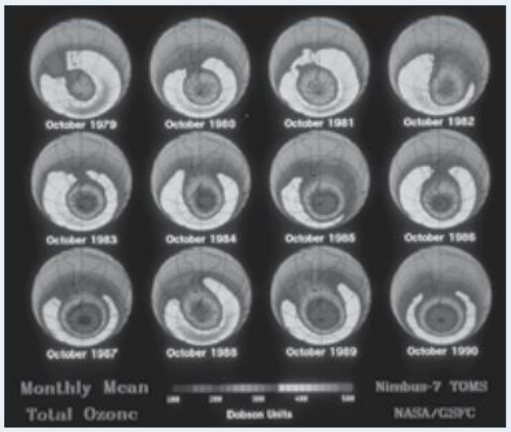
Carbon tetrachloride
- Used in many industrial processes



The destruction of ozone by free chlorine



A thinning in the ozone layer develops over Antarctica each summer, dropping the ozone well below its normal level. The size and intensity of the 'hole' is growing each year, as can be seen in the satellite photos on the right. In recent years, a similar hole has developed over the Arctic.



Photos: NASA/Goddard Space Flight Center

Dobson Unit (DU): A measurement of **column ozone** levels (the ozone between the Earth's surface and outer space). In the tropics, ozone levels are typically between 250 and 300 DU year-round. In temperate regions, seasonal variations can produce large swings in ozone levels. These variations occur even in the absence of ozone depletion. **Ozone depletion** refers to reductions in ozone below normal levels after accounting for seasonal cycles and other natural effects. For a graphical explanation, see NASA's TOMS site: **http://toms.gsfc.nasa.gov/teacher/basics/dobson.html**

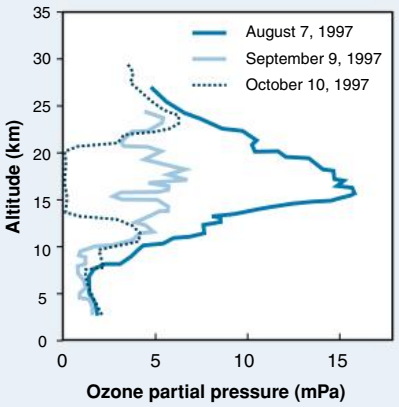
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Characteristics of the ozone 'hole'

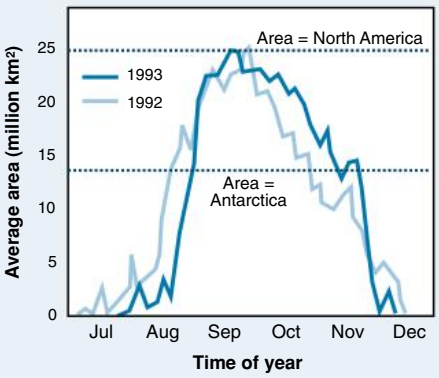
The ozone 'hole' (stratospheric ozone depletion) can be characterised using several measures. The five graphs on this page show how the size and intensity of the hole varies through the course of a year, as well as how the phenomenon has progressed over the last two decades. An explanation of the unit used to measure ozone concentration (Dobson units) is given on the opposite page. Graphs 2 and 5 illustrate readings taken between the South Pole (90° south) and 40° latitude.

Data supplied by NASA's Goddard Space Flight Center and the National Oceanic and Atmospheric Administration (NOAA) in the USA.

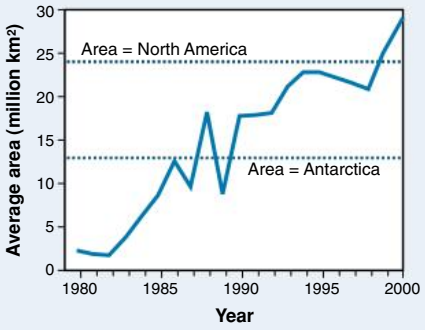
Graph 1: Ozone hole altitude profile



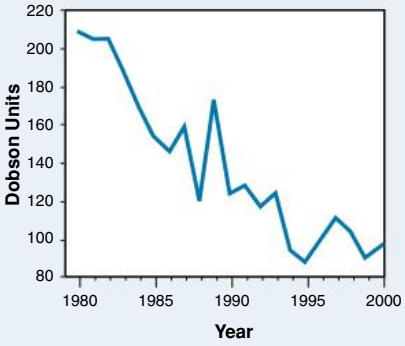
Graph 2: Antarctic ozone hole area (<220 DU, 40° – 90° South)



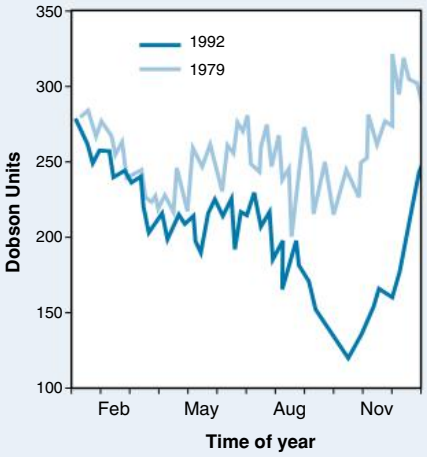
Graph 3: Change in area of the Antarctic ozone hole*



Graph 4: Antarctic ozone hole minimum values* (60° – 90° S)



Graph 5: Antarctic ozone hole minimum values (40° – 90° South)



* Date range in which samples were collected in each year: 7 Sep–13 Oct
The ozone 'hole' is defined as region with less than 220 Dobson units

Sources: NASA Goddard Space Flight Centre; NOAA / CMDL

1. What are some of the damaging effects of excessive amounts of ultraviolet radiation on living organisms?

2. How has the atmospheric release of CFCs increased the penetration of UV radiation reaching the Earth's surface?

3. With reference to the graphs (1-5 above) illustrating the characteristics of the stratospheric ozone depletion problem:

   (a) What time of year is the ozone 'hole' at its greatest geographic extent? _____

   (b) What time of year is the 'hole' at its most depleted (thinnest)? _____

   (c) Describe the trend over the last two decades of changes to the abundance of stratospheric ozone over Antarctica:

   (d) Describe the changes in stratospheric ozone with altitude between August and October 1997 in Graph 1 (above):

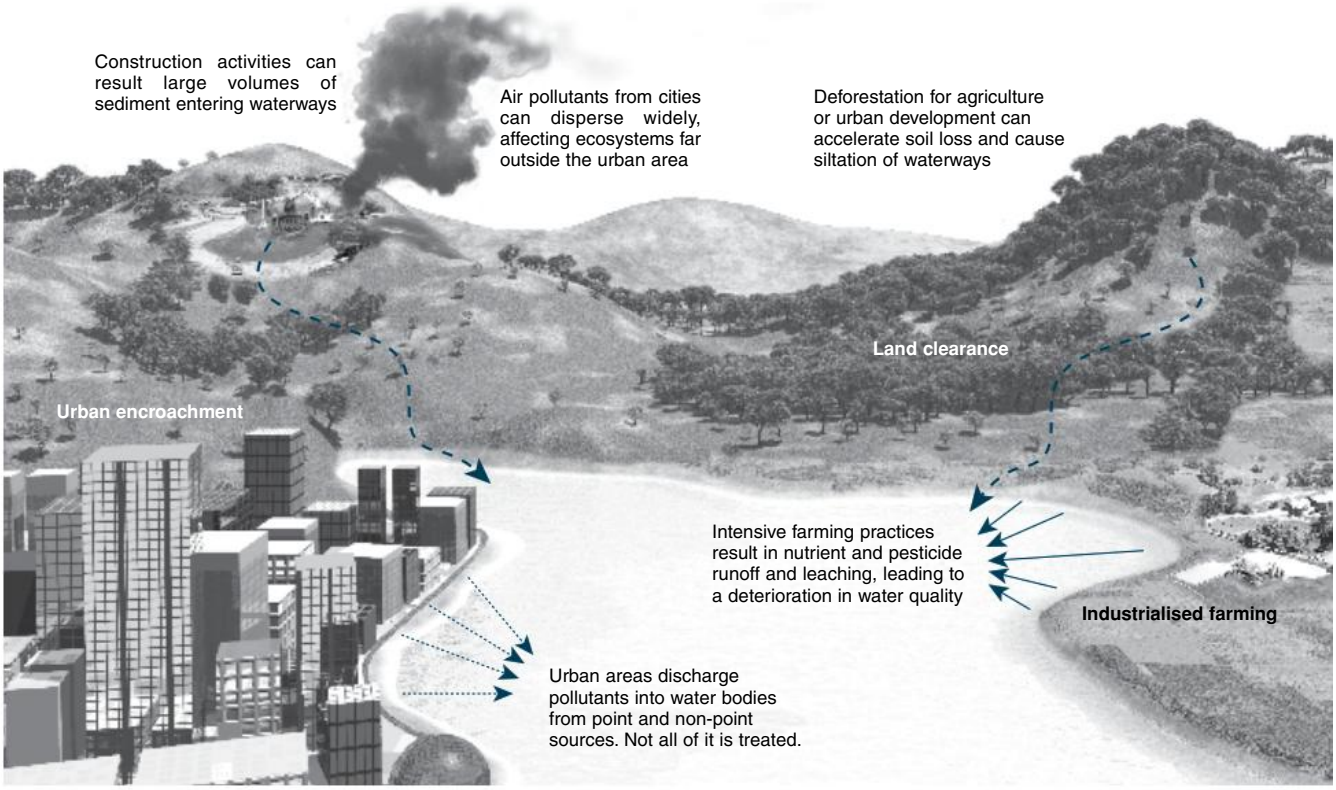
4. Discuss some of the political and commercial problems associated with reducing the use of ozone depleting chemicals:

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292 Effects of Urbanisation

Key Idea: Urbanisation can result in ecological problems such as pollution of air, water, and soil.

Urbanisation is the redistribution of people from rural to urban environments. Almost half of the world's population live in urban areas, and this is likely to increase to up to 90% by the end of the 21st century. Urbanisation has an enormous impact on the natural environment, through roading, land clearance, construction, increased population pressure and pollution. While pollutants often contaminate the areas where they are produced, they can also be carried by wind or water to other areas. Cities face a range of problems associated with providing residents with adequate water, food, sanitation, housing, jobs, and basic services, such as health care. Slums or squatter settlements are found in most large cities in developing countries as more poor people migrate from rural to urban areas.





The traditional villages characteristic of the rural populations of less economically developed countries have a close association with the land. The households depend directly on agriculture or harvesting natural resources for their livelihood and are linked through family ties, culture, and economics.



Cities are differentiated communities, where the majority of the population does not depend directly on natural resource-based occupations. While cities are centres of commerce, education, and communication, they are also centres of crowding, pollution, and disease.

Immigration pull factors

- Opportunity for better jobs
- Chance of better housing
- More reliable food supply
- Opportunity for greater wealth
- Freedom from village traditions
- Government policy

Immigration push factors

- Rural overpopulation
- Lack of work or food
- Changing agricultural practices
- Desire for better education
- Racial or religious conflict
- Political instability

1. Describe some of the detrimental effects of urbanisation: _____

_____

_____

2. Explain the impact of urbanisation on the pollution load in a given region: _____

_____

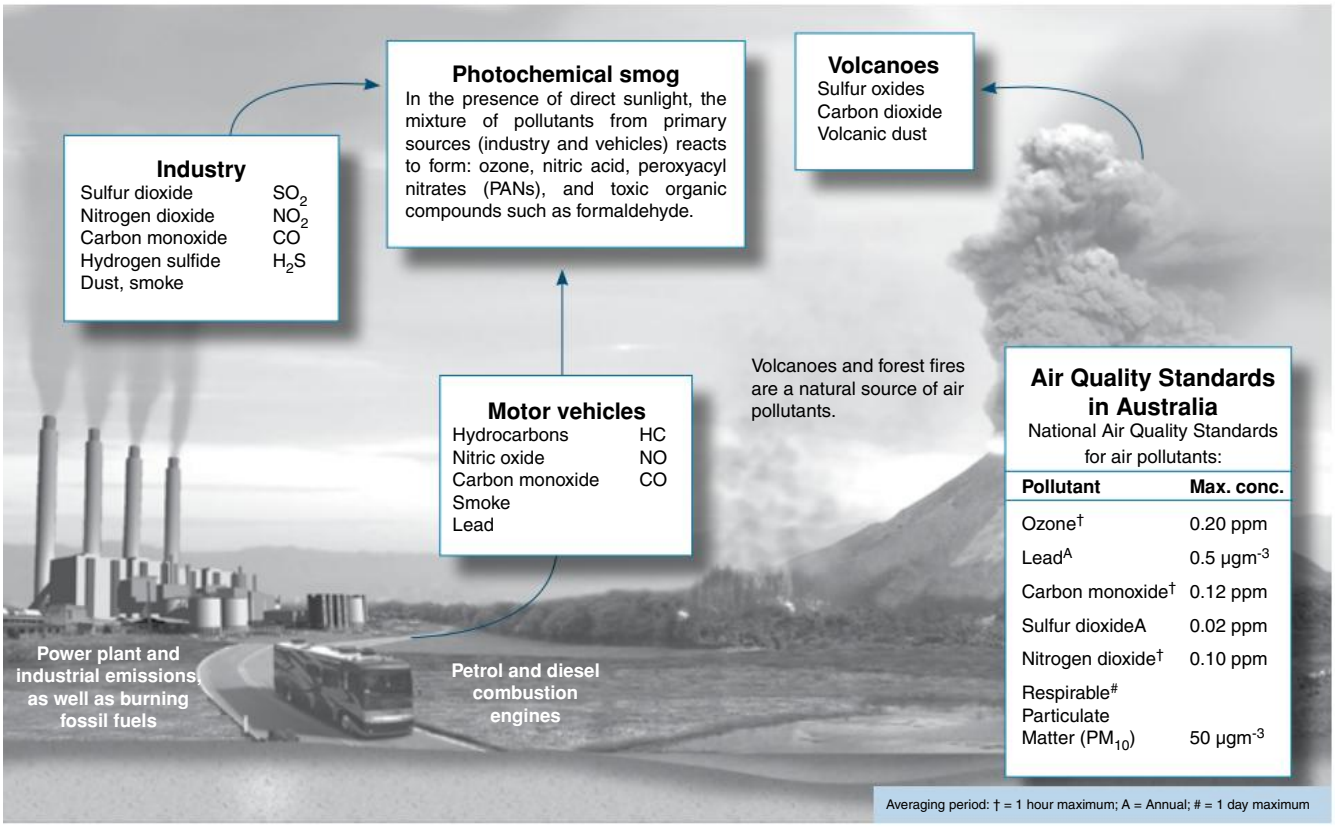
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293 Air Pollution

Key Idea: Air pollution is the presence of contaminants in the atmosphere at levels high enough to harm living things. Human activities contribute to air pollution.

Air pollution consists of gases, liquids, or solids present in the atmosphere at levels high enough to harm living things. Human activities and natural processes both contribute to global air pollution. Lightning causes forest fires, oxidises nitrogen and creates ozone, while erupting volcanoes give off toxic and corrosive gases. **Primary air pollutants** are emitted directly from the source. **Secondary air pollutants** form when primary pollutants react in the atmosphere (e.g. acid rain). Air pollution tends to be concentrated around areas of high population density. Air pollution also occurs indoors. The air enclosed in spaces such as cars, homes, schools, and offices may have significantly higher levels of harmful air pollutants than the air outdoors.



Air Quality Standards in Australia

National Air Quality Standards for air pollutants:

Pollutant	Max. conc.
Ozone†	0.20 ppm
LeadA	0.5 μgm^{-3}
Carbon monoxide†	0.12 ppm
Sulfur dioxideA	0.02 ppm
Nitrogen dioxide†	0.10 ppm
Respirable# Particulate Matter (PM_{10})	50 μgm^{-3}

Averaging period: † = 1 hour maximum; A = Annual; # = 1 day maximum



Air pollution inside buildings (sick building syndrome) can cause eye irritations, nausea, headaches, respiratory infections, depression and fatigue. Gases, ozone, and microbes are implicated.



Aircraft contribute to air pollution with their jet exhaust at high altitude (at 10,000 m). Infections (e.g. TB and SARS) can spread through the recirculated cabin air.



Automobiles are the single most important contributor of air pollutants in large cities, producing large amounts of carbon monoxide, hydrocarbons, and nitrous oxides.

1. Identify some natural sources of air pollution: _____

2. Identify a primary source of air pollution in large cities: _____

3. Distinguish between primary pollutants and secondary pollutants: _____

_____

_____

4. Suggest why secondary pollution is a particular problem in cities: _____

_____

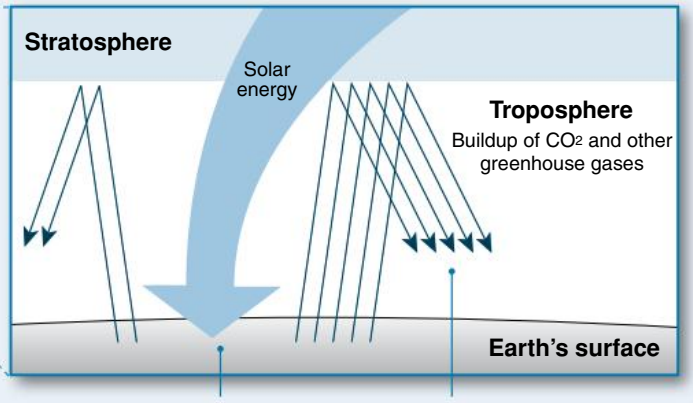
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294 Global Warming

Key Idea: Global warming refers to the continuing rise in the average temperature of the Earth's surface caused by increasing levels of greenhouse gases in the atmosphere.

Since the mid 20th century, the Earth's surface temperature has been steadily increasing. This phenomenon, called **global warming**, is attributable to the increase in atmospheric levels of **greenhouse gases** (water vapour, carbon dioxide, methane, nitrous oxide, and ozone) which occur naturally in the atmosphere. A natural process, called the **greenhouse effect**, describes how the atmosphere lets in sunlight, but traps the heat that would normally radiate back into space. This process results in the Earth having a mean surface temperature of about 15°C (33°C warmer than it would have without an atmosphere). About 75% of the natural greenhouse effect is due to water vapour. The next most significant agent is CO_2. Fluctuations in the Earth's surface temperature as a result of climate shifts are normal, but since the Industrial Revolution (1760-1840), human activities have put more greenhouse gases (primarily CO_2) into the atmosphere, resulting in global warming.





Sources of 'Greenhouse Gases'

Carbon dioxide
- Exhaust from cars
- Combustion of coal, wood, oil
- Burning rainforests

Methane
- Plant debris and growing vegetation
- Belching and flatus of cows

Chloro-fluoro-carbons (CFCs)
- Leaking coolant from refrigerators
- Leaking coolant from air conditioners

Nitrous oxide
- Car exhaust

Tropospheric ozone*
- Triggered by car exhaust (smog)

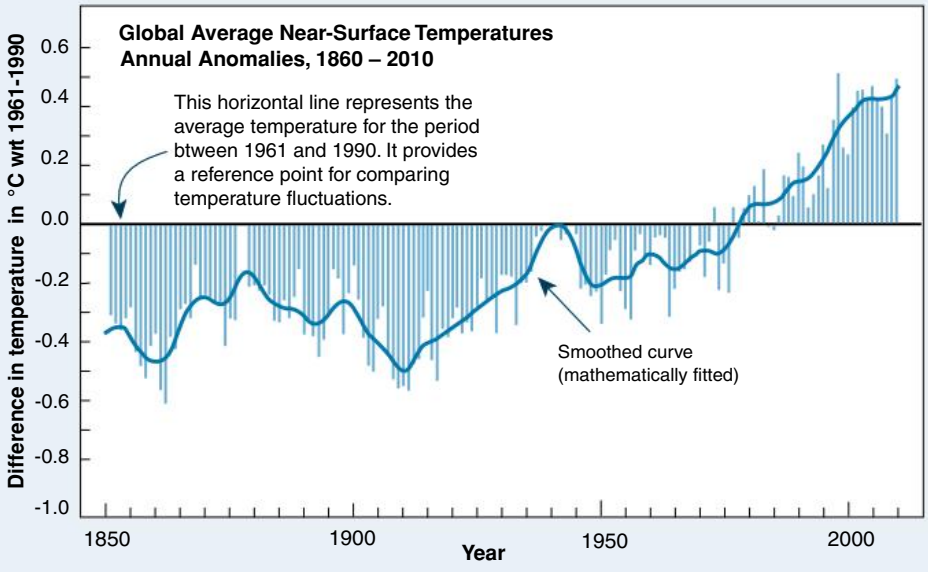
*Tropospheric ozone is found in the lower atmosphere (not to be confused with ozone in the stratosphere)

Greenhouse gas (excluding water vapour)	Tropospheric conc.		Global warming potential *(compared to CO_2)¶*	Atmospheric lifetime *(years)§*
	Pre-industrial 1750	Present day (2012*)		
Carbon dioxide	280 ppm	395.4 ppm	1	120
Methane	700 ppb	1796 ppb	25	12
Nitrous oxide	270 ppb	324 ppb	310	120
CFCs	0 ppb	0.39 ppbb	4000+	50-100
HFCs‡	0 ppb	0.045 ppb	1430	14
Tropospheric ozone	25 ppb	34 ppb	17	hours

ppm = parts per million; **ppb** = parts per billion; ‡Hydrofluorcarbons were introduced in the last decade to replace CFCs as refrigerants; * Data from 2012-2013. ¶ Figures contrast the radiative effect of different greenhouse gases relative to CO_2 over 100 years, e.g. over 100 years, methane is 25 times more potent as a greenhouse gas than CO_2. § How long the gas persists in the atmosphere. *Data compiled from the Carbon dioxide Information Centre http://cdiac.ornl.gov/pns/current_ghg.html*

This graph shows how the mean temperature for each year from 1860-2010 (bars) compares with the average temperature between 1961 and 1990. The blue line represents the fitted curve and shows the general trend indicated by the annual data. Most anomalies since 1977 have been above normal; warmer than the long term mean, indicating that global temperatures are tracking upwards. The decade 2001-2010 has been the warmest on record.

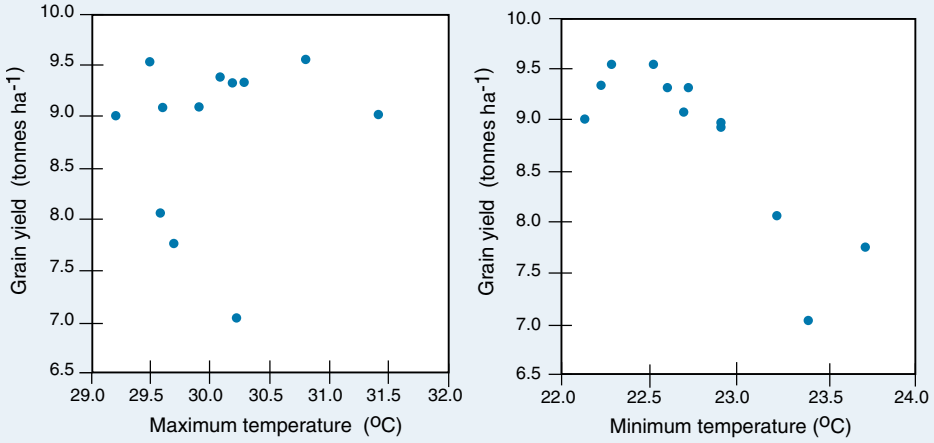
Source: Hadley Center for Prediction and Research



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Effects of increases in temperature on crop yields

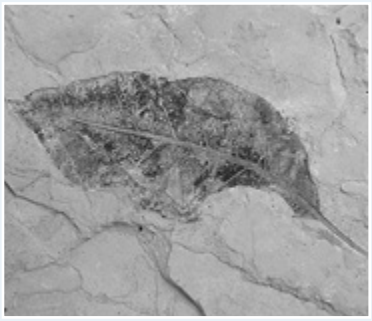


Studies on the grain production of rice have shown that maximum daytime temperatures have little effect on crop yield. However minimum night time temperatures lower crop yield by as much as 5% for every 0.5ºC increase in temperature.

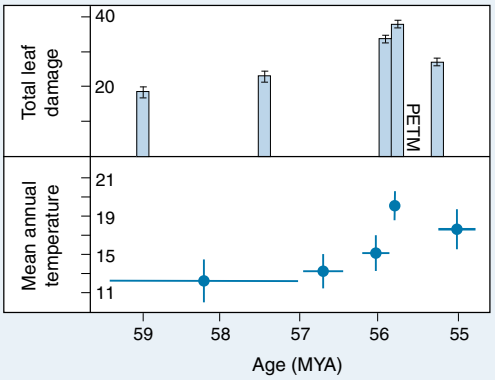


Source: Peng S. *et.al.* PNAS 2004

Possible effects of increases in temperature on crop damage



Source: Currano *et.al.* PNAS 2007



The fossil record shows that global temperatures rose sharply around 56 million years ago. Studies of fossil leaves with insect browse damage indicate that leaf damage peaked at the same time as the Paleocene Eocene Thermal Maximum (PETM). This gives some historical evidence that as temperatures increase, plant damage caused by insects also rises. This could have implications for agricultural crops.



Some sectors of Australian agriculture (e.g. timber production in SA) may benefit from temperature increases, but in general the predictions are for an overall negative impact. Net agricultural production may fall by 6% as a result of wheat production and cattle growth rates falling by 30 and 128% respectively.



A large proportion of Australia's population live in coastal communities. Climate modelling indicates that a temperature increase of 1-2°C will result in sea level rise and increased storm intensity, causing more frequent flooding and beach erosion. Property damage, loss of land, and declines in tourism are likely results.

1. Calculate the increase (as a %) in the 'greenhouse gases' between the pre-industrial era and the 2012 measurements using the data from the table above. HINT: The calculation for carbon dioxide is: (395.4 - 280) ÷ 280 x 100 =

   (a) Carbon dioxide: _____ (b) Methane: _____ (c) Nitrous oxide: _____

2. What are the consequences of global temperature rise on low lying land? _____

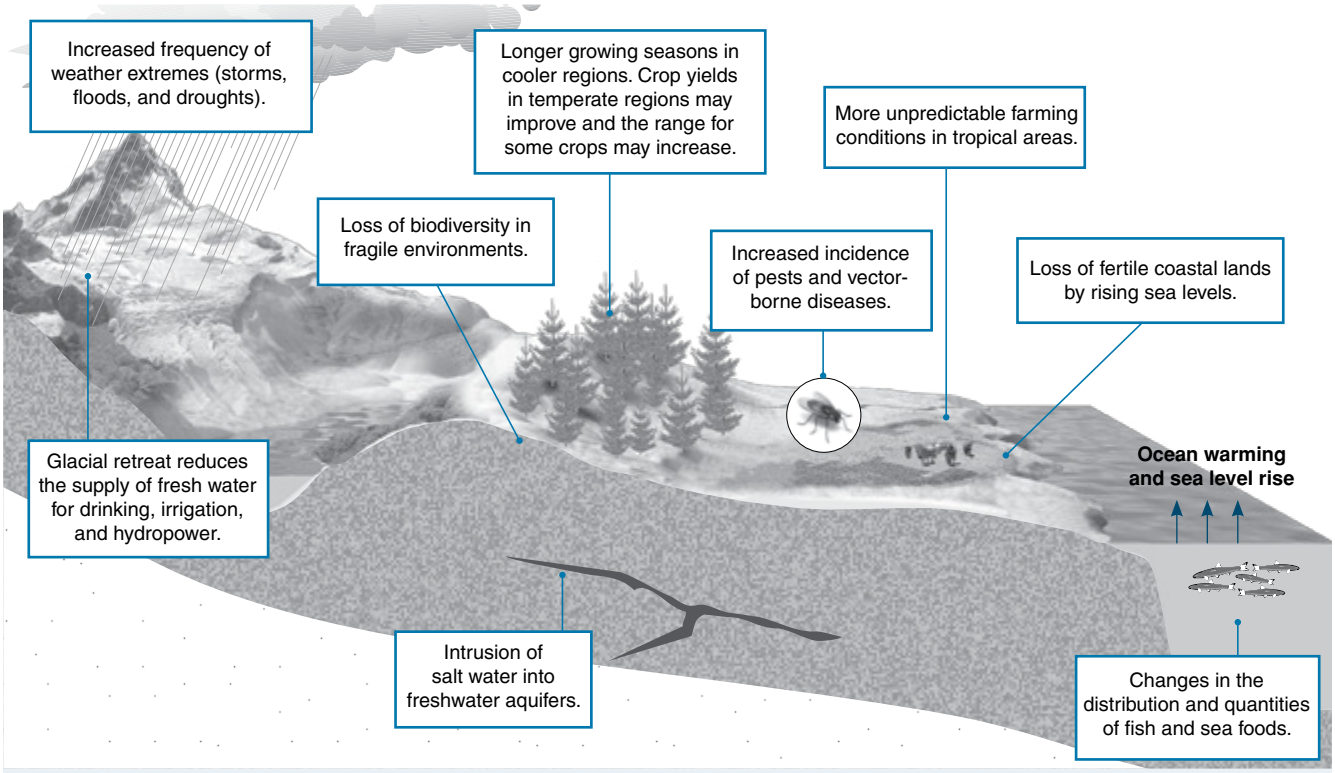
3. Explain the relationship between the rise in concentrations of atmospheric CO_2, methane and oxides of nitrogen, and the enhanced greenhouse effect:

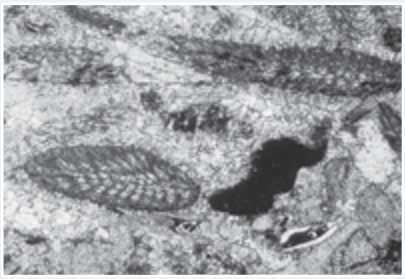
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295 Biodiversity and Global Warming

Key Idea: Global warming is causing shifts in the distribution, behaviour, and viability of plant and animal species.

Global warming is changing the habitats of organisms and this may have profound effects on the biodiversity of specific regions as well as on the planet overall. As temperatures rise, organisms may be forced to move to areas better suited to their temperature tolerances. Those that cannot move or tolerate the temperature change may face extinction. Changes in precipitation as a result of climate change will also affect where organisms can live. Long term changes in climate will ultimately result in a shift in vegetation zones as some habitats contract and others expand.

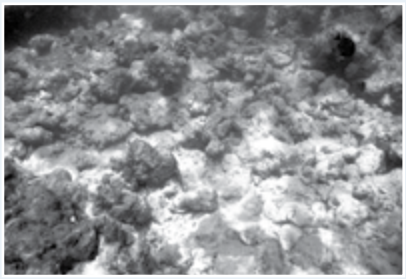




A 2009 study of 200 million year old plant fossils from Greenland has provided evidence of a sudden collapse in biodiversity that is correlated with, and appears to be caused by, a very slight rise in CO_2 levels.



An Australian study in 2004 found the centre of distribution for the AdhS gene in *Drosophila*, which helps survival in hot and dry conditions, had shifted 400 kilometres south in the last twenty years.



Warmer water threatens coral reefs, such as the Great Barrier Reef, by causing coral bleaching. Three incidents of coral bleaching have occurred in the reef in recent years with up to 90% of coral being lost in some areas.



Around 25% of eucalypts have a low tolerance to temperature change, with a less than 1ºC difference in the mean annual temperature throughout their entire habitat range. If trends in global warming continue, this could lead to a reduction in many eucalypt tree populations.



Photo: Bruce Marcot http://taos-telecommunity.org

Green ring-tail possums (*Pseudochirops archeri*) in Queensland cannot regulate their body temperature correctly if the ambient temperature rises above 30ºC. After only 5 hours at this temperature they will die. A large number died during a heat wave in 2002.

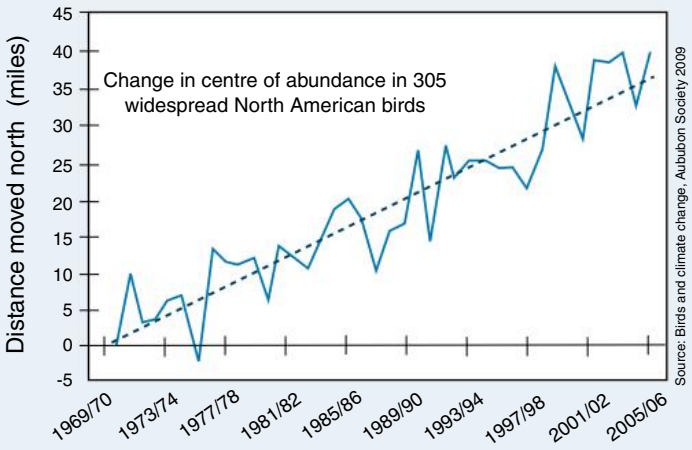


Warmer temperatures may expand the habitat for many disease-causing pests. The CSIRO predict that malarial receptive zones will move southward, the rates of Dengue fever will increase, and melioidosis disease will spread south, affecting more people.

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Effects of increases in temperature on animal populations



A number of studies indicate that animals are beginning to be affected by increases in global temperatures. Data sets from around the world show that birds are migrating up to two weeks earlier to summer feeding grounds and are often not migrating as far in winter.

Animals living at altitude are also being forced to shift their natural range as climate warms. As temperatures increase, the snow line rises in altitude, reducing the range available to alpine species. In the Australian Alps the mountain pygmy possum (*Burramys parvus)* faces reduction in its already tiny habitat range as the snow line rises and the amount of precipitation as snow declines. Early spring warming also puts it in danger of starvation, as it wakes from hibernation before its food supply, the bogong moth (*Agrotis infusa*), arrives.



http://www.abc.net.au/science

1. Describe three likely changes to the habitat range of an organism as a result of climate change:

   (a) _____

   (b) _____

   (c) _____

2. (a) How have increases in global temperatures affected some migratory birds? _____

   _____

   _____

   (b) How might these changes in migratory patterns affect food availability for these populations? _____

   _____

   _____

3. How could global warming lead to the local extinction of some alpine species? _____

   _____

   _____

4. Describe some of the historical evidence of the effect of global warming on biodiversity: _____

   _____

   _____

   _____

5. Describe the evidence that global warming is affecting the genetics of animals: _____

   _____

   _____

6. Explain how climate warming could affect organisms with a limited physiological tolerance to temperature change:

   _____

   _____

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296 KEY TERMS: Mix and Match

Test your vocabulary by matching each term to its definition, as identified by its preceding letter code.

biodiversity .....

climax community .....

conservation .....

deforestation .....

diversity indices .....

ecological succession .....

ecosystem stability .....

eucalypt .....

eutrophication .....

global warming .....

Gondwana .....

greenhouse effect .....

greenhouse gas .....

pollution .....

primary succession .....

salinisation .....

sclerophyll .....

secondary succession .....

soil degradation .....

stratospheric ozone depletion .....

urbanisation .....

A The decline in the stratospheric ozone over the Earth's polar regions.

B The number or variety of species living within given ecosystem, biome, or on the entire Earth. The species richness.

C A succession sequence that occurs on land that has not had plants or soil in the past. Usually bare rock.

D The retention of solar energy in the Earth's atmosphere by gases that absorb heat and prevent it being released back into space.

E The gain of excess nutrients into an environment, often by farm runoff or pollution.

F The redistribution of people from rural areas to urban environments.

G The active management of natural populations in order to rebuild numbers and ensure species survival.

H Vegetation characterised by hard, leathery, evergreen foliage. Adapted to minimise water loss.

I A succession sequence that takes place after a land clearance event (e.g. forest fire or landslide). It does not involve the loss of seeds and root stock.

J The progression from initial colonisation of a newly cleared area to a climax community.

K Sometimes called gum trees. Flowering trees belonging to the myrtle family (Myrtaceae). The predominant tree flora of Australia.

L A southern supercontinent which consisted of South America, Africa, India, New Zealand, Australia and Antarctica. Began breaking up in the Mesozoic.

M A reduction in the equilibrium or balance of a previously stable soil (e.g. through nutrient depletion, pollution, or salinisation).

N The process of the Earth's surface steadily increasing in temperature. Usually attributed to the rise in gases produced by fossil fuels and industrial processes.

O Statistics used to quantify the heterogeneity of a system. Often used in ecological studies to assess environmental health.

P The accumulation of soluble salts of sodium, magnesium, and calcium in soil.

Q The ability of an ecosystem to resist change.

R The act of placing into an environment chemicals that not usually found there. These are usually industrial in nature and have a detrimental effect on the environment.

S A community that has reached an equilibrium with the environment and no longer appears to be changing in composition.

T The removal of forests for fuel, building material, or grazing land.

U Any gas in the atmosphere that causes the retention of heat in the Earth's atmosphere. Major gases are water vapour and carbon dioxide.

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297 Dynamic Ecosystems Synoptic Question

1. Australia has many plants and animals that are not found anywhere else on Earth. Many of these have evolved as a result of Australia's geological isolation from other land masses. Using named examples, describe the role of Australia's geographical history on the evolution of Australia's unique fauna and flora. You may use extra paper if required.

2. Describe the role that European settlement in Australia has had on Australia's natural ecosystems and biodiversity. Include reference to the later impacts of human activity on the environment. You may use extra paper if required.

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Appendix

Questioning terms in biology

The following terms are often used when asking questions in examinations and assessments.

Analyse:	Interpret data to reach stated conclusions.
Annotate:	Add brief notes to a diagram, drawing or graph.
Apply:	Use an idea, equation, principle, theory, or law in a new situation.
Calculate:	Find an answer using mathematical methods. Show the working unless instructed not to.
Compare:	Give an account of similarities between two or more items, referring to both (or all) of them throughout.
Construct:	Represent or develop in graphical form.
Contrast:	Show differences. Set in opposition.
Define:	Give the precise meaning of a word or phrase as concisely as possible.
Derive:	Manipulate a mathematical equation to give a new equation or result.
Describe:	Define, name, draw annotated diagrams, give characteristics of, or an account of.
Design:	Produce a plan, object, simulation or model.
Determine:	Find the only possible answer.
Discuss:	Show understanding by linking ideas. Where necessary, justify, relate, evaluate, compare and contrast, or analyse.
Distinguish:	Give the difference(s) between two or more items.
Draw:	Represent by means of pencil lines. Add labels unless told not to do so.
Estimate:	Find an approximate value for an unknown quantity, based on the information provided and application of scientific knowledge.
Evaluate:	Assess the implications and limitations.
Explain:	Provide a reason as to how or why something occurs.
Identify:	Find an answer from a number of possibilities.
Illustrate:	Give concrete examples. Explain clearly by using comparisons or examples.
Interpret:	Comment upon, give examples, describe relationships. Describe, then evaluate.
List:	Give a sequence of answers with no elaboration.
Measure:	Find a value for a quantity.
Outline:	Give a brief account or summary. Include essential information only.
Predict:	Give an expected result.
Solve:	Obtain an answer using numerical methods.
State:	Give a specific name, value, or other answer. No supporting argument or calculation is necessary.
Suggest:	Propose a hypothesis or other possible explanation.
Summarise:	Give a brief, condensed account. Include conclusions and avoid unnecessary details.

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