VCE ENVIRONMENTAL SCIENCE | UNITS 3 & 4

5TH EDITION
fully revised and updated

Issues of sustainability

ENVIRONMENT EDUCATION VICTORIA

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Please be aware that this publication may contain images and names of Aboriginal and Torres Strait Islander people now deceased.

Foreword

Environment Education Victoria acknowledges the generous support from the many contributors to this fifth edition of *Issues of Sustainability*. VCE Environmental Science continues to expand as a subject, and as we head towards 2030 there is no more important time to shape the careers of young people aspiring to become environmental practitioners. The broad career options for young people studying Environmental Science, like the subject matter itself, will evolve, and the work taken on by students who continue along this path will be world changing.

We trust that this new edition provides teachers and students with the tools to go from awareness to deeper understanding, to be able to improve local ecosystems and delve into the diverse opportunities to become part of the solution for global issues and climate change.

Committee of Management
Environment Education Victoria

ENVIRONMENT EDUCATION VICTORIA

Acknowledgement of Country

Environment Education Victoria acknowledges the Traditional Custodians and Elders of the lands on which we live and work. We extend our respect to Elders past, present and emerging of all First Nations peoples. We respect and uphold Aboriginal and Torres Strait Islander peoples' vital and continuing connection to the land, air, waters, culture and all living things.

UNIT 3

UNIT 4

UNIT 3

How can biodiversity and development be sustained?

AREA OF STUDY 1

Why is maintaining biodiversity worth a sustained effort?

Australia is one of 17 countries described as being 'mega diverse' in terms of its terrestrial and marine life. While only accounting for 10% of the global surface, this group of 17 countries contains more than 70% of the biodiversity on the planet. In this area of study students use biodiversity as a lens through which to investigate the management of a single Earth system – the biosphere. They examine the categories of biodiversity, the role of biodiversity in sustaining ecosystems, the provision of ecosystem services for human well-being and the strategies employed to counteract threats, both natural and human-induced, to maintain biodiversity in the short, medium and long term.

The selection of learning contexts should allow students to develop practical techniques and undertake fieldwork and other practical activities to investigate how biodiversity is measured and monitored in the context of a selected threatened species of interest. Students generate primary data, and organise and present this data, to evaluate whether efforts to ensure the long-term survival of the selected species are justified.

Outcome 1

On completion of this unit the student should be able to explain the importance of Earth's biodiversity and how it has changed over time, analyse the threats to biodiversity, and evaluate management strategies to maintain biodiversity in the context of one selected threatened endemic species.

Key knowledge

Area	Section
Importance of biodiversity	
• the definition and categories of biodiversity: genetic, species and ecosystem	1.1
• the importance of genetic diversity within a species or population experiencing environmental change	1.2
• ecosystems as a source of renewable services that impact on human health and well-being: – provisioning services: potable water; food; fuel; fibre; and pharmaceuticals – regulating services: control of climate and disease; pollination; and water purification – supporting services that maintain conditions for life on Earth: cycling of nutrients; soil formation; and photosynthesis – cultural services: aesthetic values; recreational benefits; and sense of place	1.3

Area	Section
Biodiversity changes over time	
• evidence of variation in rate and extent of change in biodiversity over time: significant mass extinctions and periods of rapid species diversification that can be inferred from the fossil record	2.1
• natural changes occurring over different time scales that influence ecosystem diversity, species endemism, the formation of diversity hotspots, and rate of extinction: volcanic eruptions; fire; El Niño; tectonic plate movement; and evolution	2.2
Assessing changes in species diversity	
• practical techniques used for assessing species diversity: sampling with grids, transects and different shaped quadrats, including consideration of edge effects and mark-recapture	3.1
• measurement of species diversity, including species richness, endemism and the application of Simpson's Index of Diversity (SID): $SID = 1 - \frac{\Sigma[n_i(n_i - 1)]}{N(N - 1)}$	3.2
• conservation categories for ranking species according to their risk of extinction: extinct in the wild; critically endangered; endangered; vulnerable; near threatened; and least concern	3.4
• qualitative assessment of conservation status to identify the species most in need of conservation action: changes in availability of suitable habitat, geographic distribution, and population size	3.4
Threats to biodiversity	
• human and non-human threats to biodiversity: creation and isolation of small populations through habitat loss and over-exploitation; inbreeding due to small population size; loss of pollinators, dispersal agents, host species or symbionts that affect reproduction and persistence of species; bioaccumulation that concentrates some persistent pollutants within organisms and biomagnification along a food chain; climate change; disease; and introduced species that compete for shelter, food and water	4.1

Area	Section
Protection and restoration of biodiversity	
• strategies for maintaining and growing populations that also build species resilience to changes in the environment: protected areas; retaining remnant vegetation; wildlife corridors or zones; translocation of animals; captive breeding and reintroduction programs; gene banks for the collection of specimens and genetic material; and reduction and improved targeting of pesticides in agricultural and urbanised areas	5.1
• approaches to renewing and regenerating degraded ecosystems: restoration of habitat; erosion control; and reintroduction of previously endemic species	5.2
• the application of relevant international, national, state and local legal treaties, agreements and regulatory frameworks that apply to the protection of threatened species: the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); IUCN Red List of Threatened Species; classified World Heritage areas; *Environment Protection and Biodiversity Conservation Act 1999* (Cth); *Flora and Fauna Guarantee Act 1988* (Vic); and local government conservation covenants	6.1
• value systems that influence decision-making processes: anthropocentrism, biocentrism, ecocentrism and technocentrism	6.2
• sustainability principles as they apply to biodiversity conservation: conservation of biodiversity and ecological integrity; efficiency of resource use; intergenerational equity; intragenerational equity; precautionary principle; and user pays principle.	6.3

CHAPTER

1

Importance of biodiversity

CASE STUDY 1.1
The destruction of Western Port and the need to fix it

Maddison Stroud, Bachelor of Science student at Deakin University

Biodiversity can be viewed at multiple levels: genetic variation between individuals in the population (genetic diversity), variation in species numbers and abundance within an ecosystem in a particular area (species diversity), and variation between habitats, communities and processes in a region (ecosystem diversity).

Maintaining high rates of biodiversity is important in keeping ecosystems stable. A population with little genetic difference between individuals is more susceptible to harm from a virus or disease than is a more diverse population. Low genetic diversity can lead to local extinction of a population, so maintaining diversity levels is essential.

Craig Sherman from Deakin University in Victoria, Australia, researches the seagrass populations in Moreton Bay, Queensland. Seagrass is extremely important for marine environments as it provides many ecosystem services, including shoreline stabilisation, nutrient and sediment capture, and nursery areas for economically important fish. Layers of seagrass build up to form a barrier between the shore and the open ocean that keeps resources readily available for local populations.

Global seagrass populations are declining noticeably due to ongoing pollution along urbanised coastlines. Seagrasses are flowering plants and use light for photosynthesis to produce their food. Their food production is affected by the reduced availability of sunlight caused by sediments in the water column and surface pollution such as litter. Seagrass decline results in reduced water quality and loss of habitat for many organisms. Thus, the reduction of seagrass populations has reduced seagrass diversity.

One area in Victoria that has been affected by seagrass loss is Western Port (often called Westernport Bay). Western Port has experienced widely varying water quality as people built houses and towns around its coast. Since European colonisation, lots of fine sediment and run-off has washed into the bay, reducing water quality. In turn, seagrass populations have declined and many marine species have lost habitat.

Over the past few decades, Melbourne Water has been doing what they can to minimise the amount of sediment run-off in the hope that the seagrass populations would gradually return. So far, there has not been much change, so research is focusing on finding out why seagrass populations are not recovering in Western Port. It is possible that the remaining populations are too far away from the shallowest part of the bay, meaning that any seeds that make it to the area are not able to survive in the new environment. Alternatively, the environment may have simply changed to such a degree that it is no longer suitable for the growth of seagrass.

The research team from Deakin University compared the current environment in Western Port to the historical data, including the type and amount of sediment input that has impacted the bay. This involved mapping the current seagrass populations and identifying which populations have been the most affected by sediment, which areas have improved, and which areas would be most likely to benefit from the facilitation of seagrass population recovery. Unfortunately, there is little record of the structure of the bay prior to colonisation. However, the research group has access to data from more recent years that shows a significant increase in overall pollution and sediment within the bay over time. It is extremely important that this information is used to identify which areas remain unsuitable for restoration.

The researchers are also investigating the most effective methodologies for rehabilitating seagrass beds; for example, whether seedlings or sprouts grow better in the new conditions. And they are measuring the plants' resilience to relocation to work out the best populations from which to source samples for recruitment.

Further research aims to predict the vulnerability of each potential restoration site to possible future environmental changes, including their resilience to extreme events such as climate change, floods or overly hot summers. A viable site for restoration should provide seagrasses with a good chance of surviving changes that may occur in coming years.

This research is aimed at improving our understanding of how to restore sites in Western Port to increase long-term survival of seagrass populations and the biodiversity of species that rely on this habitat.

Figure 1.1. (a) Flinders Pier, Western Port, and (b) seagrass. Credit: (a) Tangerineduel CC BY-SA 4.0

1.1. Biodiversity

The definition and categories of biodiversity: genetic, species and ecosystem

One of the key elements needed for a sustainable Earth is a diverse range of plant and animal species. Maintaining biodiversity (which is short for 'biological diversity') is desirable for many reasons, encompassing utilitarian, ecological, aesthetic and moral perspectives. Consequently, governments and other organisations have established regulations and agreements (from international conventions to local laws) to protect and maintain biological diversity.

Australia is one of 17 countries described as being 'megadiverse' in terms of its terrestrial (land) and marine life, and it is the only megadiverse country with a developed economy. These 17 countries account for less than 10% of the global surface but contain more than 70% of the planet's biodiversity.

What is biodiversity?

The international Convention on Biological Diversity defines biodiversity as:

the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems.

The Convention on Biological Diversity was agreed to at the United Nations Conference on Environment and Development (The Earth Summit) held in Rio de Janeiro in June 1992. Australia signed the convention on World Environment Day (5 June) 1992 and ratified it on 18 June 1993.

As the definition says, biodiversity is the variability found across all the living organisms that make up the web of life on Earth. Furthermore, it is not just the range of organisms on Earth, but the full variety of all life forms: the different plants, animals and microorganisms, the genes they contain and the ecosystems they are part of. This living wealth is the product of billions of years of evolution.

Three levels of biodiversity

Genetic diversity

Genetic diversity is the total genetic information contained in the genes of all species on Earth. The gene is the basic unit through which inherited characteristics are transmitted from parents to their offspring. Genes are located on chromosomes within the cell nucleus. A single gene consists of a length of DNA which controls the production of a protein that, together with the proteins produced from all the other genes, determines the form and function of a cell. As a result, the genetic make-up of an individual organism determines much of its appearance and what it does.

Each gene is located on a chromosome in a certain position (locus, plural loci). At each locus, the particular gene present may be one of a number of variants (alleles). Organisms that are diploid for most of their life cycles (such as humans) have two sets of chromosomes and therefore two loci for each gene – one on each chromosome. If the alleles for a gene are the same on both chromosomes, this condition is called homozygous. If the alleles are different, it is called heterozygous.

Many deleterious conditions, such as cystic fibrosis (a disorder of the lungs and digestive system) are recessive, which means that they only show up in an individual if both alleles at that locus are the same recessive variant. If an individual is heterozygous, the dominant allele will determine the outcome. So if you have one allele for cystic fibrosis and one allele for the normal condition, you will not have cystic fibrosis.

Genetic diversity refers to the variation in genetic information between species as well as the variation between individuals of the same species. Genes that control the basic processes occurring inside cells tend to be quite similar in different organisms. It is the more specialised genes within each species that show the greatest variation and contribute most to genetic diversity. These are the genes that determine the individual characteristics of species and make species different from one another.

Species diversity

Species diversity is the variety of species on Earth. Species diversity measures the number of different species and the number of individuals within each species in a particular area or ecosystem. A species is defined as a group of organisms that are genetically so similar that they can interbreed and produce fertile offspring, and they are not normally capable of interbreeding with other groups of organisms. Individuals within a species may vary in their appearance to some extent, but they tend to be more similar to one another than they are to individuals of other species. Different species have evolved to fill particular niches within their ecosystems.

So far, about 2 million species of organisms have been identified and described. Estimates of the total number of species on Earth vary between 5 million and 30 million. Australia has between 400,000 and 700,000 species; only about one-half of the species are known and only one-quarter have been formally described. Estimates of species diversity will improve as further research is carried out, particularly into the little-known groups such as microorganisms, fungi, mites and insects.

Many Australian species are endemic – that is, they are native only to Australia – and many are found nowhere else in the world. These include 84% of our plant species, 83% of our mammals and 45% of our birds.

Species diversity varies over the globe: most species are found in equatorial regions and progressively fewer species live closer to the poles. Diversity on land tends to decrease with increasing altitude, and diversity in the sea is greatest on the continental shelves.

Figure 1.2. Coastal lagoon ecosystem showing biotic and abiotic features. Credit: Tim J Keegan CC BY-SA 2.0

Ecosystem diversity

Ecosystem diversity is the variety of habitats, natural communities and ecological processes in the biosphere. An ecosystem consists of communities of plants, animals and microorganisms (the biotic component) and the non-living factors (the abiotic component) (Figure 1.2).

The many complex interactions between the biotic and abiotic components of ecosystems result in ecosystem processes, including the water cycle, biogeochemical cycles and energy flows. These processes clearly demonstrate the interdependence of living and non-living things.

Ecosystem diversity incorporates the wide range of ecosystems on Earth, both terrestrial and aquatic. These range from polar ice caps through tropical rainforests and into the deep sea. Each of these ecosystems is made up of a wide variety of habitats, the diversity of organisms within them and the numerous interactions that occur. Ecosystem diversity is not fixed – it is dynamic as the interactions between organisms and their environment change over time.

Practical 1.1
Biotic and abiotic components of an ecosystem

Aim

To investigate the effects of changes in abiotic factors on organisms in an ecosystem.

Equipment

- bucket or scoop
- 4+ large glass containers
- microscopes
- identification texts
- other equipment as required

Method

1. Collect a sample of pond water including some bottom detritus and aquatic plant material (but no macroscopic organisms).
2. Identify and count the microscopic organisms present in the pond water.
3. Divide the pond water equally between the containers.
4. Place the containers in the same location, where they can receive natural light.
5. Label one container as the control.
6. For each remaining container, choose the abiotic factor you wish to vary (for example, light intensity, temperature, salinity) and prepare accordingly.
7. Monitor the microscopic organisms in the containers over a number of weeks and record the population changes that occur in each container.

Results

1. Construct a table to record your results, showing the change in populations over time in each container.
2. Compare the populations to see how they vary.

Discussion

1. **Explain** why each population variation may have occurred.
2. What abiotic factor seems to have the greatest effect on the types and numbers of organisms present? **Suggest** why this might be.
3. What abiotic factor seems to have the least effect on the types and numbers of organisms present? **Suggest** why this might be.

Data analysis 1.1
Interactions between biotic and abiotic components

Using the example ecosystem shown in Figure 1.2, fill in the following table considering the interactions between abiotic and biotic components of two ecosystems in two different seasons.

Ecosystem	Biotic summer	Biotic winter	Abiotic summer	Abiotic winter
Example: Pebble stream	Algae grow to the summer water line on a rock	Algae grow higher on the rock as water level rises in winter	Warm rock heats stream water	Eddies form around rock in fast-flowing stream, protecting fish

Critical and creative thinking 1.1

1. Give examples from your own life of the biological resources and social benefits you receive from biodiversity (five of each).
2. Choose three ecosystem services. Show how they affect human survival.

1.2. Importance of genetic biodiversity

The importance of genetic diversity within a species or population experiencing environmental change

Genetic diversity is valuable because a species or population with a low level of genetic diversity only has a low capacity to adapt to changes in its environment. A population with low genetic diversity may not include many individuals with the gene variations needed to survive an environmental change. The greater the genetic diversity within a species, the greater the chance that species will survive in the long term. Conversely, the capacity of a population or species to adapt to environmental change is reduced by a reduction in genetic diversity.

Environmental changes that do not lead to a species becoming extinct may still reduce the size of a population. In most cases, a smaller population will exhibit less genetic diversity than the previous larger population because of processes such as genetic drift and inbreeding. These processes are described below along with others that also affect the genetic diversity of a population or ecosystem.

Factors affecting genetic diversity in populations

Mutation and natural selection

Within a population, new alleles arise all the time by mutation, although at a very low rate. These mutations are important in increasing genetic diversity. The theory of evolution by natural selection explains the gradual change of population characteristics over time as allele frequencies change in the population. The idea of the survival of the fittest is a key part of this theory. Individuals with an advantage over other members of their species have the best chance of surviving and reproducing and thereby passing on these advantages to their offspring through their genes. Organisms less 'fit' for their environment do not produce as many offspring. Thus, natural selection acts to reduce the frequency of harmful or deleterious alleles in the population.

Over time, a population has more and more individuals who are well adapted to a particular environment. That is, the gene pool of the population evolves as the number of individuals with 'better' genes (alleles that give them a better chance of surviving and reproducing in their environment) increases. That is how the environment naturally 'selects' the individuals most suited to it.

Evolution by natural selection also gives rise to biological diversity. Because environments differ, the characteristics selected in one environment will differ from the characteristics that are selected in a different environment. Over time, and if there is no interbreeding, sub-populations of a species can evolve into separate species, with the different characteristics favoured in their different environments. Thus, over very long periods of time, evolution has produced a vast biological diversity of species.

Figure 1.3. Genetic diversity found in seeds from two different cucumber fruits found on the same plant. Credit: Jorja McKinnon

Genetic drift

Genetic drift occurs when the allele frequency in a population is determined by random events rather than by natural selection. With genetic drift, some alleles may be eliminated from a population by chance, or some previously rare alleles may become widespread, even if they are deleterious.

Figure 1.4. Koalas in southern Australia have low genetic diversity because their population has expanded from only a few individuals. Credit: Chris Fithall CC BY 2.0

It is only in very small populations that chance plays a significant enough role in survival to cause genetic drift. It is most likely to occur if a new population is established from a small founding group (for example, a few rats colonising an island) – in this case it can also be called the founder effect – or if a population crashes because of a catastrophe such as a volcanic eruption and then builds up from a small group of survivors.

Simply because of their smaller numbers, the founders or survivors will not contain all the genetic variability of the population they came from. Furthermore, their contribution to the next generation was largely due to chance rather than fitness under natural selection. Genetic drift, and the consequent loss of genetic variability, can reduce a population's ability to adapt. Many captive and wild populations of rare species face this problem.

Inbreeding

Small populations can also suffer from inbreeding, which is breeding between individuals that are closely related genetically. Because close relatives share many of the same alleles, inbreeding increases the chance of the offspring being homozygous. In turn, this increases the chances of deleterious recessive alleles being expressed.

Increased levels of homozygosity through inbreeding can reduce survival rates and reproductive success of members in population. This decline in population fitness is called inbreeding depression.

Inbreeding does not always lead to inbreeding depression. Some species of plants seem to be adapted for inbreeding and suffer no deleterious effects as a result. Koalas also seem to be unaffected by inbreeding depression, possibly because inbreeding and genetic drift have actually eliminated rare recessive alleles.

Extinction

If changes in the environment happen relatively quickly, the process of evolution may not be quick enough for a population to adapt. In these cases, populations (and indeed species) can become extinct. Extinction is the complete disappearance of a species or of a local population. Extinction can also be caused by a natural catastrophe, such as a meteorite impact, or in more recent times by human activities, such as over-hunting, removal of habitat, pollution and the introduction of species that out-compete native species.

Extinction is a natural process, and on average, each year since life began on Earth, one species has become extinct for every one million species. Around 4 billion species have evolved in the 3.5 billion years that Earth has supported life. Of these, around 99% are extinct. The rate of extinction has not been uniform over this period, and there have been several mass extinctions (see p 20). The best known of these was at the end of the Cretaceous period, about 65 million years ago, when the dinosaurs disappeared, along with many other terrestrial and marine species. Notwithstanding these events, the overall rate of extinction has been slow.

If we examine the current rates of extinction, it is apparent that the rate at which species are becoming extinct is increasing. From 1600 to 1900, around 300 vertebrate species became extinct – an average of one every year (we don't know the rates of extinction among other taxa). Over the last 100 years, however, the average is around 10 vertebrate species becoming extinct every year. This accelerated extinction is a large increase over the natural rate of extinction.

Genetic swamping

Environmental disruption caused by human activities may bring populations of a species that once were geographically isolated into contact with one another. Under circumstances of geographic isolation, these populations would not have interbred. With the barriers removed, the populations may interbreed and produce hybrids. If one of the interbreeding populations is small in number and the number of hybrids is large, the genes of the more numerous population can spread throughout the smaller population. This is called genetic swamping and can occur when any two genetically isolated populations come into contact with one another. The genetic diversity of the smaller population is lost in the process.

Demographic variation

Small populations can also exhibit demographic variation. For example, a population may grow at an average rate over a number of years, but at any one time the rate may differ from the average because of particular conditions. This chance factor will operate on a number of demographic measures, such as birth rate, death rate and sex ratio. The chance variation away from the average is likely to be greater in small populations than in big populations. Over time, this demographic variation may contribute to genetic variation.

Loss of organisms playing a key role

Biodiversity loss can result in the removal of certain species that are critical for the survival of other organisms. For example, many species of plants depend on insects or birds for pollination or for the dispersal of seed. Clearly, the loss of bird or insect species could threaten the survival of some plant species.

Some species are in symbiotic relationships in which different species live together in an intimate association. We recognise three forms of symbiosis: parasitism, commensalism and mutualism (Figure 1.5).

Parasitism occurs when one species, the parasite, lives in or on another species, the host. The parasite derives food from this association to the detriment of the host. The loss of a host species from a region will obviously have a serious impact on the parasite species.

A commensal relationship is an interaction where one species obtains a benefit from the relationship, but the other species neither derives a benefit nor is harmed.

In mutualism, two species live together and both derive benefit from the other. In both commensalism and mutualism, the loss of one of the species may have a negative effect on the other species.

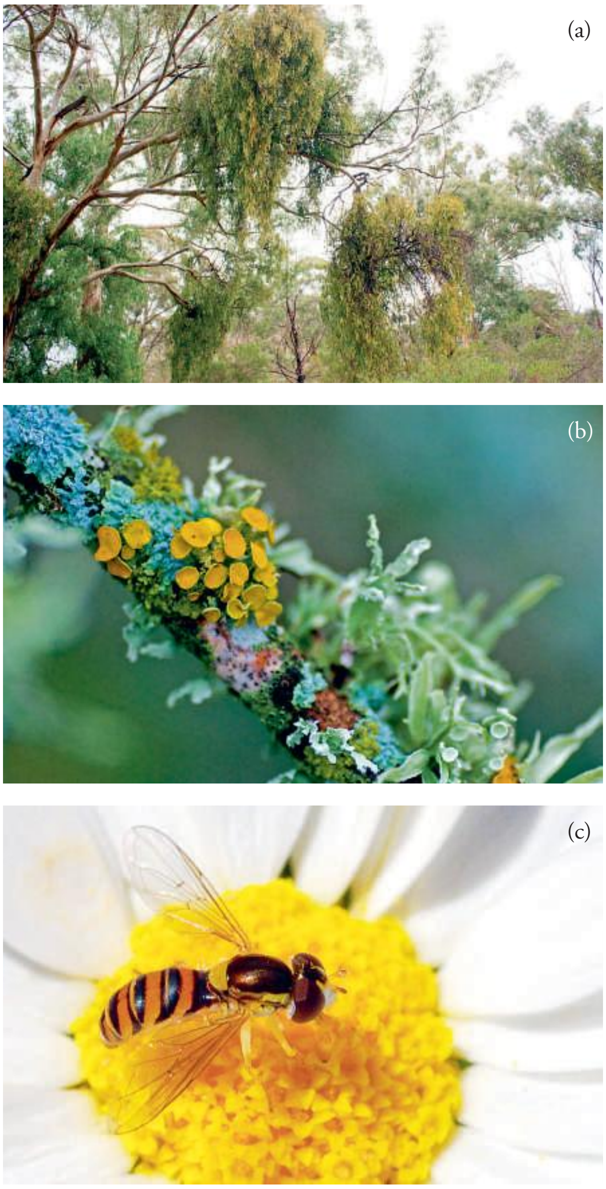

Figure 1.5. Examples of critical ecological relationships (a) parasitic mistletoe on a eucalypt (b) lichen and (c) a hover fly pollinating a daisy. Credits: Rexness CC BY-SA 2.0; jim_mcculloch CC BY 2.0; Jean and Fred CC BY 2.0

Critical and creative thinking 1.2

1. Do some research to find out what your area was probably like before European settlement. **Describe** the local ecosystem and include a list of plant and animal species that might have been present in your area.
2. **Identify** some of the organisms that have become locally extinct or that seem to be disappearing from where you live.
3. **List** some of the factors that might be reducing biodiversity in your area.

1.3. Ecosystem services

Ecosystems as a source of renewable services that impact on human health and well-being:

- **provisioning services: potable water; food; fuel; fibre; and pharmaceuticals**
- **regulating services: control of climate and disease; pollination; and water purification**
- **supporting services that maintain conditions for life on Earth: cycling of nutrients; soil formation; and photosynthesis**
- **cultural services: aesthetic values; recreational benefits; and sense of place**

In the same way that other organisms depend on the biotic and abiotic factors in their ecosystem, humans depend on their environment and its components for their survival. Ecosystem services are renewable processes that play a vital role in human survival and quality of life.

The biological components of our environment are particularly important in supplying our needs and wants, such as food, health, recreation and culture. Diversity of the environment is also important, as diverse ecosystems tend to be stable and resilient under changing conditions. Resilience is the capacity of an ecosystem (or population) to restore its structure and function following natural or human-induced stress.

Keep in mind that valuing biodiversity from the perspective of its usefulness to humans (as in these ecosystem services) is to give it an economic or utilitarian value. It can also be argued that all species have a right to exist irrespective of their value to humans and that all organisms have an intrinsic value and should be preserved.

Value systems that influence decision-making processes are discussed in section 6.3 'Guiding sustainability principles' (p 71).

Some of the benefits provided by healthy and diverse ecosystems (Figure 1.6) are examined below.

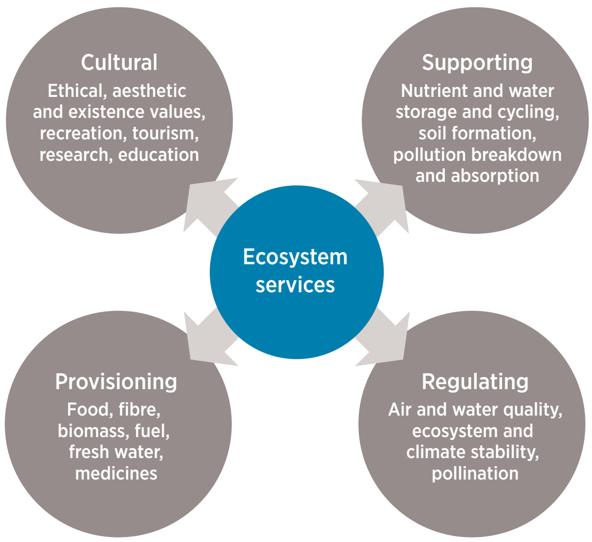

Figure 1.6. Four categories of ecosystem services.
Credit: Kate Chamberlain

Provisioning services

A provisioning service is one that provides resources such as clean water, food, fuel, fibre and medicines to individuals in the ecosystem. Organisms and products made from organisms are used directly by humans in many ways.

Food

All of the world's food comes from biological organisms, whether we eat it the organism directly (like meat or rice) or eat a product (like milk or honey). Despite the wide variety of potential food sources to sustain us, we rely on relatively few species: 90% of the world's food (in terms of energy intake) is derived from only 15 species of plants (out of 80,000 potentially edible plants). Wheat, maize and rice alone supply half the world's food.

Raw materials

Humans use many materials derived from plants and animals. Wood, bamboo and straw are used in construction of houses and many other products used by society. Fibres we use include linen from flax, rope from hemp, cotton from cotton plants, wool from sheep and goats, and silk from silkworms. Other materials include natural rubber latex from the rubber tree, ambergris from whales (used in some perfumes) and beeswax.

Medicines

Many medicines have been developed from plants and animals. For example:

- aspirin is made from an organic molecule derived from willow bark
- the yew tree is a source of taxol, a drug used to treat cancers of the breast or ovaries
- digitalin, which comes from foxglove plants, is used to treat heart defects
- the venom of certain snakes contains coagulating agents that can be used to stop bleeding during surgery
- Caribbean sea sponges can be used to combat rejection of organ transplants.

Approximately 20% of prescription drugs are derived from plants, yet the pharmaceutical potential hidden within the natural world is largely untapped. Only 1% of rainforest plant species have been tested for their possible pharmaceutical value, and plants in other ecosystems are largely unexplored.

Furthermore, only a small proportion of all species have been formally described, so we could discover many more potentially useful species.

Regulating services

A regulating service is one that provides mechanisms to regulate an ecosystem and keep it in balance. For example, natural vegetation cover in water catchments helps to maintain hydrological cycles, regulating and stabilising water run-off, and acting as a buffer against extreme events such as flood and drought. Vegetation also helps to regulate underground water tables, preventing dryland salinity, and prevents erosion of precious topsoils by anchoring the soil with the plant roots and buffering the erosive force of water and wind.

Regulating services also contribute to climate stability. Forests have a cooling effect on their local climate, using up to 70% of the solar radiation falling on them to evaporate water and redistribute heat. On average, forests redistribute 30% of the rainfall they receive back into the atmosphere through plant transpiration. Forests also stabilise climate globally through carbon sequestration. Australia's old growth mountain ash forests have recently been reported as having one of the highest rates of carbon sequestration of any forest in the world.

Ecosystem processes also regulate nutrient storage and cycling. For example, bacteria, protozoa, fungi, algae, insects and worms in the soil decompose living matter, releasing nutrients that are used by other members of the ecosystem further up the food chain. They also aerate the soil and improve soil structure and facilitate the storage and movement of soil moisture.

Supporting services

Ecosystems themselves could not be sustained without the underlying natural processes, such as nutrient cycling, that support multiple aspects of an ecosystem. An important supporting service is provided by the pollinators of crops. Native animals, including birds, arboreal mammals and insects, are thought to pollinate as much as 50% of the agricultural crops on nearby farms. These animals also assist with pollination and seed dispersal of native species.

Another supporting service provided by ecosystems is that of pollution breakdown and absorption. Ecological processes in intact ecosystems can assist with the purification of the air, water and soil. Wetland organisms and sediment can trap, break down or absorb toxic materials in polluted run-off. Up to 92% of the phosphorus, 95% of the nitrogen and 70% of the sediments can be removed from water draining from a catchment if it passes through a wetland. Wetlands can also filter out up to 90% of the bacteria in water, thus supporting other elements of a healthy ecosystem.

Another example is the symbiotic association some plants have with a fungus that colonises their roots and helps them take up nutrients and water. This relationship, called a mycorrhiza, is an example of an ecological process that assists with nutrient cycling. Mycorrhizae can also lessen the toxicity of salinity and stimulate the growth of other beneficial microbes.

Cultural services

Humans can also gain social and health benefits from the existence and maintenance of ecosystems and organisms. These cultural services include:

- research and education
- recreation
- cultural values
- aesthetic values.

Practical 1.2
Services provided by a local ecosystem

1. Choose an ecosystem in your local area to visit. This may be a local park or a more natural area such as a woodland or coastal area.

   Remember to follow safety rules such as:
   - Wear appropriate personal protective equipment, such as sunscreen, hat, hiking boots.
   - Beware of snakes or insects that may bite.
   - Ensure you have a map or compass if you are going into an unfamiliar wilderness area.
   - Ensure you take a buddy or tell someone where you are going.

   Follow ethical guidelines and do not disturb animals and plants in your ecosystem when you visit.

2. Observe the ecosystem and record the following information.

   Type of ecosystem:

   Google maps link or GPS coordinates:

3. Complete the table below by listing examples of each of the ecosystem services your chosen ecosystem would provide.

Regulating services	Provisioning services	Supporting services	Cultural services

Data analysis 1.2
Environmental services

Consider Figure 1.7 and describe one regulating service, one provisioning service, one supporting service and one cultural service provided by the Otways National Park.

Regulating service	
Name	
Description	
Provisioning service	
Name	
Description	
Supporting service	
Name	
Description	
Cultural service	
Name	
Description	

Figure 1.7. Cumberland River is one of the last remaining wild rivers in the Otway ranges. Credit: Diggers2004 CC BY-SA 4.0

Critical and creative thinking 1.3

1. It is argued that all species have a right to exist irrespective of their value to humans. **Discuss** and give your own opinion.
2. Choose an animal of interest and **describe** how it depends on both the biotic and abiotic components of its environment.

CHAPTER

2

Biodiversity changes over time

2.1. Evidence from the fossil record

Evidence of variation in rate and extent of change in biodiversity over time: significant mass extinctions and periods of rapid species diversification that can be inferred from the fossil record

The ecosystems we see today are influenced by changes that have occurred over thousands to millions of years and that continue at rates we can't usually detect in our lifetimes.

Our knowledge of extinct species and the plant and animal communities that existed millions (or hundreds of millions) of years ago comes from fossils. Organic material, such as flesh, bone, shells or leaves, does not last long after an organism has died, and most dead organisms decompose without leaving a trace. Under the right conditions, however, hard body parts or traces of an organism (like a footprint or an impression of tree bark) become mineralised and turn into a fossil – in the same shape as the original but now more like a rock.

Palaeontologists use the fossil record to understand the life forms that existed in former geological periods and to build a picture of evolutionary change over time. To do this they need to work out how old the fossils are. Two types of techniques are used for this: relative dating and numerical (or radiometric) dating.

At first, geologists and palaeontologists could only date rocks (and thus the fossils within them) relative to other rocks above or below them in the landscape. This method did not tell them how old any of the rocks or fossils were. Relative dating is based on the fact that, when layers (or strata) of sedimentary or volcanic rocks are exposed (such as in a gorge, on a hillside or through excavation), rocks in the lower strata were typically formed before rocks in the upper strata.

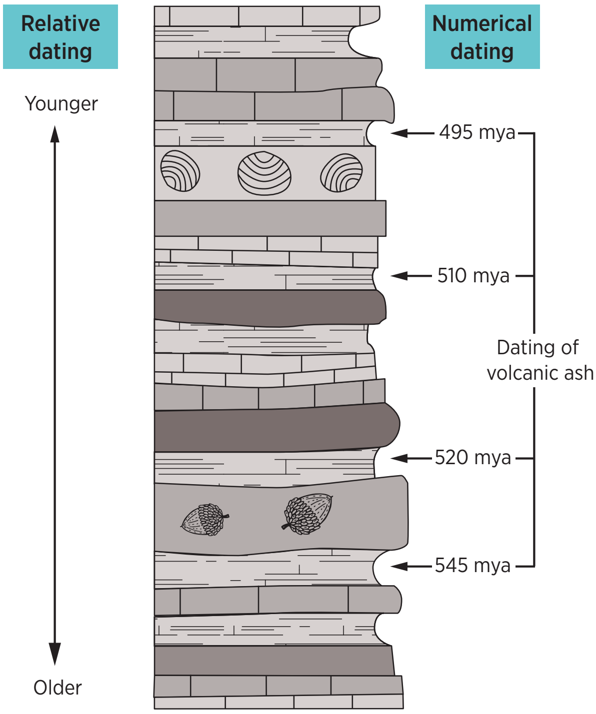

Figure 2.1. Relative and numerical dating of strata and fossils

It follows, then, that fossils found in lower strata are generally older than fossils found in higher strata (Figure 2.1), although care must be taken if fault movements have lifted or rearranged the layers

Relative dating can be aided by studying the types of fossils found in the different layers. For example, finding similar fossils in rocks a long way apart suggests that the rocks are of a similar age.

Numerical dating techniques go one step further: they provide an estimate of the actual date at which the fossil formed. These techniques were first developed after radioactivity was discovered in the late 18th century. They rely on the fact that many minerals occur in different forms (called isotopes), and some of these are naturally radioactive. Over time, the process of radioactive decay changes the 'parent' isotope to a 'daughter' isotope. For example, fossils can be carbon dated by measuring the unstable isotope carbon 14 (with six protons and eight neutrons), which decays to form nitrogen 14 (seven protons, seven neutrons).

Because the decay occurs at a stable rate, the amount of carbon 14 remaining in a specimen allows scientists to calculate how long ago the plant or animal died. This method works with material up to 70,000 years old.

Other elements used in radiometric dating include potassium (which decays to argon) and uranium (which decays to lead). Both these methods allow dating back billions of years because of their longer decay rates. Extremely old dates can be obtained from volcanic ash, and this can be used to set upper and lower limits to dates of intervening fossil layers (Figure 2.1).

Numerical dating of rocks and fossils around the world is the basis of the geological time scale which divides Earth's history into eras, periods and epochs.

Mass extinctions

Around 65 million years ago most of the dinosaurs died out, and the ones that did not evolved into present-day birds. But it wasn't only the dinosaurs that died out – around 75% of all plant and animal species on Earth became extinct. Events like this are called mass extinctions to contrast them with the much lower rate of species extinction that occurs all the time.

Over Earth's history there have been five mass extinctions, caused by a variety of factors, plus a whole range of smaller extinctions. These mass extinctions changed the course of evolutionary history – as happened when the dinosaurs disappeared which allowed the rise of mammals. Because they are so notable, mass extinctions generally mark the boundary between different geological periods.

While mass extinctions are often considered to be negative events because of the huge numbers of species lost, there is equal significance in that they set the stage for a massive diversification of taxa that evolve to fill the empty niches.

Ordovician–Silurian mass extinction

Life existed mostly in the sea in the Ordovician period (488–443 million years ago (mya)). Animals at that time included trilobites, cephalopods, reef-building invertebrates and jawless fish, which were the first vertebrates. Apart from algae, all plants were unicellular.

The mass extinction that ended the Ordovician and marked the beginning of the Silurian period was triggered by the large landmass of Gondwana gradually moving to a position over the South Pole. This led to the globe cooling, large ice sheets forming and sea levels dropping. Carbon dioxide may also have played a role, with the silicate rocks of the relatively new Appalachian mountains in North America weathering in a process that locks up carbon from the atmosphere and cools the planet.

Late Devonian extinction

In the Devonian period (416–359 mya), the land supported the first ferns and insects, and some fishes evolved limbs to became the first land vertebrates. There was a great diversity of fishes, and the period is nicknamed ‘the age of fishes’. The climate was generally warm and sea levels were high. A mass extinction occurred over about 20 million years, particularly affecting life in shallow, tropical seas which became devoid of oxygen. It’s not clear what the cause of this extinction was, and several factors may have played a role, including a meteor or comet impact, global warming, excessive sedimentation or nutrient run-off.

Permian–Triassic extinction

In the Permian period (299–251 mya), all the continents were formed into one landmass, called Pangaea, leaving the rest of the globe covered by a large ocean. Amphibians and reptiles had evolved, as had the ancestors of mammals and dinosaurs. The forests had seed ferns, tree ferns, conifers, cycads and ginkgos.

The Permian–Triassic extinction, also known as ‘the great dying’, is the greatest mass extinction on record. Around 95% of all species became extinct, especially marine organisms such as all the trilobites, and many insects, vertebrates and plants. Again, the cause or causes of this massive extinction are not clearly understood.

Jurassic extinction

The survivors of the Permian–Triassic extinction recovered gradually, coping with the effects such as low oxygen levels during the Triassic period (251–199 mya). There were no polar ice caps and the climate was generally hot and dry. The first dinosaurs and the first mammals were appearing, and pterosaur reptiles were the first animals after insects to evolve powered flight.

In this extinction, at the Triassic–Jurassic boundary, animals were more affected than plants, freeing up ecological niches that the dinosaurs took advantage of in the Jurassic period. Volcanic activity associated with seafloor spreading in the break-up of Pangaea may have contributed to the mass extinction, but other causes have also been suggested.

Cretaceous–Tertiary extinction

The Cretaceous–Tertiary extinction (65 mya) is the event that killed off the dinosaurs (apart from those which became the ancestors of birds), as well as ammonites and pterosaurs, and many marine invertebrates and flowering plants. The cause is most likely to be the impact of a huge asteroid, whose crater has been discovered on Mexico’s Yucatan Peninsula. A changing climate resulting from volcanic activity, and a falling sea level, may have already been making life hard for some species.

The sixth mass extinction?

Scientists are now starting to call the rapid loss of species we see today the sixth mass extinction. This extinction is caused by human activity, especially our alteration of habitat and our impact on climate change. Extinction is occurring 100–1,000 times (perhaps 10,000 times) faster than natural, background levels. At today’s rates of extinction, we could reach species losses equivalent to a mass extinction within 250–12,000 years, which is a much faster rate than occurred in any of the big five extinction events. One whole class of vertebrate, the amphibians, is under threat, with one-third of the world’s 6,300 amphibian species already threatened with extinction.

2.2. Natural changes in biodiversity

Natural changes occurring over different time scales that influence ecosystem diversity, species endemism, the formation of diversity hotspots, and rate of extinction: volcanic eruptions; fire; El Niño; tectonic plate movement; and evolution

CASE STUDY 2.1
Apex predators: a biodiversity regulator

Hannah Neumann, Bachelor of Science student at Deakin University

Every now and then you might hear that another animal is endangered or that more trees have been cut down to make way for housing as our population continues to increase in Australia. But the conservation problems we face go much deeper than this: since European settlement, more mammals have gone extinct in Australia than in any other country. In the last couple of hundred years, Australia has lost roughly 30 native mammal species to extinction. We are losing biodiversity due to habitat destruction for agriculture and urbanisation at an alarming rate. Feral and invasive animals, such as foxes and domestic pets, are also having large impacts, especially on native mammals, birds and reptiles. Climate change threatens to compound these issues.

Australia is a biodiversity hotspot and attracts tourists from all over the world to enjoy our weird and wonderful flora and fauna. Biodiversity hotspots are regions that are rich in diversity but have lost a significant proportion of their native vegetation. They are some of the most threatened areas around the world.

A majority of Australia's flora and fauna is globally recognised as exclusive and unique, but it seems we are continually contributing to the loss of these natural treasures. A species becoming endangered or extinct almost always causes flow-on effects in their ecosystem. The loss of one species affects other species, potentially leading to further extinctions.

We often don't recognise the dangers of losing a species until it's too late, at which point it's hard to replace the role they perform in the natural system.

Euan Ritchie is a professor in wildlife ecology and conservation in the Centre for Integrative Ecology, School of Life and Environmental Sciences, at Deakin University. Euan says "protecting biodiversity has many values" and that "there is no facet of life where biodiversity doesn't have some sort of an impact". Biodiversity obviously underpins the health of the planet, but it also seems to have direct impacts on all our lives. Put simply, reduced biodiversity means a potential future where food supplies are more vulnerable to pests and disease, and freshwater is irregular or in short supply. Euan employs ecological theory along with fieldwork to seek solutions to the challenges of conserving biodiversity. His research focuses on threatened species: identifying and managing threats, evaluating conservation actions, and on-ground monitoring.

Euan has done extensive research on the influence that apex predators have on biodiversity. Apex predators are animals at the top of the food chain (or trophic level) which have no natural predators themselves. Apex predators can limit the populations of smaller, low-order predators (or mesopredators). Mesopredators are middle-trophic-level predators that prey upon other animals and are also preyed upon. When the population of apex predators is reduced (for example, through the continuing global contraction of the areas on which they range), mesopredator populations could increase, increasing predation pressure on smaller prey species, altering ecosystem structure and contributing to biodiversity loss.

Australia's largest terrestrial apex predator is the dingo, and Euan researches how dingoes provide conservation benefits to biodiversity. It has been shown that apex predators such as dingoes are ecologically important in maintaining biodiversity. The loss of these apex predators could lead to changes in numbers of other animals in the food chain, including an increased number of herbivores, cats and foxes, which would negatively affect native species and ecological processes.

Dingoes can suppress smaller predators by outcompeting them for resources or killing them, which in turn can have positive benefits for threatened species. Dingoes can regulate the numbers of feral herbivores, such as goats, deer and rabbits, assisting in the survival of native species. These effects then cascade through the food chain, in turn helping to maintain biodiversity within an ecosystem.

As dingoes present a threat to livestock, they are classified as a pest across most of Australia and are persecuted on a large scale by baiting, trapping and shooting. For this reason, dingoes are listed as vulnerable to extinction. To allow dingoes to fulfil their role as an apex predator in sustaining biodiversity, we need a sustained effort in education and other non-lethal management strategies for deterring dingoes from agricultural land.

Figure 2.2. Dingoes are Australia's largest apex predator

Figure 2.3. Euan Ritchie attaching camera traps to a tree.
Credit: Euan Ritchie

Australia's unique flora and fauna: species endemism

Australia's high number of endemic species is largely a result of its long period of separation from other continents. Australia was once part of the great southern supercontinent, Gondwana, which also included South America, Africa, India and Antarctica. Gondwana began to break up some 140 million years ago, and Australia eventually split from Antarctica about 40 million years ago. Australia's unique plant and animal life is mostly explained by our continent's long period of isolation from other land masses.

Endemism is the term used to describe animals and plants that are native to one single geographical location. For example, an animal or plant species found only on one island is endemic to that island. Not all species found on that island will be endemic, as some will have come from elsewhere. Islands are not the only geographical areas with endemic species. Endemism can occur due to movement being restricted by mountain ranges, habitat zones or other regional features.

Three of Victoria's best known endemic species are the Leadbeater's possum, helmeted honeyeater and Baw Baw frog.

With a restricted distribution, endemic species can be catastrophically affected by short-term environmental changes, as is the case for each of these species:

- Leadbeater's possums nest in tree hollows. When a bushfire passes through their habitat, the tree hollows are lost and the possum lacks suitable nesting sites.
- The Baw Baw frog was thriving in the 1980s, but a series of droughts and bushfires have led it to become critically endangered over a very short time.
- The helmeted honeyeater suffers from loss of habitat as well as the climate pressures of drought and bushfire.

Western Volcanic Plains: a biodiversity hotspot

Biodiversity hotspots have a high representation of diversity with many locally endemic species (species not found outside the hotspot). In 2003, the Australian Government identified 15 Australian hotspots – one was the Western Volcanic Plains in Victoria (Figure 2.4).

The Victorian Western Volcanic Plains covers an area west from Melbourne to Portland. The land is flat to undulating, characterised by fertile volcanic soils that were once covered with open grasslands, grassy woodlands, large shallow lakes and wetlands. Like many grassland ecosystems, after European settlement much of the plains were converted to pasture for agricultural purposes. The region is still largely dominated by grazing and extensive crops.

This hotspot contains nine lakes listed under the Ramsar Convention as being of international importance. Sixty-five species listed as nationally threatened and 173 listed as threatened in Victoria are found in the Western Volcanic Plains. Vegetation and habitat degradation, predation by introduced species such as foxes and cats, changing fire patterns, weed invasion and the total grazing pressure of domestic stock, kangaroos and feral rabbits all pose major threats to this region's biodiversity.

Figure 2.4. Location of the Victorian Western Volcanic Plains

Environmental variation

Changes to the environment over short, medium and long time scales produce a range of outcomes for species and ecosystems. When changes act to isolate one population of a species from another, subsequent adaptations can result in two populations that can no longer interbreed so they become separate species. In other circumstances, population isolation resulting from environmental changes may lead to the local extinction of a species. This happens when the environment is no longer suitable or a species can't compete for food or shelter against other species.

Short-term changes

Short-term changes to an environment, such as fire or volcanic eruptions, can threaten the survival of individual populations or ecosystems. This is particularly true for those already vulnerable, such as ecosystems or species that are restricted to a small locality.

The 2019–20 Victorian bushfires, for example, affected many vulnerable species, such as the Leadbeater's possum, sooty owl, barred galaxias, ground parrot and spotted tree frog. The fires destroyed 43% of the Leadbeater's possum's habitat in the Victorian Central Highlands, and halved the wild population of this critically endangered species to 1,500. A 2014 study by scientists from the Australian National University (ANU) concluded there is a 92% chance the Leadbeater's possum ecosystem in the Victorian Central Highlands will

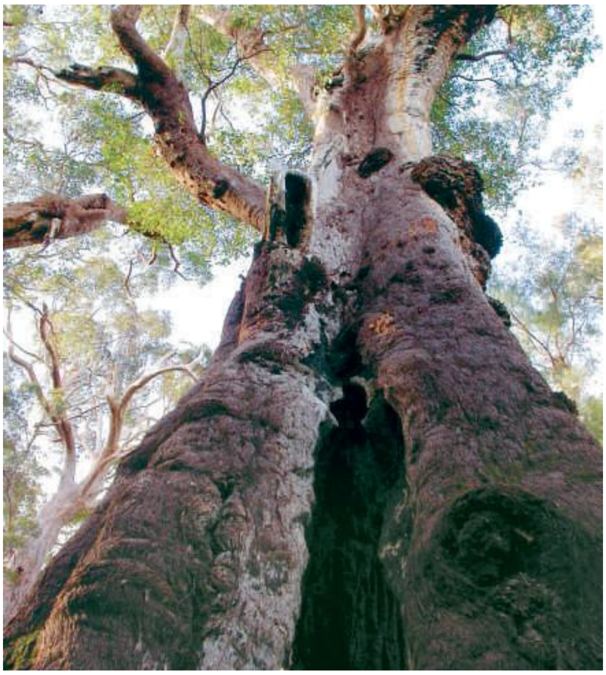

Figure 2.5. Tree hollows are important habitat for nesting and breeding. Credit: Giles Watson CC BY-SA 2.0

collapse within 50 years, largely as a result of fire and mismanagement. Wildlife of the Central Highland's mountain ash ecosystem is already affected by the loss of hollow-bearing trees. These trees are used by many species for nesting, and when burnt old trees are replaced by young regrowth, it take can take more than a century for new hollows to form.

Medium-term changes

The El Niño–Southern Oscillation (ENSO), a climatic cycle that lasts 3–8 years, is partly the cause of Australia's characteristically unreliable rainfall. The El Niño–Southern Oscillation is the name given to the see-sawing change in sea surface temperatures and average atmospheric pressure in and above the Pacific Ocean. In El Niño events, sea surface temperatures are higher than average in the eastern Pacific, and air pressure is lower than usual over the central Pacific. In eastern and northern Australia many, but not all, droughts are due to the ENSO phenomenon. ENSO-induced droughts last about a year and may sometimes extend across the whole continent. They occur at irregular intervals about every 3–8 years. During an ENSO phenomenon, populations must cope with the conditions such as warmer ocean temperatures and decreased rainfall (Figure 2.6). Some species will adjust their geographic range in order to find more favourable conditions.

On a longer time scale, ocean warming caused by climate change is affecting the ranges of some marine species. For example, fish from the tropics (such as parrotfish) are being found near Coffs Harbour in New South Wales. A number of fish and invertebrate species previously unrecorded in Tasmania have been documented there in recent years.

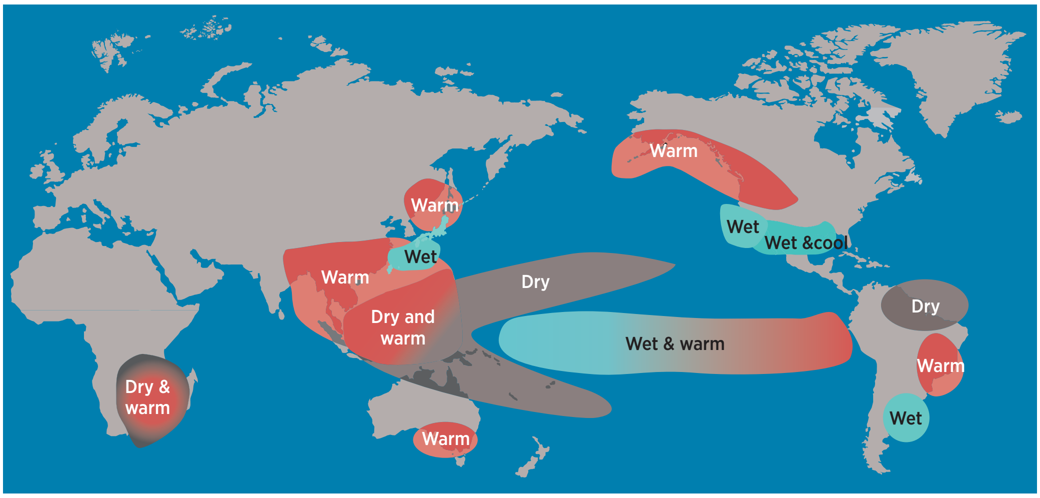

Figure 2.6. The oceanic and atmospheric anomalies associated with El Niño have impacts all over the globe

Long-term changes

Many species are endemic to different parts of the world due to the action of continental drift, which is caused by plate tectonics moving Earth's continental plates. These large, mobile plates that make up the lithosphere fit together like a giant jigsaw puzzle. Each plate is about 100 km thick and moves extremely slowly, at the rate of about 1–12 cm a year. The continents and oceans resting on these plates are carried around with them. The resulting formation of continents, mountain ranges, valleys and other landforms over long periods of time have provided the environmental conditions for isolated populations to evolve into new species.

Some areas of Earth have greater levels of diversity than others. This is due largely to the environmental conditions operating within the ecosystem (such as temperature, rainfall, nutrient availability). Rainforests and regions closer to the equator generally have greater diversity of species than do ecosystems found in temperate and arctic climates.

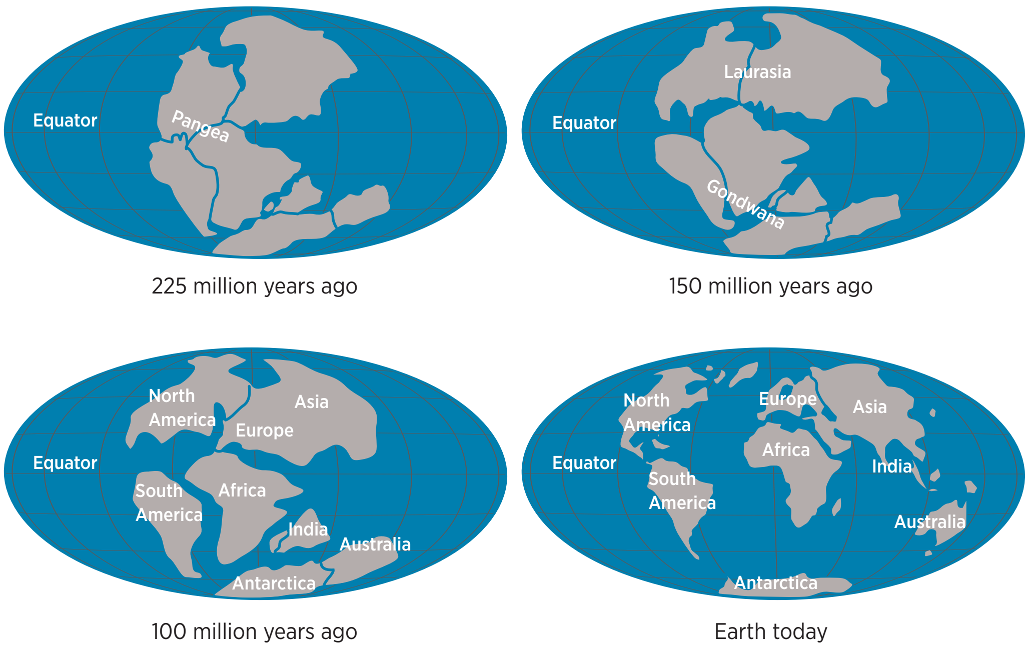

Figure 2.7. Movement of tectonic plates throughout history

CASE STUDY 2.2
Marsupials

We think of marsupials – pouched mammals including kangaroos and koalas –as typically Australian. Certainly, most of the world's marsupials – around 200 species – are found in Australia and Papua New Guinea (which were joined with a land bridge until around 15 million years ago). But another 80 or so species (opossums and shrew opossums) live in South America, and the Virginia opossum is native to North America.

It's a surprising fact that marsupial mammals probably evolved in North America. So how did Australia end up with so many? Clues came from marsupial fossils found in Australia, South America and the Antarctic. Marsupials (and also placental mammals) had travelled to Australia across Gondwana before it broke up, probably in a couple of waves of colonisation.

While placental mammals eventually dominated in the Americas, the marsupials thrived in Australia's challenging environment of low fertility soils and increasing aridity. Their success may be due to the marsupials' lower basal metabolic rate, which reduces their requirements for energy, nitrogen and water. The marsupial reproductive strategy, which allows for response to uncertain environmental conditions, may also have favoured marsupials over their early placental competitors.

Just add enough time and the result is Australia's unique and diverse marsupial fauna.

Figure 2.8. The North American opossum (a) and Australian Leadbeater's possum (b) evolved in different environments on different continents from a common marsupial ancestor. Credits: (b) Pengo CC BY-SA 3.0

Critical and creative thinking 2.1

1. **List** factors that can cause a population to become isolated, and discuss possible outcomes of these isolating factors.
2. **Explain** how time – short, medium and long term – can affect the process of evolution. Provide some examples to illustrate your response.
3. Australia has many endemic species. **Discuss** why this is the case.
4. Latitude is said to affect a region's biodiversity. **Explain** why this is the case with reference to ecosystems that demonstrate this.

Student activity 2.1 Diversification of a species: opportunity knocks

Among others, the following three factors in the environment might encourage diversification:

- The environment may have offered opportunities for specialisation.
- A fragmented environment might make reproductive isolation likely.
- The environment may have provided a release from competition with other insects.

In groups, find an example of a species that split into new species or subspecies due to the factors explained above.

Data analysis 2.1 Biodiversity changes after bushfire

A government report shows a list of species identified by the Australian Government's Department of Agriculture, Water and the Environment as requiring the highest priority for urgent management intervention after the devastating 2019–20 bushfires of southern and eastern Australia. As outlined in the document, the criteria for listing included:

- the extent to which the species' range has potentially been burnt
- how imperilled the species was before the fires (for example, whether they were already listed as vulnerable, endangered or critically endangered)
- the physical, behavioural and ecological traits that influence a species' vulnerability to fire.

1 Use the link to access the document: https://www.environment.gov.au/biodiversity/bushfire-recovery/bushfire-impacts/priority-animals

2 Note the species that are listed as *critically endangered* according to the *Environment Protection and Biodiversity Conservation Act 1999.*

3 For each such species, suggest a conservation action that could be used to protect the species and thus promote biodiversity.

CHAPTER

3

Assessing species diversity

It is rarely possible to count all individuals or species in an area, so scientists *sample* populations to assess species diversity. A variety of sampling methods are used depending on the type of species or habitat being studied. This sampling often forms part of a wider monitoring program to assess changes in biodiversity over a period of time or to evaluate the effectiveness of management strategies being used to conserve a specific species or habitat.

Ethical considerations need to be addressed when scientists conduct research or survey animal species. All such research requires ethics approval, which ensures that the welfare of animals affected is considered – both the species under investigation and other organisms within the broader ecosystem that may be affected. Beneficence is a concept important in research ethics that states that researchers should have the welfare of the research participant as a goal of any research study.

3.1. Measuring species presence and abundance

Practical techniques used for assessing species diversity: sampling with grids, transects and different shaped quadrats, including consideration of edge effects and mark-recapture

Sampling using quadrats is one of the most widely used means of obtaining quantitative information about the composition and structure of plant or sessile (attached) animal communities. If you have selected the appropriate quadrat size and shape, and a suitable number and arrangement of quadrats in the study area, these plots will give a reliable picture of the vegetation or animal community over the total study area. The following description of the quadrat method considers these factors.

The appropriate quadrat size for sampling in a study area depends on the height and density of the species present. The quadrat must be big enough to include a reasonable number of species but not so large that you can't count, identify and measure all the plants or animals within the quadrat in a reasonable time. Table 3.1 outlines some suitable quadrat sizes.

Table 3.1. Recommended quadrat sizes for different vegetation types

Vegetation type	Quadrat area
Mosses and lichens	$0.1\ m^2$
Herbs (including grasses) and tree seedlings	$1\ m^2$
Shrubs and saplings (up to 3 m tall)	$10–20\ m^2$
Trees	$100\ m^2$

If you are sampling an area where certain small species are quite abundant, you can save time by sampling those species with small quadrats. For example, you could sample the plants in a lawn with quadrats 10 cm by 10 cm (which gives an area of $0.01\ m^2$).

The number of quadrats required to sample an area effectively can range from fewer than 10 for small areas to over 100 for large areas. Some ecologists suggest that sample plots should make up about 10% of the total area being studied. To determine if there has been enough variety in the vegetation or animal community sampled, walk through the area after sampling and look for species that are abundant but missed in the sample plots.

Random sampling

It is important to study the particular community without bias. The study would be biased if quadrats were placed in the most interesting areas or in the most accessible sites.

For your results to be statistically valid, the plots should be randomly located within the study area (Figure 3.1). Locate the plots randomly as follows:

1. Place a series of grid lines on a map of the study area.
2. Number the grid lines on both the horizontal and vertical axes.
3. Record the horizontal numbers on small pieces of paper of identical size and place into a container.
4. Record the vertical numbers on small pieces of paper of identical size and place into a different container.
5. Mix each set of numbers thoroughly, then draw a number from each container. These two numbers give the location of the first plot. Mark this area on your map.
6. Repeat this procedure until you have a suitable number of plots.

Figure 3.1. Random distribution of quadrats

Figure 3.2. Systematic distribution of quadrats

Systematic sampling

Systematic sampling is used when you are trying to observe the changes in environment over a given a distance. For example, if you wanted to observe the changes in vegetation as you move inland from a rocky shore.

Systematic sampling requires the quadrats be placed in line as evenly as possible. Mark a straight line, or transect, through your site. Place the quadrats at equal intervals along this line (Figure 3.2).

Belt transect

A belt transect is a number of small quadrats joined together in a line.

Sampling edge effects

Sometimes a plant crosses the edge of a quadrat and a decision has to be made whether it should be counted or not. Overestimation of the population size can occur when these edge specimens are all counted, as is quite common. Using a circle minimises sampling edge effects because the ratio of edge to area is lower in a circle than in a square. However, the area of a circle is more difficult to calculate than the area of a square.

Practical 3.1
Class activity: Systematic sampling

Investigate the zonation (distribution) of plants or animals on a rocky shore, river bank or lake shore using systematic quadrat sampling.

Techniques for sampling mammals

Mammals are a useful group to study because they are well known both biologically and taxonomically. Their ecological requirements are probably the best known of any group.

Mammals are often used as indicator species: their presence, absence or abundance can be used to indicate the state of the environment under consideration. For instance, in disturbed environments, introduced rodents, such as the house mouse and black rat, are known to displace their native ecological equivalents, such as the brown antechinus and bush rat.

The problem confronting researchers undertaking ecological surveys is the secretive nature and nocturnal habits of so many of our mammals. Several techniques have been devised to detect the presence of mammals in the field.

Indirect signs

It is possible to identify some species by their droppings (scats), tracks (footprints, tree scratchings), feeding signs (such as the conical pits of bandicoots; incisions in the bark of eucalypts by yellow-bellied gliders), burrows, food remains and the remains of bodies (such as skulls, hair and skins). If you are unsure which species left the sign, try to collect part of it (for example, droppings or hair) or photograph or sketch it and then refer to field guides.

Spotlighting

Spotlighting involves quietly walking along tracks at night and listening for tell-tale rustlings of mammals in leaves or shrubs. The animals are then viewed with a powerful handheld torch or spotlight. Although white light is the best to detect the species, red light is often used to observe the animals for a prolonged time because this is less disturbing to the animal.

Direct observation

A few species may be observed directly during the day or by setting camera traps that can be left for a period of time. Camera traps are triggered by animal movement and may capture still images or video.

Live trapping

Small mammals can be trapped alive in collapsible aluminium Elliott traps or in wire mesh cage traps using suitable bait. Trapping can only be undertaken with a permit from the Victorian Department of Environment, Land, Water and Planning. Trapping yields the most reliable data, since an actual specimen is obtained and can be positively identified. Additional data such as sex and weight can also be collected. However, trapping interferes with the lives of animals and should be restricted.

Capture–mark–recapture

If you are trapping live animals, you can use the capture–mark–recapture technique to estimate their population size. A sample of the population is captured, marked and released. Later, another sample is captured, and the number of marked individuals within this second sample is counted.

The number of marked individuals within the second sample should be proportional to the number of marked individuals in the whole population.

$$\boxed{\frac{M}{N} = \frac{m}{n}}$$

Where:

M = number of members of the population that were captured initially and marked

N = the population size you want to estimate

m = the number of members of the second sample that were already marked

n = the size of the second sample.

Estimate the total population size using the following equation.

$$\boxed{N = \frac{M \times n}{m}}$$

The method is most useful when it is not practical to count all the individuals in the population.

Data analysis 3.1
Estimating crocodile numbers

The Parks and Wildlife Commission of the Northern Territory of Australia is sampling saltwater crocodiles *(Crocodylus porosus)* to determine how many there are in a 10 km stretch of the Adelaide River. On the first day, they catch 40 crocodiles and mark them with a blue tag. On the second day they catch 50 crocodiles. Twenty of the 50 were already marked with a blue tag. What is your estimate of the population?

Critical and creative thinking 3.1

1. How might you decide the size and number of quadrats to use when surveying a site? Give reasons for your answer.
2. Sophie is collecting fieldwork data on the species of birds located in a rainforest. **List** some direct and indirect observations she might make.
3. **Identify** one method of estimating the population size of each of the following:
   a) eastern grey kangaroos in an open woodland
   b) orange-bellied parrots migrating from Tasmania to Victoria
   c) barnacles in an intertidal zone
   d) marram grass on a sand dune.
4. Chen is studying the population of the southern brown bandicoot. He has set up a number of quadrats to examine this population. Sophie tells Chen you can't use quadrats to study mammal population abundance. **State** who you agree with and discuss why.

3.2. Measuring biodiversity

Measurement of species diversity, including species richness, endemism and the application of Simpson's Index of Diversity (SID)

The level of biodiversity in an area can be assessed in a variety of ways. The most common method is to measure the number of species. Many people only think of the number of species in an area when they talk about biodiversity, but we know that biodiversity is much more than this.

Australia is internationally recognised as one of 17 countries with major repositories of biological diversity. The 17 megadiverse regions combined account for 70% of the total biodiversity of the planet. These assessments are based on the number of species present. For example, Australia is reported as having between 400,000 and 700,000 species, estimated to be 8–10% of all species on Earth. As a comparison, the number of species in all of Europe and North America north of Mexico combined is less than half Australia's total.

Species richness

Species richness is simply the number of different species present in a particular region. The species richness of an area doesn't give a full picture of diversity because it:

- ignores the genetic variation that may be present within the species
- only partially represents ecosystem diversity
- ranks all species equally, so a rare species counts the same as a common species or even an introduced species.

For example, a recent survey of fish species in the Murray–Darling river system found 40 species, but only 35 of these were native fish of which 6, including the Murray cod and the trout cod, were rare. In terms of numbers of individuals, most of the fish recorded were introduced species, particularly European carp. The fact that there were 40 species of fish tells us very little about the biodiversity of the river system.

Species diversity

An extension of species richness is species diversity, a measure that takes into account the relative abundance of each species present as well as the number of different species. This introduces the concept of equitability, which is the extent to which each species contributes to the ecology of the community. For similar-sized species, this ecological importance can be measured by numbers of individuals present. Communities are considered to have a higher diversity if species occurring within a particular trophic level are present in roughly equal numbers, compared with a community where a trophic level is dominated by only a few species.

Species diversity measures involve a calculation that yields a diversity index. One commonly used measure is Simpson's Index of Diversity (SID), which is based on the probability of two specimens belonging to the same species.

The formula for Simpson's Index of Diversity Index is

$$\boxed{\mathrm{SID} = 1 - \frac{\Sigma[n_i(n_i - 1)]}{N(N - 1)}}$$

Where:

N = the number of organisms

Σ = sum of

n_i = the number of individuals in species i.

Below is shown some hypothetical sampling data from a study site and the steps in calculating Simpson's Index of Diversity.

Species	No. of organisms N	$n_i(n_i-1)$
Bandicoot	2	2(2 − 1) = 2
Numbat	8	8(8 − 1) = 56
Echidna	1	1(1 − 1) = 0
Green frog	1	1(1 − 1) = 0
Wallaby	3	3(3 − 1) = 6
Total	15	64

$$\begin{aligned} SID &= 1 - \left(\frac{64}{15(14)}\right) \\ &= 1 - \left(\frac{64}{210}\right) \\ &= 1 - 0.3 \\ &= 0.7 \end{aligned}$$

Simpson's Index of Diversity ranges from 0, which indicates low diversity, to a maximum of 1, which indicates very high diversity. The index gives relatively little weight to rare species and more weight to common species.

Table 3.2 shows the results of a survey of aquatic invertebrates from a creek in the highlands of central Victoria. Site 1 is in the forested headwaters of the creek where there is little human impact and site 2 is in the lower reaches below a settlement where there is some drainage of waste water into the creek. Although the lower site has more individuals, it has a lower species richness and lower species diversity, as indicated by both indices. This data is fairly typical of the changes that occur in the invertebrate community of a creek as a result of a nutrient enrichment due to human activity.

Table 3.2. Results of a survey of invertebrates from a creek in central Victoria

Site	No. of individual organisms	Number of species (species richness)	Simpson's Index of Diversity
1 Forested headwaters	86	19	0.864
2 Lower reaches	147	10	0.365

Practical 3.2
Interpreting Simpson's Index of Diversity

Aim

To determine the biodiversity of a number of ecosystems.

Procedure

1. Using the information on species composition provided, calculate the diversity of a site before and after an impact such as sheep grazing at the site.

Determining diversity at site A before sheep grazing

Species	No. of organisms N	$n_i(n_i-1)$	Total
Shrub 1	3		
Shrub 2	7		
Understorey 1	5		
Understorey 2	6		
Understorey 3	94		
Understorey 4	75		
Weed 1	0		
Weed 2	0		
Total			
Simpson's Index of Diversity SID =			

Determining diversity at site A after sheep grazing

Species	No. of individuals N	$n_i(n_i-1)$	Total
Shrub 1	1		
Shrub 2	2		
Understorey 1	0		
Understorey 2	2		
Understorey 3	94		
Understorey 4	75		
Weed 1	2		
Weed 2	20		
Total			
Simpson's Index of Diversity SID =			

Results

Describe the species diversity at site A before and after the impact of sheep grazing.

Discussion

1. What does the calculated Simpson's Index tell you about the species richness before and after the sheep grazing?
2. Describe and **compare** the species composition of site A before and after the impact. How does this analysis compare with the analysis using Simpson's Index?
3. What effect has sheep grazing had on the species composition of the site?
4. Using this example, **explain** the limitations of relying only on Simpson's Index as a determinant for species diversity.
5. What do you **suggest** could improve the data collection and analysis to determine a site's diversity?
6. If you were asked to manage this site for species diversity, what would you aim to do?

Practical 3.3
Measuring biological diversity

Aim

To investigate ecosystems in the local area,such as school grounds, a local park, your garden at home or a local creek.

Equipment

Equipment for marking out quadrats and transects, such as string, 1 m rods or poles, measuring tapes, metre rulers.

Procedure

Alternative 1 – Random sampling

1. At each site you have chosen, randomly select a number of quadrat areas that you think will accurately represent the area (see 'Random sampling', p 30).
2. In each quadrat, draw up a list of plants and animals present and count the number of individual organisms of each type present (be careful not to overlook very small organisms).

Alternative 2 – Systematic sampling

1. At each site you have chosen, mark out a transect by using a piece of string and placing it straight across each site.
2. Along the transect, set out a series of quadrats at regular intervals (see 'Systematic sampling', p 31).
3. In each quadrat, draw up a list of plants and animals present and count the number of individual organisms of each type present.

Remember to undertake fieldwork with minimum impact on the environment.

Results

1. For each site, record the location, date, type of ecosystem and number of quadrats used.
2. Draw up a table of your results similar to this one.

	Site 1 [example]		Site 2	Site 3	Site 4
Location	Local creek				
Ecosystem type	Riparian				
Identity and no. of species present	Species 1	3			
	Species 2	6			
	Species 3	1			

3. Use Simpson's Index of Diversity to measure the diversity of each site. Rank the sites in terms of their diversity.

Discussion

What actions could be undertaken to improve the biodiversity of your sites?

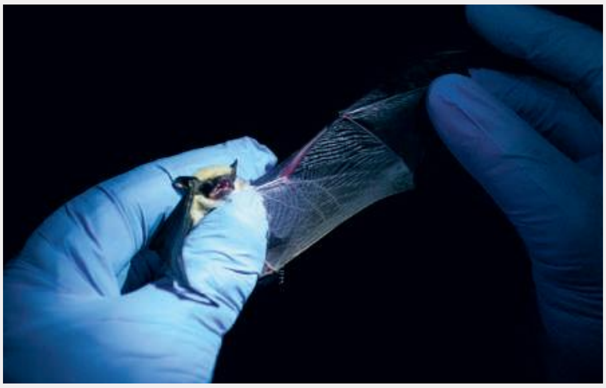

Figure 3.3. Small mammal trapping.
Credit: Joshua Tree National Park, Public Domain Mark 1.0

Degree of endemism

Another way of evaluating biodiversity in an area is to examine the degree of endemism of the species present. A species is considered to be endemic if it is native to that area only. So the endemism of the biodiversity of a region can be expressed as the percentage of endemic species present.

Earlier in this section we described Australia as one of the 17 megadiverse regions of Earth. These megadiverse regions are identified not only by their species richness but by their level of endemism. Australia has 8–10% of Earth's species, of which a high proportion are endemic (Table 3.3).

Table 3.3. The level of endemism among Australian species

Group	Number of species	% endemic
Vascular plants	19,324	92
Mammals	386	87
Birds	828	45
Reptiles	917	93
Amphibians	227	94
Invertebrates	98,703	unknown

Source: Chapman, AD, 2009, Numbers of living species in Australia and the world, 2nd edn, Report for the Australian Biological Resources Study, Canberra, Australia.

Vegetation structure

The biodiversity of flora also can be assessed in terms of the physical structure of the vegetation, that is, the size and shape of the plants. The vegetation structure of an area is determined by the type of vegetation present, the age of the plants, the environmental conditions to which the plants are exposed and how the individual species of plants respond to these conditions.

Two characteristics are taken into account when classifying the vegetation structure of a community. One of these is the height of the tallest vegetation present. This can vary from tall forests, such as mountain ash forests where the dominant vegetation is more than 30 m tall, to mallee scrub and low grasslands.

The other characteristic is the projective foliage cover of the tallest level (or stratum) of vegetation. Projective foliage cover is the percentage of the ground below the stratum that is covered (shaded) by the foliage of the plants in the stratum. This foliage cover also varies quite considerably, from more than 90% in tropical rainforests through about 30% in eucalypt forests to 10% in arid shrublands.

Table 3.4 presents a classification of Australian vegetation based on these two characteristics. This classification can be used to give a measure of the biodiversity of an area (in terms of the number of different vegetation categories), which can be particularly useful if it is combined with the species composition and abundance within the area.

Table 3.4. Structural forms of vegetation in Australia

Height of tallest stratum	Protective foliage cover			
	Dense (70–100%)	Mid-dense (30–70%)	Sparse (10–30%)	Very sparse (<10%)
Trees >30 m	Tall closed forest	Tall open forest	Tall woodland	Tall open woodland
Trees 10–30 m	Closed forest	Open forest	Woodland	Open woodland
Trees 5–10 m	Low closed forest	Low open forest	Low woodland	Low open woodland
Shrubs 2–8 m	Closed scrub	Open scrub	Tall shrubland	Tall open shrubland
Shrubs <2 m	Closed heath	Open heath	Low shrubland	Low open shrubland
Hummock	–	–	Hummock	Open hummock
Grasses <2 m	–	–	Grassland	Grassland

Source: based on Specht, RL, 1970, 'Vegetation', in GW Leeper (ed.), Australian Environment, 4th edn, pp. 44–67, Melbourne: Melbourne University Press.

3.3. Statistical techniques to evaluate management

A question we often want to answer is: how can we scientifically determine if a development or environmental change has had a significant effect on biodiversity?

We often want to make a comparison between two situations, for example, a study site before and after a change, or a site after a change compared to a reference (or control) site. Usually, the results will not be identical, but we want to know if this difference is real (possibly caused by the change, for example) or simply due to chance. This can be determined by statistical analysis of the data.

Statistical analysis starts with setting up a hypothesis to test the difference between the two conditions. The null hypothesis (shown as H_0) states that there is no difference between the two conditions. The alternative hypothesis (H_1) is that there is a difference between the conditions.

A statistical test, such as a t-test, can be applied to the data to test the null hypothesis. If there is less than a 5% probability that the difference observed between the two sites is due to chance, the difference is considered significant. This means that we reject the null hypothesis (no difference) and accept the alternative hypothesis that there is a difference between the conditions. If the test does not show a significant difference, then we accept the null hypothesis and reject the alternative.

Remember that this testing simply tells us whether there is a difference between the conditions. It does not tell us what caused the difference – the difference could have been caused by some other factor, not the one we are investigating. In order to establish that the change you are studying has caused the difference we find, you need to design a controlled experiment. Experiments where you vary only one or two factors are relatively easily set up in the laboratory. In contrast, ecological studies and field experiments are usually influenced by many environmental variables, which are difficult or impossible to control.

We can define the statistical power of an analysis as the confidence we have in detecting a particular effect, if it exists. The statistical power of an analysis is determined by the design of the program and depends on factors such as the sample size, the variability of the data and the measurements made.

The power of the monitoring or assessment analysis is important if we wish to have confidence in the assessments used in conservation planning. High-powered tests will ensure that we can detect even small impacts, but they can be expensive (for example, requiring large sample sizes), so they are not always possible. Environmental management involves an evaluation of the costs and benefits of any proposal. The final decision is usually a balance between the scientific requirements and the political and economic realities of the situation.

Practical 3.4
Does biodiversity vary with human impact?

Aim

To compare the biodiversity of two areas that have experienced different levels of human impact.

Procedure

1. Select two sites that have been subject to differet levels of human impact. For example, you could compare two sites on a creek, one above and the other below the discharge of a drain into the creek. Or you could compare two areas of bushland in a park, one near a road or picnic area and the other distant from such disturbances.
2. Survey the biodiversity of the two sites by examining a number of quadrats at each site to test the difference between the two sites.

   You don't have to survey all the species of organisms in your sites; you can analyse a single group of organisms. For example, you could compare only the macroinvertebrates of creek sites, or the birds, plants or soil invertebrates of bushland sites.
3. Determine the diversity of the two sites using the Simpson's Index of Diversity calculations. The null hypothesis is that there is no difference in the diversity of the two sites. What is your alternative hypothesis?

Results

1. Record your results in the table below.

Quadrat	Number of species	
	Site A	Site B
1		
2		
3		
4		
Total		
Mean (total ÷ no. quadrats)		

2. Plot the means for each sample on a piece of paper.
3. Examine the difference between the means.

Discussion

1. Can you offer an explanation for the difference between the mean number of species at your two sites?
2. **Suggest** some management strategies to improve the diversity of your sites.
3. Prepare a brief report of your findings and recommendations.

Critical and creative thinking 3.2

1. **Explain** the terms 'species richness' and 'species diversity'.
2. **Define** 'endemism'.
3. What is a diversity index? Give an example.
4. Find an example of an Australian endemic species for each of the groups of organisms mentioned in Table 3.3.

3.4. Conservation status

Conservation categories for ranking species according to their risk of extinction: extinct in the wild; critically endangered; endangered; vulnerable; near threatened; and least concern

Assessing risk of extinction

Risk is the possibility of suffering some harm as a result of some activity. The harm could be physical damage or injury, economic loss or environmental damage. Risk assessment involves using data to estimate the probability of some harmful event occurring.

Risk assessment is an important part of environmental management. Regulatory authorities have set the maximum allowable levels of various chemicals in streams and rivers based on data about the toxic effects of these compounds on aquatic life. We can also use risk analysis in the conservation of biodiversity. One way we can do this is by estimating the probability of a species or population becoming extinct.

Estimating the risk of extinction is difficult; however, two approaches have been developed with limited success.

One approach extends the theory of island biogeography to estimate the number of species that can be maintained in a given area (or, conversely, the area of habitat necessary to maintain a given number of species). These analyses produce general predictions; for example, reducing habitat in an area by 90% will result in a loss of 30–60% of the species present. These figures will vary with different habitats.

This form of analysis can be used to predict the effects of habitat loss and fragmentation on species and to estimate the size of reserves necessary to preserve species. Predictions such as the one above tend to have a fairly high level of uncertainty, and the results should be used with caution.

The second approach to assessing the risk of extinction uses collections of organisms in herbariums and museums to calculate the probability of a species being extinct. An organism is classified as extinct if it has not been collected for some period of time (currently, this is arbitrarily set at 50 years). The probability that a species has not become extinct can be calculated by considering the time since the last collection or sighting, the time since the species was first collected, and the number of specimens collected. For example, if the last collection is quite recent, the calculation returns high probability values that the species is not extinct.

This method assumes that the collections are made at random, so that the chance of collecting a species does not change over time. This is not the case in practice, with recent intensive surveys in specific areas and for particular species, and the fact that some species live only in very remote areas. Several species have been found after being considered extinct in this way. Nevertheless, this technique provides a useful estimate of the relative threat of extinction for species. Although the procedure is based on historical evidence, it should be used in conjunction with current data, in particular, information about threatening processes.

Population viability analysis

Population viability analysis is a technique that assists with risk management in conservation biology. Population viability analysis can be used to examine how management decisions may produce changes in population numbers and affect the risk of extinction. This allows managers to rate different management options and highlight areas where more research is needed. Forms of population viability analysis have been used in managing several Australian mammals, including the eastern barred bandicoot and Leadbeater's possum.

The analysis usually involves constructing a computer model of the population under investigation incorporating available demographic and ecological data (such as population age and structure, birth and death rates, migration, behavioural ecology and competition). Likely sources of variability or threats, such as environmental variation, demographic variation and spatial variation (fragmentation), can also be included in the model. This process will identify any gaps in knowledge about the species and suggest where more research needs to be done.

The model is used to generate a series of population projections and the probability of each of these occurring. Different management strategies can be evaluated by comparing outcomes based on different inputs. Thus, managers can make informed recommendations for the management of the species.

Although population viability analysis is primarily used to evaluate different management strategies, it can also help determine a minimum viable population for a species. This is the smallest population that has a reasonable probability of surviving for some time into the future (the outcome will depend on factors such as the length of time considered and the level of risk considered acceptable). Generating a minimum number for a viable population is useful for estimating the minimum size a conservation reserve for a species should be.

Models are not perfect tools for managing risk in conservation biology. Their major limitation is that we do not have complete data on any species. Nevertheless, models are important management tools as long as their limitations are recognised and the underlying assumptions are clearly stated. Models assist in setting priorities for conservation programs and providing a scientific input into decision-making, along with social, political and economic considerations.

Data analysis

Scientists sometimes use a simplified probability analysis of one or more populations of a species to determine the overall likelihood of extinction of a species in a given timeframe.

For example, we can calculate the probability of species A going extinct in the next 5 years, according to the probability of extinction of its two remaining populations.

Location 1:
Species A has a 50% (represented as 0.5) probability of extinction in 5 years.

Location 2:
Species A has an 80% (represented as 0.8) probability of extinction in 5 years.

The overall probability that species A will become extinct in 5 years = 0.5 x 0.8 = 0.4.

Expressed as a percentage, the probability = 0.4 x 100 = 40%.

Thus, there is a probability of 40% that species A will become extinct within 5 years.

Conservation status categories

Categorising species according to their conservation status provides a framework for setting priorities for allocating the limited resources available for conservation. Ecologists classify plants and animals on a scale that reflects the degree of threat to the species, ranging from being under no immediate threat through varying levels of risk to critically endangered and extinct.

One aspect that is often used in assessing conservation status is how rare a species is. As discussed in section 1.2. 'Importance of genetic biodiversity' (p 12), small populations are much more likely than large populations to become extinct. But rarity encompasses more than just a small population size.

Three factors contribute to rarity of a species:

- population size – the density or number of individuals within a local area (may range from high to low)
- geographic range – the spatial distribution of the species (may range from restricted to widespread)
- specificity of habitat – the variety of ecological conditions within which a species can survive (may range from wide or general through to specific or narrow).

Each of these factors covers a range of conditions, and a species' rarity depends on the combination of factors. For example, a small population occurring in a restricted range and with a narrow habitat requirement is obviously rare. However, a large population that is found over a widespread range but has a very narrow habitat specificity can also be rare and at risk of extinction.

A population described as rare is not necessarily faced with imminent extinction. There are many examples of species with small populations that are stable and have persisted for long periods of time. Nevertheless, rarity is an important factor underlying the classification of threat confronting species. The International Union for the Conservation of Nature (IUCN) has developed a classification scheme for degrees of threat to species that is widely used in conservation management (Figure 3.4 and Table 3.5).

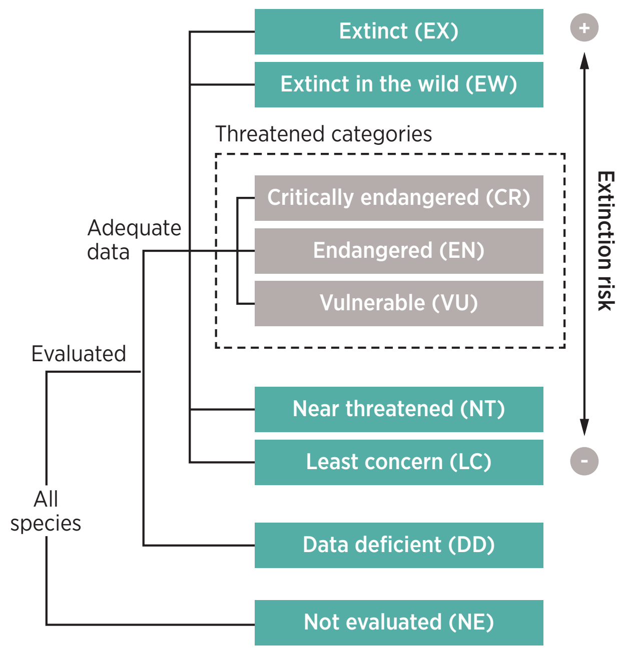

Figure 3.4. IUCN threatened species categories

Table 3.5. IUCN categories and their definitions

Category	Definition
Extinct	There is no reasonable doubt that the last individual has died.
Extinct in the wild	The taxon is known to survive in cultivation, in captivity or as a naturalised population well outside its past range. Exhaustive surveys have failed to record an individual in the wild.
Critically endangered	The taxon is facing an extremely high risk of extinction in the wild in the immediate future.
Endangered	The taxon is not critically endangered, but is facing a very high risk of extinction in the wild in the near future.
Vulnerable	The taxon is not endangered, but is facing a very high risk of extinction in the wild in the medium-term future.
Near threatened	The taxon is close to meeting the threatened thresholds or would be threatened were it not for an ongoing taxon-specific conservation program. (The latter were formerly known as conservation-dependent species. In 2012, this category merged with the near threatened category.)
Least concern	The taxon has been evaluated to have a low risk of extinction.
Data deficient	There is inadequate information to make a direct or indirect assessment of its risk of extinction based on its distribution or population status.
Not evaluated	The taxon has not yet been assessed against the criteria.

Criteria have been published for determining when species fit into the three categories of threatened taxa (critically endangered, endangered and vulnerable). These criteria include assessments of the species' population size, its geographic distribution, the number of mature individuals in the population and an estimate of the probability of future extinction in the wild.

For example, criteria for considering a species critically endangered include:

- an observed population decline over the last 10 years or three generations of at least 80%
- the extent of occurrence is estimated to be less than 100 km^2
- the population is estimated to be fewer than 50 mature individuals
- the probability of extinction in the wild is at least 50% within 5 years, or two generations.

The complete set of criteria can be found at www.iucnredlist.org.

Conservation categories and other classification systems are useful for determining priorities and planning conservation programs. However, often we lack the complete set of data required to determine these classifications. In these cases, some guesses or value judgements need to be made in assessing the conservation status, which means that ratings may be inconsistently applied depending on the individual bias of the scientists and experts making the judgements. Nevertheless, despite the limitations of current data, these classifications are an important management tool.

Critical and creative thinking 3.3

1. **Define** these three conservation categories: critically endangered, endangered and vulnerable.
2. **Explain** why it is useful to have a system of conservation categories.
3. Research an Australian species you have identified as either critically endangered or endangered and **discuss** the factors that have put it in this conservation category.
4. Threatened plant and insect species often receive less funding and attention than do threatened large vertebrate species. **Discuss** why you think this might be the case.

3.5. Biodiversity conservation

Qualitative assessment of conservation status to identify the species most in need of conservation action: changes in availability of suitable habitat, geographic distribution, and population size

In conservation planning, it is important to consider biodiversity conservation on four levels: genetic, population, species and ecosystem.

Conservation of genetic diversity

Genetic diversity is important because a species or population with a low level of genetic diversity is less able to respond to changes in its environment. Such a population does not contain a sufficient range of genetic material to ensure that it can adapt to environmental change through natural selection.

Genetic diversity can be measured in terms of the number of alternative forms (alleles) of each specific gene. It can also be measured by recording the variation in morphology (appearance) of individuals within the species or population. Morphology is largely determined by individual genes or groups of genes.

One of the difficulties in using genetic diversity in conservation planning is that very little information is available on the level of genetic variation within species. Less than 1% of plant and animal species have been assessed for their genetic diversity. Consequently, the external appearance of individuals within a species is used as a measure of genetic variation. This is generally quite reasonable as morphology is due largely to the expression of genes. However, organisms with similar morphology may differ in genetic make-up (or genotype), and organisms with quite different appearances may be genetically very similar. Care should be taken when conservation strategies are based solely on morphological estimates of genetic diversity as these are not necessarily a true representation of the underlying genetic diversity.

Conservation of population diversity

Conservation planning can also operate at the level of populations. A population is defined as a group of organisms of the same species living within a particular area. Populations are a common focus of conservation strategies. However, populations can be separated from one another geographically, and gene flow between populations can be restricted. As a consequence, the genetic composition of populations will vary as each population becomes adapted to the environment it occupies. The extent of the difference between populations will be determined by how isolated they are from one another, the difference in the environments they inhabit and the length of time they have been separated.

This genetic difference has implications for the management of species. For example, it may not be possible to revegetate an area or reintroduce animals to a region if the plants and animals that are being introduced are derived from populations different from those originally occupying the area. These new organisms may well have a genetic composition that has adapted them to a particular geographic area, but which will not suit them to the region where they might be introduced. On this basis, it is important to preserve not just a single population of a species but a range of populations, which will encompass a greater range of genetic diversity.

Conservation of species diversity

The species is the basic unit of most conservation programs. Usually, government legislation that deals with conservation includes reference to preservation of species. We also commonly talk about extinction of species and whether species are threatened. While we recognise a species as a group of organisms that resemble one another in appearance, behaviour, chemical processes and genetic structure, it is not easy to develop a strict definition of species.

The commonly used definition defines a species as a group of individuals that actually or potentially interbreed with one another and produce fertile offspring. Of course, it is hard to determine whether geographically isolated groups of organisms can interbreed. In addition, many defined species quite readily hybridise and so do not strictly conform to this definition. Many species of plants, including eucalypts, fall into this category.

Organisms that do not reproduce sexually are not covered by the above definition. In these organisms, species are defined in terms of their morphological or biochemical characteristics or their habitat range.

In reality, because of the difficulties associated with determining whether interbreeding can occur, many of our species are distinguished on the basis of morphological characteristics. Thus, using the species as the basic unit of conservation has some limitations.

Conservation of ecosystem diversity

Ecosystem diversity refers to the variety of ecosystems in a given place. Any broad landscape contains a mosaic of interconnected ecosystems. Conservation at the landscape level is critical to conserve biodiversity. This enables the protection of a representative array of interacting ecosystems and their associated species and genetic diversity. Different ecosystems support different ecological processes and provide different environmental services. The greater the number and types of ecosystems present in the biosphere, the more resilient the environment and the more likely that its processes will continue to provide the essential services needed to support all life on Earth.

Practical 3.5
Urban spread

The council of a small coastal town in Victoria gave planning approval for a landowner to develop large amounts of farmland surrounding the town into 20,000 house lots. Many trees must be removed to make way for the housing development. The townspeople did not want the trees removed and lobbied the Victorian Government to save the trees. It was determined that none of the trees were of ecological importance, either in size or age; however, one tree had an active wedge-tailed eagle nest in it. Use the concepts of:

- conservation of genetic diversity
- conservation of population diversity
- conservation of species diversity
- conservation of ecosystem diversity
- the precautionary principle (see p 71)

to develop an argument either for or against the housing development and the conservation or removal of the trees.

Critical and creative thinking 3.4

1. Many scientists now argue that ecosystem conservation is more important than conservation of a single species.

   a) **Explain** why scientists might put forward this argument based on your knowledge of conservation.

   b) Do you agree or disagree with this argument? **Discuss** in reference to your own opinion.

2. **Explain** the benefits for humans when a wide range of ecosystems are conserved and maintained for our generation and future generations.

3. Environmental managers are deciding where to spend their conservation budget. They can spend it to conserve one of two populations of a particular species. Population A has fewer than 50 individuals, but the animals can move between it and other populations through existing patches of remnant vegetation and there are few threatening processes acting upon it. Population B is a large population with over 200 individuals; however, their habitat is isolated from other existing populations and it is increasingly coming under pressure from growing urban sprawl.

Which population (A or B) do you think should be conserved? **Explain.**

CHAPTER 4

Threats to biodiversity

Plants and animals are constantly under pressure from many different external factors that affect their environment. These pressures can have a direct impact on the survival of organisms themselves. They can also affect the environment the organism lives in, thus indirectly affecting the organisms' survival. These threats result from both human and non-human influences.

4.1. Threats to survival

Human and non-human threats to biodiversity: creation and isolation of small populations through habitat loss and over-exploitation; inbreeding due to small population size; loss of pollinators, dispersal agents, host species or symbionts that affect reproduction and persistence of species; bioaccumulation that concentrates some persistent pollutants within organisms and biomagnification along a food chain; climate change; disease; and introduced species that compete for shelter, food and water

Modification

Habitat modification results from a change in local environmental conditions where the native habitat is changed in some way from its original condition. These changes in environmental conditions can be caused both by natural events (such as volcanic eruptions, earthquakes, floods, fires and cyclones) and by human-induced events (such as the clearing of land for agricultural purposes, urbanisation or other developments).

Habitat degradation refers to a reduction in the quality of a habitat. When the natural environment is altered so dramatically that it no longer supports native species, such as the habitat destruction from the broadscale clearing of native land, plants and animals die or disperse, reducing biodiversity.

Habitat loss and fragmentation

Habitat fragmentation can occur through the development of roads, towns, factories, fences, powerlines and pipelines, and the planting of fields – all these activities form barriers between the remaining isolated areas of suitable habitat. The once-large populations of species are reduced to several smaller populations (Figure 4.1). These smaller populations are more susceptible to changes to their environment and are at risk of possible inbreeding and outbreaks of diseases.

The size and shape of an area of remnant vegetation (such as patches of native trees, shrubs and grasses remaining after habitat fragmentation) affect a site's conservation value and overall biodiversity. The edges are most susceptible to impacts from the surrounding areas often due to impacts relating to human activity – this is sometimes referred to as the edge effect. (Note that this habitat edge effect is different to the sampling edge effect discussed in Chapter 3.) A narrow linear shape is most prone to impacts from surrounding areas because it has a higher ratio of edge area to core area, while a circular shape has the lowest ratio and thus provides the best protection (Figure 4.2).

Native vegetation clearing continues in Australia, although clearing rates have decreased over time, mainly due to the reduced availability of native land to clear. In 1990, a total of 5,610 km^2 (561,000 hectares) were cleared compared with only 2,165 km^2 in 2008.

The 2016 State of the Environment report found that, since European settlement, approximately 44% of Australia's forests and woodlands have been cleared, with 39% being cleared before 1972. The most heavily cleared areas previously covered more than 170,000 km^2; less than 20% of the original communities remain.

Over-exploitation

Over-exploitation is the result of human harvesting of food or the use of natural resources from forests, fisheries and wildlife above a sustainable level. As human populations have expanded, so too has the impact of their harvesting, hunting and catching. With improvements in technology over time, the rate of deforestation has increased due to faster and larger scale timber cutting. In the oceans, the development of radar, sonar and factory ships with trawling nets has resulted in more fish being caught more quickly, and also more bycatch (marine species that are of not used for human food sources).

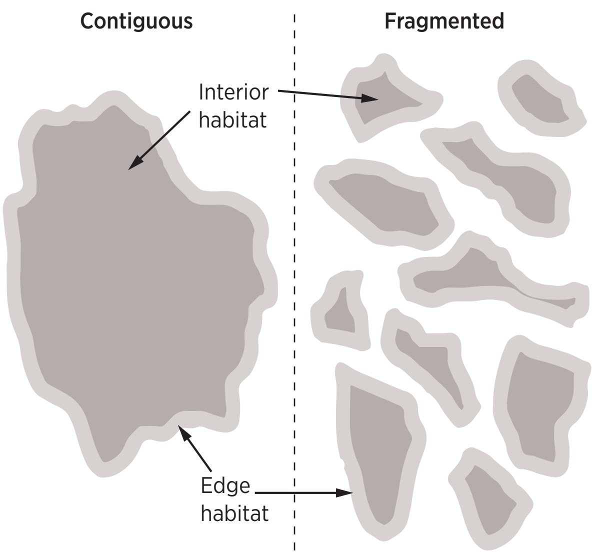

Figure 4.1. Contiguous (connected) habitat vs fragmented habitat

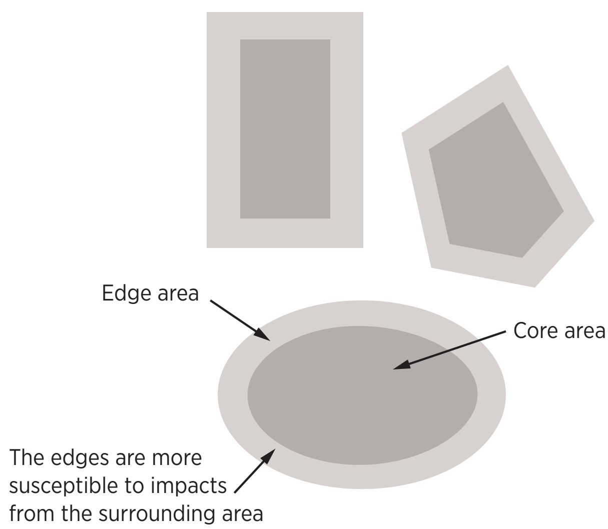

Figure 4.2. Remnant shapes and sizes affect the ratio of edge area to core area

Other examples of over-exploitation include the harvesting of whales and the exploitation and illegal poaching of endangered animals, either for body parts or for trade in exotic pets. All these processes result in the degradation and loss of habitats and ecosystems and the reduction of populations of species, making them vulnerable to disease and other changes.

Inbreeding due to small population size

Small populations can suffer from inbreeding, which is breeding between individuals that are close genetic relatives. Relatives share more of the same alleles, so inbreeding increases the chances of offspring being homozygous, which increases the chances of deleterious recessive alleles being expressed. Increased levels of homozygosity through inbreeding can reduce the survival rates and reproductive success of members in the population; this decline in population fitness is called inbreeding depression.

Small isolated populations of organisms can be at risk of inbreeding. Small captive populations that are not carefully monitored can also be at risk of inbreeding.

Effects of inbreeding include reduced fertility and birth rates, reduced immune function resulting in increased susceptibility to disease, increased risk of genetic disorders and mutations.

Loss of pollinators, dispersal agents, host species or symbionts

Biodiversity loss can lead to the removal of certain species that are critical for the survival of other organisms. Some species are in symbiotic relationships, where different species live together in an intimate association. Many plant species rely on other organisms to distribute their pollen and seeds in order to reproduce. A loss of the insect, bird or mammal species that is vital for this process can result in the subsequent loss of the plant species.

Bioaccumulation and biomagnification of pollutants

There have been many instances of pollutants, such as herbicides and pesticides, being used in agricultural settings and then making their way into the natural environment where they have significant impacts on organisms. **Bioaccumulation** is the build-up of persistent, non-biodegradable pollutants within an organism when it takes in more of the substance than its body can remove. **Biomagnification** is the increasing concentration of a pollutant along a food chain through the different trophic levels. Due to the biomagnification process, the organisms at higher trophic levels can be more greatly affected by a pollutant than those lower in the food chain.

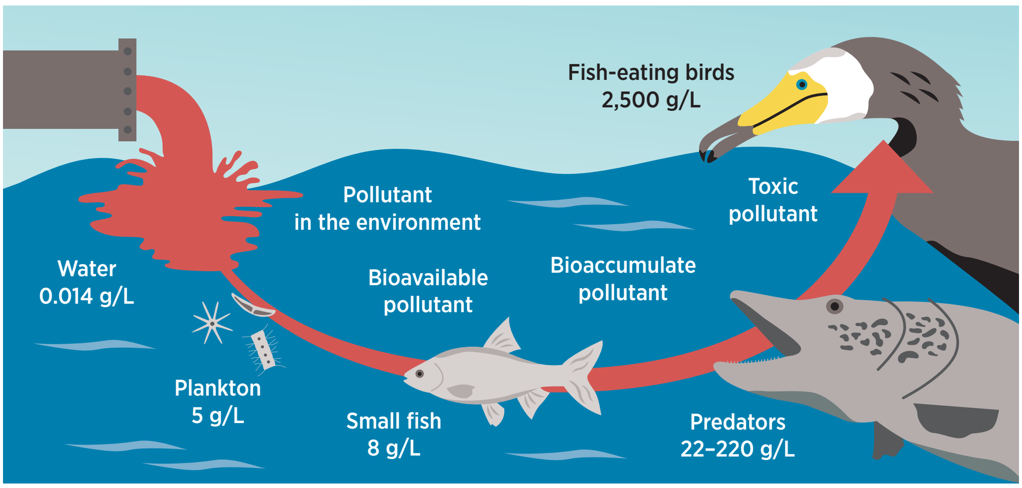

Figure 4.3. Biomagnification of a toxic pollutant

The effects of herbicides and pesticides were not widely known when they were first used. Often the effects do not show up for many years or generations of the organisms at the top of the food chain. This was the case with the use of the pesticide DDT (dichlorodiphenyltrichloroethane), which was used to control mosquitos. Eventually it was discovered that biomagnification of DDT in the food chain had resulted in high levels of DDT in birds of prey (in the top trophic level). This caused their egg shells to be thin and reduced the number of young that hatched successfully.

Climate change

Effects of climate change include increasing global temperatures and frequency of extreme weather events. These changes will have significant adverse effects on biodiversity, and they are likely to alter ecosystem structure and function. The extent of these impacts will depend on the capability of organisms to adapt to the climatic changes, which is affected by the rate at which these changes occur and whether species can move to more suitable areas as their natural habitat changes. The impact of climate change will be more pronounced on species in remnant or fragmented habitats that are isolated and offer little opportunity for movement.

Global temperatures are increasing and climates around the world are changing. Some organisms are suited to particular temperature ranges and can be severely affected by a change from their ideal temperature. Also, a change in temperature can have an effect on the habitat the organism is best suited to.

It has been estimated that each 1 °C rise in temperature will displace the range of terrestrial species about 125 km towards the poles or 150 m vertically up mountains. This has implications for our system of parks and reserves, which are intended to conserve flora and fauna. The present distribution of these reserves may not provide adequate protection for many species, particularly threatened species.

Climate change is also affecting sea levels. Rising sea levels are flooding low-lying coastal areas and submerging many islands.

The Bramble Cay melomys (*Melomys rubicola*) was a native Australian rodent endemic to a small island in the Torres Strait. The rodents' low-lying island, Bramble Cay, sat just 3 m above sea level and was inundated by ocean water during high tides and storms. The Bramble Cay melomys was declared extinct by the Australian Government in 2019 – it is considered the first mammal to become extinct due to human-induced climate change.

Disease

The spread of disease can decrease biodiversity. Diseases tend to be species-specific, but if they mutate they can infect across the species barrier and this is an ever present threat. Domesticated animal diseases can pass to native animals and have devastating effects on these populations. An ecosystem with lots of variation is more resilient to the impacts of disease.

An example of a species-specific disease is the Tasmanian devil facial tumour disease. This transmissible cancer is spread by biting and causes tumours on the face and inside the mouth of those animals affected. This disease has caused a massive decline in the Tasmanian devil population, and the species is now considered endangered.

Figure 4.4. Tasmanian devil facial tumour disease affects some populations of devils and not others. Credit: Menna Jones CC BY 2.5

Introduced species

Introduced (or exotic) species are species that have been deliberately or accidentally introduced into a new region. Introduced species compete with indigenous species for niches, and exotic predators can have a big impact on native prey populations. Australia has many introduced species, and they have directly or indirectly led to many extinctions.

The European red fox (an introduced predator) has been implicated in the disappearance of remnant populations of endangered mammals and may be affecting ground-dwelling birds such as the malleefowl. Exotic herbivores, such as feral pigs, rabbits, cattle, goats and buffalo, have degraded large areas of land. Many introduced plants have become environmental weeds. In many places, exotic weeds are replacing native plants and eliminating native animal species that depend on the native plants for food and shelter. For example, boneseed (*Chrysanthemoides monilifera*) is a now-infamous invader of Victorian coastal vegetation that reduces the ability of native trees and shrubs to reproduce.

Aquatic environments are also being affected by introduced species. Many inland waterways are clogged with introduced water plants such as water hyacinth and salvinia. Introduced fish have also affected some rivers. The best known of these is the European carp, but trout are also introduced and are producing changes in aquatic systems.

Figure 4.5. The introduced European carp stirs sediment in rivers, reducing the oxygen available for native fish species

Recently, it has been recognised that our marine environment is also being invaded by exotic species. About 15 exotic marine species, including seaweeds and seastars, have been detected in Australian waters to date. These organisms have probably been introduced and spread through the discharge of ballast water from ships. A particularly notable introduction is the European fan worm (*Sabella spallanzanii*). This species is extremely voracious and is having a major impact on other marine animals. It was first noticed at Albany in Western Australia in 1970 and has since been found in South Australia, Victoria, Tasmania and New South Wales. The worm has reached plague proportions in Port Phillip Bay in Victoria where it is posing a threat to the commercial scallop industry.

Data analysis 4.1
Controlling an introduced weed

Salvinia (*Salvinia molesta*) is a free-floating, mat-forming aquatic fern. It is native to South America, and all salvinia species are prohibited entry into Australia. The only species currently present in Australia is *S. molesta*.

The plant has pairs of oval-shaped leaves covered in hairs. A horizontal stem sits just below the water surface. Plants float together, forming mats over the surface of the water. Still or slow-moving fresh water where nutrients are readily available is ideal for the growth of the plant.

Figure 4.6. A *Salvinia molesta* plant.
Credit: Harry Rose CC BY 2.0

Under ideal conditions, a mass of salvinia can double in size in less than 3 days. The ideal temperature for growth is 30 °C; however, growth can occur between 10 °C and 43 °C. Salvinia can also regenerate after being drought-stressed or heat-stressed or even after frost. Rates of growth vary according to climate zones, with an increase as temperatures warm, peaking in late summer. In southern Australian climates growth is seasonal, whereas in northern Australia growth is uniform throughout the year.

Small outbreaks of salvinia can be controlled by physical or chemical means; however, in 1980, CSIRO introduced the the salvinia weevil (*Cyrtobagous salviniae*) as a biological control agent. The weevil was a huge success: the first field release resulted in 50,000 tonnes of salvinia infestation being destroyed in 11 months.

Table 4.1 shows the impact of the salvinia weevils on the salvinia plants.

1. Using a spreadsheet or graph paper, graph the data in the table.
2. Describe the overall trend in weevil numbers.
3. Describe the overall trend in plant bud damage.
4. Would the weevil population numbers keep increasing? Explain.
5. Would the infestation of *Salvinia* ever reach 0% coverage? Explain.
6. What would the effects on the environment be with the decrease in the salvinia infestation?

Source: Salvinia control manual: Management and control options for salvinia (Salvinia molesta) in Australia, NSW Department of Primary Industry (https://www.dpi.nsw.gov.au/biosecurity/weeds/weed-control/management-guides/salvinia-control-manual).

Table 4.1. Number of damaged salvinia buds and adult salvinia weevils over 6 months

Month	% of damaged buds in 50 plants	% of adults seen on 50 plants
September	10 (i.e. 5 buds out of 50 were damaged)	0 (i.e. 0 adults were seen on 50 plants)
October	24	6 (i.e. 3 adults were seen on 50 plants)
November	48	12
December	60	15
January	72	14
February	90	18

Figure 4.7. *Salvinia molesta* forming a mat that suffocates other aquatic life. Credit: Harry Rose CC BY 2.0

Figure 4.8. The salvinia weevil. Credit: CSIRO CC BY 3.0

Critical and creative thinking 4.1

1. **Determine** if each of the following statements is true or false. Explain why.

   a) Changes to fire regimes can modify habitats.

   b) Trade in precious commodities, such as ivory, can lead to over-exploitation of plant or animal species.

   c) Symbiotic relationships always benefit the organisms involved.

2. Give an example of an exotic species that threatens Victoria's biodiversity and explain its impacts.

3. Using three different specific examples, **explain** how and why exotic pest species are now prevalent in Australia's natural environment. Describe the particular impacts these species have on the ecosystems they are in.

4. **List** some factors that are a threat to biodiversity in your area.

5. **Explain** why Australian customs and border control is very strict with incoming travellers and biosecurity measures in regards to plant and animal products.

CHAPTER

5

Management strategies for protecting biodiversity

Strategies for maintaining and growing populations that also build resilience to environmental change are vital for the conservation of a range of species, populations and ecosystems.

A range of strategies are used in conservation management, and the best results are achieved when a number of different management tools are used in combination. Some of these strategies are outlined in this chapter.

5.1. Conserving threatened species

Strategies for maintaining and growing populations that also build species resilience to changes in the environment: protected areas; retaining remnant vegetation; wildlife corridors or zones; translocation of animals; captive breeding and reintroduction programs; gene banks for the collection of specimens and genetic material; and reduction and improved targeting of pesticides in agricultural and urbanised areas

Protecting in conservation reserves

Conservation reserves are protected areas of land or water that are managed for nature conservation. There are different categories of reserves. National parks are reserves that are intended to protect natural and scenic areas of national or international significance for scientific, educational and recreational use. Other types of reserves do not provide as high a level of protection for flora and fauna. For example, multiple-use management areas provide for the sustained production of water, timber, wildlife, pasture and recreation with the conservation of nature primarily oriented towards the support of economic activities.

Reserves should be located in areas that will protect a region's biodiversity, taking into account the need to protect biodiversity at various levels: individual species, communities, ecosystems and landscapes. However, in Australia, conservation reserves have largely been established in areas not wanted for other uses rather than by strategically selecting areas that will meet conservation objectives.

Thus, although about 15% of Australia is in reserves, the current system of reserves does not adequately represent all the ecosystems or species within the regions. Some are represented in many reserves, while others are not represented at all. The land available for reserves has tended to be land of little economic value. Land of high economic value, such as areas with soil suitable for agriculture and forests valuable for timber protection, is under-represented in reserves, although forest areas have received additional protection in recent decades. Consequently, these areas have not been sufficiently well protected from threatening processes. Procedures are now being developed to ensure that a representative system of reserves becomes established, at least for forested areas.

Connecting remnant vegetation patches

Clearing vegetation is one of the threatening processes for biodiversity. In many cases, clearing has resulted in fragmentation, where small patches of remnant vegetation remain among the cleared areas. Research has shown that these pockets of remnant vegetation are important for the conservation of some animal populations. However, these patches are often small and isolated from one another. While they may have significant conservation value, they are often difficult and relatively expensive to manage.

The concept of a metapopulation has been used in the study of fragmentation. A metapopulation is made up of all the local populations in each of the patches. The local populations interact with one another when individuals move between the populations. The local populations can undergo large fluctuations as they are confronted with different environmental variations, but the overall metapopulation will not vary as much.

One way to improve the conservation potential of these fragments is to improve the connection between them by having a network of linking remnant vegetation that acts as wildlife corridors. These corridors:

- allow animals to move between patches
- provide habitat for plants and animals
- provide avenues for possible recolonisation
- allow for the exchange of genes between sub-populations to reduce the impact of genetic drift and inbreeding.

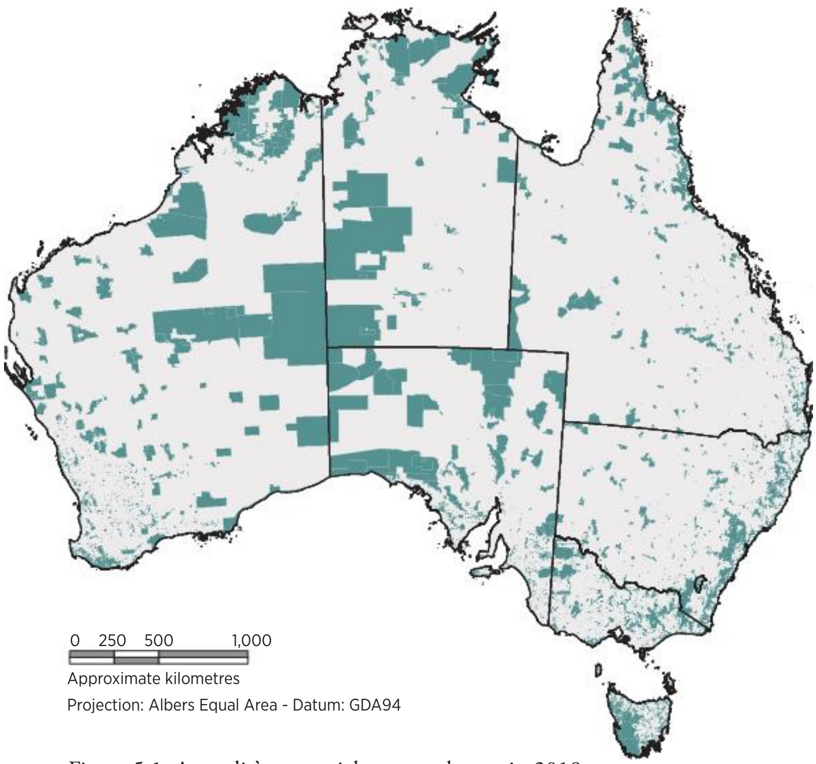

Figure 5.1. Australia's terrestrial protected areas in 2018

Potential disadvantages of wildlife corridors include that they may:

- aid the spread of diseases, pests and weeds
- suppress genetic variation if the gene pool of a sub-population is swamped by the gene pool of the immigrants
- help the spread of fire
- be very costly to establish and maintain at the expense of other conservation methods that may be more effective.

We usually think of wildlife corridors in rural areas but they also have potential in urban environments. There are patches of remnant vegetation in urban areas, and some local governments have initiated replanting programs. These habitat restoration and regeneration programs aid in restoring pathways (and habitat) for a range of animals to increase resilience among populations and species.

Urban creeks can also be useful as corridors, as they form an existing network throughout the urban area. Unfortunately, water management authorities historically treated urban creeks as drains, and many creeks have been concreted or barrel-drained to reduce flooding.
However, some urban creeks retain their native vegetation and are useful as corridors. Water authorities have recently modified their attitude to urban creeks, and many are now rehabilitating creeks, which will further enhance their usefulness as corridors. In addition, reductions in pesticide run-off from agricultural and urban areas has improved water quality, which benefits creek ecosystems and enhances their usefulness as wildlife corridors.

Reintroducing plants and animals

In some cases, plants or animals may be returned to an area from which they have been eliminated or where their numbers are low. This is a process called translocation. When plants or animals are translocated to an area that used to be part of their range, but where none of that species remains, this is called reintroduction. For example, in recent years the eastern quoll (*Dasyurus viverrinus*) has been reintroduced to mainland Australia from a population in Tasmania.

Organisms for reintroduction can be ones collected from the wild or, as is often the case for rare species, from plants that have been grown in a nursery or animals that have been bred as part of a captive breeding program (such as the orange-bellied parrots bred at Healesville Sanctuary).

Conservation strategies often recommend translocation or reintroduction to help overcome a reduction in numbers of a threatened species. For example, reintroduction has been recommended in 30% of the action plans developed for threatened vertebrate species in Australia. Reintroductions must be carefully researched and implemented to ensure they are effective and appropriate. Ecological implications must be considered for both the reintroduced species and other species at the reintroduction site.

Worldwide, there have been many attempts at translocation and reintroduction, but many have failed. A major reason for the lack of success was that the threatening processes that led to the decline of the species in the first place were not known or were not adequately addressed before the reintroduction. There is little value in returning an animal to an area where an introduced competitor or predator is still active or where degraded habitat has not been restored. Careful planning and research are needed before undertaking a translocation or reintroduction program.

To ensure that the translocated individuals will survive well in their new environment, their genetic make-up should be similar to that of the area's original population. This may not be possible if the original population is extinct, and some trial reintroductions may be necessary to determine the likely success of a translocation program.

CASE STUDY 5.1
Eastern barred bandicoot

The mainland subspecies of the eastern barred bandicoot (*Perameles gunnii*) is listed as threatened under the *Victorian Flora and Fauna Guarantee Act 1988*. It has been placed on the Threatened List under the act, and is now considered extinct in the wild. Federally, the mainland eastern barred bandicoot subspecies is listed as endangered under the *Environment Protection and Biodiversity Conservation Act 1999* and the Tasmanian subspecies is listed as vulnerable.

Eastern barred bandicoots were once widespread across grasslands and grassy woodlands of western Victoria and South Australia. By 1991, however, the mainland subspecies was at the brink of extinction primarily due to habitat loss (for agriculture and development) and predation by introduced foxes and cats.

A captive breeding program was established using eastern barred bandicoots from the last known population at Hamilton, Victoria. Since then, a coordinated recovery program has focused on captive breeding, habitat management and predator control. There are currently three small reintroduced populations of eastern barred bandicoots and other reintroductions are underway. Five previous reintroductions have been unsuccessful, mainly due to predation, drought and/or overgrazing by kangaroos.

Zoos Victoria coordinates the captive breeding program and plays a key role in the recovery of this species through:

- supplementing reintroduced wild populations through captive breeding for reintroduction
- maintaining an insurance population in captivity
- conducting research to improve breeding and reintroduction success
- increasing community awareness and support for the eastern barred bandicoot.

Questions

1. What are the main threats facing the eastern barred bandicoot?
2. Has the captive breeding program been successful so far? Give reasons for your answer.
3. What factors might be important to consider when planning for the future of the eastern barred bandicoot?

Figure 5.2. Eastern barred bandicoot. Credit: JJ Harrison CC BY-SA 3.0

Figure 5.3. Mountain pygmy-possums build up their food reserves for the winter by eating berries and fat-rich Bogong moths. Credit: Zoos Victoria

Data analysis 5.1
Measuring the success rate of a reintroduction program

The mountain pygmy-possum (*Burramys parvus*) is listed as endangered under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999*. It is also listed as endangered under the New South Wales *Biodiversity Conservation Act 2016* and as threatened under the Victorian *Flora and Fauna Guarantee Act 1988*. The species is also listed as Critically Endangered on the IUCN Red List of Threatened Species. The mountain pygmy-possum is the largest of the pygmy-possum family (Burramyidae), but weighs only around 45 grams. It is endemic to the alpine areas of south-eastern Australia, and populations are now found in three geographically separate locations: one in Kosciuszko National Park and two in Victoria's Alpine National Park (Mount Bogong – Mount Higginbotham and Mount Buller). The total population of this species is less than 3,000 and they face a range of threats.

The success of a reintroduction program for mountain pygmy-possums at Mount Buller is calculated based on the reproductive rate and the number of young surviving into the following reproductive year over a 5-year period (using hypothetical data).

1. Based on the data provided in Table 5.1, what is the likelihood of this mountain pygmy-possum introduction being successful over a period of 5 years?
2. Is this a favourable program outcome for this species or does more need to be done (in terms of management) to increase the chance of survival for the Mount Buller population?

Table 5.1 Hypothetical reproductive rate and survival of young for mountain pygmy-possums on Mount Buller over a 5-year period

	Reproductive rate (no. young born per female)	Average number of female (F) and male (M) young surviving to following year (per brood)
Year 1	4	F1 M2
Year 2	3	F2 M1
Year 3	4	F1 M2
Year 4	2	F0 M2
Year 5	3	F2 M1
Total		

Banking genes

Scientists currently rely on studying fossils and other data to understand extinct animals like dinosaurs and woolly mammoths. A gene bank provides future generations with a more complete and accurate record of now-threatened species, such as black rhinos, giant pandas, tigers and a range of Australian species, that may become extinct.

The Frozen Ark project began in 2004 as a result of three British institutions, the University of Nottingham, the Institute of Zoology and London's Natural History Museum, coming together as a repository of all the 7,200 endangered animals on the IUCN Red List.

Frozen Ark is an example of a gene bank, and the process of collecting the genetic samples and storing them is called gene banking. Gene banking is an important way of preserving genetic material as the populations of endangered animals shrink, because their genetic diversity also shrinks. If the only remaining members of a particular species were in a zoo, valuable genetic material from a gene bank could be used to keep the species genetically diverse until it could be reintroduced into the wild. There are hundreds of gene banks in the world, including seed banks for the conservation of plant species.

Data analysis 5.2
Designing conservation reserves

Figure 5.4 shows the layout of various conservation reserves. The reserves represent 'islands' containing protected ecosystems surrounded by unprotected areas affected by human activity.

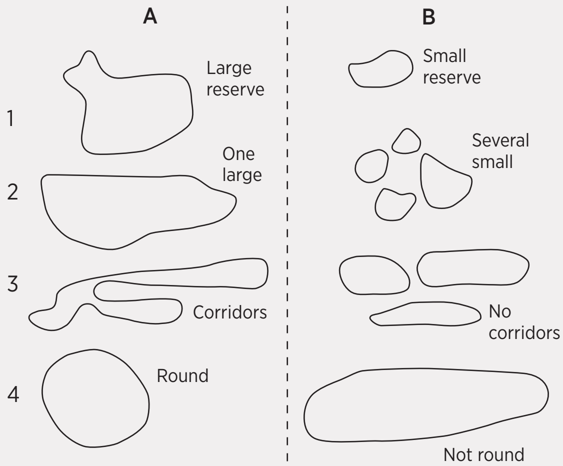

Figure 5.4. Conservation reserve layouts

For each pair 1–4, explain why the areas in column A might be considered better for conservation than the areas in column B.

Student activity 5.1
Dingo conservation

Using the information in 'Case study 2.1 Apex predators:a biodiversity regulator' (p 22), answer the following questions:

1. What conservation pressures do dingoes face in the past, present and future?
2. How are dingoes going to be protected to ensure the survival of the species?
3. What would happen to other species if the dingo became extinct? Report on three different species.
4. Think about the impact cultural belief has had on the dingo. Has it been positive or negative?

Critical and creative thinking 5.1

1. Some scientists are concerned that gene banks could give a false sense of security. **Discuss** why this may be the case, using examples.
2. Consider the advantages and disadvantages of wildlife corridors. Write a paragraph arguing for or against including them as part of a biodiversity management strategy, Give reasons for your opinion.
3. Which conservation strategy or strategies would you recommend when trying to ensure the long-term survival of a species of your choice? **Explain** your response.

5.2. Restoring degraded ecosystems

Approaches to renewing and regenerating degraded ecosystems: restoration of habitat; erosion control; and reintroduction of previously endemic species

A functioning ecosystem is a biological community plus all the abiotic factors influencing that community. A degraded ecosystem is lacking one or more essential abiotic components to an extent that has negative effects on its biological structure, composition or function. A degraded ecosystem often results from natural or human-induced disturbance that alters ecosystem structure and function.

A range of different approaches can be applied to renewing and regenerating degraded ecosystems. They include restoration of habitat, erosion control and reintroduction of previously endemic species. The most suitable approach depends on the degree of degradation, what has been affected within that degraded landscape, and how species will respond to restoration changes. Often multiple approaches are required to rehabilitate degraded environments.

Habitat restoration

Restoration of habitat (or a whole ecosystem) is the process of repairing degraded ecosystems through human intervention. Habitat restoration requires an understanding of population genetics and ecological processes (such as disturbance, succession and fragmentation). The goal of restoration may be to recreate an ecosystem as it was before it became degraded or to to create a new ecosystem that had not previously been present.

Erosion control

Living within Australia's highly dynamic environment, we are familiar with erosion as it shapes and scars the landscape. Erosion is the combination of processes that wear rock and soil from the land surface; it is caused by moving water (such as run-off), air (wind) or ice (glaciers). Erosion can wear away topsoil, subsoil and stream banks, and it can lead to small channels (rills), large channels (gullies), 'scalded' areas of exposed saline soils and tunnels.

Erosion control is often important in renewing and regenerating a degraded landscape. Control measures will depend on the type of erosion occurring. A common control measure to reduce erosion is to plant trees or other vegetation in locations with loose soil that are susceptible to water or wind erosion. Locally adapted species that are deep-rooted and fast growing are often suitable. Plantings may also help to ensure water run-off doesn't form channels that speed water flow and increase erosion.

Figure 5.5.
Gully erosion has followed the removal of ground vegetation and destabilisation of the stream bank as water flow removed the soil.
Credit: Soil Science

Practical 5.1
Restoring a coastal habitat

Create a management plan (which may incorporate a species reintroduction) that outlines management activities over a period of a year for the restoration of a coastal habitat. Consider types of plants and what sort of habitats they will provide. Also consider how these plants may interact with potential endemic and non-endemic species. Consider relevant legislation and how you will measure the success of your management plan.
The plan should include monitoring, surveying and data collection.

Critical and creative thinking 5.2

1. a) Apart from erosion control, what other ways are there of renewing and regenerating degraded ecosystems?

   b) Which approach do you think is the most practical and feasible when you consider financial and logical aspects?

2. **Define** and give examples of disturbance, genetic diversity, succession and fragmentation.

3. Investigate further a particular type of erosion (for example, sheet, rill, gully, tunnel, stream bank or wind erosion) and how it can be controlled. Research if the control measure is being used within Australia and provide an example of that use at a particular location.

4. Research a species that has been reintroduced to a habitat where it was once endemic.

CHAPTER

6

Legal and social mechanisms for biodiversity conservation

In Chapter 1, we established the importance of conserving biodiversity and the benefits we gain from a healthy environment. The *World Conservation Strategy* defines conservation as:

the management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations.

This definition clearly indicates that we have a responsibility to maintain biodiversity for future generations. This is an important component of intergenerational equity. Just as important is the concept of intragenerational equity, which refers to equity applied across communities and nations within one generation. Intragenerational equity is a key principle of sustainable development, not only in order to be consistent in our approach from our own backyard to across the globe but also because inequities are a cause of environmental degradation.

6.1. Legal and policy mechanisms protecting biodiversity

The application of relevant international, national, state and local legal treaties, agreements and regulatory frameworks that apply to the protection of threatened species: the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); IUCN Red List of Threatened Species; classified World Heritage areas; *Environment Protection and Biodiversity Conservation Act 1999* (Cth); *Flora and Fauna Guarantee Act 1988* (Vic); and local government conservation covenants.

With the growing concern about species loss, a number of mechanisms have been established, at both international and national levels, to conserve biodiversity.

These include international conventions, treaties and agreements, and domestic laws. We will examine some of these mechanisms in this chapter.

International agreements and programs

Convention on Biological Diversity

The Convention on Biological Diversity was tabled at the United Nations Conference on Environment and Development in Brazil in June 1992 and came into force on 29 December 1993. Today, nearly 200 countries are parties to the convention.

The major objectives of the convention are the:

- conservation of biological diversity
- sustainable use of its components
- fair and equitable sharing of the benefits arising out of the utilisation of genetic resources.

The convention requires each participating country to develop a program of conservation. It also monitors progress and provides assistance for developing countries. In 2019, Australia released its *Strategy for Nature 2019–2030.* The strategy aims to establish effective mechanisms for the identification, conservation and management of Australia's biological diversity.

CASE STUDY 6.1
The IUCN Red List of Threatened Species

The following description is from the IUCN Red List website, and the conservation categories for the IUCN threatened species list were presented in Table 3.5 (p 43).

The IUCN Red List is the world's most comprehensive information source on the extinction risk of animals, fungi and plants. Assessors place species into one of the IUCN Red List Categories, based on a series of assessment criteria. For each species, The IUCN Red List provides information about its range, population size, habitat and ecology, use and/or trade, threats and conservation actions. The goal of the IUCN Red List is to provide information and analyses on the status, trends and threats to species in order to inform and catalyse action for biodiversity conservation.

A variety of people, governments and organisations use The IUCN Red List. International policy makers, government agencies, wildlife departments, and non-governmental organisations (NGOs) use the data to support and plan conservation actions and priorities.

Source: https://www.iucnredlist.org/fr/about/faqs

Figure 6.1. The Floreana mockingbird, listed as Endangered, is restricted to two islets in the Galapagos Islands where it is threatened by habitat loss and predation from invasive species

World Heritage Convention

In the 1960s, the world suffered many environmentally damaging events, including floods in the museums of Venice, which alerted the United Nations Educational, Cultural and Scientific Organization (UNESCO) to threats to the preservation of the world's heritage, both natural and built. This led to the creation in 1992 of a treaty known as the World Heritage Convention (its full name is the Convention Concerning the Protection of the World Cultural and Natural Heritage).

Australia became a signatory to this convention and ratified it in 1974; the convention came into force in 1975. The convention has since been implemented in Commonwealth legislation; the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is currently the relevant act. Australia has also listed iconic sites such as the Great Barrier Reef, the Wet Tropics of Queensland and, more recently, the Budj Bim Cultural Landscape in Gunditjmara Country in south-west Victoria.

Heritage includes the cultural and natural heritage that all people have an interest in protecting and conserving for future generations. Cultural heritage includes items such as monuments, paintings and cave dwellings. Natural heritage includes examples of geological, ecological and biological processes and important habitats for conservation of biological diversity.

Nations are responsible for assisting in the identification, protection and conservation of items listed on the World Heritage Register.

A World Heritage listing begins with an evaluation of the site or item by the country's government against criteria set by the World Heritage Committee. The government then submits the nomination to the World Heritage Committee in Paris. After an extensive evaluation by the Committee, the nomination is rejected, deferred or accepted for listing as World Heritage. Australia has 19 sites on the World Heritage List.

Once a site or area is accepted on the World Heritage List, and thus is subject to an international agreement, the Australian Government can take measures to help ensure its protection. On a number of occasions, state governments have come into conflict with the Australian Government over management of listed areas.

The first use of World Heritage listing to protect the environment from state development occurred in 1983 when the newly elected Hawke Government banned clearing and excavation for a dam on the Franklin River in Tasmania. The law that the Australian Government introduced to protect the river (the *World Heritage Properties Conservation Act 1983*, now repealed) was able to prevent the Tasmanian Government's development plans because the Australian constitution gives the Australian Government power over external affairs, which includes meeting the obligations of international treaties.

Australian governments have made management recommendations to the World Heritage Committee for the preservation of wilderness areas such as south-west Tasmania and the Great Barrier Reef. These recommendations are likely to enhance the maintenance of biodiversity by restricting the changes allowed to the habitat and ecosystems in these regions. The recommendations will also reduce the exploitation of the species that inhabit these areas. However, this is not without contention as was seen in 2014 when the Australian Government led by Tony Abbott tried to delist 74,000 hectares of Tasmanian old growth forest to open it up for logging. Luckily, the United Nations' World Heritage Committee rejected this proposal.

Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)

One threat to species and genetic diversity, particularly for endangered species, is commercial exploitation. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which came into force in 1975, aims to ensure that species are not threatened by international trade. CITES currently has 183 parties. The convention lists all endangered species that are affected by trade or are likely to be. Nations that are party to the convention must regulate international trade in these listed species through permits, licensing and even prohibitions.

Figure 6.2. Illegal wildlife products seized.
Credit: USFWS Mountain Prairie CC BY 2.0

CITES has not halted the trade in endangered species, partly because some trade is permitted and partly because the controls cannot always be applied or enforced:

- CITES allows permits to be granted for trade in endangered species for certain non-commercial purposes, such as scientific research, under strict conditions. The value of this research is often hard to assess, and research could be used as a smokescreen for commercial trade in an endangered species.
- Not all nations are signatories to CITES; those who are not parties to the convention are not bound by its decisions.
- Illegal trading, poaching and smuggling continue, often on a large scale (Figure 6.2). For example, the ivory industry in parts of south-east Asia is catered to by large-scale killing of elephants in parts of Africa. In 2016, the Kenyan Government set alight tusks from over 6,000 illegally killed elephants in the Nairobi national park to highlight the poaching crisis and send a very clear message to poachers.

Australia places considerable emphasis on confiscating imported souvenirs made from endangered species and preventing the smuggling of native flora and fauna, particularly birds and reptiles. Australia controls the export of its own species, and Australian native fauna can only be exported under very special arrangements, for example, with overseas zoos.

Domestic legislation and policies

Australian legislation provides clear rules that must be abided by to ensure the conservation of biodiversity within Australia.

Environment Protection and Biodiversity Conservation Act 1999 (Cwlth)

This Australian Government legislation replaced five previous acts from the 1970s, 1980s and 1990s to establish a streamlined environmental assessment and approvals process and an integrated regime for biodiversity conservation and the management of important protected areas. It focuses the Australian Government's attention on aspects of national environmental significance and recognises the responsibility of the states for carrying out the actual management of natural resources. The EPBC Act commenced on 16 July 2000.

The EPBC Act contains provisions dealing with:

- identifying and monitoring biodiversity and preparing bioregional plans
- listing nationally threatened species and ecological communities, migratory species and marine species
- preparing national recovery plans and wildlife conservation plans for listed species, and additional protection for listed species in Commonwealth areas
- identifying key threatening processes and preparing threat abatement plans for such processes
- establishing the Australian Whale Sanctuary in Australia's exclusive economic zone
- accessing biological resources on Commonwealth areas
- managing invasive species
- establishing voluntary conservation agreements, which may cover environmentally significant private land, including Indigenous land
- protecting and managing protected areas, including Commonwealth reserves (such as marine parks and a handful of national parks), World Heritage properties and Ramsar wetlands.

Flora and Fauna Guarantee Act 1988 (Vic.)

The Flora and Fauna Guarantee Act 1988 (FFG Act), enacted by the Victorian Government in September 1988, aims to ensure that Victoria's native species survive, flourish and keep their potential for evolutionary development. The act was developed to recognise, identify and manage the processes that lead to extinction. It involves maintaining genetic diversity and protecting habitats, endangered species and sites or areas of environmental significance. The legislation was updated by the *Flora and Fauna Guarantee Amendment Act 2019*.

The act provides management systems, controls and regulations, programs for community education, and assistance and incentives for people to conserve our native flora and fauna. It encourages all community efforts in nature conservation. The act allows for public participation in all of its processes.

Any member of the public may nominate a species or community of flora and fauna for consideration. The nomination then undergoes a thorough investigation, undertaken by a Scientific Advisory Committee. The Scientific Advisory Committee makes a preliminary recommendation on the status of the nomination and suggests what action if any should be taken. The recommendation is available for public comment for 30 days. Then a final recommendation is made, taking into account all public submissions, to the Minister for Energy, Environment and Climate Change and the Minister for Agriculture and Food Security. The ministers have 30 days in which to decide whether or not to recommend that the item be listed.

In critical habitats where a species is being threatened by human activity, an Interim Conservation Order may be given to provide immediate protection of the species' habitat.

The FFG Act operates alongside other legislation relating to wildlife conservation. These include acts responsible for environment protection, fisheries and national parks.

Victoria's biodiversity strategy

Victoria's biodiversity strategy, *Protecting Victoria's Environment – Biodiversity 2037*, was released in 2017 and meets Victoria's commitment to the Australia's national biodiversity strategy. It also fulfils the requirements of the FFG Act for the preparation of a strategy that shows how to achieve the act's objectives of conserving native species, communities and gene pools, preventing threats and encouraging community involvement.

Local planning controls

Local governments implement the state's planning laws that guide the planning and development of private land, including the *Planning and Environment Act 1987* and the *Environment Effects Act 1978*. These laws include provisions to ensure that the impact on the environment and associated biodiversity value is considered in planning decisions. Local governments also pass their own by-laws, which can include special measures for environmental protection.

For example, 12 'green wedge' areas have been designated around Melbourne outside the urban growth boundary. These circle the metropolitan area, from the coast near Werribee to Whittlesea, the Yarra Valley and the Mornington Peninsula, and include areas of national and other parks, reserves, closed protected water catchments and other areas of public land (amounting to around one-third of the total area). The councils responsible for these green wedges are required to prepare a management plan for the area's sustainable use and development.

Individual landowners are also able to protect conservation values of their land by putting a legally binding covenant on their land which states that it is only to be used for conservation purposes. In Victoria, these covenants can be made as an agreement between landholders and the Trust for Nature. The purpose is to protect private land that has significant environmental or cultural values. The Trust for Nature conservation covenants are entered into under the *Victorian Trust Act 1972*; they are registered on the title and are legally binding forever.

Practical 6.1
A threatened species

Choose an animal species that is threatened.

Browse the Red Lists or the World Wide Fund for Nature (WWF) if you cannot make up your mind. Find one or more images and research the following information on your chosen species to prepare an information sheet for the rest of the class.

- What is the Red List category of your species? (It must be CR, EN or VU.)
- What is the global distribution of your species? Find a map if possible.
- What is the estimated current population size?
- In which CITES Appendix is your species listed?
- What threats does your species face (for example, ecological, social and economic pressures)?
- What conservation strategies have been suggested to remove the threat of extinction?
- How are local people and government actions involved in helping your species to recover?

Present your assignment to your class and hand out an information sheet.

Data analysis 6.1
Benefits of conserving species

CITES has collected data from a range of countries to document the livelihood benefits of implementing the CITES legislation.

1. Go to https://cites.org/eng/prog/livelihoods.
2. Choose five fact sheets from five different case studies.
3. Complete the data analysis table below by summarising each case study.

Animal common name and scientific name	Country	Species use after CITES intervention	Livelihood benefits from protecting the species	Conservation impact data

Critical and creative thinking 6.1

Select a species that is listed under the *Victorian Flora and Fauna Guarantee Act 1988* and prepare a report on it. Your report should include:

- basic information about your species and its preferred habitat
- your species' present status and distribution, as well as its previous distribution
- the threatening processes responsible for its decline
- an outline of any action plans that have been prepared and management strategies that have been implemented to conserve the species
- an assessment of how successful these plans and strategies have been.

6.2. Value systems

Value systems that influence decision-making processes: anthropocentrism, biocentrism, ecocentrism and technocentrism

Our ideas about biodiversity conservation are shaped by our underlying values, which can vary on a number of levels – from person to person through to different national perspectives. A basic understanding of some of these values helps us to understand how different people, communities or nations value biodiversity conservation.

Anthropocentrism is the belief that humans are the central or most significant species on the planet. This largely comes from the view that humans have a moral status or value higher than that of all other organisms. Anthropocentrism is generally the prevailing perspective in western cultures.

Biocentrism is the belief that biology is the central and driving science of the universe, and that humans are no more important than any other living things.

Ecocentrism is the perspective that places greatest intrinsic value on species and their natural environments (rather than on individual organisms). Many indigenous cultures hold this perspective; they have an inclusive view of humans being part of an intricate web of life.

Technocentrism is the belief that humans are separate from nature and are able to manage nature for humanity's advantage. This management can extend to believing that modern technology or understandings can manage humanity out of an environmental collapse.

Both biocentrism and ecocentrism perspectives value other species and the environment regardless of their perceived usefulness or importance to human beings.

6.3. Guiding sustainability principles

Sustainability principles as they apply to biodiversity conservation: conservation of biodiversity and ecological integrity; efficiency of resource use; intergenerational equity; intragenerational equity; precautionary principle; and user pays principle.

The precautionary principle

We must bear in mind our responsibility to future generations when making decisions about conservation of biodiversity. A decision is irrevocable if it involves the loss of a species or an ecological process, so we need to exercise extreme care in biodiversity planning. This has been referred to as the precautionary principle, which suggests that we should not allow anything to happen that could lead to the irreversible loss of biological resources through ignorance of the impact or because we think that a resource is of no value. Our responsibility to future generations implies that we need to maintain our biological resources because of their potential future use as well as their intrinsic value.

This principle has now been included in a variety of treaties and agreements. For example, the Australian Intergovernmental Agreement on the Environment (1992) defined the precautionary principle as follows:

where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

Social justice

Despite widespread efforts to conserve a range of species and ecosystems around the world, we are still fighting an uphill battle. Poverty threatens wildlife conservation efforts in many parts of the world as many local communities are not included in the decision-making processes and often have little understanding of the reasons why such conservation programs are being initiated.

Integrating conservation programs with development of local communities is an important aspect of ensuring conservation programs are effective. If the local community benefits from being involved in the conservation effort, these communities are less likely to unwittingly undermine such programs through poaching or habitat destruction for livestock and agriculture, for example.

Poverty threatens wildlife conservation despite widespread efforts to integrate conservation and development so that local communities benefit. So what is going wrong? Some suggest it is social justice that is missing.

Critical and creative thinking 6.2

1. **Define** the terms ‘anthropocentrism’, ‘biocentrism’ and ‘ecocentrism’.
2. Choose three of the conventions or treaties outlined in this chapter and identify which of the above perspectives guides each convention chosen. **Justify** your decision for each.

EXPLORING SCIENCE 1.
Hope is on the horizon: the critically endangered orange-bellied parrot

Article by Zoos Victoria

Figure 6.3. Orange-bellied parrot at Healesville Sanctuary. Credit: Zoos Victoria

"The recovery of most threatened Victorian species is entirely achievable. But it requires knowledge, innovation, adequate resources and determination. Why would we not try?"

Dr Michael Magrath, Senior Research Manager, Wildlife Conservation and Science, Zoos Victoria

A population under threat of extinction

The orange-bellied parrot (OBP) is one of only a few migratory parrot species in the world and one of Australia's most threatened species. Not much larger than a budgerigar, these tiny birds migrate from their breeding grounds at Melaleuca in south-western Tasmania across the dangerous waters of the Bass Strait to spend the winter months in saltmarsh habitat along the south-eastern coast of mainland Australia. In spring, the birds must repeat the journey and return to breed at Melaleuca.

The wild population has been in decline for at least the last century, and this critically endangered species faces a 90% chance of extinction in the next 20 years without scientific and management intervention to save them. Along with collaborators from around Australia, Zoos Victoria is working to make sure that this remarkable species is not lost forever.

Threats to the OBP are not well understood, but include the degradation of critical habitat, loss of genetic diversity in the population, outbreaks of beak and feather disease, predation by introduced predators, and competition for nesting at the breeding sites.

Recovery efforts

Zoos Victoria is playing a key role in the recovery of this species. We manage part of the national captive population at our zoos as insurance against the extinction of the orange-bellied parrot in the wild. We also contribute to the annual releases of captive-bred birds to the wild and 'over-winter ranching' to enhance survival of selected birds between breeding seasons. The recovery program is complex, multijurisdictional, and relies on a diverse array of partners, including the Orange-bellied Parrot Recovery Team; the Victorian Department of Environment, Land, Water and Planning; the Tasmanian Department of Primary Industries, Parks, Water and Environment; the Commonwealth Department of Agriculture Water and the Environment; Moonlit Sanctuary; Birdlife Australia; Melbourne Water; Parks Victoria; and researchers at several universities.

Recovery actions for the OBP have diversified over recent years. New actions have been initiated to improve the survival of captive-bred released birds and the breeding performance of the wild population. These include improvements to the nutritional quality of supplementary food, the use of controlled habitat burns to promote food availability around the breeding site, and the trial release of birds on the mainland to attract migrating birds to high-quality habitat. Attempts are also underway to establish a second breeding site away from Melaleuca to grow the wild population and mitigate the risk of wildfire. We are optimistic that this suite of actions will translate to a sustained increase in the wild population, but the next 5 years will be a critical period to evaluate their effectiveness.

New technology and research are also enabling us to investigate initiatives including trials to improve egg fertility in the captive breeding program, vaccine development for the problematic beak and feather disease, and exploration of options for improving the genetic health of the population.

In recent years, we have begun trials of satellite transmitters with the aim of tracking birds during migration and movements on the mainland. Only recently have these devices potentially become small enough to attach to the bird without compromising flight ability. This tracking information will provide us with a much better understanding of migration pathways and where the birds spend their time on the mainland (most birds are never seen while on the mainland) and insights into the key factors responsible for mortality outside the breeding season. This information will be invaluable in the fight to save this species.

The actions undertaken to promote recovery of the orange-bellied parrot are detailed in the *Orange-bellied Parrot Recovery Plan* (2016) and supported by the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* and the Victorian *Flora and Fauna Guarantee Act 1988*. Many of the conservation actions for this species require state government wildlife permits and animal ethics committee approval.

Zoos Victoria fighting extinction

Zoos Victoria has made a commitment that no Victorian terrestrial vertebrate species will go extinct on our watch. This pledge resulted in us directing our local conservation efforts towards 27 species (our Fighting Extinction 27) due to their urgent situation and current trajectory towards extinction. These are the 27 local species assessed as most likely to go extinct without help, which includes the orange-bellied parrot. Criteria used to select these priority species include small population size, declining population trend, restricted distribution, and knowledge of the key threatening processes. One of Zoos Victoria's key values is connecting people to wildlife, helping them understand the threats they face, and inspiring tangible conservation action through shaping wildlife friendly attitudes and beliefs.

How you can help

- Raise community awareness and support for the orange-bellied parrot.
- Join Birdlife Australia's winter surveys on the mainland and see if you can locate any orange-bellied parrots.
- Visit our zoos to support our work to fight extinction.
- Donate if you can, because every little bit helps. As we are a not-for-profit organisation, all donations go towards our important conservation efforts.
- Discover more about local conservation events and join the growing number of wild activists taking action for local wildlife.

Figure 6.4. Close-up of orange-bellied parrot feathers. Credit: Zoos Victoria

Figure 6.5. Orange-bellied parrot at Werribee Open Range Zoo. Credit: Zoos Victoria

Society requires sustainable solutions for the environmental challenges it is facing today. In this area of study students explore variations in definitions of sustainability and consider how these may be interpreted and applied in addressing a selected environmental science case study.

The selection of learning contexts should allow students to study one environmental science case study in depth using Earth systems thinking. The selected case study should have an environmental management strategy, including risk assessment. Students assess the environmental impacts and risks associated with the environmental science case study, and examine the elements of environmental management and its relationship to sustainability principles. They examine the perspectives of stakeholders involved, analyse scientific data related to the monitoring of the case study, and evaluate the effectiveness of the environmental strategy implemented by the organisation.

Suitable environmental science case studies include:

- *geotechnical and transport engineering activities* that may involve construction of roads, freeways, railways, airports, mines, shopping centres and housing developments
- *environmental engineering activities* that may involve coastal erosion protection, mine revegetation, municipal recycling systems and freeway revegetation
- *water conservation and water engineering activities* that may involve studies of pollution in bays and oceans, sewage treatment plants, desalination plants, river diversion tunnels and stormwater drainage systems
- *energy and pollution minimisation activities* that may involve air quality monitoring, electrostatic precipitation in smoke stacks, waste minimisation plans, cleaner production plans, waste heat re-use in industry, and energy-efficient housing and commercial buildings
- *soil remediation and soil erosion activities* that may involve bioremediation of soils, studies of dryland salinity, and total catchment management to reduce soil erosion
- *broadacre, intensive or alternative agricultural practices* that may involve feedlots, irrigation, organic farming and biological controls in farming
- *land management and development practices* that may involve ecotourism, hazard reduction burns in fire-prone landscapes, Aboriginal and Torres Strait Islander restoration projects, plantation forestry, green roofs and infrastructure, and urban housing projects.

Outcome 2

On completion of this unit the student should be able to explain how sustainability principles relate to environmental management, analyse how stakeholder perspectives can influence environmental decision-making, and evaluate the effectiveness of environmental management strategies in a selected case study.

AREA OF STUDY 2

When is development sustainable?

Key knowledge

Area	Section
Case study overview	
• the aim and strategies proposed for addressing the environmental science challenges associated with the selected case study	7.1
Sustainability principles	
• the variations in definitions of sustainability and the distinction between sustainability and sustainable development	8.1
• sustainability principles as they apply to environmental management: conservation of biodiversity and ecological integrity; efficiency of resource use; intergenerational equity; intragenerational equity; precautionary principle; and user pays principle	8.2
• challenges to upholding sustainability principles, including population, food, water and energy	8.3
Environmental decision-making and management	
• circular economy thinking and tools for integrated sustainability assessment, including qualitative risk analysis, and cost-benefit analysis	9.1
• interconnections and tensions between factors that influence responsible decision-making, including diverse stakeholder values, knowledge and priorities, regulatory frameworks that inform environmental management strategies, use and interpretation of historical and current scientific data, and application of new technologies	9.2

CHAPTER

7

Environmental science case study overview

7.1. Choosing a development project

The aim and strategies proposed for addressing the environmental science challenges associated with the selected case study

When assessing an environmental problem it is useful to begin with a case study. Case studies give management organisations the chance to look deeply into an issue from all sides before settling on a course of action.

A number of factors must be considered to ensure that a proposed project comprehensively meets the principles of ecologically sustainable development. This chapter lists some of the concepts that should be considered with some examples of possible projects that could be researched.

Explore a project in one of these areas and explore how it fits under the goal of ecologically sustainable development:

- **geotechnical and transport engineering activities** that may include construction of roads, freeways, railways, airports, mines, shopping centres and housing developments
- **environmental engineering activities** that may include coastal erosion protection, mine revegetation, municipal recycling system and freeway revegetation
- **water conservation and water engineering activities** that may include studies of pollution in bays and oceans, sewage treatment plants, desalination plants, river diversion tunnels, and stormwater drainage systems

- **energy and pollution minimisation activities** that may include air quality monitoring, electrostatic precipitation in smoke stacks, waste minimisation plans, cleaner production plans, waste heat re-use in industry, and energy-efficient housing and commercial buildings
- **soil remediation and soil erosion activities** that may include bioremediation of soils, studies of dryland salinity, and total catchment management to reduce soil erosion
- **broadacre, intensive or alternative agricultural practices** that may include feedlots, irrigation, organic farming, and biological controls in farming
- **land management and development practices** that may include ecotourism, hazard reduction burns in fire-prone landscapes, Aboriginal and Torres Strait Islander restoration projects, plantation forestry, green roofs and infrastructure, and urban housing projects.

7.2. Assessing the sustainability of your chosen development

The beneficial and harmful impacts of the selected case study on Earth's four interrelated systems (atmosphere, biosphere, hydrosphere and lithosphere)

Now it's time to explore your chosen project in depth. The list below outlines the key areas that should be explored.

- Name the environmental project you will investigate. Describe the project in terms of its aims, location and time frame.
- Explain how this project contributes to ecologically sustainable development.
- Describe any environmental management tools and strategies that were used to address the environmental aims of this project or to protect against environmental damage during the project. This includes any environmental impact assessment, risk assessment or environmental management system.
- Identify the process taken to identify the potential environmental impacts of the project and describe how the environmental assessment was carried out.
- Outline the role or influence of regulatory frameworks and stakeholder groups in the development and operation of the project.
- Name the organisation that was responsible for monitoring the environmental impacts of the project and list at least two of the guidelines that were set for the project.
- Describe any stakeholder consultation process.
- Assess and discuss any harmful or beneficial impacts of the development on any of Earth's four systems.
- Discuss the application of impact minimisation and risk management strategies and any new technologies being employed.
- Evaluate the effectiveness of the project in meeting the prescribed goals of your school-assessed coursework; include some numerical or qualitative data as evidence to support your assessment (use historical and current data).

Critical and creative thinking 7.1

1. Construction of a new freeway is about to start. Identify and discuss which of Earth's four systems could be affected.
2. a) Look closely at Figure 7.1 and consider the features and activities that could have an effect on the environment (air, water, land and biota). List them in the second column in the table below.
   b) Consider which features and activities at the mine site could reduce these impacts. List these in the last column of the table.

Aspect of environment	Mining activities that may affect the environment	Action taken to reduce the impact
Air		
Water		
Land		
Biota		

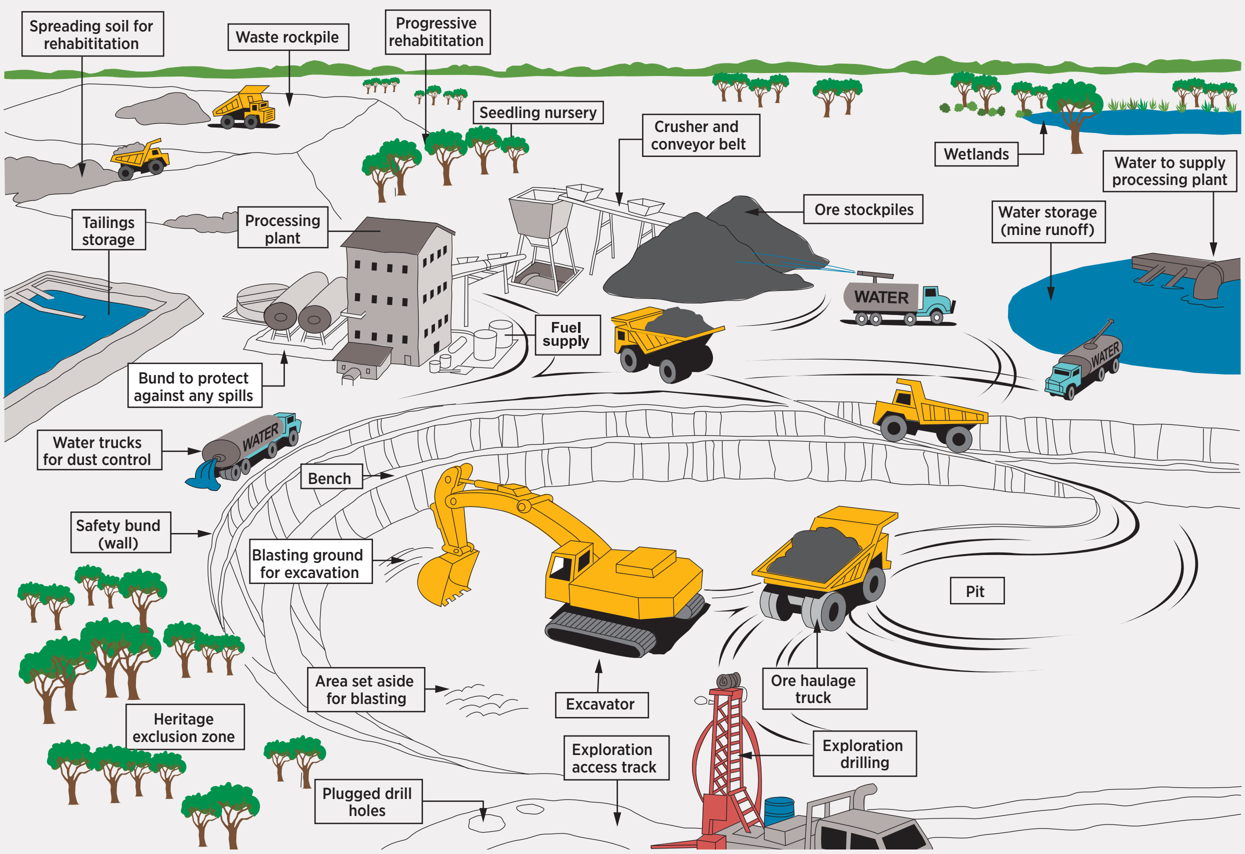

Figure 7.1. Mining activities have many impacts

CHAPTER 8

What is sustainability?

8.1. Ecologically sustainable development

The variations in definitions of sustainability and the distinction between sustainability and sustainable development

Ecologically sustainable development (ESD) has been discussed at length since the United Nations Conference in Rio de Janeiro in 1992. The most commonly used definition of sustainable development is that given by the World Commission on Environment and Development in its 1987 report *Our Common Future*:

development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Put simply, ESD means using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained and the quality of life for both present and future generations is also maintained. This requires ensuring that the nature of production and consumption continues to better satisfy human needs, while using fewer raw materials and producing less waste.

The key to ESD is integrating environmental and developmental considerations in decision-making processes. Importantly, ESD takes into account and weighs the overall benefits and impacts across three areas: environment, society and economy (Figure 8.1).

Figure 8.1. Zone of ecologically sustainable development

Zone of sustainability

Ecologically sustainable development is a good concept but it is important that it be actually implemented. This can be difficult for commercial organisations that have to provide a financial return to shareholders or owners. However, various strategies can be used to start the process of implementing ecological sustainable development. Careful decision-making is vital to ensure that whatever is implemented is actually sustainable in the long term.

The following chapters describe a number of practices and procedures that are used as environmental management tools and can be used to help achieve ESD.

Student activity 8.1
Ecologically sustainable development

1. Write down your own definition of ESD.
2. Discuss this with other people in your class. What are the common elements of each of the separate definitions and what are the individual elements?

Sustainability versus ESD

It is also important to also understand the more generally used term 'sustainability'. In essence, sustainability refers to an ability or capacity of something to be maintained or to sustain itself. For example, the main challenges to a sustainable future are population growth, food security, water security and efficient energy resource use. However, sustainability can have many connotations, and the term has been appropriated by many people and used for a range of different ideas, which can lead to confusion.

Human impacts on Earth's systems

Everything that humans do has an impact, whether beneficial or harmful, on one of Earth's four systems:

- biosphere: the place on Earth where all life exists
- hydrosphere: all the water found on Earth
- lithosphere: the outermost solid layer of Earth (including the crust and upper mantle)
- atmosphere: the gaseous envelope of air surrounding Earth that protects life.

When conducting any sort of environmental project, consideration of potential impacts is paramount in ensuring minimal (if not zero) harm comes to the environment. Thus we must carefully and scientifically evaluate all possible impacts and choose the management option that best addresses these impacts. This will help us to meet the principles of ESD.

Practical 8.1
Story of a river

Half fill a transparent 4-litre container with water – a small fish tank is ideal. Give each student one of the small containers filled with one of the 26 items of contamination. Read the story as a class and pause during the story so the contaminant can be poured in.

Read the story of a river:

High up in the pristine mountains, snow begins to melt and trickle down to form small rivulets that make their way down to the valley below. These rivulets join up to form a creek, which meets with other creeks as it continues on its journey. As more creeks join together, the flow becomes large enough to be called a river. The river travels many kilometres before it eventually reaches the sea. As it makes its journey, it passes through varied scenery and land uses. People use its resource ... and abuse it. Let's follow the voyage of this clean, clear water and see what happens.

To start with, all is well, as the river travels through wild uninhabited country.

Soon, however, it passes a ski resort, just closing for the season. Skiers have left litter on the ski slopes, and as the water melts and runs down, it takes some of the litter with it. **(Add litter)**

As it winds down into the valley, we travel through a large cattle station. Cows dig up the earth on the banks as they drink, causing mud to slide into the water. **(Add mud)**

Their manure also drops into the water. **(Add cow manure)**

Next we pass a logging operation. Sawdust blows into the water. **(Add sawdust)**

Removing all the trees causes the sides of the banks become unstable and soil to wash into the river when it rains. **(Add soil)**

A tannery is around the bend, and toxic chemicals seep from here into the water. **(Add tannery chemicals – yellow food colouring mixed with water)**

Power boats buzz along the river, leaking oil into the water. **(Add oil)**

Nearby is a camping ground where litter is carelessly disposed of and ends up in the water. **(Add litter)**

Someone has dumped some old rusting barrels of chemical waste on the banks in a secluded spot. They are beginning to leak, and nasty, frothy chemicals seep down into the river. **(Add barrel chemicals – vinegar can act as acid)**

A few kilometres on we find a large piggery. Effluent ponds for their waste have been built too close to the river and revolting smelly sludge is overflowing and making its way down to the water. **(Add piggery sludge)**

Further along we travel through wheat crops treated with chemical fertilisers and pesticides which drift down to the river. **(Add fertiliser and pesticide – bicarb soda can act as fertiliser and pesticides)**

Several houseboats motor past with happy holiday-makers. Water with food scraps is let out of the kitchen sink directly into the water from one of the houseboats. **(Add sink scraps)**

On another boat someone is having a shower, and shampoo passes out into the water as they wash their hair. **(Add shampoo)**

Yet another houseboat decides to empty its sewage tank directly into the water instead of at the sewage pumping station. Untreated waste flows into the river. **(Add sewage – chocolate sauce can act as sewage)**

Next we wind through a sheep station where sheep regularly leave their manure where it can easily be washed into the river. **(Add sheep manure – sultanas can act as manure)**

Around a few more bends and we flow past a factory which is piping its effluent directly into the river. **(Add factory effluent – vinegar can act as acid)**

continued next page

Practical 8.1 (continued)

Not far from the factory, the river flows past a picnic area where children splash in the shallow water. Careless picnickers throw their litter on the ground and it ends up in the water. **(Add litter)**

People love to bring their dogs with them on their picnics, but they don't all bother to pick up their droppings, which often get washed down into the river. **(Add dog droppings – chocolate sauce)**

The next few kilometres are home to various orchards, where fertilisers and pesticides are once more used; these drift or wash down to the water. **(Add fertiliser and pesticide – bicarb soda)**

Located on the other side of the river among magnificent cliffs is a quarry. Sand and gravel from the operation ends up in the river. **(Add sand and gravel)**

The quarry is supplying road-making materials to a new housing development not too far further down the river. Disturbed soil and builders rubble ends up in the water. **(Add soil and rubble)**

A new shopping centre has opened to service the community. Unfortunately littering in the car park is common, and items such as plastic bags, packaging and cigarette butts get blown down to the river. **(Add supermarket litter)**

The banks of the river by the new development are mowed regularly and lawn clippings blow into the water. **(Add lawn clippings)**

Local people like to go fishing from the walkway that crosses the river here, but sometimes their lines break and fishing lines, hooks and other rubbish are left in the river. **(Add fishing line etc.)**

Along this populated stretch of the river an algal bloom is out of control. **(Add algae – green food colouring mixed with water)**

As lots of water has been removed from the river along its path, for irrigation and town water supplies, the salinity is high. **(Add salt)**

There is talk of building a reservoir nearby to service the new building development, but there is community concern about the quality of the water and how practical it would be to make it drinkable.

So, for now the river runs into the sea – taking with it all it has collected along the way. And the people wonder why their beach always seems to be so smelly and messy and have so much litter about.

I think I can guess why. Can you?

Critical and creative thinking 8.1

1. Some people use the terms 'sustainability' and 'ecological sustainable development' interchangeably. Do they mean the same thing? **Explain**.
2. How does global population growth affect the sustainable use of energy, food and water? **Discuss** the main threats to sustainability.
3. **Define** the four main systems on Earth and identify a human activity that can negatively impact each system.

Data analysis 8.1
Costs and benefits of tourism

A proposal has been developed to construct a tourist resort on Bathurst Island, one of the Tiwi Islands off the coast of the Northern Territory. Most of the land on Bathurst Island is currently untouched bushland. Bathurst Island is thought to have a population of the critically endangered Tiwi hooded robin as well as many native rainforest trees that can provide habitat for the Tiwi masked owl. Currently the only access to the island for both tourists and locals is by boat.

The island is already popular with tourists, and developers want to build a large resort on the island. The intention is for the resort to run entirely on solar power for all of its energy requirements, be largely built by recycled materials and be highly energy efficient.

The island has a permanent population of five small communities, but if the resort goes ahead an extra 300 people will be living on the island as staff for the resort. In addition to staff, the resort can accommodate up to 1,000 guests at one time during the peak season.

The island will be able to compost food waste but all plastic waste will need to be burnt, buried or shipped back to Darwin by boat.

Construction of the resort will require large machinery that will have to be transported to Bathurst by barge from Darwin.

The ecological importance of Bathurst currently is that it contains many species endemic only to the Tiwi group of islands; it also holds a great amount of cultural significance to the local Aboriginal communities.

1. In the table below, summarise the major arguments for and against the proposal, focusing on social, environmental and economic factors.
2. Using the information in the table, make a recommendation as to whether the project should proceed. Justify your recommendation.
3. Explain whether the proposal is an example of ecologically sustainable development. In your answer give a definition of ecologically sustainable development.

Aspect of environment	For	Against
Social factors		
Environmental factors		
Economic factors		

8.2. Principles for ecological sustainable development

Sustainability principles as they apply to environmental management: conservation of biodiversity and ecological integrity; efficiency of resource use; intergenerational equity; intragenerational equity; precautionary principle; and user pays principle

Conservation of biodiversity and ecological integrity

Conservation of biodiversity and ecological integrity is an important concept in assessing whether an ecosystem may be affected by a proposed development. Ecological integrity assessments provide a standard 'biophysical examination' that assesses how well an ecosystem is doing, including its size, its component vegetation, soil and hydrology, and its interactions with the surrounding landscape. A three-level approach to assessing ecological integrity can include remote sensing imagery, rapid field assessments and detailed quantitative assessments.

Ecological integrity assessment models provide land managers, conservationists and agencies with critical information on factors that may be degrading, maintaining or helping to restore an ecosystem.

Efficient resource use

Efficient use of resources is an essential part of ecologically sustainable development. Reducing energy and fuel consumption will reduce the costs of a project as well as reduce its environmental impacts and improve its environmental sustainability. For some projects, water use may be significant; for others a key concern may be efficient use of raw materials.

Cleaner production and waste minimisation

Cleaner production is defined by the United Nations Environment Programme (UNEP) as:

the continuous application of an integrated, preventive strategy applied to processes, products and services in pursuit of economic, social, health, safety and environmental benefits.

Governments around the globe are realising that an environmental strategy based on pollution control, clean technology and environmentally responsible goods and services is necessary for sustainable economic development and economic growth.

Waste minimisation is often thought of in the context of pollution prevention rather than the conservation of materials and energy, although this concept is changing. The management hierarchy for waste management presents ways to deal with waste in descending order of preference:

- avoid
- minimise
- re-use
- recycle
- recover energy
- treat
- contain
- dispose of.

While this approach aims to minimise the amount of wastes generated (with the associated reduction in raw materials and energy use), it recognises that wastes will unavoidably be generated. This being the case, treatment processes that reduce toxicity and volume of wastes, such as incineration, are preferred prior to final disposal (such as in a landfill).

For most of human history, waste management technologies were effective because the wastes generated were mostly biodegradable and populations were small and dispersed. Historically, waste has been dealt with in a 'burn, bash or bury' approach; for example, waste has been:

- placed in piles away from residences
- incinerated (burnt in the open)
- disposed of into rivers and oceans
- placed in holes and gullies and covered with dirt.

However, as waste has been produced in different forms and in greater amounts, the need for more sophisticated means of disposing of our wastes has grown.

In addition, costs of waste disposal are increasing and will continue to increase. Reasons for this include:

- landfills filling up, requiring waste to be transported greater distances for disposal
- increased disposal charges that reflect all costs.

Intragenerational equity

Fairness, justice and equal access to services and resources are key factors when it comes to sustainable development and environmental management. Intragenerational equity refers to the equal distribution of, or access to, resources between people across the same generation, including between different nations. For example, improved technology for a new series of pipes and pumping mechanisms from a water reservoir is able to provide water to new housing developments in a growing city, to farmers for irrigation of crops and livestock, and in the form of environmental water to rivers in the vicinity. This technology is then also shared with other countries to aid in the distribution of water to people of other nations.

Intergenerational equity

Intergenerational equity considers the impacts of a development on future generations, taking into account future environmental, social and economic factors. These could be creating ongoing employment opportunities, the development of technology to provide clean water for many years to come, or the creation of green spaces in a residential development.

The precautionary principle

The precautionary principle changes the nature of evidence needed when assessing the impact of developments. It should not be up to conservation managers to demonstrate that a proposed development will harm biodiversity; it should be the responsibility of the proponents of a particular activity to show that their proposal will not reduce biodiversity or that the environmental costs are minimal or worthwhile.

User pays principle

In order to ensure that environmental costs are not overlooked in planning and management decisions, governments are increasingly adopting the 'user pays principle', which is a variation on the 'polluter pays principle'. The user pays principle is based on the idea that the price of a natural resource or environmental service should reflect its full cost, including, for example, the cost of managing wastes. Then the financial decisions made by consumers and businesses will lead to efficient allocation of resources because the cheaper options will also be those with a lower environmental cost.

CASE STUDY 8.1
Wastewater treatment

Domestic and industrial wastewater are normally collected in a public sewer system. This contains domestic sewage as well as liquid wastes from commercial and industrial establishments. These wastes vary in the type, volume and toxicity of substances they contain and require processing before being discharged into the environment (Table 8.1).

If industrial wastewater does not fit the limits set by the sewerage authority, it must be treated on-site or at a treatment facility before being discharged to a sewer.

Stormwater is run-off from rainfall that flows into rivers, oceans or bays via the stormwater system, usually without any form of treatment. In metropolitan areas, this run-off contains litter, fallout from air pollution and organic matter (for example, animal faeces). In rural areas, run-off contains pesticides, fertilisers, animal manure and other particulates.

Prescribed liquid waste is liquid waste generated by industry that cannot be disposed of via the sewer system and has to be treated on-site or transported off-site for treatment.

If wastewater is not treated correctly, it can have detrimental effects on the hydrosphere, biosphere and lithosphere.

The choice of wastewater treatment process will depend on the contents of the water and where it will be discharged. Treated water is tested to assess water quality and make sure it meets limits for different parameters on discharge. Both organic and inorganic parameters are tested (Table 8.2).

Table 8.1. Estimated rates of wastewater generation for metropolitan Melbourne

Waste stream	Generation rate (kg/person/week)	Disposal
Domestic sewage	1,330	Rivers or sea – after treatment to lower biological oxygen demand (BOD), solids and some nutrients
Industrial sewage	420	Rivers or sea – after treatment to lower BOD, solids and some nutrients
Industrial liquid waste	0.5	Treatment facility followed by disposal of suitably treated liquid to rivers, sea and land (irrigation)

Table 8.2. Tests for wastewater

Organic parameters	Inorganic parameters
Biological oxygen demand (BOD)	pH (acidity/alkalinity)
Chemical oxygen demand (COD)	Dissolved solids
Total organic carbon (TOC)	Heavy metals
Miscellaneous (e.g. oil/grease and phenols)	Suspended solids

Biological oxygen demand is a measure of the rate at which oxygen is used up by microorganisms to break down organic matter. The BOD test exploits the capacity of microorganisms to oxidise organic material to CO_2 and H_2O. Factors affecting the test are light (photosynthetic organisms replenish the oxygen being used up), temperature (higher temperatures increase metabolic rates and thus oxygen consumption) and time (more oxygen is used up over time). Low BOD could indicate:

- clean water
- available microorganisms are not using the available organics
- microorganisms are dead (for example, from arsenic contamination).

Chemical oxygen demand was developed as a test that gives a good estimate of biological oxygen demand but is much quicker to run. COD involves oxidising the organics chemically (generally by using potassium dichromate).

Total organic carbon provides a quick measure of organic contamination in a water sample. Organic contaminants enter waterways and water bodies in a variety of ways, either in the form of natural organic substances or from anthropogenic sources (such as pesticides, other agricultural chemicals, sewage or industrial organic wastes). TOC can be measured by oxidising or combusting the organic carbon to carbon dioxide at a very high temperature (680 °C).

Acidity and alkalinity are important inorganic parameters because microorganisms need a neutral pH and are sensitive to fluctuations. The presence of heavy metals is another measure of the suitability of water for microorganisms and larger organisms.

Dissolved solids is a measure of the amount of material dissolved in water; the solids are mostly inorganic salts. Suspended solids is a measure of the material suspended in water; that is, the material (such as fine dirt) that is contained in the water but not dissolved in it. Suspended solids could contain organic and inorganic matter.

Practical 8.2
Detection of coliform bacteria in polluted water

Sewage can contaminate waterways with various bacteria. One of them, *Escherichia coli (E. coli)*, lives in the human intestine and its presence is an indication of sewage pollution.

Aim

To observe the presence of *E. coli* on an agar plate.

Equipment

- 10 g peptone or stock cubes
- 10 g lactose or glucose
- 2 g sodium hydrogen phosphate (Na_2HPO_4)
- 0.4 g eosin stain
- 0.1 g methylene blue dye
- 15 g agar powder
- pressure cooker or autoclave
- 5+ sterile Petri dishes
- 3+ polluted water samples (collected from waterways or drains around the school)
  CAUTION: Take care that the water collected does not pose a health hazard.
- 1 L distilled water
- inoculating loop or platinum wire
- Bunsen burner
- incubator
- 2 L beaker or conical flask

Time required

45 minutes

continued next page

Practical 8.2 (continued)

Procedure

1. Prepare 1 L of agar solution:

   To 1 L of distilled water add 10 g of peptone, 10 g lactose, 2 g Na_2HPO_4, 0.4 g eosin stain and 0.1 g methylene blue dye. Stir the ingredients. Add 15 g agar powder and warm until it dissolves.
2. Pour the agar into five or more sterile Petri dishes labelled 1 to 5. Replace the lids and place them into an autoclave for 15 minutes.
3. Sterilise an inoculating loop in a Bunsen flame, and streak agar plate 1 with a drop of ordinary tap water. Replace the lid immediately after streaking.
4. Sterilise the loop again and streak plate 2 with distilled water.
5. Streak plates 3 to 5 with the samples of collected water, replacing the lids immediately after streaking. Sterilise the loop between each streak.
6. Incubate the agar plates for 24 hours.
7. Inspect the plates and record the number of colonies observed.
8. Incubate for another 24 hours and again record the number of colonies.

Results

Record your results in the table below.

Discussion

1. Comment on the quality of your water samples.
2. Why was it necessary to streak two agar plates with ordinary and distilled water?
3. Why is it necessary to monitor *E. coli* levels in water, given they live in the human body?
4. What are some diseases transmitted by polluted water?

Agar plate	1	2	3	4	5
Streak	Tap water	Distilled water	Polluted water 1	Polluted water 2	Polluted water 3
No. of colonies of *E. coli* after 24 hours					
No. of colonies of *E. coli* after 48 hours					
Other observations					

Practical 8.3
Quantitative analysis of a water sample

Aim

To visually inspect the quality of a water sample and estimate its pH.

Equipment

- 2 water samples collected from waterways or other sources

  CAUTION: Take care that the water collected does not pose a health hazard.
- distilled water
- portable pH meter OR universal indicator and narrow range paper, pH (5 to 9)
- 3 × 25 mL conical flasks with stopper
- stopwatch

Time required

60 minutes

Procedure

1. Visually inspect the two collected water samples and distilled water for hydrocarbons (that is, oil and petrol). Look for a rainbow effect and test for odour. Record your observations.
2. To test for the presence of detergents, half fill a conical flask with each water sample, stopper it and shake for 1 minute. Stop shaking and immediately start the stopwatch. Record the time taken for any bubbles to disappear.
3. To test for turbidity repeat step 2, but record the time taken for any visible solids to settle.
4. Insert the probe of the portable pH meter into each water sample and record the reading. OR use universal indicator paper to establish the general pH range, then use the appropriate narrow range pH paper and estimate the pH as accurately as possible.

Results

Record your results in the table below.

Discussion

1. Describe the quality of your water samples.
2. List the pollutants that could contribute to bad odours.
3. List possible pollutants that could contribute to:

   a) high pH

   b) low pH.
4. If the turbidity is very high, it could be due to the suspension of very fine clay particles, which are charged. How could such suspended solids be removed?

Test	Distilled water	Sample 1	Sample 2
Hydrocarbons			
Colour			
Odour			
Detergents			
Turbidity			
pH			

Practical 8.4
Determination of total solids in water

Aim

To determine, in a water sample, the suspended solids by filtration and dissolved solids by evaporation of the filtrate.

Equipment

- 100 mL water sample collected from a waterway or other source
  CAUTION: Take care that the water sample does not pose a health hazard.
- distilled water
- filter funnel
- glass rod
- large evaporating basin
  (must be able to hold more than 100 mL)
- drying oven
- tripod
- gauze mat
- Bunsen burner
- retort stand
- filter paper
- 100 mL measuring cylinder
- 200 mL jar with lid, with 100 mL marked on the outside of the jar
- electronic balance OR analytical balance

Time required

90+ minutes

Procedure

1. Collect a 100 mL sample of water from a waterway or other polluted source.
2. Weigh a dry filter paper that has been dried in a drying oven for at least an hour.
3. Weigh a large evaporating basin.
4. Set up the equipment as shown in Figure 8.2.
5. Shake the water in the collecting jar and pour it through the filter paper via a glass rod into the evaporating basin.
6. Rinse out the jar of polluted water with distilled water several times, pouring out each rinse through the filter paper.
7. When filtration is completed, remove the filter paper and place it in a drying oven at a temperature of 110 °C until it is dry (allow at least an hour).
8. Place the evaporating basin on a tripod and gently heat it over the Bunsen flame, as shown in Figure 8.3, until there is only about 5 mL of water left.
9. Transfer the evaporating dish into a drying oven and let it dry overnight.
10. Reweigh the filter paper and evaporating basin.
11. Record your results.

Results

	Filter paper (g)	Evaporating basin (g)
Mass before filitration		
Mass after filtration with dry solids		
Mass of solids collected		

1. Calculate the mass of:
   a) solids left on the filter paper in g/100 mL
   b) solids left in the evaporating dish in g/100 mL.

2. Pollutants are normally reported as mg/L or parts per million. Calculate the concentration of solids in your water sample in mg/L and record it as:
   a) suspended solids
   b) dissolved solids
   c) total solids (dissolved + suspended).

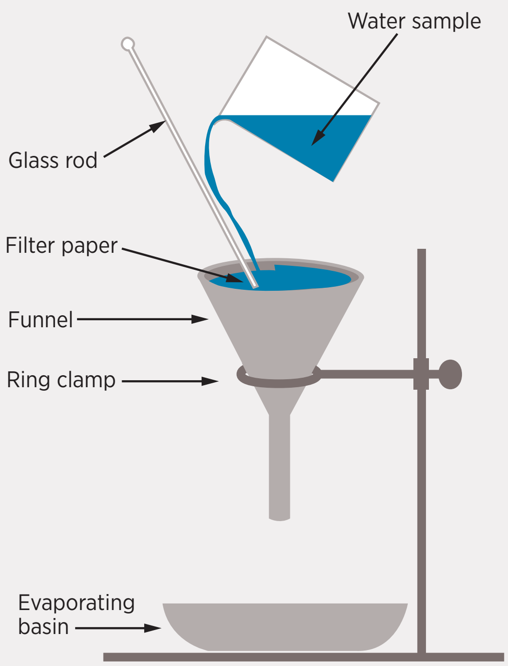

Figure 8.2. Set-up of apparatus 1

Discussion

1. What is the most likely chemical composition of the dissolved solids?
2. What is the most likely source of the suspended solids?
3. What are the effects on aquatic life of a high level of suspended solids?
4. Compare your results with the results obtained by other members of the class. Suggest reasons why results may differ within the class.

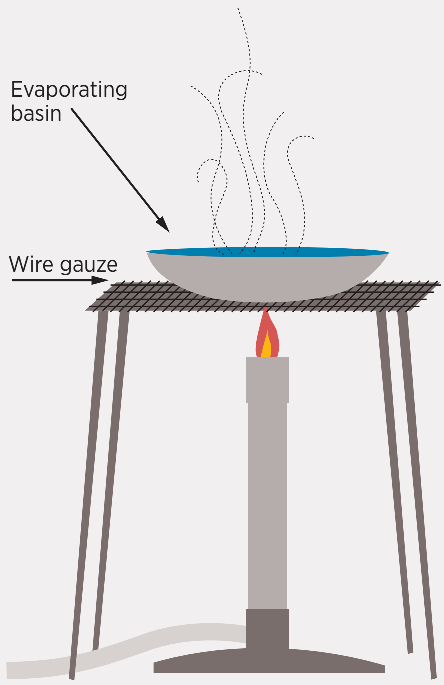

Figure 8.3. Set-up of apparatus 2

Practical 8.5
Purification of polluted water

Aim

To remove the colour and odour from a sample of polluted water.

Equipment

- 250 mL polluted water
  CAUTION: Take care that the polluted water does not pose a health hazard.
- 500 mL beaker
- 0.1 M potash alum solution
- limewater
- activated charcoal
- filter funnel
- 2 filter papers
- 2 × 100 mL flasks
- 2 × 10 mL measuring cylinders
- glass rod

Time required

20 minutes

Procedure

1. Collect approximately 250 mL polluted water in a 500 mL beaker.
2. Carefully, smell the sample before beginning to treat it. Record your results.
3. Using separate measuring cylinders, add 10 mL of limewater and 10 mL of potash alum solution to the polluted water.
4. Stir the polluted water with a glass rod and then allow it to stand for 5 minutes. Observe and record.
5. Filter 50 mL of the solution into a 100 mL flask and observe the filtrate. Carefully, smell it and record.
6. Add one small spatula of activated charcoal to the filtrate, swirl the flask and allow it to stand for 1 minute.
7. Swirl the flask again, then filter the solution into a second 100 mL flask. Observe and smell the filtrate in this second flask. Record your observations of the appearance and odour of the treated water sample.

Results

Sample	Observations	
	Odour	Appearance
Polluted water		
Filtrate 1		
Filtrate 2		

Theory

The limewater and alum add hydroxide ions and aluminium ions respectively to the polluted water sample. These combine in a precipitation reaction to produce a gelatinous (jelly like) precipitate or floc of aluminium hydroxide.

$$Al_3^+(aq) + 3OH^-(aq) \longrightarrow Al(OH)_3(s)$$

This floc has the ability to entrap other particles. It will entrap any suspended solids, some of the colour-causing particles and even some suspended odour in polluted water. When the precipitate is filtered off, the entrapped particles stay with the precipitate and are therefore removed from the water.

Activated charcoal consists of tiny particles of carbon. These particles have large surface areas and the ability to absorb other molecules, including ones that cause odour. When mixed with water, molecules that cause odour are absorbed onto the surface of the carbon particles. When the charcoal is filtered off, the odour molecules stay with the carbon and are therefore removed from the water.

8.3. Challenges to sustainability principles

Challenges to upholding sustainability principles, including population, food, water and energy

With increasing demand for development, it becomes increasingly harder to uphold the sustainability principles as described in section 8.2 (p. 84). In an ideal world, all sustainability principles would be met in some way. In the real world, the best that can be achieved is to uphold as many as possible for any particular project or development.

With a growing human population, there are challenges to maintaining adequate supplies of food and clean water and also in providing the energy required to support the population.

Population

The current population of Earth is approximately 7.9 billion people, and it is growing by around 74 million people each year. By 2060, Earth is likely to have a population of 10.2 billion.

The 20th century saw the biggest increase in the world's population growth in human history (Figure 8.4). As Earth's population grows, so do the demands on the environment to support us, most importantly with regards to energy, food and water. And that's before we consider the needs of other species on Earth. In the last 50 years alone we have consumed more resources than the whole of humanity before us! As the population grows, we need more of everything. How do we meet our growing food security needs while also conserving land for biodiversity? How do we ensure more efficient use of energy resources?

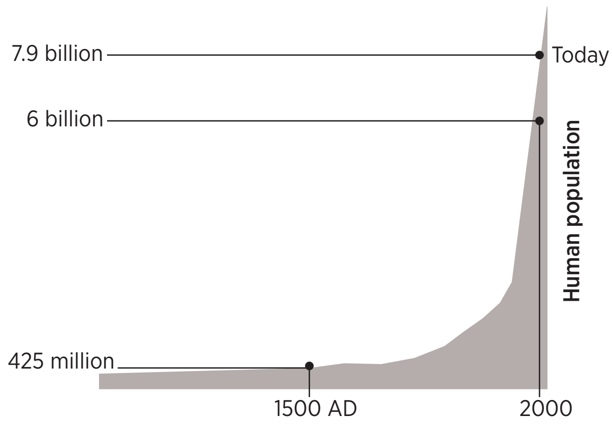

Figure 8.4. Earth's population growth

How can we ensure water availability for everyone on Earth? These are the big questions we are grappling with at every level of society.

Food

The supply of food is vital for a growing population. This requires major use of land for crops and livestock. Of the world's habitable land, half is used for agriculture (see Figures 8.5 and 8.6). This has put significant pressure on natural ecosystems and their biodiversity. The IUCN has listed agriculture as a threat for approximately 86% of the species evaluated to be threatened with extinction. By increasing the productivity of land, reducing the amount of resource-intensive consumption and improving the technology and products used in agriculture, it is possible to reduce the impact of agriculture on the environment.

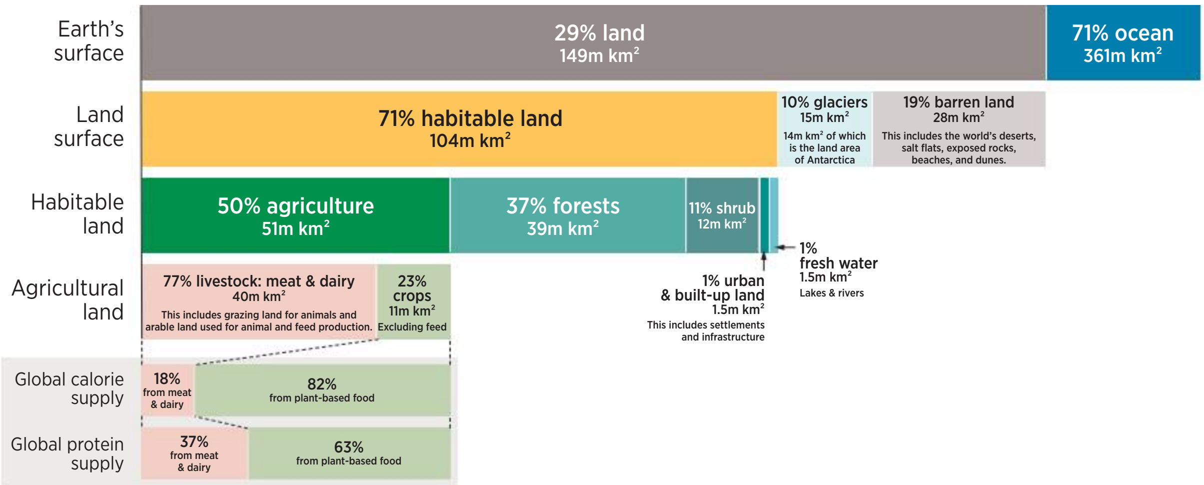

Figure 8.5. Global land use for food production

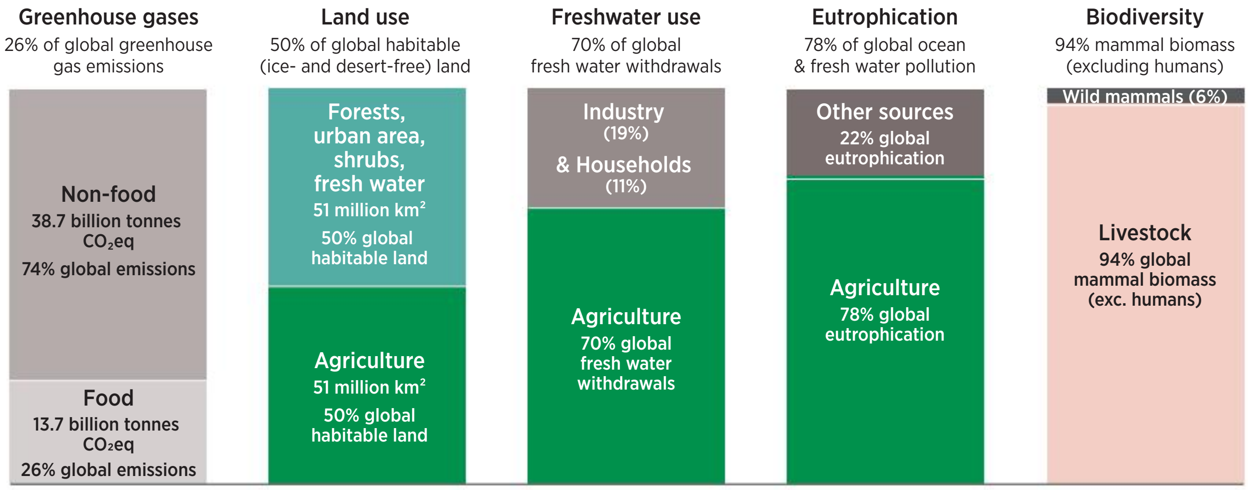

Figure 8.6. Environmental impacts of food and agriculture

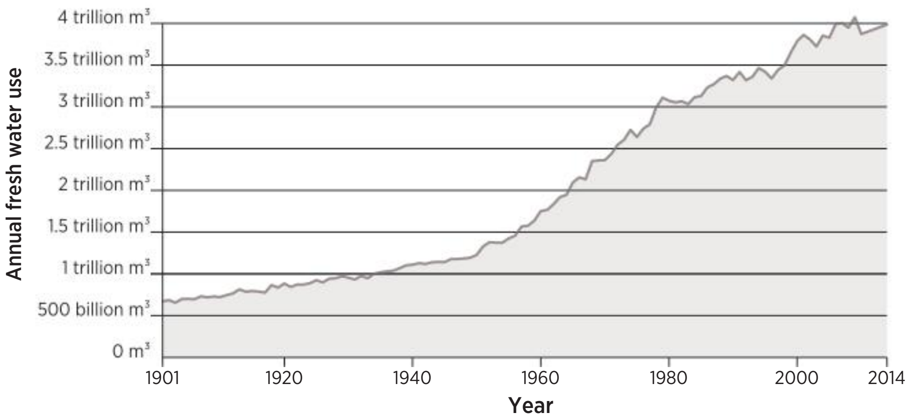

Figure 8.7. Global fresh water use

Water

The availability of water for both humans and the environment is vital. Clean fresh water is key for healthy human populations. Unsafe water is responsible for approximately 1.2 million deaths per year.

An increasing need for the supply of fresh water (Figure 8.7) is resulting in the construction of structures to store and supply water. If water is scarce at ground level, then underground supplies are sourced and tapped.

Water is also vital for healthy ecosystems. A constant supply of water in the environment is vital to uphold the health of ecosystems such as wetlands, rivers and lakes. If these areas lose their source of water, the resulting loss of biodiversity can be devastating. It is estimated that approximately 64% of the world's wetlands have disappeared since 1900.

Energy

Access to an adequate energy supply is a key prerequisite for economic, social and cultural development. The different forms of energy are essential to providing equal access to basic resources such as education, health services, food, housing and employment.

Statistics from Our World in Data show that, in 2016, 13% of the world did not have access to electricity and 40% did not have access to clean fuels for cooking. The increased demand for energy is putting increasing demand on its provision. How this energy is provided is an ongoing dilemma for society. The provision of energy can have both positive and negative impacts on society and the environment. A key aspect of becoming sustainable is reducing the use of non-renewable energy and shifting to using renewable energy sources.

Critical and creative thinking 8.2

The Victorian Government has designated a growth area to accommodate the state's growing population. They have approved development that will provide approximately 22,000 residential homes, along with primary and secondary schools, a retail centre, sporting and recreational facilities, parks and open spaces with bike paths and walking tracks. There will also be upgrades to access the public transport of the area.

The development is on 2,500 hectares of agricultural land that also contains a natural waterway and some areas of native vegetation. There are plans to enhance the waterway and designate the native vegetation areas 'no development' zones. These native vegetation areas will be connected throughout the development.

Approval has been given to seek innovative solutions to capture, recycle and use water. Wetlands and water storage ponds beside open spaces will be used for irrigation, and recycled water will be provided to residential homes. Drought-tolerant native landscaping and use of water tanks will be encouraged.

Housing lots will be sited to achieve the best solar orientation and public lighting will also use solar technology. Commercial buildings will incorporate environmentally sustainable design features, using shared facilities where applicable. All residential construction will also be required to incorporate the minimum sustainable design features.

Describe how this development project could address each of the six sustainability principles (conservation of biodiversity and ecological integrity; efficiency of resource use; intergenerational equity; intragenerational equity; precautionary principle; user pays principle) and also how it plans to meet the four challenges to sustainability (population, food, water, energy).

CHAPTER 9

Environmental decision-making and management

9.1. Circular economy

Circular economy thinking and tools for integrated sustainability assessment, including qualitative risk analysis, and cost-benefit analysis

You may have heard the term ‘circular economy’ floating around recently. The term is becoming more widely used within the field of sustainability as we are starting to learn how important and useful a circular economy approach is within the manufacturing industry. In 2020 the Victorian Government released a circular economy policy and action plan called *Recycling Victoria: a new economy*. This document outlines the government’s “sweeping plan of reform to establish a recycling system that Victorians can rely on. It transforms how our economy uses materials and how our state reuses, repairs and recycles.”

So what exactly does circular economy mean? A circular economy, as defined by the Victorian Government, “continually seeks to reduce the environmental impacts of production and consumption and gain more productive uses from natural resources”. Where, “*resource use* is minimised, and waste and pollution are avoided with good design and efficient practices. This reduces environmental impacts while maintaining or increasing the value people obtain from goods and services”. From here, “products are designed so that they are durable and can be readily repaired, reused and recycled at the end of their lives”. *Business models* are also addressed, in terms of “encouraging intense and efficient product use, like sharing products between multiple users, or supplying a product as a service that includes maintenance, repair and disposal”. The last component of the definition is that “*innovations* are to increase resource productivity and bring a range of benefits including jobs, growth and social inclusion to local, regional and global economies”.

Integrated sustainability assessment

Integrated sustainability assessment is a way to comprehensively assess the long-term sustainability impacts of both international and national government policies against sustainability targets and criteria. This approach provides a key element for advancing sustainable development through assessing the economic, environmental and social impacts of various policy proposals. There are various tools and methods for conducting integrated sustainability assessments, including qualitative risk analysis, life cycle analysis and cost-benefit analysis.

Cost-benefit analysis

Cost-benefit analysis is a technique companies use to determine if an idea or product is worth the money that is needed to be invested (cost) to make the product or idea come to life (benefit). Often this includes considering how much time the product will take to develop, how much money it will cost to produce and whether the company can sell it for the right price so that the product or idea is profitable. Cost-benefit analysis usually only considers the cost for the company and not the cost to the environment or the people on the production line in the factory. An ethical company will include these factors in a cost-benefit analysis.

Assessing and managing environmental risks

A *hazard* is a thing (such as a substance or situation) that can cause harm or create adverse impacts on people, the environment and/or property. *Risk* is the probability that a hazard will cause harm or create adverse impacts.

For example, chlorine is a toxic chemical so storage facilities sited in the community represent a hazard to the community. However, if there are adequate safety systems in place, then the risk of exposure is negligible or low.

Every day, people are at risk of being adversely affected through exposure to all kinds of pollutants and contaminants found in the home, the workplace and the outside environment.

Risk management for a particular project entails:

1. identifying potential risks (risk assessment)
2. analysing these risks (risk analysis)
3. selecting appropriate risk responses (risk management)
4. monitoring the project as it progresses.

Risk assessment

All substances and activities involved in our lives can have risks associated with their use or from contact with them. For example, water is essential for life but can kill us by drowning. Snakes can be lethal, but only if we are bitten, sufficient toxin enters our system and medical help is not available. Radiation from a leaking nuclear reactor could also kill us, but only if we are exposed to lethal levels of the radiation. There is not much point saying that there is a substantial risk to human health or the environment if the risk is not quantified.

Because hazards have plagued humans for centuries, individuals, groups and societies have developed various methods of managing the risks associated with being exposed to the hazard. Risk assessment is often carried out when a new product or project, such as building a new factory or constructing a new freeway, is being considered.

The objective of risk assessment is to provide details of the potential adverse effects of substances or activities on humans and the environment. Risk assessment applies a logical approach to analysing and interpreting data with the purpose of predicting and evaluating potential adverse effects on the health of living things. Environmental risk assessment integrates:

- toxicological data
- human experience
- exposure information
- fate of a chemical and transportation data
- statistics and probability.

A risk assessment gives an understanding of the degree of hazard and illustrates where most benefit can be gained by modifying the system to reduce the risk. Figure 9.1 illustrates the steps that should be undertaken in the process of identifying and analysing potential hazards and risks.

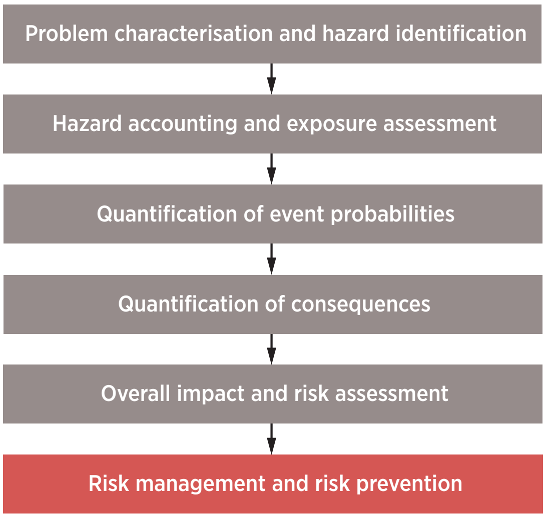

Figure 9.1. Steps in the analysis of hazards and risks

Environmental risk assessment has mainly been applied in the field of human health. Limitations in the investigation of a chemical are associated with the modelling methods and/or tools, the methods of obtaining data, and limits to our understanding of the metabolic and physiological processes involved. Nevertheless, environmental risk assessment provides a formalised process for assessing the impact of a chemical or activity on an ecosystem. The results of an assessment give decision-makers a greater understanding of the environmental processes involved and the potential impacts of their decisions.

Qualitative risk analysis

Risk analysis can be qualitative or quantitative. In the latter, data inputs are analysed to assign a numeral value to a risk. Qualitative risk analysis, which is our focus here, is a more subjective process of assessing individual project risk characteristics.

Qualitative risk analysis addresses the probability of risk occurring and the potential impact on a project (or an individual) if that risk occurred, against a known scale. Rather than using a numerical scale, risk is categorised on a scale such as low, medium and high. Creating a table of risk likelihood (probability) against severity of consequences (degree of hazard) produces a risk assessment matrix (Figure 9.2). This method lets you prioritise risks according to their probability and potential impact.

Student activity 9.1
Circular economy

1. Using your knowledge from previous chapters and extra research, how could the process of circular economy be improved? Consider the current environmental focus on single-use products. Research and investigate the processing and regulations around e-waste or building and infrastructure materials.
2. Define ‘quantitative risk analysis’ and give examples of the techniques used.
3. List and explain 3–4 other tools for integrated sustainability assessments.

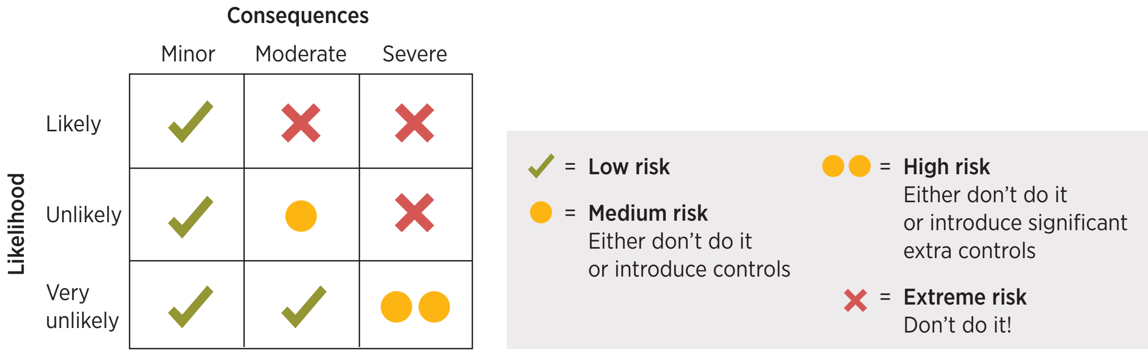

Figure 9.2. A risk matrix

Risk management

Having identified and quantified all the risks associated with the project, it is appropriate to develop a management strategy. What has to be determined is the amount of risk the community is willing to accept. This level of risk is usually considered along with the benefits a particular project may provide.

Those who favour a no-risk option argue that no amount of risk is tolerable, and a project should be terminated if any risks have been identified. The more accepted approach defines risk management as providing strategies and actions that either stop or minimise an event that is deemed harmful or dangerous.

In response to identified risks, individuals, industry and governments use techniques to reduce or mitigate adverse risks (especially risk to health, but applicable to all risk assessment). These techniques include:

- prohibiting the use of a potentially damaging process, object or substance
- regulating or modifying activities
- reducing the vulnerability of those threatened, for example, by relocation
- requiring regular ongoing monitoring of environmental health impacts
- developing and implementing post-event emergency response procedures
- instituting compensation schemes.

Perceptions of risk

In addition to the scientific assessment, people's perception of risk (and therefore their willingness to accept the risk) can vary depending on the situation (Table 9.1).

Table 9.1. Characteristics affecting attitudes to risk

Characteristics that tend to increase people's acceptance of a risk	Characteristics that tend to decrease people's acceptance of a risk
Voluntary (e.g. smoking)	Involuntary (e.g. passive smoking)
Familiar	Unfamiliar
Immediate impact	Remote impact
Detectable by individual	Undetectable by individual
Controllable by individual	Uncontrollable by individual
Fair	Unfair
Non-catastrophic	Catastrophic
Well understood	Poorly understood
Natural	Artificial
Trusted source	Untrusted source
Visible or direct benefits	No visible or direct benefits

Student activity 9.2
Perceived risk

1. In a group, try to give an example for each characteristic listed in Table 9.1.
2. a) The table below lists potential hazards you are probably familiar with.

   Give each hazard a rating from 1 to 5 (with 1 being the greatest risk and 5 no risk), based on your perception of the risk associated with each.

   Place your answers in column A.

   b) Discuss your answers with a small group of students in your class and place the group's ratings in column B. Share the reasons as to why you rated the hazards as you did.

   c) Now, within your class and by consensus, not a vote, establish new ratings for the items that reflects the class's perception. List these in column C.

   d) Compare the different perceptions of risk between your perceptions and your class's responses. Why do the different groups have different perceptions of risk?

Potential hazard	Perceived risk		
	A	B	C
Aerosol spray cans			
Alcoholic beverages			
Antibiotics			
Aviation			
Bicycles			
Electric power			
Food preservatives			
Food colouring			
Handguns			
Football			
Motor vehicles			
Motorcycles			
Nuclear testing			
Oral contraceptives			
Pesticides			
Power mowers			
Smoking			
Surgery			
Vaccinations			
X-rays			

Critical and creative thinking 9.1

1. Research a company of interest and illustrate visually their circular economy process.
2. Critically analyse their process. Does it meet the circular economy definition? Why or why not?
3. Consider other components, such as qualitative risk analysis and cost-benefit analysis.

Life cycle analysis

Life cycle analysis (LCA) aims to quantify all environmental impacts of a product over its entire life cycle. Attention is given mainly to consumer products, but life cycle analysis may also be applied to services and policies. A life cycle analysis should cover the entire life cycle of the product, from extracting raw materials, through manufacturing, distribution and use to disposal. For all stages, life cycle analysis identifies:

- materials used (and their source and processing)
- energy used
- water consumed
- the types and quantities of materials discharged (including wastewater).

Life cycle analysis improves the information base for decision-making by assessing the impact of energy and material use and waste discharges. This information can be used to adopt alternative materials or methods to reduce the product's environmental impact. Life cycle analyses should consider aspects including ecological health, human health and resource depletion. The basic steps in a life cycle analysis are:

- **goal definition**: decide the purpose and conduct of the study and the product, service or policy to be analysed
- **inventory**: identify the systems or stages in the life cycle to be analysed and all inputs from, and outputs to, the environment
- **impact assessment**: convert the inputs and outputs into their contributions to environmental problems to produce an environmental profile of the product, service or policy
- **improvement**: evaluate alternative strategies that could reduce lifetime environmental impact.

9.2. Environmental management systems

Interconnections and tensions between factors that influence responsible decision-making, including diverse stakeholder values, knowledge and priorities, regulatory frameworks that inform environmental management strategies, use and interpretation of historical and current scientific data, and application of new technologies

Many responsible organisations are developing management systems to identify and reduce risks. These management systems can be used on a day-to-day basis or for specific projects. For example, they can be a tool for ensuring that management strategies are in place before the project begins for risks that were identified in the planning stages. If the identified risks cannot be managed, then a decision has to be made as to whether the project should be abandoned or modified.

Table 9.2 presents the requirements for safe operation and the basic features of a management system. Developing a management system ensures that:

- environmental and safety risks are identified
- progress is made towards reducing risks
- a process is in place to ensure that procedures are monitored and reviewed.

Table 9.2. Safe operation parameters for a pipeline project

Fundamental requirements for safe operation	Basic features of a management system
Hazards are recognised and their risks understood	Hazard assessment
Appropriate equipment and facilities are provided to reduce the risks from these hazards	Design considerations
Systems and procedures exist to operate the equipment satisfactorily within the design intent and to maintain its integrity Adequate facilities exist to detect and control emergencies	Standard operating procedures Maintenance policies and procedures Inspection and testing policies and procedures Modification control policies and procedures Emergency response procedures and plans
Appropriate personnel are employed and given sufficient information, instruction, supervision and training to operate the equipment, system and procedures	Staff selection policies and procedures Training policies and procedures
Effective systems exist to promote safety, to audit safety performance and to progress safety issues	Incident investigation and analysis Safety and environmental audits

Standards

An environmental management system (EMS) is defined in the Environmental management systems standard (AS/NZS ISO 14001: 2016) as:

that part of the overall management system which includes organisational structure, planning, activities, responsibilities, practices, procedures, process and resources for developing, implementing, achieving, reviewing and maintaining the environmental policy.

In the late 20th century, it became apparent that there was a need for management systems that dealt specifically with environmental performance yet meshed effectively with more general quality management systems. In 1992, one of the first standards for environmental management systems, the British Standard BS 7750, was developed. The European Eco-Management and Audit Scheme followed a year later.

The International Organization for Standardization (ISO) has developed a standard for environmental management systems (ISO 14001). Instead of developing its own standard, Australia has had significant input into the ISO process. The aim of ISO 14001 is to develop a standard that is flexible enough to apply across different organisational structures and in different regions. The International Standard, British Standard and the European Scheme are all very similar in approach. Their common key elements include:

- a defined and documented corporate environment policy
- a commitment to comply with all legislative requirements
- a commitment to continual environmental improvement
- identification of a management representative with responsibility for implementing and maintaining the system
- specification of environmental objectives at all levels within an organisation
- monitoring of compliance with requirements and achievement of objectives
- procedures for corrective action and dealing with emergencies
- establishment of an environmental management program
- designation of responsibilities, means and time frames
- employee awareness and training
- establishment and maintenance of an audit program.

The environmental management system process is one of continual review and assessment (Figure 9.3). Most EMSs consist of several interrelated functions, as described in Table 9.3.

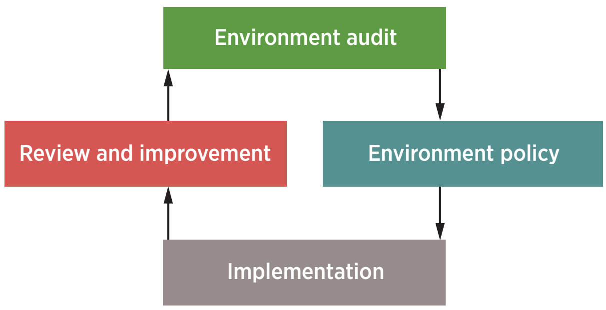

Figure 9.3. The environmental management system process

Table 9.3. Environmental management system functions

Planning	Organising	Implementing	Controlling
Policies and procedures Planning process Regulatory tracking and influence on regulatory departments	Management organisation Reporting level and line responsibility	Compliance management Risk assessment and risk management Issue-specific environmental programs Project or program environmental review	Management information systems Assurance (environmental auditing) Monitoring programs

Implementing an environmental management system will produce a better environmental outcome. While the EMS does not specify a particular outcome, the discipline imposed by adopting such a system increases environmental awareness, which helps a company reduce or avoid damage to the environment and recognise waste minimisation opportunities.

Figure 9.4 compares models of industrial facilities with and without EMS implementation. Without an EMS, the company focuses on their manufacturing process, considering what can be done to reduce inputs while increasing product and reducing wastes (Figure 9.4a). A company implementing an EMS does an environmental audit to obtain data and feedback on how their processes are working. This results in a more sophisticated model of an industrial facility (Figure 9.4b).

Monitoring: an important part of the process

Vital to the implementation of an environmental management system is the continual monitoring of the effectiveness of the system. To effectively evaluate the success of an EMS, an organisation needs to compare historical data with current data to measure the changes (whether desired or not). The monitoring strategies used will depend largely on the type of project. Technology is constantly evolving to allow organisations to reduce their impact on the environment by implementing measures arising from their environmental management strategy.

Advantages of environment management systems

In addition to benefits to the environment, implementing an environmental management system also provides benefits to the organisation itself, its stakeholders, the community and environmental regulators.

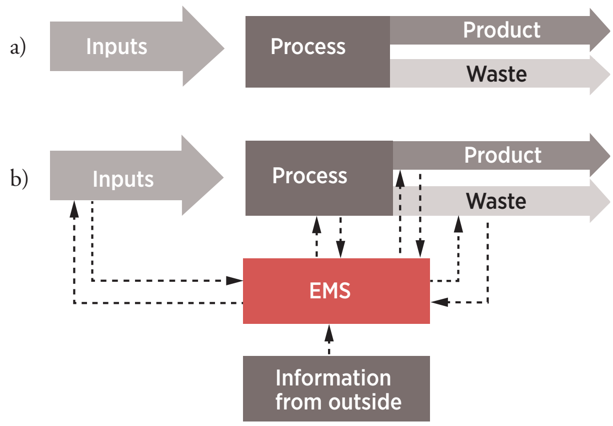

Figure 9.4. Model of an industrial facility (a) without an EMS, (b) with an EMS

Industry efficiency

Environmental management systems generate operational efficiencies for companies. Reducing raw material input, energy usage and waste helps to cut a company's costs. Also, when plants operate efficiently, employees are more productive, there are fewer industrial incidents, senior management waste less time on crisis management, and legal action and recovery costs are reduced.

Implementing an environmental management system gives a company a competitive edge, as markets, especially in Europe, are increasingly looking for environmental credentials before doing business. A certified EMS provides evidence of this. The local community also responds favourably to improved environmental performance.

As more companies implement an environmental management system, the potential exists for a reduced regulatory response. For example, Victoria's Accredited Licensee concept aims to achieve environmental improvements through the cooperation of industry, communities and government. This is achieved by all stakeholders setting and committing to achieving the goals required to achieving environmental improvement.

It is not always economically feasible for companies to implement an environmental management system. Small to medium-sized enterprises may save money by adopting a waste management system, but they may not have the necessary expertise or resources (time and money) to develop a management system that encompasses all environmental aspects.

Stakeholder engagement

Stakeholders are people, groups or organisations who have an interest in, or could be affected by, an organisation's actions or policies. Most effective environmental projects will incorporate consultation with all relevant stakeholders before the project starts. The most successful environmental development projects include continued consultation with stakeholders throughout the duration of the project.

Community confidence

An environmental management system leads to greater community confidence that the environment will be protected, particularly when improvements in environmental outcomes can be demonstrated.

The ISO 14001 includes a requirement for companies to respond to relevant interested parties on matters covering environmental effects and management. Many environmental management systems include regular community consultation by the company. This helps the community understand the company's management issues.

Advantages for regulators

The workload of environmental regulators is lighter if companies take a greater responsibility for their own environmental performance. Environmental management systems encourage such responsibility, so companies that implement an EMS show they are taking responsibility and are likely to have fewer environmental breaches. Accordingly, regulatory resources can be reduced or redirected to other environmental issues.

Implementing environmental management systems is also likely to lead to less adversarial, and hence more cooperative, relationships between companies and regulators. In such circumstances, opportunities exist for developing cost-effective and environmentally beneficial solutions to problems – win-win solutions.

Environmental impact assessment

Each week, many decisions are made that affect the quality of the environment. Commonwealth, state and local governments, businesses and individuals all make decisions. These decisions can be influenced by a range of factors, such as economics, politics, legal frameworks, community perceptions and the current state of the environment. Making a particular decision, such as whether to allow a landfill to operate in a particular area or to allow a residential complex to be built in a sensitive area, is made more difficult because of the competing interests of all affected parties.

Take the example of a landfill being constructed in a rural area. Residents living close by would be concerned about their quality of life being affected by noise from traffic and landfill operations, odour and pests, such as birds and flies. However, all members of the community, including residents living close to the landfill, need somewhere to dispose of their waste economically. If the landfill was not constructed, then waste would need to be transported further, adding to the cost of disposal, increasing pollution from the transport and simply transferring the problem to another community. Additionally, there is the possibility of increased dumping of waste, leading to contamination of waterways and litter.

Decision-makers need a method of determining which is the better decision – to allow the landfill construction to proceed or to develop some other strategy to dispose of the community's waste.

The decision needs to take into account the potential effect on the environment, which involves determining the environmental impacts, the extent to which the impacts may occur and the safeguards that could be applied.

Student activity 9.3 Costs of 'environmentally friendly' products

Go to the supermarket and compare the prices of products that are marketed as 'environmentally friendly' with those that are not (for example, dishwashing liquid, toilet paper, laundry detergent). Why do you think that the price differences exist?

Planning process

For large construction or development projects, an environmental impact assessment (EIA) is normally undertaken, in compliance with the Victorian *Environment Effects Act 1978*, to determine the environmental effects of a proposed action prior to a planning approval being given.

Environmental impact assessments often also include economic and social analyses of the project. An environment impact assessment both outlines processes and provides information. An EIA aims to:

- describe the proposed action and alternatives
- predict the nature and magnitude of likely environmental changes
- identify the relevant human concerns and social impacts
- define criteria to be used in measuring the significance of environmental changes, including relative weightings given to different changes
- estimate the significance of predicted environmental changes
- describe planned mitigation measures
- recommend monitoring procedures to be followed after the action is completed
- evaluate the implications of not proceeding with the project
- recommend acceptance or rejection of the project or of one of the alternatives under consideration.

Environmental approvals processes differ depending on the type of the project and the Australian state or territory in which the project is located. In Victoria, the environmental impact statement is known as an environment effects statement (EES). Assessment of the potential environmental impacts of a proposed development is required under the *Environment Effects Act 1978* if decided by the Minister for Planning. The environment effects statement process, which includes two periods of formal public comment, results in an assessment by the Minister for Planning that the decision-makers must consider when deciding whether to grant approval for the proposed development.

Typically, the initial stages of the EIA (describing the project and identifying the impacts) are undertaken by the project proponent (the company proposing to undertake the project) or an environmental consultant working for the project proponent.

As outlined on the Victorian Government's 'EES process in Victoria' web page, an environment effects statement usually contains:

- a description of the proposed development
- an outline of public and stakeholder consultation undertaken during investigations and the issues raised
- a description of the existing environment that may be affected
- predictions of significant environmental effects of the proposal and relevant alternatives
- proposed measures to avoid, minimise or manage adverse environmental effects
- a proposed program for monitoring and managing environmental effects during project implementation.

As part of the overall project approvals process, the EES is reviewed by an independent government-appointed authority and made available to the community. A panel must then weigh up the benefits and impacts of the project, and in particular take into consideration any concerns raised by the community.

The panel will then make a recommendation on whether the project should proceed, and make recommendations on what particular conditions should be imposed on the project if it is to proceed (for example, restrictions on operating hours, requirements to monitor air quality). These recommendations are normally made by the panel to the responsible government minister. The minister's recommendation then goes to the decision-making authority, who makes the final decision on whether the project can go ahead.

Most EIA procedures can be described as a compromise between the desire for development and the corresponding imperative not to hinder projects, and a desire to minimise the environmental impacts or to avoid unacceptable impacts of projects.

Student activity 9.4
Environmental impact assessments

Seek out copies of EESs that were prepared for developments that have been completed. (EESs are advertised in newspapers or placed for viewing in local council libraries.) Review the scope of the EES and the projected environmental outcomes.

1. List the projected adverse outcomes of the project.
2. What factors could affect whether the projected environmental outcomes actually occur?
3. What monitoring programs are proposed?
4. How accurate do you think the EES is?
5. Draw up a list of the general issues that you think should be covered in an EIA. How does this compare with guidelines issued by the state or local government?
6. Do you agree with the claim that, to a proponent of a new project, an EIA is an expensive hurdle? Why or why not? What alternative mechanisms could you propose?

Student activity 9.5
Preparing an environment effects statement

Smith Holdings is a development company that holds a large parcel of land that borders a wetland (Figure 9.5). It plans to extend its golf course into the wetlands and construct a small jetty with a number of holiday cabins. Access for boats will be provided by a channel connecting Sandy River with the wetlands. The company plans to maintain the heron breeding grounds and to minimise environmental disturbance.

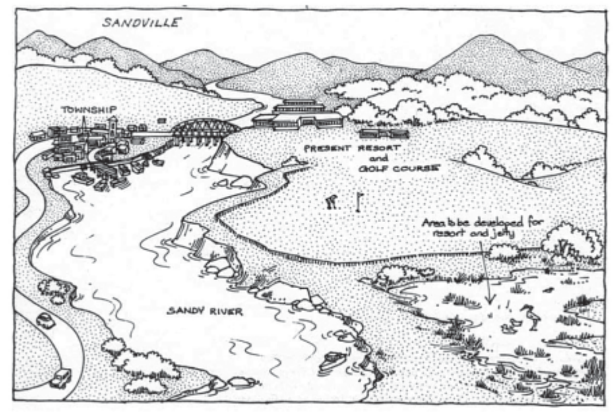

Figure 9.5. Sandville, the Smith Holdings development site

1. You have been employed by the company to write the environment effects statement for submission to the Minister of Planning. The EES is to be written under the following headings:
   - Aims of the project
   - Description of the existing environment
   - Description of the likely effects of the project on the environment:
     - Physical changes to landscape
     - Likely changes to existing vegetation and animals
     - Likely discharges to air, water and land
     - Short-term environmental effects due to construction
   - Environmental, social and economic effects of the project on the nearby township
   - Necessary safeguards needed to minimise environmental problems caused by the project
   - Possible alternatives to the proposed project.
2. As a member of the EES assessment panel, would you recommend that the proposal be given approval (with or without modifications)? Explain your decision.

Student activity 9.6
Role of stakeholders: community, media and environmental groups

Some infamous environmental incidents, known by the name of the place where they occurred, are:

- **Bhopal**: methyl isocyanate was released into the atmosphere in a densely populated town in India. Many thousands of people died and thousands more were injured.
- **Minamata**: mercury polluted a bay near a fishing village in Japan. Through the process of biomagnification, seafood the villagers consumed had high levels of mercury and birth defects resulted.
- **Chernobyl**: a release of radioactive substances into the atmosphere resulted from a breakdown in the nuclear reactor of a nuclear power plant in the former USSR (now Ukraine). The contamination was very widespread and affected things such as cows' milk. Higher-than-normal incidences of cancers are attributed to this accident.

In groups, choose an environmental incident and prepare an overview of the cause of the incident and the resulting environmental and social impacts.

Discuss whether the incidents described above could happen in Australia. Why or why not? Consider the roles of the community, media, environmental interest groups, government and non-government agencies in encouraging responsible environmental practices.

Below is a list of activities that are happening or could happen in Australia:

- uranium mining at Jabiluka (Northern Territory)
- extension of freeways
- extension of public transport
- introduction of carbon taxes to help reduce carbon emissions
- nuclear waste disposal
- use of wood for home heating
- increased water flows in the Snowy River.

Choose one activity. How would you determine the actual environmental impacts of the activity? (These issues often elicit personal opinions and the scientific facts can be lost.) Identify the information required and how it should be evaluated.

Critical and creative thinking 9.2

1. An EMS does not specify particular outcomes, so how does it hope to achieve better environmental outcomes for the company that implements it?
2. Why is monitoring an important part of an EMS? **Explain**.
3. **Summarise** the advantages of an EMS to:
   a) industry
   b) the community
   c) regulatory bodies such as the Environment Protection Authority (EPA).
4. How does an environmental impact assessment help decision-makers resolve the interests of different stakeholders in a particular project?
5. **List** the things an environmental impact assessment would hope to achieve prior to a development starting.
6. What happens after the environmental impact assessment has been drawn up?

EXPLORING SCIENCE 2.
Concrete coastlines: it's time to tackle our marine 'urban sprawl'

Katherine Dafforn, Senior Research Associate in Marine Ecology, University of New South Wales (UNSW); Emma Johnston, Professor of Marine Ecology and Ecotoxicology, UNSW; Joanne Banks, Project Coordinator, World Harbour Project; Mariana Mayer-Pinto, Research Associate in Marine Ecology, UNSW

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How would you feel if half of Sydney's beaches were replaced with concrete walls? Unfortunately, this scenario is already common in urban estuaries around the world.

According to our research, published this month [March 2015] in *Frontiers in Ecology and the Environment*, some estuaries in Australia, the United States and Europe have had more than 50% of their natural coastline modified with artificial structures.

This 'marine urbanisation' – including foreshore developments, port facilities, marinas and even offshore energy platforms – is most widespread in Europe where over 9,000 marinas and more than 200 offshore energy installations are operational. Australia and the United States are catching up with the Bass Strait a focus for oil and gas platforms, and the Gulf of Mexico supporting some 2,000 oil and gas installations.

Thankfully, there are lessons we can learn from land-based sustainable architecture that will help us save our seas from the effects of all this concrete.

The coastal concrete jungle

You have probably noticed the amount of concrete and other building materials that have begun to encroach on many of our shorelines, amid the growing demand for coastal urban development.

Not even the deep ocean, generally considered a haven for marine organisms, is safe, with a steady increase in the construction of offshore energy infrastructure such as platforms for oil and gas exploration.

The reality is that urban sprawl is no longer just a land-based problem. Developments are spreading out into the oceans, creating tangles of structures beneath the water's surface. Seawalls, breakwaters and boating infrastructure such as marinas are becoming increasingly conspicuous in the marine environment.

We build concrete walls to protect our coasts from nature's forces. We add wooden pylons and floating structures to support a burgeoning shipping industry. Mountains of underwater scaffolding support a growing offshore energy and resource sector. There are more than 7,500 offshore rigs worldwide and the number is growing rapidly, but at the same time more than 6,500 rigs are expected to require decommissioning by 2025. Hence we are dealing with a double-edge sword of how to manage impacts from new installations and how to minimise the disturbance associated with removal of these enormous structures.

And we are finding more novel ways to build into the sea, such as entire artificial islands built in Dubai and the (not so) futuristic underwater hotels proposed for Fiji and the Great Barrier Reef.

Figure 9.6. Development off the coast of Dubai. Image courtesy of the Earth Science and Remote Sensing Unit, NASA Johnson Space Center, ISS022-E-24940, https://eol.jsc.nasa.gov/

Hard problems

These artificial structures present a range of ecological problems, including loss of native species diversity and the spread of introduced species. Furthermore, the defences to coastal shores that these structures, such as groynes and seawalls, are meant to provide could actually be causing more bad than good.

Indiscriminate construction within urban seascapes is, among other things, responsible for the loss and degradation of important habitats such as sediments, seagrasses, mangroves and wetlands. In the UK, proposed offshore wind energy developments will replace an area of soft sediment habitat close to the size of Melbourne. These habitats are not only highly productive, supporting a variety of species, including some economically important, but some provide natural protection for the coastal zone against storms and waves.

Eco-engineering the ocean

Fortunately, not everything is bad news. The silver lining is that urban seascapes are still a relatively new phenomenon and we can learn from the pitfalls of urban land-based developments.

More alternative methods have been used to armour our coastal zones against climate change. These include soft engineering approaches, e.g. managed realignment, which involves the removal of hard defence structures and restoration of natural coastal vegetation, and beach replenishment where sand is deposited on beaches to build up the surf zone and dune protection. Where these approaches are not possible then increasingly we need to build ecologically sensitive artificial structures.

Combining ecological principles with engineering designs is probably the most promising solution for the current urban sprawl, with terms such as green or eco-engineering being more frequently used (and applied) to urban seascapes. Practices of eco-engineering are driving innovative strategies on how to manage coastal development, and increasingly, things are being built 'with nature' instead of 'against nature', with encouraging results.

Artificial structures, where they are needed, can and should be built in a more ecologically friendly way. Currently, most artificial structures in the marine environment are built for a single purpose, such as coastal protection, tourism, energy or food production. We suggest that multipurpose structures should be built instead. Why can't offshore oil and gas platforms serve as aquaculture areas or even diving spots – they tend to attract plenty of fish.

Similarly, we can build seawalls and breakwaters in ways that not only help to protect the local area but are also designed to avoid environmental impacts. Why not transfer the urban concept of 'green roofs' to the sea, by seeding artificial structures with key desired and/or threatened species. Breakwaters in the Adriatic Sea have been successfully 'seeded' with the seaweed *Cystoseira barbata* and oyster reef restoration efforts can be applied to new foreshore developments. Seeding of key species can also improve water quality through the absorption or removal of contaminants.

Natural seascapes

Thankfully, there are now several global initiatives that try to solve, or at least mitigate, the many problems caused by underwater urbanisation. The Nature Conservancy's Southern Seascapes project aims to restore coastal estuaries that are home to shellfish and seagrass, whereas the Sydney-based World Harbour Project is working to make the world's urban ports and harbours more sustainable. Projects such as these will provide the basic research needed to progress eco-engineering designs on a large scale.

Many of the world's major cities – including Sydney, New York, Rio de Janeiro, Shanghai, San Francisco, Singapore, Hong Kong, Stockholm, Abu Dhabi, Tokyo, and Qingdao – are on the coast or in large estuaries. However, eco-engineering remains under-utilised in the management of marine urban sprawl.

This is partly due to the lack of policy and incentives driving ecologically sustainable development below the waterline. Europe leads the way in strategies to promote green infrastructure through policy.

The rest of the world needs to catch up before concepts such as underwater cities escape the realms of science fiction.

UNIT 4

How can climate change and the impacts of human energy use be managed?

Climate change is a complex challenge facing today's society. It is a multidimensional and global issue, with regional impacts, including risks and opportunities. Effective adaptation and mitigation options are essential for reducing future risks and realising potential opportunities.

In this area of study students investigate natural as well as human-based factors that affect Earth's climate. Students compare natural and enhanced greenhouse effects and their significance for sustaining ecological integrity. They explain different methods for measuring and predicting climate change, and consider the degree of certainty associated with climate projections. Students explore risks and opportunities for human societies and ecological systems associated with climate change at a selected region or location, and evaluate mitigation and adaptation strategies for managing climate change.

The selection of learning contexts should allow students to develop practical techniques and undertake fieldwork and other practical activities to model and investigate drivers of climate change. Students develop skills in the use of scientific equipment and apparatus to investigate the effects of altering different climate factors on selected environmental parameters, model different climate scenarios by accessing the internet or using simple climate models, and use practical activities, fieldwork and/or simulations to make and test predictions.

Outcome 1

On completion of this unit the student should be able to analyse the major factors that affect Earth's climate, explain how past and future climate variability can be measured and modelled, and evaluate options for managing climate change.

Key knowledge

Area	Section
Major factors that affect Earth's climate	
• identification of natural phenomena and anthropogenic factors that affect Earth's energy balance: volcanic eruptions; solar variability; and changes in atmospheric gas composition due to human activities	10.1
• the interactions between solar energy that is absorbed, re-emitted and reflected by atmospheric gases and other matter, including the albedo effect, the natural greenhouse effect, and ocean circulation	10.2
• carbon sequestration in land and water that results in short-term (less than 100 years) and long-term (more than 1000 years) changes in the carbon cycle	10.3

AREA OF STUDY 1

How can we respond to climate change?

Area	Section
Understanding climate change	
• the differences between natural and enhanced greenhouse effects	11.1
• altered greenhouse gas concentrations over different time periods – seasons, years, centuries and millennia – due to natural events, and human activities associated with the combustion of fossil fuels, cement production, agriculture and land use changes	11.2
• greenhouse gas warming potential as a measure of the infrared radiation the gas will tend to absorb over its lifetime in the atmosphere	11.1
• methods used for measuring past and present changes in the atmosphere: ice core sampling; use of palaeoclimate records; and atmospheric and ocean temperature monitoring	12.1, 12.2
• data accessed through direct measurements and from modelling in assessing the rate of local, global and regional past and future climate variability: global average temperatures; local climate extremes; sea level rise; and snow and ice coverage	12.3
• climate change projections: comparison of observed and simulated current and past climate; and rating of confidence in global, regional and local climate projections expressed as very high, high, medium, low or very low, based on Intergovernmental Panel on Climate Change (IPCC) guidelines	13.1
Managing climate change	
• the risks and opportunities associated with climate change for humans and ecological systems at a selected region or location: increase in range of exotic species; changes in length of plant growing seasons and animal breeding cycles; phenological changes for plant-pollinator interactions; increasing risks to coastal infrastructure from continuing sea level rise; reduction in agricultural production due to warmer and drier conditions	13.2
• mitigation options for reducing net greenhouse emissions to slow climate change	13.3
• adaptation options for building resilience to the effects of unavoidable climate change at a selected region or location	13.3
• interconnections and tensions between factors that influence responsible decision-making around managing climate change: diverse stakeholder values, knowledge and priorities, regulatory frameworks that inform environmental management strategies, use and interpretation of historical and current scientific data, and application of new technologies	

CHAPTER

10

Major factors that affect Earth's climate

CASE STUDY 10.1
Blue carbon: the forgotten asset of the sea

Hannah Neumann, Bachelor of Science student at Deakin University

Climate change is a significant issue of our time and we are approaching a defining moment. From unpredictable weather patterns that threaten food production to rising sea levels that increase the risk of flooding, the impacts of climate change are global in scope and unprecedented in scale. Without radical action, we can expect more frequent and severe heat waves, sea level rise and irreversible damage to our environment. We all know reducing carbon emissions is necessary, but what can be done about carbon that has already been released into the atmosphere?

Carbon sinks are natural reserves that absorb more carbon than they release, thereby reducing the concentration of carbon dioxide in the atmosphere. The two most common forms of carbon sinks are vegetation and the ocean. Carbon storage in vegetation on terrestrial land is becoming more vulnerable to logging and large-scale fires.

As the prospect of using terrestrial systems is becoming limited, a new hope has emerged in 'blue carbon'. Blue carbon is carbon captured and stored by the ocean in vegetated coastal habitats, predominantly mangroves, seagrasses and salt marshes. Mangroves are a type of shrub that live on the coastal foreshore, seagrasses grow in shallow waters and salt marshes are wetlands that are flooded and drained by sea water brought in by tides. Australia is surrounded by these vegetated coastal habitats and is in one of the best positions to capitalise on its blue carbon sinks. Blue carbon also has the benefit of being stored below ground for centuries to millennia, making coastal wetlands the most secure and reliable form of carbon sink.

Through the process of biosequestration, these coastal habitats are able to capture carbon 30–50 times faster than forests can. Blue carbon has the potential to offset carbon emissions, clean and store water, protect our coastlines, enhance biodiversity and mitigate climate change. However, despite the benefits and services of blue carbon, the ecosystems that store it are some of the most threatened in the world. By destroying these ecosystems, we are actually releasing carbon that was once stored within coastal vegetation.

The challenge Australia faces is to maintain the potential of blue carbon ecosystems and prevent further loss. The Blue Carbon Lab at Deakin University, directed by Peter Macreadie, is providing much needed research and citizen science programs to educate the general public and major stakeholders about the importance of protecting and restoring coastal habitats to enhance their carbon sink potential.

Peter is a professor of marine science in the Centre for Integrative Ecology, School of Life and Environmental Sciences, at Deakin University in Victoria, Australia. Peter has a strong connection to the ocean, which he describes as a "magical place". It was a place where he spent a lot of his younger years; he was always "snorkelling, fishing and just in the water", and he remembers thinking, "Gee, what if I could do this for a living?" Peter followed his passion; he didn't become a snorkeller or fisher but did become a marine biologist, as he strived for a "sense of purpose" in his life. Peter considered the environment and Earth to be in a pretty bad shape and that if nothing was done there would be a flow-on effect for further generations. On a personal level, Peter says that some of his "best memories are spent out completing fieldwork with his colleagues". Peter is joined by fellow researchers in the field at the Blue Carbon Lab, which specialises in climate change mitigation by advocating the importance of protection and restoration of coastal blue carbon ecosystems. The Blue Carbon Lab communicates to the general public and stakeholders on the importance of studying, valuing and protecting coastal habitats due to their ability to mitigate climate change.

Peter is currently involved in research that is using tea bags to determine the capacity of our coastal wetland habitats to store carbon. Not all coastal habitats are created equal. Some store carbon better than others, and some even emit carbon, so Peter has been involved with coming up with a solution. The project, called 'TeaComposition H_2O', aims to help the world understand the importance of coastal habitats by identifying the coastal ecosystems that have the greatest potential to store carbon.

I know what you're thinking: how does tea determine the ability of coastal habitats to store carbon and contribute to carbon mitigation? The answer lies in measuring how quickly it decomposes. First, the team dig a 10 cm hole in the ground and drop the tea bag in. The tea bag is numbered and labelled, and the GPS location is recorded. Roughly 40–80 teabags are buried at each site and monitored for the next 3 years. By monitoring how quickly tea bags decompose when buried in coastal wetlands, the scientists can determine the carbon sink potential. If the buried teabag is quickly decomposed by microbes living within the wetlands, it is not an ideal spot for storing carbon. However, if the tea bag stays relatively intact, that wetland is a stable environment, perfect for storing carbon. This easy and cost-effective experiment lets scientists identify and map the most important coastal habitats for carbon sequestration across the world.

With the accurate mapping of profitable coastal wetlands, efforts can be concentrated on the most valuable blue carbon sites for climate mitigation.

To stay up to date with the Blue Carbon Lab's latest programs and research, follow their social media accounts and subscribe to their newsletter via the website below. Students are also always welcome to volunteer with the Blue Carbon Lab team in a variety of roles. It is a great opportunity to learn skills and meet some of the leading scientists in the field. For more information, visit bluecarbonlab.org.

Figure 10.1. Barwon River mangroves form a critical carbon sink. Credit: Andrew McKinnon

10.1. Natural and human factors that affect Earth's energy balance

Identification of natural phenomena and anthropogenic factors that affect Earth's energy balance: volcanic eruptions; solar variability; and changes in atmospheric gas composition due to human activities

Anthropogenic factors are usually the first that come to mind when we think about Earth's temperature and the greenhouse effect, but many natural factors play a role in Earth's energy balance.

Solar variability

The radiation reaching Earth varies on a larger scale than that caused by seasons and location. People have known for 150 years that the Sun's activity level goes in cycles. Roughly every 11 years, the Sun cycles through periods of lots of activity (called the solar maximum) and periods of low activity (the solar minimum) (Figure 10.2). The level of activity is visible to us in the form of sunspots – dark spots on the Sun's surface, usually relatively close to the Sun's equator. Although they look small in relation to the Sun, the spots are roughly the size of Earth on average, and some are as big as 20 Earths.

Sunspots, and associated flares, are a sign of changes in the Sun's magnetic field. Because the Sun's interior contains flows of hot gas, the shape and intensity of its magnetic fields change quite rapidly. Sunspots are regions of intense magnetic field which are cooler than the surrounding surface and hence look darker. The magnetic field rises out of the surface of the Sun, and streams of charged particles (plasma) can erupt into a solar flare.

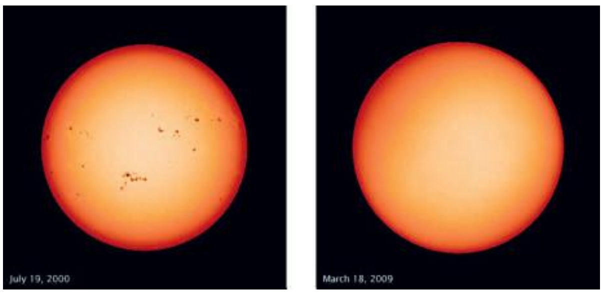


Figure 10.2. Sunspots at a solar maximum (left) and a solar minimum (right). Images courtesy SOHO, the EIT Consortium, and the MDI Team, NASA

There has been debate as to whether the solar cycle affects Earth's weather, climate and sea surface temperatures. The difference in the Sun's output between solar maximums and solar minimums is less than 1%. Data show a historical correlation between sea surface temperatures and the activity level of the Sun. However, temperature increases in recent years are greater than could be accounted for by solar activity. The International Panel on Climate Change has concluded that the Sun's activity does not account for global warming.

Although not responsible for global warming, the solar cycle does influence water and air circulation patterns on Earth, and may influence cloud cover. The difference between outputs at the maximum and minimum is up to tenfold in the extreme ultraviolet portion of the solar spectrum, and this is thought to influence the chemistry of the stratosphere (the atmospheric layer above 15 km altitude).

At solar maximum, ozone concentrations are higher in the stratosphere, which can affect that layer's temperatures and winds. Solar flares can also cause geomagnetic storms, which can affect our communication satellites, overload our power grids and drown out radio transmissions. Large clouds of plasma hitting Earth's magnetic fields also cause the southern and northern auroras.

Volcanic eruptions

Volcanoes are common in many parts of the world, such as along the Indo–Pacific Ring of Fire (Figure 10.3). An erupting volcano shoots out a variety of gases, some of which are greenhouse gases. Carbon dioxide is the most common greenhouse gas released from volcanoes. In addition to CO_2, volcanoes release sulfur dioxide, hydrogen sulfide and hydrogen halides, which can be harmful to humans, vegetation and agriculture depending on their concentrations.

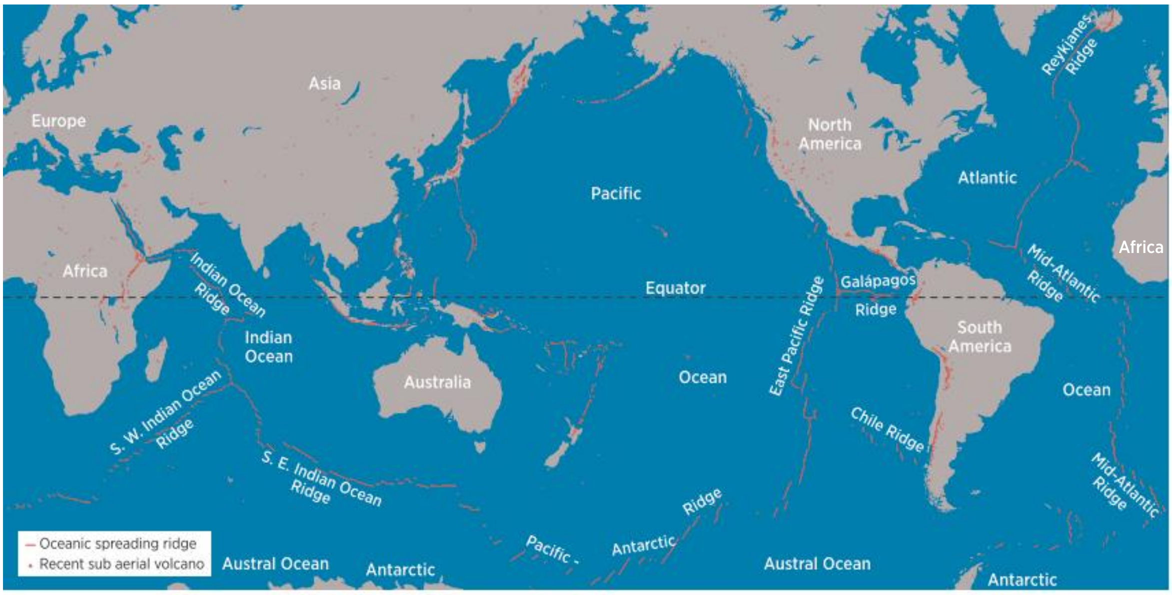


Figure 10.3. Indo–Pacific Ring of Fire. The red dots represent active volcanoes that extend north from New Zealand, forming a ring around the Pacific from Asia around to South America. Credit: Eric Gaba – Wikimedia Commons user: Sting CC BY-SA 2.5

Carbon dioxide forms around 0.04% of Earth's atmosphere and is a potent greenhouse gas. In an average year, Earth's active volcanoes release between 180 and 440 million tonnes of CO_2 in total. This release of CO_2 was important factor in making Earth suitable for the formation of life, and it continues to be important in maintaining Earth's natural greenhouse effect. While the amount of CO_2 released by volcanoes may seem large, human activity was responsible for the release of 36.8 billion tonnes of CO_2 in 2019. Even the most violent eruption would only match human CO_2 emissions for a few hours before reducing in size.

Human activities

There is no question that human activities have changed the gas composition of Earth's atmosphere. Activities that produce greenhouse gases include burning fossil fuels, which releases carbon dioxide, and farming livestock, such as cows, that expel methane as a by-product of metabolism.

There is clear data showing changes in atmospheric CO_2 as well as methane and nitrous oxide over the past 200 years. This contrasts with the previous thousands of years since the end of the last ice age in which concentrations changed little.

The concentration of CO_2 in the atmosphere has increased from 280 parts per million (ppm) before 1800, to 418 ppm in 2021. Historical greenhouse gas concentrations have been established analysing the composition of air bubbles found in polar ice (see 'Ice core samples', p 136).

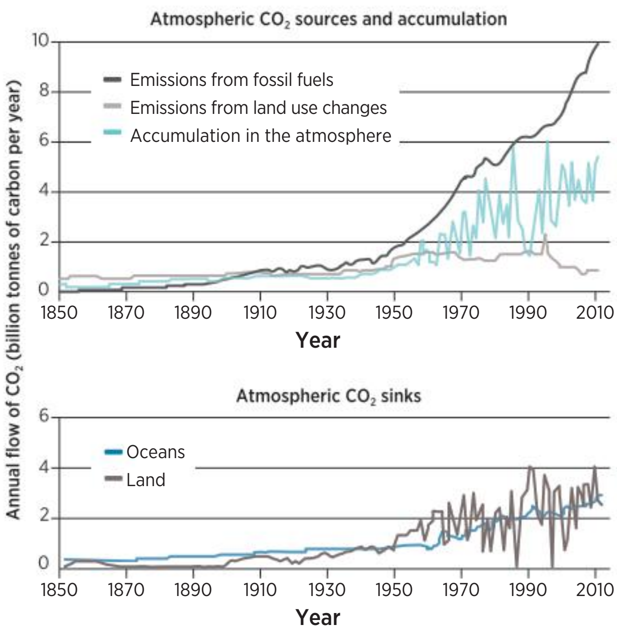


Figure 10.4. Atmospheric CO_2 sources and sinks

10.2. Earth's energy budget

The interactions between solar energy that is absorbed, re-emitted and reflected by atmospheric gases and other matter, including the albedo effect, the natural greenhouse effect, and ocean circulation

Natural greenhouse effect

Earth's temperature is determined by the balance between energy input and output. The energy input is solar radiation from the Sun, and the level of energy output is determined by gases in the troposphere.

Only a small portion of the Sun's energy is absorbed by Earth and life on Earth (Figure 10.5). About 34% of solar energy is reflected straight back into space. Another 19% is absorbed by the atmosphere, particularly water vapour, carbon dioxide and other gases. Therefore, just under half (47%) of the solar energy received by Earth reaches the planet's surface, although this amount varies greatly with location and time of year.

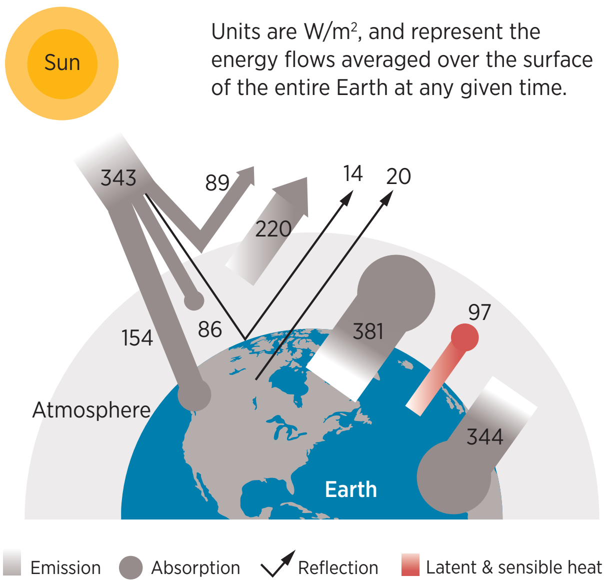


Figure 10.5. Earth's energy budget. Latent and sensible heat are measures of change in energy. Sensible heat can be measured (sensed) as a change in temperature, for example, as heat moves around the atmosphere via convection. Latent heat is the heat that causes changes in phase between liquids, gases and solids, so water evaporating at Earth's surface (where heat is absorbed) and condensing in the atmosphere (where heat is released) moves energy around.

The radiation absorbed by Earth is reradiated in the form of infrared radiation back into the atmosphere – some escapes back into space but most is absorbed by greenhouse gases. The main greenhouse gases are water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons and halons. Water vapour is the most significant greenhouse gas; carbon dioxide is the next most significant and the one which contributes most to the enhanced greenhouse effect.

The process of retaining heat in the atmosphere is called the greenhouse effect. It is a natural process that warms Earth's surface, keeping Earth's surface at a fairly constant temperature of about 15 °C. Without the greenhouse gases absorbing radiation, Earth would be about 30 °C colder, and life as we know it would not have developed on Earth.

Radiation from the Sun

The wavelength of radiation emitted from a body varies with the surface temperature of the body. The surface temperature of the Sun is high (about 5,800 °C) so the wavelength of solar radiation is at the short end of the electromagnetic spectrum, mainly in the range of 300–2,500 nanometres (a nanometre (nm) is 10^{-9} of a metre).

Much of the incoming radiation (38%) is visible to the human eye as light (with wavelengths of 390–700 nm). A considerable amount (53%) is at longer wavelengths in the infrared part of the spectrum (>700 nm) and a small amount (9%) is in the shorter wavelength ultraviolet part of the spectrum (<390 nm). As solar radiation moves through Earth's atmosphere, different molecules absorb different frequencies of light. Therefore, not all the radiation that travels from the Sun to Earth reaches Earth's surface: there is a change in solar radiation from the top of the atmosphere to the lower parts of the atmosphere. (Figure 10.8).

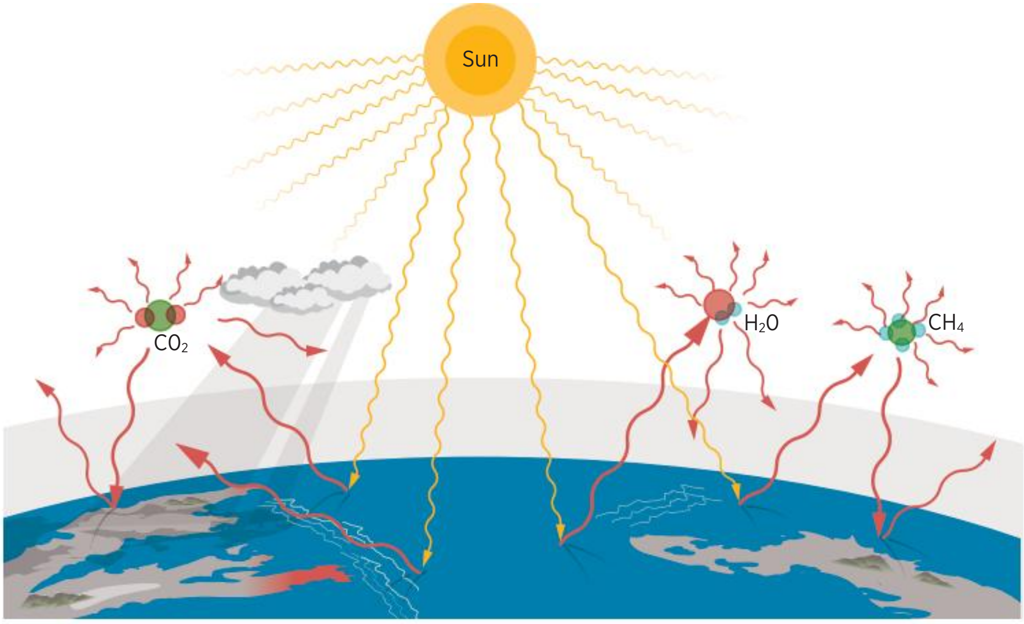


Figure 10.6. Light energy (yellow arrows) emitted by the Sun warms Earth's surface, which reflects the energy as heat (red arrows) that warms the atmosphere. Much of the heat is captured by greenhouse gas molecules such as water, carbon dioxide and methane.

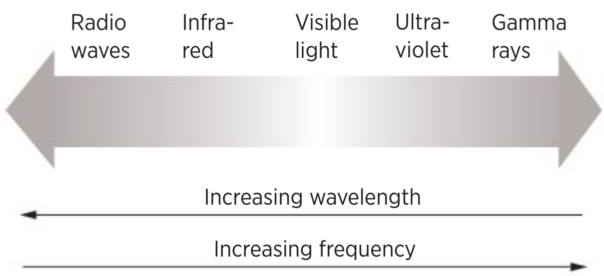


Figure 10.7 Radiation emitted from the Sun

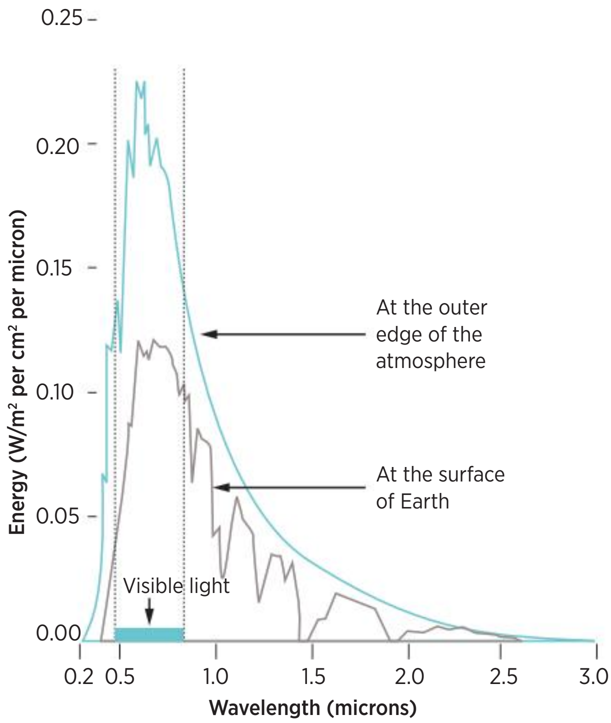


Figure 10.8 Wavelengths of energy reaching Earth

Ozone in the stratosphere absorbs most of the ultraviolet radiation, so very little of this penetrates through the atmosphere. The radiation reaching Earth's surface is mainly in the visible and infrared part of the spectrum.

This solar energy absorbed by Earth is reradiated into the troposphere as infrared radiation (heat). Infrared radiation has a much longer wavelength than visible light, ranging from 750 nm to 1 mm. Some of this reradiated energy escapes into space; the rest is absorbed by the greenhouse gases in the troposphere and contributes to warming the troposphere and Earth's surface. The greenhouse gas molecules absorb those frequencies of radiation that match their characteristic resonant frequencies. They gain kinetic energy which causes the temperature to rise. The processes that in recent years have led to the enhanced greenhouse effect are explored in Chapter 11.

The albedo effect

Albedo is the fraction of solar energy that is reflected from Earth back into space. Albedo can range from a value of 0 (no reflection) to a value of 1 (100% reflection). Light surfaces reflect more radiation than do dark surfaces. Ice and snow have a high albedo (0.6–0.9), whereas water is much more absorbent and less reflective (with an albedo of 0.1). Clouds also have a relatively high albedo, reflecting radiation back to space. Earth reflects around a third of incoming solar radiation back into space, with an average albedo of 0.31. Forests, oceans, cities and deserts all have different albedos.

What happens when Earth's temperature warms? As snow and ice cover decreases, albedo decreases; less energy is reflected back into space and more is absorbed by the ground and water. This warms Earth and causes more ice and snow to melt. This cycle is known as the ice–albedo feedback. Scientists are also interested in the role that clouds play in this scenario: with more melting of snow and ice there is more water vapour in the air available to create clouds and increase albedo. The question is: will rising temperatures increase or decrease Earth's albedo?

Ocean circulation

Earth's oceans play a major role in the storage and distribution of heat energy around the globe. Most of the heat stored at Earth's surface is in the oceans. Circulating oceanic water in ocean currents, both surface and deepwater, helps to distribute this heat around the globe and stabilise global climate patterns. For example, surface currents are important in moderating the climate by transferring heat from the equator towards the poles. Oceanic circulation also affects local weather patterns, cycling of gases and delivery of nutrients throughout marine ecosystems.

Surface currents occur in the upper 400 m of the oceans. They are created and shaped by global wind patterns, the rotation of Earth and the shape of ocean basins, and they move water both vertically and horizontally. Global winds are caused by the Sun heating different parts of Earth by different amounts. These winds blow in a constant direction, and the surface water is pushed in the direction of the major wind belts (trade winds, westerlies and polar easterlies). Earth's rotation deflects the currents being pushed by the winds and increases their circular movement. This is known as the Coriolis effect.The topography and shape of ocean basins and nearby land masses also influence surface ocean currents.

Deepwater currents create a pattern of thermohaline circulation, also known as the 'oceanic conveyor belt'. These currents are driven by the differences in the densities of oceanic waters. Water density is affected by temperature (*thermo*), salinity (*haline*) and depth. Colder, saltier water is more dense than warmer, less salty water. The greater the differences in density within the layers of the water column, the greater the mixing and circulation. The density differences in ocean water contribute to the global oceanic conveyor belt. Not only do deepwater currents circulate warm and cold water around the globe, the oceanic conveyor belt is responsible for the movement of nutrient-rich water and dissolved carbon dioxide.

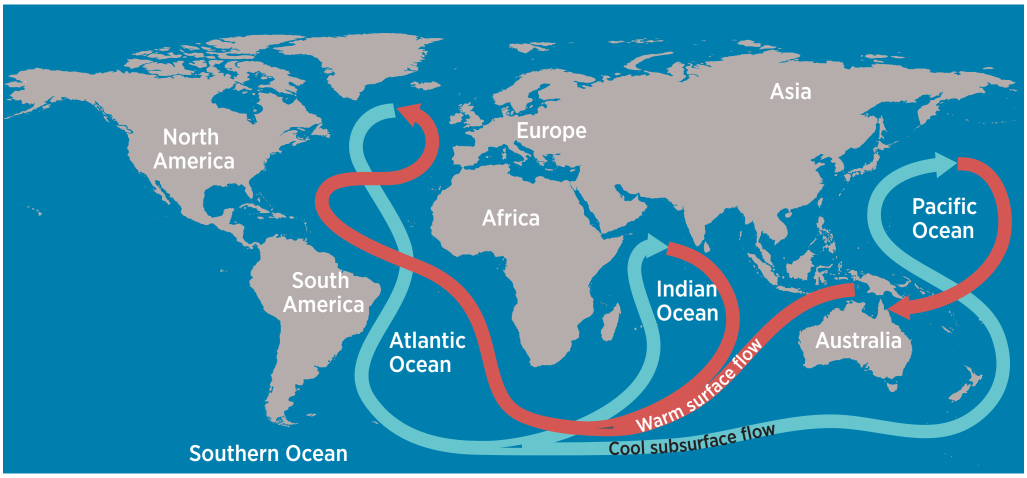


Figure 10.9. Thermohaline circulation around the globe

Ocean currents regulate global climate by helping to counteract the uneven distribution of solar radiation hitting Earth's surface. Water has a higher heat capacity than land, which means that the oceans heat up and cool down more slowly than land masses do. Land areas close to seas and oceans have milder climates with moderate winters and cooler summers.

Examples of major currents affecting local climates include the:

- Gulf Stream/North Atlantic Drift moderating the climate of north-western Europe
- Benguela Current moderating the climate of the Namibian Desert
- Humboldt Current moderating the climate of Peru.

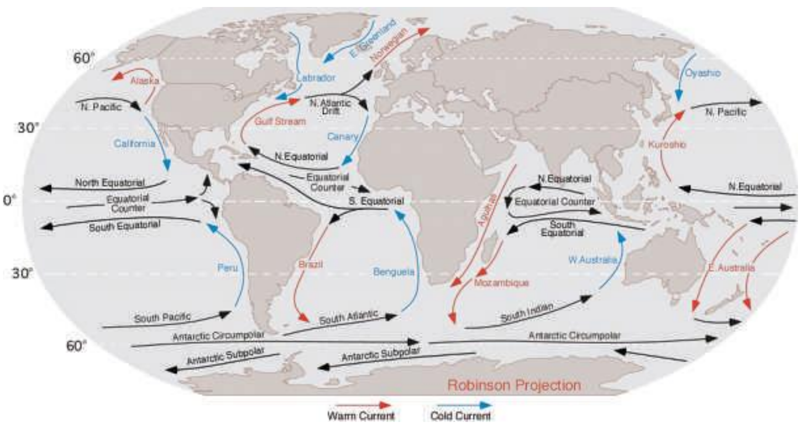


Figure 10.10. Major ocean surface currents.
Credit: Dr Michael Pidwirny (see http://www.physicalgeography.net)

10.3. Carbon sequestration in natural systems

Carbon sequestration in land and water that results in short-term (less than 100 years) and long-term (more than 1000 years) changes in the carbon cycle

The consequences of fossil fuel combustion for the carbon cycle

Carbon sequestration, or storage, is a natural part of the carbon cycle and has been happening for billions of years on Earth. In natural systems, carbon cycles continuously from organisms to the atmosphere: carbon dioxide is released by the respiration of organisms and the decomposition of organic material and is taken up by plants in photosynthesis.

Carbon dioxide is removed from the cycle into long-term storage in all of Earth's major systems: the atmosphere, hydrosphere, lithosphere and biosphere.

Oceans

Up to 40% of Earth's carbon emissions are absorbed and stored in the oceans because carbon dioxide dissolves in seawater to form carbonic acid (H_2CO_3). That makes the ocean a major carbon sink, but the ocean's ability to take up carbon is decreasing as its water chemistry is being altered. Cool ocean waters are more effective than warm waters as sinks, and rising water temperatures are slowing down the rate at which the oceans can absorb carbon dioxide.

Plants and animals play a lesser role in storing carbon in the ocean. Phytoplankton are the basis of the marine food chain; these tiny plants take up carbon dioxide which becomes incorporated into the biomass of the oceans. However, the biomass of phytoplankton is limited by the supply of nutrients in the upper zones of the ocean (that is, where there is light for photosynthesis).

Carbon is also incorporated into the shells of many aquatic organisms as calcium carbonate ($CaCO_3$). As these organisms die they fall to the ocean floor, and over a long period they are compacted into limestone, so the carbon is locked up for thousands of years.

The increasing concentration of carbonic acid is making the oceans more acidic – a process known as ocean acidification. Ocean acidification is a threat for the many marine organisms that have calcium carbonate shells or skeletons, including corals, mussels and some plankton. In a more acidic ocean, water may also dissolve limestone and make the carbon available again.

Forests

Forests are the most widely cited carbon sinks, storing much of the world's carbon. Tropical and old growth forests have the highest carbon storage potential. In some forests, carbon may be stored for centuries, while in other forests carbon is released because of fire or deforestation or simply because the trees are not as long lived.

Note that not all of the stored CO_2 is released when a forest is destroyed. Carbon that remains as plant tissue is consumed by animals or added to the soil as litter when plants decompose. In soil, carbon is primarily stored as soil organic matter. Carbon can remain stored in soils for millennia, or it can be quickly released back into the atmosphere.

About 30% of a tree's biomass is in its roots, and this figure is likely to be higher for trees growing on less fertile soils where they need more extensive root systems. After forest clearing, the rate of release of carbon dioxide from the soil depends on how rapidly the soil microflora decompose the roots. The rate of carbon release from the soil is high if the land is cleared for grazing, while on improved pastures (where crops are sown), the soil carbon levels do not drop much. Climatic conditions, natural vegetation, soil texture and drainage all affect the amount of carbon stored and how long it is stored for.

CHAPTER

11

The enhanced greenhouse effect

Although natural forces still influence the concentration of greenhouse gases in the atmosphere (for example, forest fires in summer increase atmospheric concentrations of carbon dioxide, methane and nitrous oxides), the biggest driver of climate change today is human activity. In recent years, the concentrations of greenhouse gases in the atmosphere have increased as a result of human activities. This is concerning because a higher concentration of greenhouse gases leads to more heat energy being absorbed in the atmosphere and a gradual warming of Earth's surface temperature. This process is known as the enhanced greenhouse effect.

11.1. Comparing the natural and enhanced greenhouse effect

The differences between natural and enhanced greenhouse effects

Greenhouse gas warming potential as a measure of the infrared radiation the gas will tend to absorb over its lifetime in the atmosphere

The natural greenhouse effect (see p 120) results from the layer of greenhouse gases surrounding Earth that maintains an average temperature which makes Earth suitable for life to exist. The major greenhouse gas responsible for the natural greenhouse effect is water vapour.

Since the Industrial Revolution (that is, after 1750), human activities have had an increasingly marked effect on the atmosphere. Before industrialisation, the levels of greenhouse gases in the atmosphere had remained fairly constant for thousands of years.

The growth of industrialisation has led to increased production of greenhouse gases, primarily through the:

- increased combustion of fossil fuels and associated release of greenhouse gases in response to the growth in energy demand in both developed and developing countries
- loss of vegetation cover (and therefore of forests acting as carbon sinks) due to the expansion of agricultural activities resulting from population pressures
- the manufacture and use of artificial gases such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs).

After water vapour, the three most prevalent greenhouse gases in Earth's atmosphere are carbon dioxide, methane and nitrous oxide. The atmospheric abundances of these gases are directly connected with human activity, and carbon dioxide and methane are most responsible for the enhanced greenhouse effect (Figure 11.1). In contrast, the abundance of water vapour, which is the most important greenhouse gas, is controlled by short-term climate feedback mechanisms.

Global warming potential

Not all gases in the atmosphere act as greenhouse gases, and some greenhouse gases have more warming potential than others. Greenhouse gases are those that get excited by solar radiation at a specific frequency, so they absorb energy from incoming radiation and also prevent heat escaping out to space. Due to their varying chemistries, some of these gases absorb more heat than others and contribute more to warming.

The contribution a gas makes to the greenhouse effect depends upon:

- the capacity of the gas to absorb heat (radiative efficiency)
- the length of time it persists in the atmosphere (lifetime)
- its concentration in the atmosphere.

The global warming potential (GWP) was developed to enable the comparison of the impact of different gases in the atmosphere. Specifically, the GWP of a gas is the measure of how much energy can be absorbed by the emission of 1 tonne of gas over its lifetime relative to the emission of 1 tonne of CO_2. The larger the GWP, the more a gas can warm Earth compared to CO_2 over a 100-year period.

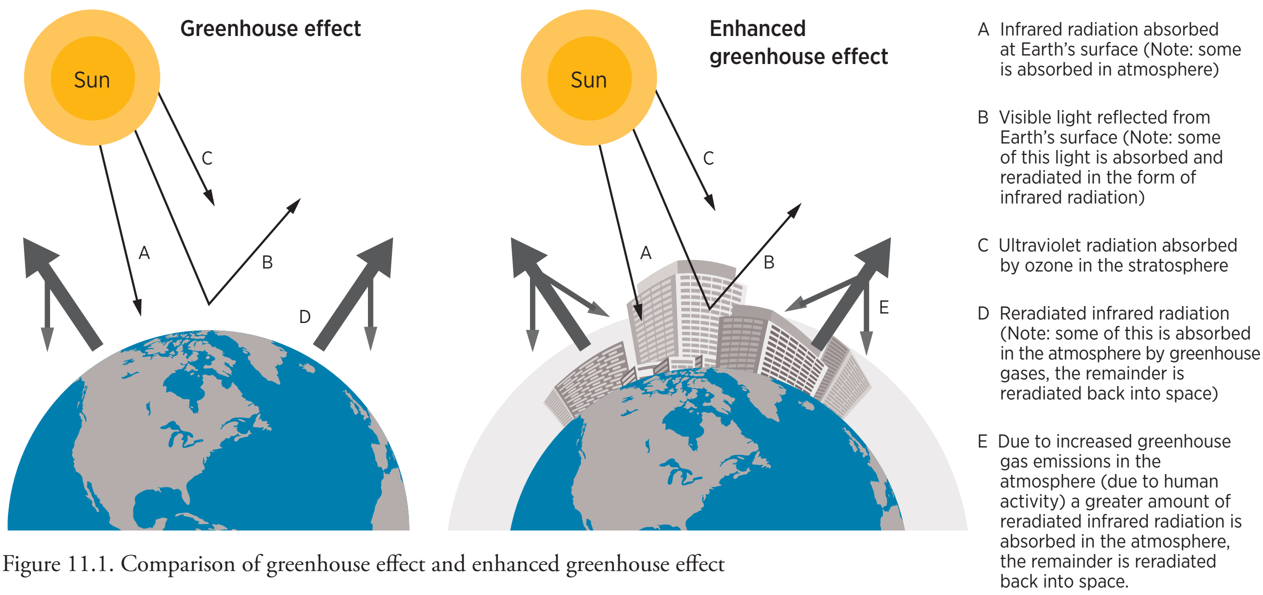


Figure 11.1. Comparison of greenhouse effect and enhanced greenhouse effect

- Carbon dioxide (CO_2) has a GWP of 1 regardless of the time period as CO_2 is the reference that all other gases are measured by.
- Methane (CH_4) is estimated to have a GWP of 28–36 over 100 years. Methane emitted today will last about a decade on average, which is less than CO_2, but methane absorbs much more energy than CO_2 does. The shorter lifespan but higher energy absorption is reflected in the GWP.
- Nitrous oxide (N_2O) has a GWP of 265–289 over a 100-year period. Nitrous oxide emitted today stays in the atmosphere for around 120–150 years.

Table 11.1 presents these factors for the major greenhouse gases.

Data analysis 11.1
Greenhouse gas concentrations

1. Use the internet to find historic and current data on the concentrations of the greenhouse gases carbon dioxide and methane in the atmosphere.
2. Determine the percentage change in carbon dioxide concentration from pre-industrialisation to now.

Table 11.1. Attributes and concentrations of major greenhouse gases

Greenhouse gas	Formula	Pre-industrial concentration	2021 concentration	Atmospheric lifetime (years)	Global warming potential over 100 years
Carbon dioxide	CO_2	280 ppm	418.21 ppm	300–1,000	1
Methane	CH_4	700 ppb	1,875.9 ppb	12	28–36
Nitrous oxide	N_2O	275 ppb	327 ppb	120–150	265–298
Chlorofluorocarbons (CFCs) and halons	e.g. CF_2Cl_2 (known as CFC-12)	0	868 ppt	102	125–152
Hydrochlorofluorocarbons (HCFCs)	e.g. $CHClF_2$ (known as HCFC-22)	0	202 ppt	12	125
Perfluorocarbons (PFCs)	e.g. CF_4	0	77 ppt	50,000	6,500
Sulfur hexafluoride	SH_6	0	5.6 ppt	11,000	23,900

NOTE: ppm = parts per million (by volume); ppb = parts per billion; ppt = parts per trillion

11.2. Greenhouse gases

Altered greenhouse gas concentrations over different time periods – seasons, years, centuries and millennia – due to natural events, and human activities associated with the combustion of fossil fuels, cement production, agriculture and land use changes

The consequences of fossil fuel combustion for the carbon cycle

Carbon dioxide

Carbon dioxide (CO_2) is the major contributor to the enhanced greenhouse effect. The concentration of CO_2 in the atmosphere has increased from 280 ppm before the Industrial Revolution to 418 ppm in 2021, the highest recorded in history. This represents an increase of about 43%, and levels have been predicted to increase further over the next 50 years.

The current rate of CO_2 increase is about 0.5% per year. Most of this increase is the result of burning fossil fuels, but clearing and burning forests also contribute significantly. The yearly output of CO_2 is estimated at over 19,000 million tonnes. About half of this is taken up by the atmosphere and the rest is absorbed by vegetation or dissolved in the oceans.

Figure 11.2 shows rising carbon dioxide concentrations in the atmosphere over the past six decades. It is based on long-term measurements taken at the Mauna Loa Observatory in Hawaii that were initiated in 1958 by Charles David Keeling.

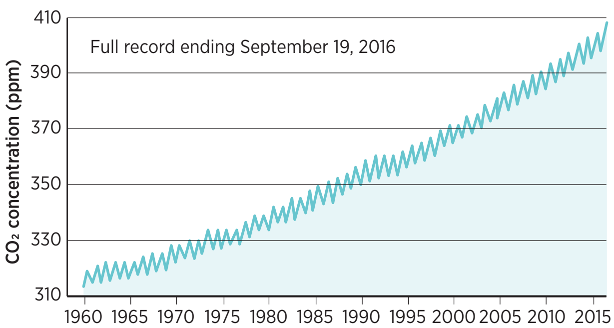


Figure 11.2. The Keeling Curve

Keeling's measurements showed the first significant evidence of rapidly increasing carbon dioxide levels in the atmosphere. Many scientists credit Keeling's graph with bringing the world's attention to the effects that human activity is having on Earth's atmosphere and climate.

Student activity 11.1
Carbon cycle

Draw a sketch of the carbon cycle to show how carbon dioxide moves through the ecosystem both naturally and as a result of human activities.

Figure 11.3 is a flow diagram showing the amount of carbon in each of the components and interactions of the carbon cycle. Incorporate these figures into your cycle.

On the basis of these figures, how much carbon dioxide is being added to the atmosphere each year?

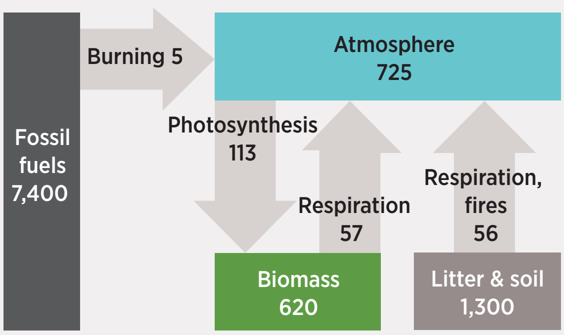


Figure 11.3. Simplified diagram of the terrestrial carbon cycle showing reservoirs and fluxes (in 10^9 tonnes of carbon/year)

Methane

Methane (CH_4) is produced naturally by the breakdown of organic material in environments where the supply of oxygen is limited and carbon dioxide cannot form. Human activities, including extracting fossil fuels, leaving vegetation to rot in rice paddies, burning biomass, disposing of garbage in landfills, treating sewage and farming ruminant animals (such as cows), account for some 60% of atmospheric methane emissions. Natural processes, including the release of methane from wetlands (produced by decaying peat in bogs and tundra) and termite activity, produce the remaining 40%.

Although methane is in relatively low concentration in the atmosphere, it has a global warming potential at least 28 times that of carbon dioxide due to its molecular spectral characteristics. That is, one molecule of methane has at least 28 times the ability of one molecule of CO_2 to absorb reradiated heat (see Table 11.1).

The 2021 globally averaged methane concentration of 1,875 ppb was 9% higher than that of the previous year. Current levels are about 154% higher than the pre-industrial concentration of 700 ppb. After water vapour and CO_2, methane is the third most prevalent greenhouse gas in Earth's atmosphere.

Nitrous oxide

Nitrous oxide (N_2O) occurs naturally in the atmosphere at very low concentrations. Concentrations are now increasing as a result of chemical manufacture, fertiliser use, soil cultivation, catalytic converters in cars and growing leguminous crops. Human activity accounts for approximately 40% of all N_2O emissions.

The World Meteorological Organization reported that concentrations of N_2O reached a record high in 2021 at 327.2 ppb, up 1.1 ppb from the previous year (data for subsequent years is likely to show further increases). Although this concentration is relatively low, N_2O makes a significant contribution to the greenhouse effect because it has 265–298 times the capacity of carbon dioxide to absorb heat (Table 11.1).

Chlorofluorocarbons and halons

Chlorofluorocarbons and halons do not occur naturally in the atmosphere. From the 1930s, chlorofluorocarbons (CFCs) were produced for use in refrigeration and air-conditioning, as propellants in aerosol spray cans and in the manufacture of foam products for packaging and insulation. Halons were used in some fire extinguishers. The use of CFCs and halons is being phased out in accordance with international treaties, but they still make an important contribution to the greenhouse effect. These gases are of particular concern as they have a greenhouse effect more than 5,000 times that of carbon dioxide. Once produced, chlorofluorocarbons and halons resist chemical breakdown in the atmosphere and may persist for over 100 years.

Chlorofluorocarbons and halons are also the major contributors to the depletion of the ozone layer. Some of the replacements for CFCs and halons now being used, for example hydrofluorocarbons (HFCs), are less harmful to the ozone layer, but are still powerful greenhouse gases.

Perfluorocarbons

Artificial gases known as perfluorocarbons have been recognised as contributing to the greenhouse effect – their capacity to absorb infrared radiation is 6,500 times that of carbon dioxide. The molecules of these gases are extremely stable and they may persist in the atmosphere for 50,000 years. Perfluorocarbons are largely produced during the electrolytic production of aluminium. Perfluorocarbons are also used in electronics, as refrigerants and for some medical and cosmetic purposes. In Australia, perfluorocarbon emissions decreased by 90.4% between 1990 and 2008 due to improved methods of aluminium processing.

Ozone

In the troposphere, ozone (O_3) is a greenhouse gas. Ozone in the troposphere is produced by ultraviolet radiation interacting with atmospheric hydrocarbons and nitrogen oxides produced from car exhausts and coal-burning plants (which result in photochemical smog). At present, the greenhouse contribution of tropospheric ozone is very low; current tropospheric concentrations are about 0.03 ppm. However, increases in tropospheric ozone have been observed in recent years, mainly in the Northern Hemisphere. Tropospheric ozone concentrations are increasing at an annual rate of 0.5%, and it appears that there will be greater increases in the future, reflecting the level of fossil fuel combustion.

Remember that ozone in the stratosphere protects Earth by filtering out harmful ultraviolet radiation. Close to the ground, ozone irritates the respiratory systems of animals and damages trees.

It is a common misconception that 'the hole in the ozone layer causes global warming'. In fact, they are two different, but related, environmental issues.

Water vapour

We have seen that water vapour is a greenhouse gas and and contributes to global warming, but its role in the enhanced greenhouse effect is unclear. Water vapour is generally not considered in greenhouse gas inventories, as human activity has little direct effect on the concentration of this gas in the atmosphere.

As Earth's temperature increases, the atmosphere will be able to hold more water vapour, which will increase its warming capacity. On the other hand, increased levels of water in the atmosphere may increase cloud cover and therefore reduce surface temperatures as the clouds reflect more heat and light back out into space. On balance, the warming effect of increased atmospheric water vapour is likely to outweigh any cooling effect due to increased cloud cover.

Aerosols

Another impact of burning fossil fuels is the release of small aerosol particles into the atmosphere. These particles produce a haze in the atmosphere that is common in urban centres. Sometimes we see such a haze over Melbourne and Sydney. Aerosols have a direct influence on the greenhouse effect by scattering and reflecting short-wave radiation. This reflection of incoming solar radiation can have a cooling effect.

An indirect influence of aerosols is that they affect the formation of clouds. The aerosol particles become the nuclei for the condensation of water droplets and the formation of clouds. Clouds formed in polluted air are brighter due to the pollutants causing the early nucleation of water vapour into water. These clouds reflect more solar radiation, leading to further cooling of Earth's surface. Aerosols have a complex role once they have escaped into the atmosphere and therefore are treated a little differently to greenhouses gases.

Practical 11.1
Modelling the greenhouse effect

Aim

To compare the warming of an atmosphere high in carbon dioxide with one low in carbon dioxide.

Materials

- 2 clear 2 L PET bottles with the labels removed
- 2 identical thermometers
- opaque tape
- source of carbon dioxide (see below)
- plasticine
- rubber stoppers to fit bottle necks
- heat lamps (infrared)

NOTE: For your source of carbon dioxide, you may use your own method or try one of the following to set up one bottle with CO_2 and one without:

- Place 2 teaspoons of baking soda (8 g sodium bicarbonate) into one bottle. Add 6 tablespoons (120 mL) of vinegar (5% acetic acid) into the bottle. Add the same amount of vinegar to your second bottle to ensure the conditions are the same in each bottle (with the exception of the baking soda). Put lids on both bottles.

  OR
- Place a small amount of water into each bottle. Add a small amount of dry ice to one bottle. Put lids on both bottles. Allow the CO_2 to completely fill the bottle with dry ice.

Procedure

1. Formulate a hypothesis as to what you are expecting to happen in this experiment.
2. Prepare bottle lids that will hold a thermometer without allowing gas to escape: either drill the caps of the bottles to the same diameter as your thermometer or use the rubber stoppers. Place the thermometers several centimetres through the holes in the caps/stoppers. Use the plasticine to hold the thermometers in place and seal the holes completely.
3. Use one of the CO_2 methods above to create one bottle with a carbon dioxide–enhanced atmosphere and one equivalent bottle without the extra carbon dioxide. Make sure the liquid in both bottles is at the same temperature when starting the experiment.
4. Place the caps/stoppers with thermometers onto the tops of the bottles, making sure they are sealed with plasticine or tape.
5. Place your bottles in front of the heat lamps. NOTE: You must be very careful to place each bottle at exactly the same distance from the lamp.
6. Shade the thermometers by putting a strip of opaque tape on the outside of the bottles. This will ensure the temperature reading is affected by the contents of the bottle and not surrounding heat. The tape must be the same length on both bottles.
7. Measure and record the temperature of each bottle every 2 minutes for half an hour. (You may like to adjust the frequency and length of time tested.)
8. Turn the heat lamps off and record the temperature of each bottle every 2 minutes for a further half hour.

Results

Record the temperatures in a table. Compare what happens in your two synthesised atmospheres.

Discussion

1. Did your observations match your hypothesis? Explain.
2. How does this experiment aim to model the greenhouse effect? Explain.
3. If you were to repeat this experiment, is there anything you would do differently? Explain.

Source: adapted from 'Making a greenhouse', Jet Propulsion Laboratory, California Institute of Technology, NASA, sealevel.jpl.nasa.gov

11.3. Australia's contribution to the enhanced greenhouse effect

Australia is a relatively small producer of greenhouse gases, accounting for only about 1.5% of global emissions, but we are still among the top 20 emitters in the world. In 2020, we rated highest in the world per capita: each person in Australia emitted an average of 16.6 tonnes of CO_2-equivalent emissions.

Australia's high per capita emissions are due to a number of factors, including our:

- reliance on brown coal for electricity production
- emission-intensive extraction and processing of mining resources, which are largely destined for export
- large-scale primary production – agriculture is emission-intensive and the products are consumed overseas
- high levels of vehicle use owing to our sparse population and poor public transport options outside major hubs.

The pattern of greenhouse gas emissions in Australia since 1990 has been recorded in the National Greenhouse Gas Inventory. Figure 11.4 shows the contribution of each sector of Australia's economy to greenhouse gas emissions in 2020.

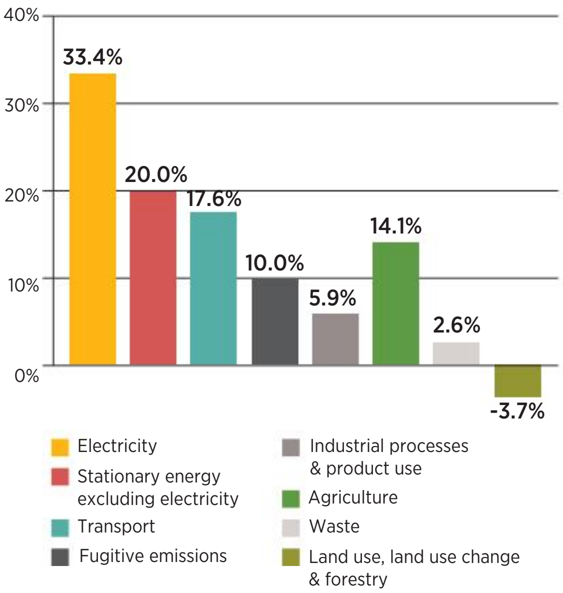


Figure 11.4. Australia's 2020 greenhouse gas emissions by sector

Data analysis 11.2
Australia's contributions to global CO_2 emissions

Figure 11.5 shows carbon dioxide emissions per person in Australia from 1915 to 2017.

1. Describe the pattern of emissions shown in the graph (remember to refer to the data in the graph).
2. Calculate the change in per capita CO_2 emissions between the years 1980 and 2017, expressing your answer as a percentage.
3. List two sources of CO_2 that have contributed to the increase in Australia's per capita emissions since 1915.
4. From approximately 2014 to 2017, carbon dioxide emissions per person were roughly stable. Suggest a reason why.

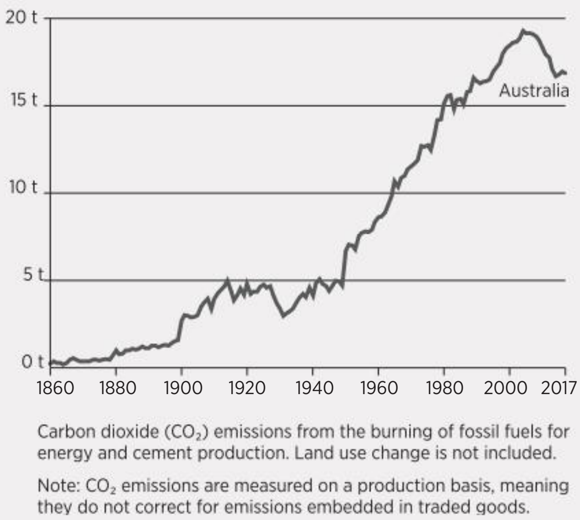


Figure 11.5. Australia's per capita carbon dioxide emissions (tonnes)

Critical and creative thinking 11.1

1. Complete the following table.

Greenhouse gas	Natural source(s)	Source(s) from human activity
Water vapour		
Carbon dioxide		
Methane		
Nitrous oxide		
Chlorofluorocarbons		
Ozone		
Perfluorocarbons		

a) Why are these gases called greenhouse gases? In your answer, clearly explain what greenhouse gas means.

b) Why are increases in these gases defined as pollution? In your answer, clearly explain what pollution means.

2. What human activities contribute most to the enhanced greenhouse effect?

3. Why are scientists so concerned about the enhanced greenhouse effect?

Practical 11.2
Visualising parts per million

Aim

To gain an understanding of the concept of parts per million (ppm).

Materials

- 1 kg rice
- large jar, big enough to hold all the rice
- electronic scales
- plastic container
- food dye or turmeric
- measuring cylinder
- calculator
- water

Procedure

Grains of rice

1. Weigh out exactly 10 g of rice.
2. Count the grains and then count them again to be sure.
3. Divide 10 g by the number of grains. This gives an estimate of the average mass of one grain of rice in grams.
4. Take this number and multiply it by 1,000. Round to the nearest integer. This is the mass of one grain of rice in milligrams.
5. Now multiply that figure by 1,000,000 to get the mass of 1 million grains of rice.
6. What is the mass of 1 million grains (in milligrams, grams and kilograms)?
7. Estimate how many grains there are in 1 kg of rice.
8. Colour 1 g of rice with the food dye or turmeric and add it to the jar.
9. Add the rest of the white rice and estimate your concentration:
   - 1 g in 1 kg is 1:1,000 or 1,000 parts per million (ppm) by mass.
   - 1 g in 1,000 kg is 1 ppm.
   - 1 grain of rice in about 27.33 kg of rice is 1 ppm.

Water

Using water, one drop (0.05 mL) of food dye in 50 L of water is 1 ppm. To simulate the current concentration of carbon dioxide in our atmosphere (418 ppm) add two drops of food colouring to 250 mL of water.

Distance

Another way to visualise one part per million is to think about 1 mm in 1 km of road – a very small distance!

CHAPTER 12

Measuring climate change

12.1. Atmospheric greenhouse gas concentrations: a key indicator

Methods used for measuring past and present changes in the atmosphere: ice core sampling; use of palaeoclimate records; and atmospheric and ocean temperature monitoring

Global greenhouse gas concentrations vary naturally over time, largely due to processes such as volcanic eruptions, forest fires and decomposition of plant and animal matter. In Chapter 11 we explored the changes in concentrations of the various greenhouse gases in Earth's atmosphere over the past few hundred years. Here we look deeper into Earth's history and see how past concentrations compare to the present day. This chapter also explores some of the methods scientists use to measure past climate and how they can help us to assess the rate of present-day climate change.

We know that there is a direct link between atmospheric greenhouse gas concentrations and climate. Changes in the rate and magnitude of the release of these greenhouse gases have significantly influenced Earth's climate system.

Ancient climate change

Earth has experienced significant changes in climate over its billions of years of history, some of which are correlated with mass extinctions (see p 20). These changes occurred before modern humans existed, so they were driven by natural forces, including volcanic eruptions, Milankovitch cycles, solar flares, weathering of silicate rocks, limestone formation, photosynthesis rates and decomposition of plant and animal matter.

Around 600–700 million years ago, Earth's land surface (and possibly much of the oceans) was covered with ice. This 'snowball Earth' ice age is thought to have been ended by volcanic activity that raised greenhouse gas levels, and the global temperature, to much higher than we have today.

Since then, Earth has experienced another four major glacial–interglacial cycles. That is, we can infer from the data that Earth has had warmer periods interspersed with cooler periods when it was covered in ice.

Around 55 million years ago, Earth went through a 'hothouse' period – the Paleocene–Eocene Thermal Maximum (PETM) – associated with a huge release of carbon and a 4–7 °C jump in temperature at a time when temperatures were already rising steadily. Around 50–52 million years ago, atmospheric CO_2 may even have been as high as 1,000 ppm.

Recent changes

Although Earth has experienced significant changes in climate over its geological history, the human-induced climate change of the past 200 years is occurring at a rate 10–20 times faster than changes caused solely by non-human causes.

Without the impact of human activities, Earth would be currently in a fairly stable pattern of glacial and interglacial periods as it has experienced over hundreds of thousands of years (Figure 12.1).

Even with these natural changes, global atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the past 800,000 years have not been as high as they are today. Figure 12.2 shows the dramatic increase in greenhouse gas concentrations that has occurred over the past 50–100 years.

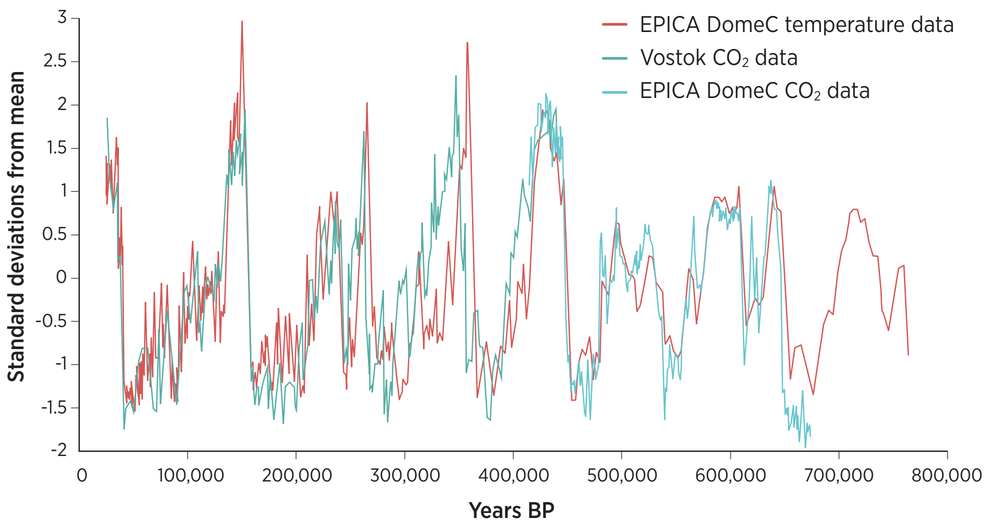


Figure 12.1. Variation in atmospheric carbon dioxide and temperature over past 800,000 years

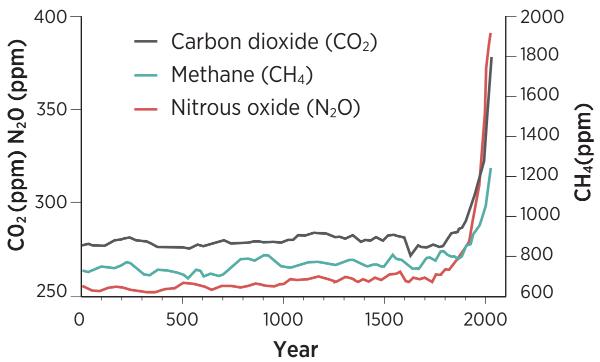


Figure 12.2. Atmospheric concentrations of important greenhouse gases over the past 2,000 years

12.2. Measuring changes in the atmosphere

Scientists use a range of methods for understanding past atmospheres for comparison with today. No method is without error, so usually multiple sources of data are gathered. With these techniques, scientists understand what has been happening over the past millennia with a high degree of confidence.

Ice core samples

Ice cores are cylinders of ice drilled out of an ice sheet or glacier. Tthey reveal information about past temperatures and many other aspects of the environment. The ice holds small bubbles of air that contain a sample of the atmosphere as it was when the ice formed. This gives us the opportunity to directly measure the past concentrations of gases – primarily carbon dioxide and methane – in the atmosphere. Also, the ratio of oxygen 16 to oxygen 18 isotopes in the water molecules provides information on past temperatures.

Most ice core records come from Antarctica and Greenland. The oldest continuous ice core records extend back 123,000 years in Greenland and 800,000 years in Antarctica. The longest ice core extends to a depth of 3 km.

Scientists can compare modern data with past temperatures and concentrations of CO_2 and methane from layers in ice cores. Ice core measurements from Antarctica show that before industrial emissions started atmospheric CO_2 sat at approximately 280 ppm, and had stayed between 260 and 280 ppm during the preceding 10,000 years. Over a longer timeframe, CO_2 concentrations varied between 180 and 300 ppm. Figure 12.3 shows the changes in key greenhouse gas concentrations, sea levels and temperatures since 1850.

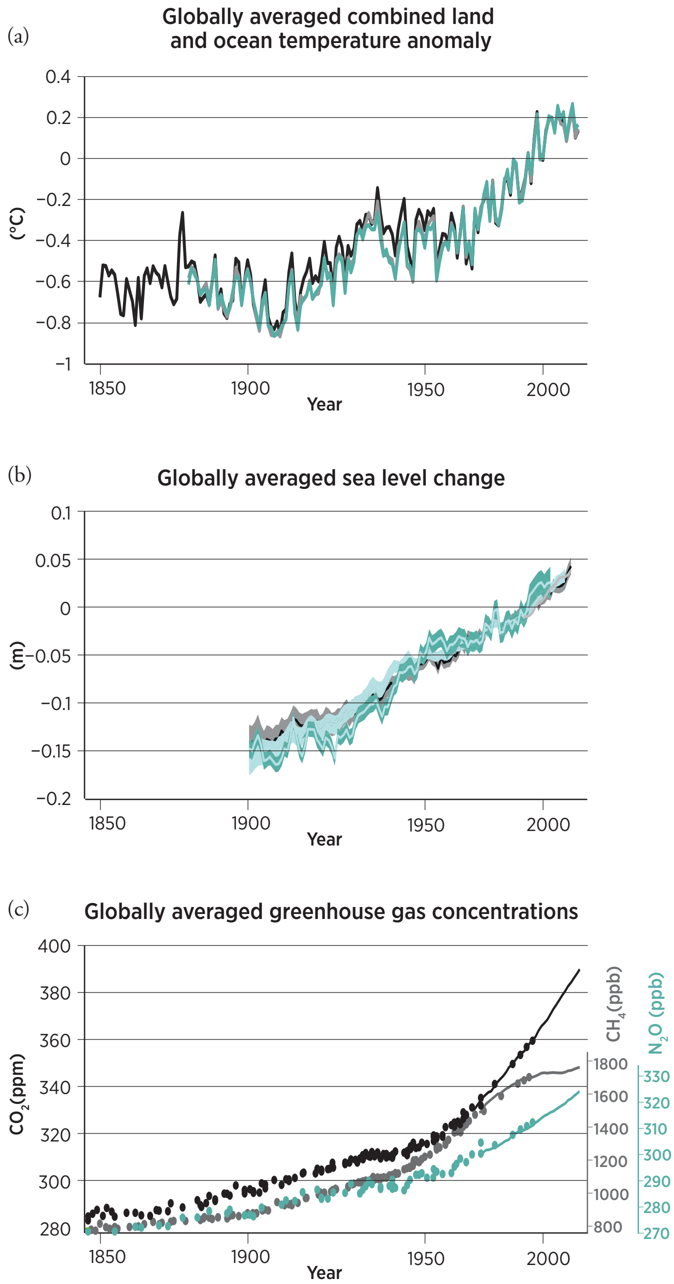


Figure 12.3. Ice core results showing that changes in greenhouse gases (c) match graphs of global temperatures (a) and sea level change (b)

Palaeobotany

We only have weather records from the last few hundred years or so, but we can get information about earlier climates from plant records. Palaeoclimatologists and palaeobotanists have found ways of identifying the kinds of plants that grew in a given area, from which they can infer the kind of climate that must have prevailed. This study of plant life of the geological past is known as palaeobotany.

Scientists use plant fossils, or impressions of plant parts, that have been preserved in sedimentary rocks, coal or other geological deposits. The most ancient plant fossils are over 1 billion years old, such as microscopic impressions of Precambrian algae. Because plants are generally distributed across the landscape based on temperature and precipitation patterns, plant communities change as these climatic factors change. By knowing the conditions that plants preferred, scientists can make general conclusions about the past climate. The climate over the last few hundred million years has seen some pretty big changes!

How do palaeobotanists work out plant distribution over time? One way is to study the pollen left in lake sediments by wind-pollinated plants that once grew in the lake's vicinity. Sediment in the bottom of lakes is ideal for determining pollen changes over time because it tends to be laid down in annual layers (much like trees grow annual rings). Each layer traps the pollen that sank into the lake or was carried into it by stream flow that year. Scientists can infer the climate of the layer being studied by relating it to the current climatic preferences of the same plants.

Atmospheric and ocean temperatures

Atmospheric and ocean temperatures are clearly linked, with both significantly influencing the other. As we noted in 'Ocean circulation' (p 122), the ocean is a major heat sink, and sea surface temperature is a critical indicator of climate change. Major ocean currents move water, and the heat contained in that water, around the globe, affecting climate on a regional to global scale. Observing the changes in atmospheric and ocean temperatures over both short-term and long-term timeframes provides vital information about past climate change, for understanding the present climate and for input into predictive climate models.

Atmospheric and ocean temperatures are recorded in many ways, including direct measurements from weather stations on land and on water and remotely by thermal and microwave imaging sensors on satellites.

Evidence on changing surface temperatures has come from analysis of long-term temperature records, studies of ocean temperature records, studies using balloon-borne sensors, and surface and satellite observations of stratospheric cooling.

Data analysis 12.1
Long-term changes in concentrations

Compare Figures 12.2 (p 135) and 12.3 (opposite). Comment on the correlation between the graphs.

Critical and creative thinking 12.1

1. **List** and compare the different methods used to measure changes to atmospheric conditions over time.
2. Has Earth's climate always been the same as it is today? **Explain**.
3. What factors are considered when assessing the rate of climate change? **Discuss**.
4. Where are most ice core samples collected? Why do you think these areas are used?
5. Why do scientists use a range of factors to assess the rate and magnitude of climate change?

12.3. Climate models and assessing the rate of climate change

Data accessed through direct measurements and from modelling in assessing the rate of local, global and regional past and future climate variability: global average temperatures; local climate extremes; sea level rise; and snow and ice coverage

Climate models are sophisticated mathematical representations of the climate. They simulate the interactions of the important drivers of climate, including processes in the atmosphere and oceans, and on the land surface and ice sheets. Climate models are vital for understanding global climate change and generating global climate models that allow us to predict future outcomes.

The International Panel on Climate Change (IPCC) Fifth Assessment Report states:

Warming of the climate system is unequivocal and, since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and the sea level has risen.

Measuring these changes helps us map the rate and extent of change in Earth's climate. Each measurement in isolation provides only one piece of the puzzle. Climate models combine many measurements from different sources to provide the data needed to understand, and effectively manage, potential impacts from climate change.

Climate models vary in how they represent different components, such as clouds and the interaction between clouds, general warming and the water cycle. For example, it is not yet clear the extent to which global warming will be delayed by the thermal capacity of the ocean and any possible changes to ocean circulation. A further uncertainty in predicting the impact of greenhouse gases is the effect of aerosol particles in the atmosphere, especially those formed from sulfur compounds emitted by industry. These aerosols reduce the transparency of the atmosphere and so reduce the amount of sunlight reaching Earth's surface. This cools Earth's surface and may well mask the warming impact of greenhouse gases in the Northern Hemisphere. Furthermore, climate projections must also take into account a range of possible scenarios in terms of how societies from around the world will manage climate change in the years to come.

CASE STUDY 12.1
What can our past tell us about our future?

Carly Martin, Bachelor of Science student at Deakin University

Climate models are very useful tools that use sophisticated computer programs to predict the change in annual rainfall and mean temperatures globally. Using climate models, environmental scientists concerned with climate change can manipulate variables, such as greenhouse emissions, in an effort to understand what impact they will have.

Our best estimates, under low emissions scenarios, suggest that the global mean temperatures will increase by 0.3–1.7 °C over the next 20 years. In a future in which emissions were not regulated, global mean temperatures would be estimated to increase by 2.6–4.8 °C. Rainfall patterns are expected to shift, with less rainfall occurring in Australia's subtropical region, which currently houses the dairy, beef and corn industries.

Although climate models are useful for predicting how our weather conditions are going to change in the future, they cannot predict how Australia's flora and fauna will react to these changes. To make informed decisions on how we should manage biodiversity, the environment and climate change, we need information. But where can we get the information we need?

Paleoecology is the study of past environments through fossil records. The insights gained through the study of fossil records about the interactions of plants and animals with their environment can be used to inform our decisions about resource management and climate change. We can see how rising temperatures will affect the Australian landscape by identifying a time in our geological history that experienced the same or similar weather conditions.

The Pliocene epoch occurred between 5.3 and 2.6 million years ago (mya) and marks a period when the sea surface temperature sustained an increase of between 4 and 6 °C. This sustained increase is considered to be consistent with the possible increases forecast by climate modelling of human-induced climate change. With this time period in mind, researchers, including Dr Nicholas Porch of Deakin University, can use core samples from regions of interest to determine what changes, if any, occurred in the fossil record to begin to predict what effect global warming may have on Victoria's ecosystems.

Nicholas conducted a study on core samples taken in the Nullarbor that date back to the early Pliocene. He examined the samples for changes in the pollen species present and found evidence of two floral changeovers during the Pliocene. At the beginning of the Pliocene, which marked the end of global cooling in the Miocene (23.0–5.3 mya), the pollen record was mainly populated with woodland species typical of semi-arid climates such as *Glischorcaryon* and *Haloragodendron*.

With the end of the cooling period also came increasing annual rainfall, which soon led to the shrubland species being replaced by forests dominated by species such as *Banksia* and *Eucalyptus*.

By the late Pliocene warming period that occurred approximately 3.5 mya, the annual rainfall began to decrease and the pollen record had shifted again to indicate the landscape was dominated by shrubland species more typical of today's Nullarbor Plain, such as Poaceae (grasses) and Chenopodiaceae (shrubs).

The pollen records from the past can help us extrapolate what our landscape will look like in the future. The mesic forests that were present in the Nullarbor samples are typical of species currently found in Victoria and Australia's coastline west of the Great Dividing Range. If the models prove to be accurate, we could expect to see the forests in this region being replaced by a more shrubby landscape more typical of Australia's arid and semi-arid regions.

CHAPTER

13

Impacts and consequences of climate change

13.1. Analysing and reporting on climate change data

Climate change projections: comparison of observed and simulated current and past climate; and rating of confidence in global, regional and local climate projections expressed as very high, high, medium, low or very low, based on Intergovernmental Panel on Climate Change (IPCC) guidelines

In recent decades, climate change has affected natural and human systems on all continents and across the oceans. All four of Earth's major systems (atmosphere, biosphere, lithosphere and hydrosphere) have been affected, and projections lead us to expect further significant detrimental consequences on a regional and global scale. This chapter explores the potential consequences of climate change on both natural and human systems.

The reports developed and released by the International Panel on Climate Change give the current internationally accepted understanding of climate change. The panel reviews the most current and widely accepted scientific evidence and climate modelling and uses that information to report on the current state, projected impacts and likely consequences of climate change.

The IPCC has examined various scenarios for future carbon dioxide emissions, ranging from a low estimate, in which annual global carbon emissions fall to 5 gigatonnes by the year 2100 (from 9.8 gigatonnes in 2020), to the high estimate, in which emissions increase to 35 gigatonnes by 2100. (One gigatonne is 1 billion tonnes, or 10^9 tonnes.) Based on these scenarios, the IPCC concluded in 2014 that global mean surface air temperature is likely to increase between 1.5 °C and 5.8 °C by 2100.

The IPCC Fifth Assessment Report states:

Future climate will depend on committed warming caused by past anthropogenic emissions, as well as future anthropogenic emissions and natural climate variability. The global mean surface temperature change for the period 2016–2035 relative to 1986–2005 is similar for the four RCPs and will likely be in the range 0.3 °C to 0.7 °C (medium confidence). This assumes that there will be no major volcanic eruptions or changes in some natural sources (e.g. CH_4 and N_2O), or unexpected changes in total solar irradiance. By mid-21st century, the magnitude of the projected climate change is substantially affected by the choice of emissions scenario.*

Relative to 1850 to 1900, global surface temperature change for the end of the 21st century (2081 to 2100) is projected to likely exceed 1.5 °C (high confidence). Warming is likely to exceed 2 °C for RCP6.0 and RCP8.5 (high confidence), more likely than not to exceed 2 °C for RCP4.5 (medium confidence), but unlikely to exceed 2 °C for RCP2.6 (medium confidence).

**Representative concentration pathways [RCPs] describe four possible climate futures, all of which are considered possible depending on how much greenhouse gas is emitted in the years to come.*

Degrees of warming

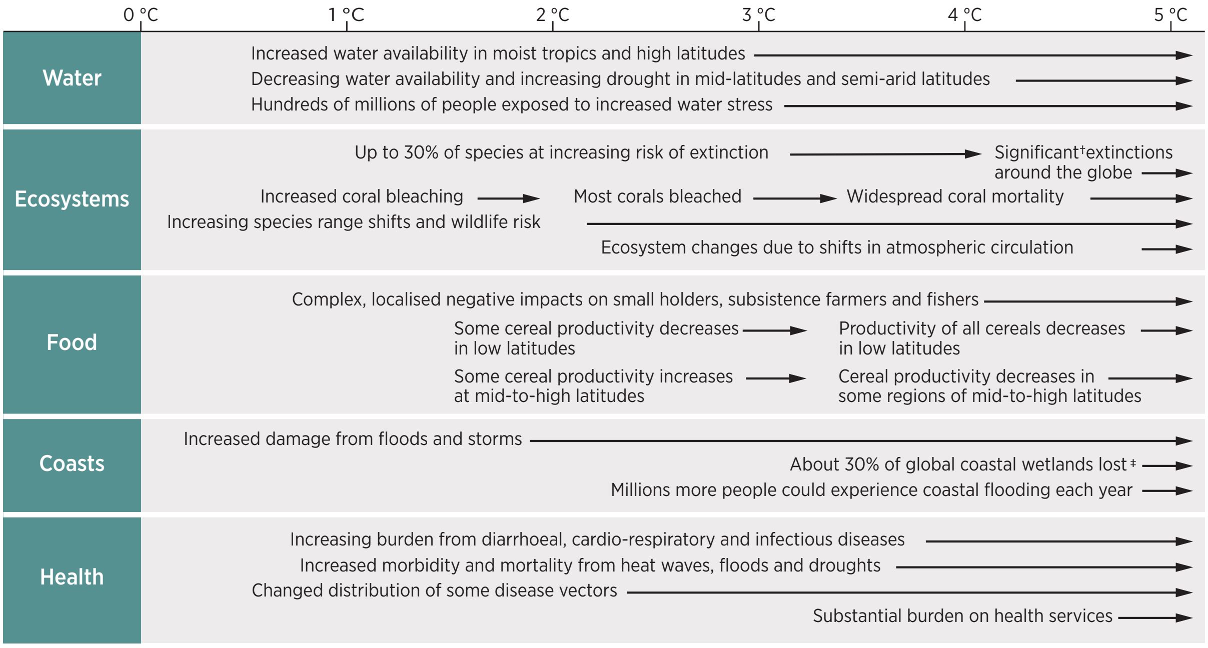
Earth's climate system is clearly warming, as is evident from observations of increased global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. The last decade has seen the warmest global surface temperatures since records began in 1850. Humans, other organisms and ecosystems generally are already feeling the impacts of warming, and these impacts will continue into the future. Some impacts affect specific regions while others will have global consequences. The severity of these impacts on people over the next 100 years depends on the degree of warming Earth will experience over that time.

When we consider how variable the temperature is from day to day and from season to season, an increase of 1 °C does not seem very significant. However, a 1 °C increase in the global mean temperature is large compared to the natural variability of mean global temperatures over the past 100 years. Furthermore, a small change in temperature can produce quite large climatic changes. In addition, there will be quite pronounced local changes that exceed the overall global averages. Projecting consequences of the enhanced greenhouse effect on the four major Earth systems at specific regions around the world poses uncertainties depending on how each region will manage these potential consequences.

The overall risks of future climate change impacts can be reduced by limiting the rate and magnitude of climate change, including ocean acidification. The precise levels of climate change sufficient to trigger abrupt and irreversible change remain uncertain, but the risk associated with crossing such thresholds increases with rising temperature (medium confidence).

Figure 13.1 (p 142) outlines a number of potential impacts associated with climate change on different systems. Remember that there is considerable uncertainty about the extent of these climate changes, their timing and how the different regions will be affected.

Predicting the response of the environment to climate change has become a critical skill the scientific community is refining. Being able to predict impacts and responses to climate change gives society the information required to make decisions and design policies to reduce or eliminate the climate change risk. While there is uncertainty about how much effect climate change is having already the science is clear: widespread impacts are already being observed across almost the whole globe and affecting all of Earth's four spheres. This conclusion was highlighted in the IPCC Fifth Assessment Report.



* Impacts will vary by extent of adaption rate to temperature change and socio-economic pathway
† Significant is defined here as more than 40%
‡ Based on average rate of sea level rise of 4.2 mm/year from 2000 to 2080

Figure 13.1 Potential impacts of different levels of temperature increase

Communicating the degree of certainty in assessment

The analysis and reporting of climate data and the relevant climate projections come with a range of confidence measures (from high to low), and this can be confusing. What does it mean when the IPCC state that there is a high confidence that temperature will exceed 1.5 °C while other forecasts have a medium confidence measure?

We know that, as with any prediction, climate projections can never claim 100% certainty, because the accuracy of climate models depends on their assumptions; the modelling equations that link cause and effect in complex physical, biological and societal processes; and the accuracy of data that is put into the model. As the IPCC did in the text quoted on p 141, anyone reporting on the predictions should include information on their degree of certainty.

The IPCC established a standard approach to evaluating and communicating the degree of certainty in the findings of the assessment process, based on the quality of evidence (low, medium or robust) and the level of agreement between different scientists (low, medium or high).
The IPCC report uses five levels of confidence: very low, low, medium, high and very high.

Furthermore, the probability of a particular outcome is described using the following terms, which also vary in how precisely they predict an outcome:

- virtually certain (99–100%)
- extremely likely (95–100%)
- very likely (90–100%)
- likely (66–100%)
- more likely than not (>50–100%)
- about as likely as not (33–66%)
- unlikely (0–33%)
- very unlikely (0–10%)
- extremely unlikely (0–5%)
- exceptionally unlikely (0–1%).

13.2. Regional impacts of climate change in Australia

The risks and opportunities associated with climate change for humans and ecological systems at a selected region or location: increase in range of exotic species; changes in length of plant growing seasons and animal breeding cycles; phenological changes for plant-pollinator interactions; increasing risks to coastal infrastructure from continuing sea level rise; reduction in agricultural production due to warmer and drier conditions

The effects of climate change will vary across different parts of Australia:

- By 2020, significant loss of biodiversity is projected to occur in some ecologically rich sites, including the Great Barrier Reef and Queensland Wet Tropics.
- By 2030, water security problems are projected to intensify in southern and eastern Australia, due to increased drought and fire.
- By 2050, ongoing coastal development and population growth in some areas of Australia are projected to exacerbate risks from sea level rise and increases in the severity and frequency of storms and coastal flooding.

Changes in temperature and rainfall

CSIRO has released a set of scenarios for climate change within Australia using global climate models and the IPCC projections. Table 13.1 shows the predicted temperature changes for different regions of Australia for every degree of global warming. The predicted air temperature increases by 2030 and 2070 are also shown, based on the IPCC predictions for the low-emission and high-emission scenarios.

Changes in rainfall or precipitation are more difficult to predict than changes in temperature. In addition, precipitation patterns are likely to be affected by local changes in ocean circulation, changes due to sulfate aerosols and changes in the behaviour of El Niño and the Southern Oscillation (ENSO).

Rainfall models show an expected decrease in rainfall over most of mainland Australia in winter and an increase over Tasmania. There is uncertainty about the rainfall patterns over south-east and south-west Australia. The models predict either an overall increase in summer rainfall or a general decrease in the west of Australia and an uncertain pattern in the east. Spring and autumn rainfall are expected to be transitional between the summer and winter patterns. Where the rainfall is predicted to increase, the models also predict an increase in rainfall intensity.

Snow cover in Australia is expected to be severely reduced by climate change. Snow cover is more affected by temperature changes than by rainfall patterns. The impact of reduced snow cover on plant and animal communities is likely to be significant, and the reduced snow-melt in spring will have implications for hydro-electric schemes and downstream irrigation.

Table 13.1. Air temperature change predictions for different regions in Australia (low-emission to high-emission scenarios)

Region	Local warming per degree of global warming (°C)	Predicted increase by 2030 (°C)	Predicted increase by 2070 (°C)
Northern coast (north of 25°S)	0.9–1.3	0.5–1.3	1.3–2.6
Southern coast (south of 25°S)	0.8–1.6	0.5–1.2	1.2–2.1
Inland	1.0–1.8	0.6–1.4	1.5–2.9

Source: adapted from www.climatechangeinaustralia.gov.au

Likely consequences of climate changes in Australia

Agricultural production

One effect of changing patterns of temperature and rainfall in Australia may be a change in the distribution of insect pests. For example, the potential range of the cattle tick, which is at present confined to northern Australia, could extend much further south. New South Wales already spends $9 million a year in quarantining the northern part of that state against cattle tick. These programs may have to be increased in future.

Climate change will reduce the frequency of extreme cold events, that is, when the temperature falls below 0 °C. The amount of fruit produced by many deciduous fruit trees is determined by the amount of winter chilling; low winter temperatures are required to ensure good flowering and fruit setting. The plum and apricot production in Western Australia was reduced by 30–40% by a mild winter in 1988. A 1 °C increase in Victoria's temperature could lead to the failure of flowering and fruit setting in 5 out of 10 years, while a 2 °C increase would result in failure in 9 out of 10 years.

Not all the likely climate changes will be negative. For example, milder winters and warmer conditions in spring would mean a reduction in the frequency of frost damage to crops. In addition, many plantations will produce more wood under changed climate conditions. This effect may be further increased due to enhanced photosynthesis brought about by the higher levels of carbon dioxide in the atmosphere. This process is sometimes referred to as carbon dioxide fertilisation, and it could be responsible for increased growth in many plant species. In some plants, increased levels of carbon dioxide result in reduced opening of the stomata, thereby reducing water loss from transpiration. These plants will remain productive in reduced soil moisture, allowing them to survive in areas where climate change has reduced rainfall.

Human health

Human health may also be affected by changes in insect distribution associated with climate change. The range of the *Anopheles* mosquito, which carries the malaria parasite, could expand to cover much of Australia. Malaria is currently confined to the tropics and its spread into new regions could be devastating as few people in those regions would have any immunity to the disease. Increasing temperatures could also lead to increased risks from other insect-borne diseases.

Extreme events

Climate change is predicted to increase the frequency of extreme events such as droughts, floods and storms. This is because increased temperatures mean more evaporation and more wind energy. The evidence so far supports this prediction, with extreme events such as forest fires, extreme storms and flooding already being observed more frequently around the world and within Australia.

Biodiversity

Evidence of species extinctions caused directly by climate change is limited, but the consensus is that climate change will surpass habitat destruction as the number one threat to biodiversity over the next two decades.

Climate change affects all levels of biodiversity, from organisms (including humans) to biomes, which emphasises that climate change is a complex problem that requires complex and multidisciplinary thinking. Some of the most obvious biodiversity concerns are:

- reduction in species' ability to fight disease
- reduction in genetic diversity
- altered ecosystem function
- reduced ecosystem resilience
- modifications to the 'web of interactions' that cascade as species dependent on a climate change–affected species are themselves affected. An estimated 6,300 species are in danger of extinction in this way.

As the climate changes, some species are able to change their range, either expanding into areas that were once not suitable or moving their activities to areas that are more suitable. Using a CSIRO model, zoologists have shown that a 1 °C increase in average regional temperature could alter the ranges of many vertebrate species: the ranges of 33 species would contract, two would fragment and six species would expand. A 3 °C increase would lead to the complete loss of bioclimatic range for nine species, including Victoria's bird emblem, the helmeted honeyeater.

Many regular events in plant and animal life cycles, such as migration and breeding, are influenced by climate – the study of such relationships is called 'phenology'. Changes to climate affect these biological events, and sometimes relationships between different species are affected by phenological changes.

For example in recent years the mountain pygmy-possum has missed out on its expected feast on migrating Bogong moths. The possums are triggered to wake from their winter inactivity by temperature. Different climate triggers signal to the moths to leave their feeding grounds and head to their breeding grounds where the possum has co-evolved to anticipate a hearty feed. However, the moths are not arriving when expected, and in recent years they have not arrived in large numbers at all. It is not clear if the moths are not breeding or are breeding elsewhere, but their lack in numbers lead some to believe that climate change has affected the Bogong Moth breeding and migration patterns and that this has in turn affected the feeding cycle of the possums.

This type of interdependence can also be seen in bees and other pollinators of flowering plants. When their previous phenological patterns are disrupted by changes in climate triggers, each misses the vital interaction and survival is threatened: bees lack food and plants do not get fertilised.

CSIRO scientists have suggested possible impacts of climate change in Australia (Table 13.2) and recommended further research to determine the effects of the changes.

Table 13.2. Examples of potential impacts of climate change in Australia

Land use	Impact
Coastal	Increased erosion of low-lying areas and formations Flooding of low-lying areas Salt water intrusion into underground water systems
Water resources and hydrology	Requirement for spillways and drainage systems to cope with more water Increased river erosion and dam salination Greater chance of salination of urban water supplies Reduced rainfall
Natural ecosystems	Altered amount and frequency of water availability Increased frequency of extreme events (temperature, precipitation, fires, tides) Increased extinction rates for species and ecosystems, particularly in alpine and coral regions
Agriculture and forestry	Concern over water availability Enhanced growth because of higher CO_2 levels Increased damage to crops by extreme events Increased pests and diseases Some new opportunities for agriculture Reduced income Reduced frost damage
Tertiary effects	Changed power generation requirements throughout the year (e.g. less heating, more cooling) Increased insurance claims due to extreme events Requirement for public works, urban design and the built environment to consider climatic changes Altered tourism destinations Economic implications for industry

Student activity 13.1
Redmap citizen science project

Redmap stands for Range Extension Database and Mapping project. This project invites Australians to share sightings of marine species that are 'uncommon' to their local seas. Over time, Redmap will use this 'citizen science' data to map which Australian marine species may be extending their distribution range – a.k.a moving house – in response to changes in the marine environment such as ocean warming.

Redmap members use their knowledge of the seas to help monitor Australia's vast coastline. The citizen science data also highlights regions and species that may be experiencing more distribution changes so that research can focus on these areas.

In this activity you will log onto Redmap to research a sighted species.

1. Head to www.redmap.org.au.
2. Choose Victoria and pick a species that has been logged as out of range.
3. Research that animal to:
   a) discover its normal range
   b) calculate how far out of it normal range it was sighted
   c) determine the features of its normal range and identify an evidence-based scenario that could explain its expansion in range.
4. Prepare a presentation of your choice to communicate your finding to a chosen audience.

Critical and creative thinking 13.1

1. What is a confidence measure? **Explain** how they are used to describe the degree of certainty when reporting data about projected climate change consequences.
2. Complete the following table by listing some of main impacts associated with increasing temperature on Earth.

Temperature increase	Impacts
1–2 °C	
3–4 °C	
5 °C	

3. **List** and explain some of the projected impacts from climate change in Australia.
4. Are the impacts of climate change already being observed regionally and globally? **Explain** using examples.
5. Why are multiple climate models used to project potential impacts from climate change? **Explain.**

13.3. Responding to climate change

Adaptation options for building resilience to the effects of unavoidable climate change at a selected region or location

Mitigation options for reducing net greenhouse emissions to slow climate change

Some climate change has already occurred in Australia. We have seen a reduction in rainfall during winter in the southern parts of the country and an increase in summer rainfall in the north of the country. In addition, the nation has an increased frequency of hot days compared to cool days, and longer and more severe heat waves are leading to extreme bushfires. There is also a detectable rise in sea levels both locally and globally. Therefore building resilience to the effects of unavoidable climate change is a necessary function of society and government.

Australia has a number of options for responding to climate change, including to:

- reduce emissions
- protect ourselves from extreme climate events
- provide positive environmental outcomes.

Climate change mitigation is taking steps to reduce (or avoid) greenhouse gas emissions to minimise the rate and speed of climate change. Climate change adaptation is taking steps to prepare and respond to the effects of climate change so as to minimise their impact (Table 13.3).

Table 13.3. Mitigation and adaptation strategies identified by the Australian Government in the *National climate resilience and adaptation strategy*

Mitigation	Adaptation
Enhancing energy efficiency by reducing personal electricity use	Changing land use to protect buildings and infrastructure from existing and new hazards
Increasing the uptake of renewable energy	Upgrading design of buildings and infrastructure to protect from wind damage in areas expected to see an increase in storms
Improving industrial processes to increase energy efficiency and reduce waste and pollution	Adjusting activities and lifestyles to prevent additional stress on already stressed environments
Increasing the uptake of sustainable transport, such as commuting by public transport	Updating emergency and business planning as the economic cost of natural disasters in Australia rises
Enhancing carbon sinks by replanting vegetation and maintaining vegetation of significance	Increasing community understanding of climate risk to build capacity in the community to adapt to a changing climate

In this area of study students explore the concepts associated with the use of different energy sources by human societies. Students develop their understanding of the advantages and disadvantages of the uses of different sources of energy and consider the local and global impacts of these uses, including possible consequences over short (seconds to years), medium (multiple years to hundreds of years) and long (thousands to millions of years) time scales. They investigate the extent, availability and consequences of selecting alternative sources of energy for meeting current and projected energy demands, while considering the environmental, sociocultural, economic and ethical challenges involved in building a sustainable energy future.

The selection of learning contexts should allow students to develop practical techniques and undertake fieldwork and other practical activities to investigate and/or to compare options for building a sustainable energy future. Students develop skills in the use of scientific equipment and apparatus, model different energy scenarios, and use simulations to make and test predictions.

Outcome 2

On completion of this unit the student should be able to compare the advantages and disadvantages of using a range of energy sources, and evaluate the suitability and impacts of their use in terms of upholding sustainability principles.

Key knowledge

Area	Section
Comparison of different energy sources	
• non-renewable energy sources: oil, coal, natural gas, coal seam gas and nuclear	14.3
• renewable energy sources: biomass, biofuels, solar, hydro-electric, wind, tidal and geothermal	14.4
• the consequences of fossil fuel combustion for the carbon cycle	10.3, 11.2
• changes in the rate of the use of fossil fuels over time and the concept of peak oil	15.1
• energy efficiency calculations of single and multi-step conversions between different forms of energy, including potential, mechanical, kinetic, thermal, and chemical energy, to generate electricity	15.2

AREA OF STUDY 2

What might be a more sustainable mix of energy sources?

Area	Section
Comparison of different energy sources	
• the implications of the first and second laws of thermodynamics in making energy choices	15.2
• sustainability principles as they apply to accessing, extracting, processing, transporting, and using energy resources: conservation of biodiversity and ecological integrity; efficiency of resource use; intergenerational equity; intragenerational equity; precautionary principle; and user pays principle	
Managing the impacts of human energy use	
• mechanical and biological processes involved in rehabilitating sites from which energy has been sourced	15.3
• the extent to which different energy sources can supply current and projected base and peak load energy needs, and how these can be met at individual and societal levels	15.4
• options for building a sustainable energy future that produces lower greenhouse gas emissions and supplies reliable and affordable energy services: improving resource efficiency; increasing the efficiency of energy conversion devices; replacing fossil fuels with non-fossil fuel energy sources; and reducing personal energy consumption	15.5
• interconnections and tensions between factors that influence responsible decision-making around building a sustainable energy future, including diverse stakeholder values, knowledge and priorities, regulatory frameworks that inform environmental management strategies, use and interpretation of historical and current scientific data, and application of new technologies	

CHAPTER 14

Comparison of different energy sources

CASE STUDY 14.1
The fate of orangutans is in your hands

Piera Sfameni, Bachelor of Science student at Deakin University

The continual degradation of our environment sees many treasured species teetering on the edge of extinction. In fact, it is projected that half to two-thirds of our world's species will become extinct within the next four generations. This threat extends to orangutans who are members of the ape family and are found in jungle habitat in Borneo and Indonesia.

Shockingly, the predicted decline in diversity of species is due not to natural causes but to the humans who have destroyed and fragmented habitat. The greatest threat to orangutans is in palm oil production, which creates competition for lowland terrain and releases greenhouse gases as peatlands are burnt for palm oil expansion.

Janine McBurnie is the Associate Head of School within the School of Life and Environmental Sciences at Deakin University. Specialising in environmental education, Janine believes an informed and knowledgeable public will have more positive attitudes to conservation and be more likely to take action. Her research into community perception of orangutan conservation investigates both public knowledge and perception of orangutan conservation. She also surveys people across Melbourne to discover their attitudes towards, and intentions for, behavioural change to protect orangutans.

Even though orangutan habitat degradation primarily occurs in Malaysia and Indonesia, Australians have a crucial role in conservation as it is the action of the consumer that shapes the demand for products, in this case palm oil. As consumers, Australians have a responsibility to support orangutan conservation and alter our behaviour to mitigate the effects of palm oil production.

If our consumption was focused more on conservation, we would demand more sustainably produced goods. However, with half of all packaged items in Australian supermarkets containing palm oil, the issue is complex. Janine found that less than half of the participants (43.9%) had intentionally bought palm oil–free products within the last 12 months.

Beyond purchasing sustainable products, we also have the ability to financially support in situ conservation programs.

Janine found that current public knowledge of the impact of palm oil farming was relatively high, with 91.7% of participants aware that palm oil degrades orangutan habitats. Further, basic information, such as where palm oil is grown and that we consume palm oil as a foodstuff, was also known. There was less knowledge of orangutan social structure, how long infant orangutans are dependent on their mothers and the current size of orangutan populations.

Janine explains that we have different attitudes to different animal species. We tend to have a positive response towards animals that are similar to human beings, and are more sympathetic to animals that are aesthetically pleasing and vulnerable. On this Animal Attitude Scale, 74% of Janine's survey participants showed a positive attitude to oranguntan conservation, considering it to be important or very important.

According to the theory of planned behaviour, our attitude significantly shapes our intention to act, with positive attitudes making us more inclined to positive behaviour. Another key predictor of behaviour is our intention of action. A vast majority of participants (92.7%) expressed a willingness to adopt behavioural changes that support orangutans.

However, the greatest inhibitor to behavioural change and conservation action is lack of knowledge, including lack of knowledge about how to participate in conservation-related behaviour and act more sustainably in everyday life. Increased knowledge allows us to have empathy for the plight of dwindling species and to discover how to adopt conservation-related behaviour. With more knowledge comes more awareness of the damage inaction can cause, spurring change in our behaviour and increasing our chance of protecting orangutans. High levels of knowledge about human impacts tend to coincide with positive attitudes towards conservation from which the greatest reduction in human impact may occur.

Superficial knowledge or lack of knowledge of the issues surrounding orangutan conservation can play a significant role in driving the species to extinction.

The solution to the lack of knowledge in the community lies in creating more-effective education tools with targeted educational strategies. The media is crucial in terms of environmental education, as television is a wideranging method of communication, and in facilitating community-based marketing. Other barriers to action must also be removed, such as inadequate labelling of products and knowledge.

Conserving orangutans is part of a much greater mission of safeguarding and conserving the biodiversity of our world before a myriad of species encounter extinction.

As Janine says: "Only if we understand can we care. Only if we care will we help. Only if we help shall they be saved."

14.1. What is energy?

An object or a defined group of objects (sometimes called a system) possesses basic properties such as mass, volume and energy. Energy can be defined as the capacity to perform work, because when energy is transferred from an object or system it can perform useful work. The work done is a measure of the amount of energy transferred.

There are many different forms of energy, including:

- mechanical
- chemical
- heat
- electrical
- nuclear
- light.

Objects have energy either because of their motion or because of their position. Kinetic energy is energy associated with an object's speed (motion) and potential energy is associated with an object's position (for example, height). Potential energy refers to 'stored' energy that can be released to perform work.

An example of energy being used for work is a pile driver that uses the impact of a heavy mass to drive a pile (pole) into the ground. Energy is required to lift the mass to a height – a motor may perform the work to lift the heavy object, which then gains potential energy equal to the work done on it. When released, the object accelerates until it strikes the pile. As it falls, the object's potential energy is converted to kinetic energy. Upon striking the pile and driving it a relatively small distance into the ground, the kinetic energy is transformed into sound and heat.

The movement of objects and the conversion of potential energy into other forms of energy involving movement can also be described as mechanical energy. For example, the potential energy stored in water can be converted into mechanical energy either in a waterwheel (which can be used to grind grain) or in a turbine (which can be used to produce electrical energy).

Heat and temperature

Heat (thermal energy) plays an important role in nearly all energy transformations. The molecules of all objects are in motion; that is, they have kinetic energy. Temperature is a measure of the average kinetic energy of the molecules within a material. In solids, such as ice, the molecules vibrate around basically fixed positions (Figure 14.1).

At lower temperatures, the speed of vibration is lower. Higher speeds and higher average molecular kinetic energies are observed at higher temperatures. To increase molecular vibration (kinetic energy), and therefore temperature, energy must be transferred into a material. The energy transferred is thermal energy (also known as heat).

Thermal energy is also required to cause a change in state, such as from solid to liquid or liquid to gas. For example, to melt ice, the molecules need to gain sufficient energy to slip past one another. Thus, heat energy must be supplied to break the bonds between molecules and cause the solid to melt. Similarly, heat is required to change a liquid into a gas, such as changing water into steam.

Whenever the total thermal energy increases, temperature will increase or a change of state will occur.

The terms heat and temperature are commonly used interchangeably, but they are not identical.

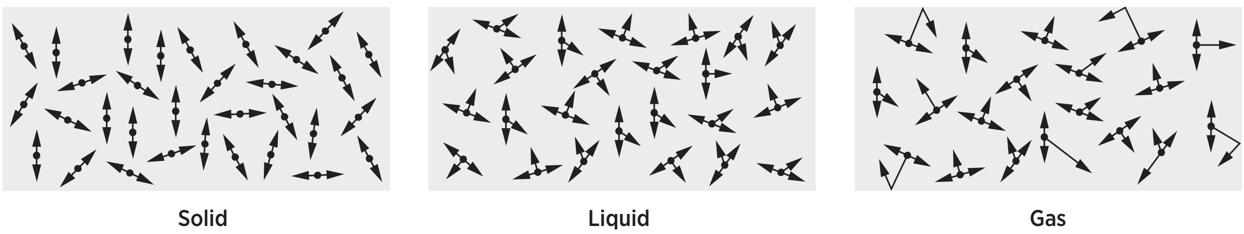


Figure 14.1. Movements of molecules in a solid, liquid and gas

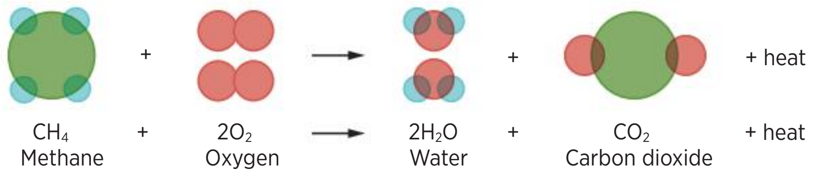


Figure 14.2. The combustion of methane, the main component of natural gas

When two objects of different temperature are in contact with one another, thermal energy will transfer from the hotter one to the cooler one until they are at the same temperature. Defined strictly, heat is this transfer (flow) of energy.

Reactions that release heat are called exothermic reactions. Reactions that take up heat are endothermic reactions. Physical changes can also be exothermic or endothermic. For example, freezing water is exothermic and forming steam from water is endothermic.

Chemical energy

Chemical energy is a form of potential energy that arises from the relative positions of atoms and their electrons in the molecules that make up a substance. For example, methane has chemical energy due to the particular arrangement of the carbon and hydrogen atoms within the methane molecules. This stored energy can be converted into other forms of energy by combustion. Combustion is the reaction of a substance with oxygen resulting in the release of the chemical energy as chemical bonds are broken (Figure 14.2).

The units of energy

The basic unit of energy is the joule (J), which is a very small amount of energy. One joule of energy would lift a 100 g mass by 1 m or raise the temperature of 1 cubic centimetre of water by 0.25 °C. One joule is also the energy content of 0.00003 mL of petrol or a crumb (0.0001 g) of bread. Because the joule is so small we usually talk about energy in multiples of joules. For example, the energy content of 1 kg of wood from the grey box eucalypt is 17.2 megajoules (MJ), that is, 17,200,000 J.

Practical 14.1
Heat of combustion of candle wax

Aim

To calculate the energy released by a burning candle.

Equipment

- candle (ensure it can stand upright)
- balance beam
- steel can
- retort stand and clamp
- measuring cylinder
- stirring rod
- thermometer
- match

Procedure

1. Weigh a candle and record its mass.
2. Place the candle 2–3 cm below a steel can that is supported by a retort stand and clamp (Figure 14.3).

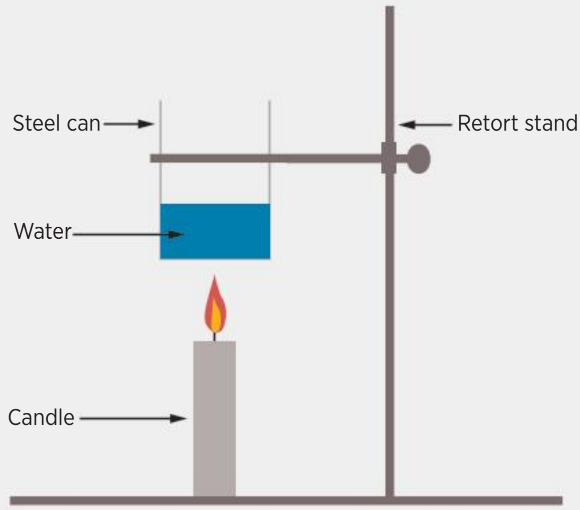


Figure 14.3. Set-up of apparatus

continued next page

Practical 14.1 (continued)

3. Add 200 mL of water to the can and record the temperature.
4. Light the candle and heat the water while stirring.
5. When the water temperature has risen about 20 °C, extinguish the candle. Record the temperature of the water.
6. Reweigh the candle and record its mass.

Discussion

1. Calculate the energy absorbed by the water in the can while the candle was burning. (We know that it takes 4.184 J of energy to raise 1 g (or 1 mL) of water by 1 °C.)
2. Calculate the heat of combustion of the candle wax (that is, energy released per gram).
3. Assuming that the chemical formula for candle wax is $C_{25}H_{52}$, calculate the heat of combustion in joules per mole. (A mole is the molecular weight of a substance expressed in grams.)
4. Comment on the main sources of error in this experiment. How accurate was your calculation of the heat of combustion?
5. Repeat the experiment using other sources of energy such as methanol, ethanol, kerosene, fire starters or vegetable oil. Compare your results and discuss.

Power

Power is a term related to energy. It is the amount of energy available or used over a given time (for example, joules per second), so we can see that power is the rate at which energy is being used or that work is being done. The unit for power is the watt (W) and power can be calculated from the following:

power (watts) = energy (joules)/time (seconds)

One watt is 1 joule per second.

The energy rating of electrical appliances is usually given in watts. For example, an electric radiator rated as 1,000 W is converting electrical energy into heat energy at the rate of 1,000 J/s.

The typical power output of a human is 100 W; for a horse it is about 500 W. The commonly used term ‘one horsepower’ is actually 746 W. Petrol-driven car engines have power ratings of about 150,000 W (150 kW).

Practical 14.2
Student power

Aim

To understand the power required to ascend a flight of stairs.

Equipment

- measuring scales
- stairs
- stop watch
- ruler

Procedure

1. Weigh yourself and record the result.
2. Calculate the height of the stairs by multiplying the height of one stair by the number of stairs.
3. Note the time it takes to climb a flight of stairs slowly.
4. Note the time it takes to climb the stairs as quickly as possible.
5. Repeat the exercise with other students.

Results

Calculate the power required each time the stairs were climbed using the following equations:

Power = energy (joules)/time (seconds)

energy (J) = mass (kg) x 9.8 x height (m)

NOTE: The figure of 9.8 refers to the acceleration due to gravity in m/s/s.

14.2. Energy sources

Energy resources are naturally occurring fuels or energy sources that can be converted into forms of energy useful to society. Fuels are substances that contain chemical (potential) energy that is released when oxidised, usually by combustion.

The sources of energy we use today can be considered as either renewable or non-renewable. Renewable energy resources are those that can last indefinitely without any reduction in their supply – they are either essentially inexhaustible or they can be replaced through natural processes quicker than they are used. Solar energy is considered to be inexhaustible in human terms (even though the energy content of the Sun is slowly running down), and wood is an example of an energy source that is continually being renewed as trees continue to grow.

Some resources can be considered renewable only if they are managed in a sustainable manner. For example, wood can be considered renewable only as long as we continue to plant trees at least at the same rate as they are being harvested. Renewable energy sources are explored further below (p 162).

Non-renewable energy resources are those that exist only in limited deposits in various parts of Earth. They can be replaced, but only over very long periods of geological time. We consider them to be exhaustible because we are using them at a much faster rate than they are being replaced. Coal and oil are examples of non-renewable energy resources. We rely heavily on non-renewable energy: most of the energy we use in Australia comes from non-renewable sources (Table 14.1).

Table 14.1. Australian energy production and consumption by fuel type

	Production 2018–19 (PJ)	Consumption 2018–19 (PJ)
Coal	12,593.7 (black coal) 444.4 (brown coal)	1,801.6
Oil	676.8	2,402.1
Gas	5,498.1 (natural gas) 98.1 (liquefied petroleum gas, LPG)	1,592.7
Renewables	399.6	399.6
Total	19,710.7	6,196.0

NOTE: PJ = petajoules (1 PJ = 1015 joules)
Australia also mined 7,618 tonnes of uranium oxide, but uranium is not used as a fuel in Australia.

Source: Department of Industry, Science, Energy and Resources (2020) Australian Energy Statistics.

Producing electricity

Both renewable and non-renewable sources of energy can be harnessed to produce electricity. Electricity is produced when fuel or another source of energy is used to drive a generator or a turbine. An electric generator is a device for converting mechanical energy into electrical energy.

Electricity is the flow of electrons. All matter is made up of atoms, and within the nucleus of each atom are protons (positively charged) and neutrons (uncharged). The nucleus is surrounded by negatively charged electrons. When an outside force upsets the balancing force between protons and neutrons, an atom may gain or lose an electron. When this occurs, the free movement of these electrons creates an electric current.

An electricity generator has a magnet at the end of a rotating shaft; when the magnet rotates it induces an electric current. The shaft is attached to a turbine. In a power plant, the blades of the turbine may be turned by steam (created by burning fuel such as coal or gas), wind or moving water (see Figure 14.4).

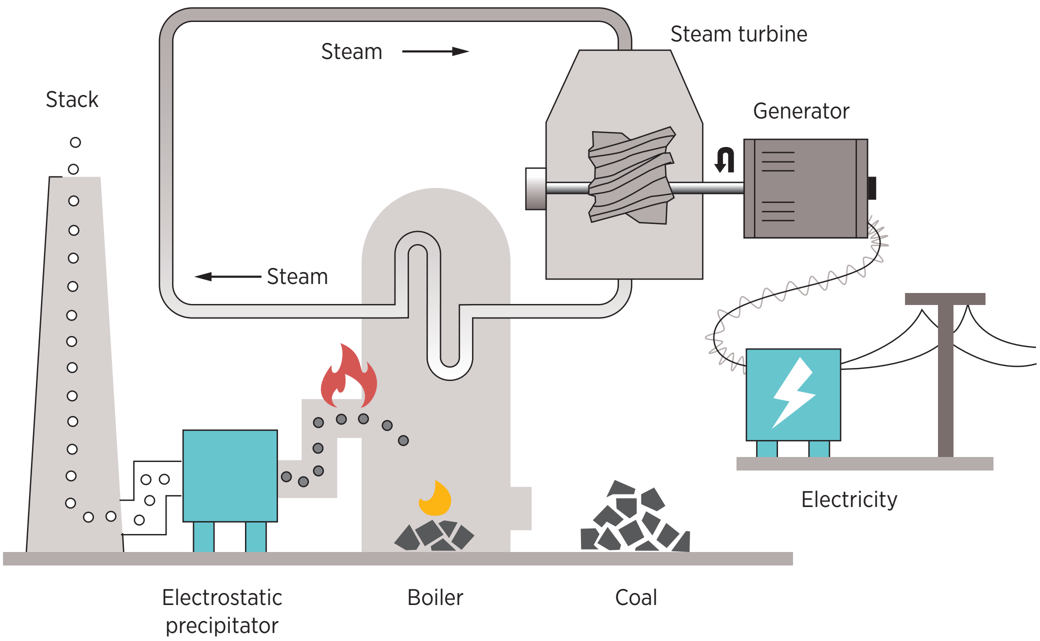


Figure 14.4. Traditional energy generation from solid fuel combustion turbines

Electricity consumption varies across the day. Peak energy times are those hours when electricity is in highest demand. These times put extra pressure on electricity distributors, which must ensure enough electricity is being generated and transmitted to homes and industry to cope with the high demand. Off-peak times are when the least energy is being used – generally overnight when most people are sleeping. In analysing how different fuels can meet a community's electricity needs, we must consider the peak demands of a community. Distributors may charge higher rates for electricity at peak times to encourage consumers to spread the demand to off-peak times.

14.3. Non-renewable energy sources

Non-renewable energy sources: oil, coal, natural gas, coal seam gas and nuclear

Fossil fuels

Fossil fuels include coal, petroleum (crude oil) and natural gas. Fossil fuels formed from dead and decaying organisms trapped below layers of sediments or rocks. Coal formed from ancient forests that were buried in swamps 300–400 million years ago. Over time, the amount of rock and sediments above the buried forest increased, as did the pressure and the temperature. The plant material became fossilised and compressed and eventually converted into coal.

In contrast, petroleum and natural gas formed from marine plants and animals that died and sank to the bottom of oceans, lakes and estuaries. These dead organisms were decomposed by bacteria, and sediments were deposited over them. As the sediments built up, the temperature and pressure increased and the organisms were converted into oil and natural gas (which are frequently found together).

Since the Industrial Revolution began in the mid-1700s, and we harnessed fossil fuels to power machinery and produce electricity, we have witnessed enormous advances in almost every facet of society. We have all reaped the many benefits associated with energy produced from these fuels. As our population increases and living standards continue to improve around the world, our demand for fossil fuels increases.

Coal

Coal is the most plentiful of the fossil fuels, making up about 94% of Australia's fossil fuel energy reserves and providing 66% of our total energy production (see Table 14.1).

The formation of coal begins with layers of decaying trees and other vegetation in swamps. The bottom layers become compressed and lose some water. This form is called peat, which can be dried and used as a fuel.

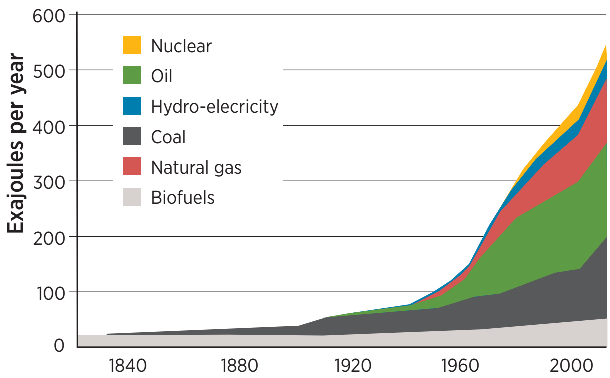


Figure 14.5. World energy consumption since the Industrial Revolution

Further deposits increase the pressure and heat in the peat and convert it into a soft coal called brown coal (lignite).

Over time, brown coal can be transformed into black coal (anthracite) by further deposition of sediments and subsequent increases in temperature and pressure. Sub-bituminous coal and bituminous coal are two intervening stages between lignite and anthracite. Anthracite contains less oxygen and moisture and more carbon than other forms of coal, and provides much more heat when it burns.

Australia is the fourth-largest producer of coal and has about 8% of the world's total coal reserves. The major anthracite deposits are in Queensland and New South Wales, with smaller deposits in Western Australia, South Australia and Tasmania. Three-quarters of our black coal production is exported (mainly to Japan), and this contributes significantly to our export income. Locally, black coal is used mostly to generate electricity.

Victoria's main coal reserves, which are brown coal, are located in the Latrobe Valley in Gippsland and are used to generate most of Victoria's electricity. These deposits lie close to the surface, which means that the coal can be extracted economically by open-cut mining.

Because we have such large reserves of coal and it is relatively accessible, Victoria could theoretically rely on coal to meet its energy needs for generations to come.

Despite having this available resource, we must weigh up the benefits of using brown coal for electricity against the impacts it has on environment. The overall efficiency of brown coal (from extraction to use) is approximately 25–30%.

Petroleum

Early civilisations first encountered petroleum as a black tarry substance seeping out of the ground – 'petroleum' simply means oil from rock – which they put to a variety of uses. The first oil well was drilled in Pennsylvania in the United States in 1859. Oil then became more readily available and started to replace coal as an energy resource. In Australia, significant oil reserves are located on the North West Shelf off Western Australia and in Bass Strait.

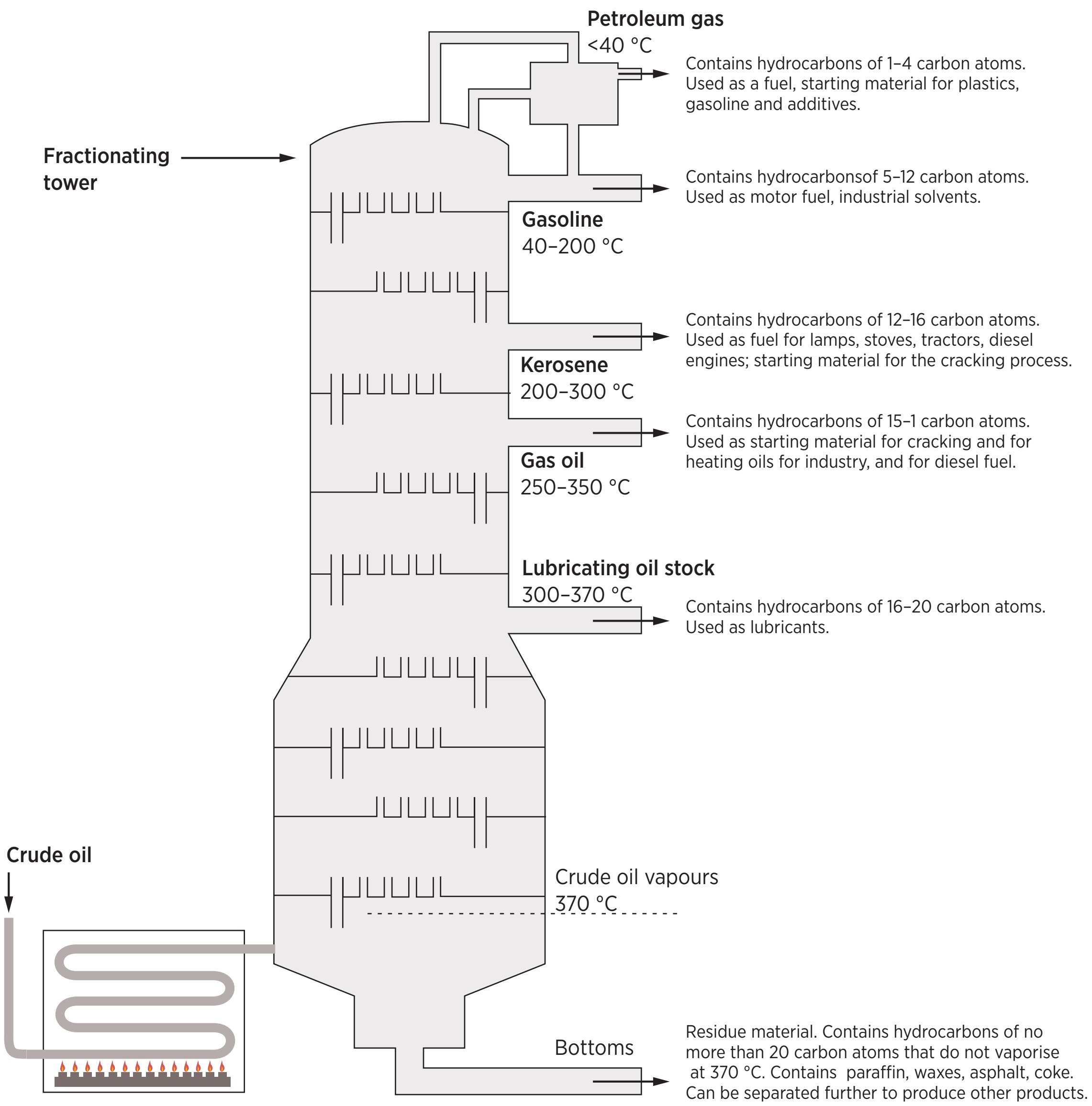


Figure 14.6. Distillation tower and various fractions

Crude oil pumped from the ground is a heavy, sticky black substance. Crude oil is heated in a refinery and different products are extracted at different temperatures (Figure 14.6). These products range from bitumen, through to diesel oils, kerosene, petrol and gas. All petroleum products are primarily hydrocarbons; that is, they are made up of carbon and hydrogen atoms.

Oil is a more convenient fuel than coal as it is easier to transport, has higher energy content, burns more cleanly and produces less smoke. These advantages, along with the development of the internal combustion engine, led to the increased use of petroleum products during the 20th century, particularly in transport.

About 75% of the oil consumed in Australia is used for transport. The remaining oil is used by industry in processes such as heating and in the production of plastics, paints and bitumen for roads. In some countries, oil is commonly used as a source of energy for heating.

Despite technological advances, modern internal combustion engines are still only 25–30% efficient. This means that up to 70% of the oil used in transportation is either lost as heat through the exhaust pipe or is lost in friction of moving parts.

Natural gas

Natural gas often occurs with oil reserves, and it was originally regarded as a nuisance and burnt off as waste. The gas was not used as a fuel because it was difficult to deliver to the user. With the development of high-pressure pipes and improved welding and pipe-laying techniques, natural gas began to be used. Today, natural gas is a very important fuel and constitutes about 20% of the world's, and of Australia's, energy use.

Australia has about 1% of the world's reserves of natural gas. Most of our natural gas resources are located in the basins of the North West Shelf and in Bass Strait, off Victoria. The Bass Strait basin supplies much of Victoria with gas, and much of the gas from the North West Shelf is exported.

Natural gas is a mixture of hydrocarbon gases; it is mostly methane (CH_4) but also contains small amounts of ethane (C_2H_6), propane (C_3H_8) and butane (C_4H_{10}). We look at how methane burns in section 14.1 'What is energy?' (p 152).

The combustion of methane releases energy and forms carbon dioxide and water; other hydrocarbon gases burn in the same way. The combustion of natural gas is quite a clean process compared to the combustion of other fossil fuels, which produce pollutants like sulfur dioxide and nitrous oxide (in addition to carbon dioxide). Natural gas is used in homes for heating and cooking, and by industry for heating and manufacturing. Natural gas has an overall energy efficiency of approximately 30% for electricity production and 90% for heating.

Coal seam gas

Natural gas that collects in underground coal seams and bonds to the surface of coal particles is called coal seam gas (CSG). The coal seams are generally filled with water, and it is the pressure of the water that keeps the gas as a thin film on the surface of the coal, generally at depths of 300–1,000 m. Australia has large coal seam gas reserves, particularly along the east coast.

Coal seam gas is considered an unconventional gas due to the methods used to extract it. Hydraulic fracturing, often called 'fracking', is one of the more commonly used methods of extraction. This process involves high-pressure injections of sand, water and chemicals into the coal seam gas well. The injection causes fractures in the coal seam, allowing the gas to flow to the surface of the well. Fracking is causing significant concern in Australia and worldwide in recent times because of the potential for fugitive gases to contaminate water sources and possible seismic activity and tremors associated with the drilling process. In 2016, the Victorian Government was the first Australian state to ban coal seam gas and fracking, and Tasmania soon followed.

Nuclear reactions

Nuclear fission (uranium)

Uranium is not a fossil fuel, but it is another non-renewable energy resource. Uranium is used in nuclear reactors to produce heat, which is used to generate electricity. Nuclear reactors make use of nuclear fission chain reactions to release energy. A fission reaction is initiated by a neutron striking the nucleus of an atom with a large mass number and splitting that nucleus into smaller nuclei. Each reaction liberates energy and additional neutrons, which can continue the reaction by striking other large nuclei (Figure 14.7).

Uranium 235, an isotope of uranium, is an example of an atom whose nucleus can take part in nuclear fission reactions. In these reactions, a small amount of mass from each nucleus is converted into energy. Nuclear energy is a highly efficient fuel source with a total energy efficiency of approximately 90%.

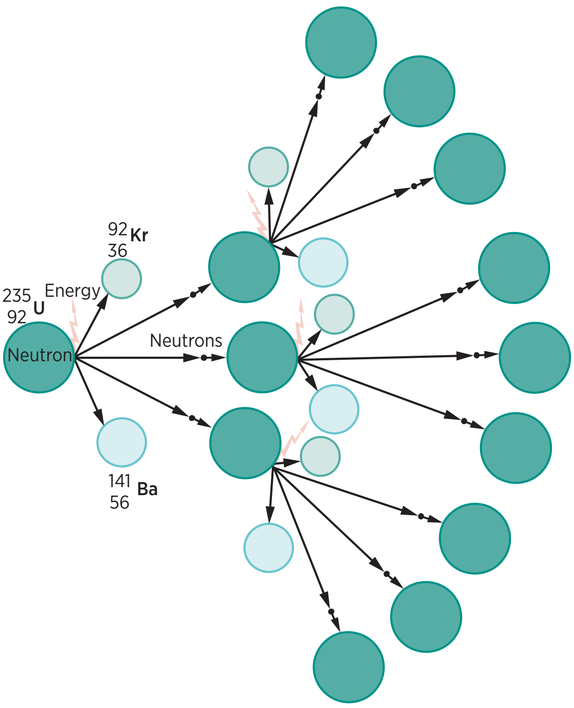


Figure 14.7. A nuclear fission chain reaction

Student activity 14.1
Uranium isotopes

Uranium 235 and uranium 238 are both isotopes of uranium.

1. What is an isotope?
2. What is the mass number of an atom?
3. What is the atomic number?

Nuclear power plants for generating electricity were developed during the 1950s, and many plants were built during the 1960s and 1970s. Nuclear energy produces about 15% of the world's electricity. The rate of growth in nuclear power has slowed in recent years as a result of accidents in nuclear power plants and growing concerns about the safety of the plants, the health risks associated with nuclear radiation and the difficulties of nuclear waste disposal. There is also the problem that nuclear proliferation leads to an increase in fissionable material, which could be used for nuclear weapons.

Australia has about 20% of the world's known reserves of uranium and produces about 20% of the world's uranium. Australia has only one nuclear reactor, at Lucas Heights in Sydney. This reactor is used not for electricity generation but to produce radioactive materials used in medicine and medical research. Radiation can also be used to sterilise food and instruments and to take X-ray-like photographs of weaknesses in metals.

Nuclear fusion

Another type of nuclear reaction is fusion. In a fusion reaction, energy is released when two atoms are forced together. This is the type of reaction that creates the energy given off by the Sun. The hydrogen bomb also makes use of fusion reactions.

Fusion appears to be an attractive source of clean, sustainable energy for the future. The most likely fuels for a future fusion power source are the heavy hydrogen isotopes deuterium (hydrogen 2) and tritium (hydrogen 3). These are so abundant that fusion power, even if not technically renewable, could meet the world's electricity needs for millions of years.

However, despite many years of research, controlled fusion reactions have occurred only on a small scale in the laboratory. The likelihood of a full-sized fusion reactor being feasible in the near future appears small.

Data analysis 14.1
Global use of nuclear energy

Figure 14.8 shows the amount of nuclear power generated by countries across the world in 2020.

1. Considering Figure 14.8, describe the global use of nuclear power.
2. Describe two negative environmental impacts associated with the construction and operation of nuclear power plants.

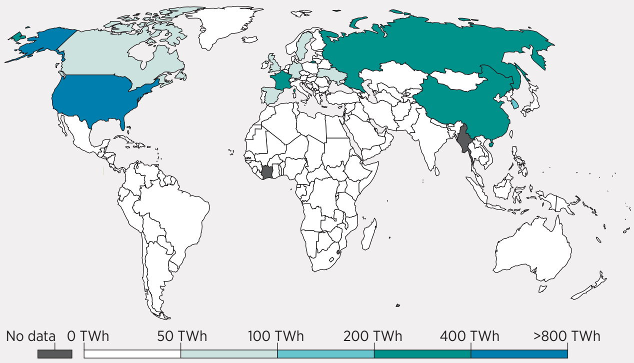


Figure 14.8. Nuclear power generation in 2020 (terawatt-hours)

Critical and creative thinking 14.1

Coal, natural gas, petroleum and uranium are all considered non-renewable energy resources. Complete the table below:

	Coal	Natural gas	Petroleum	Uranium
Classify this energy resource as non-renewable and/or fossil fuel. Justify your classification.				
How is this energy source formed?				
How is this energy source extracted, processed and distributed for use?				
What are the main uses of this energy source?				
Where are the major global reserves of this resource?				
What is the approximate overall efficiency from extraction to use?				
What advantages are associated with extraction and use of the energy source?				
What disadvantages are associated with extraction and use of this energy source?				

14.4. Renewable energy sources

Renewable energy sources: biomass, biofuels, solar, hydro-electric, wind, tidal and geothermal

Renewable energy sources are those that can last indefinitely without any reduction in their supply. Why are they so important? With the remaining fossil fuel reserves declining and climate change already affecting many parts of the world, renewable energy technologies are necessary to provide the energy the current generation and the many generations to come need to develop and flourish. This chapter explores some forms of renewable energy.

Solar energy

Solar energy is energy from the Sun. Inside the Sun, nuclear fusion reactions release large amounts of energy: 3,800 million million million million watts! Earth receives about 1/200,000,000,000 of the Sun's energy output. Even 1% of the energy reaching Earth could supply the energy needs of all the people on Earth.

Solar energy cannot be collected at night, and the amount of sunlight received varies with location, time of day, time of year and weather conditions. These limitations are being tackled with ongoing improvements in solar energy technology: more efficient harnessing methods are being developed and storage battery technology is improving.

Heat collectors

One simple way to capture and use solar energy is to heat water, such as occurs in the heat collectors used to heat water for swimming pools. Often placed on the roof of a house, these collectors are simply large areas of tubing (of black plastic or synthetic rubber) through which the pool water circulates. Heat from the Sun is absorbed by the black tubing and heats up the water moving through it, warming the swimming pool water.

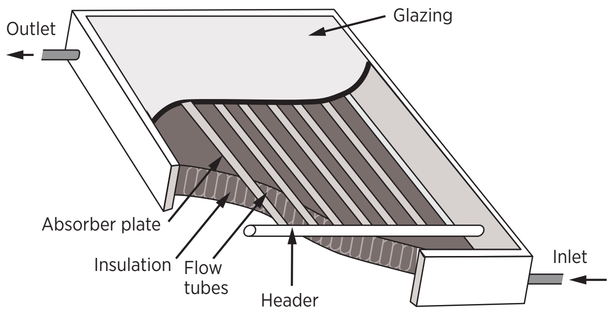


Figure 14.9. Flat plate collector

Water can also be heated to temperatures up to 100 °C by flat plate solar collectors (Figure 14.9). These are used for hot water supply in homes, hospitals, industry and agriculture. Flat plate collectors consist of a black metal absorber plate with a series of tubes bonded to it, enclosed in an insulated box with a transparent cover. The absorber plate is heated by the solar radiation and transfers heat to the water flowing through the riser tubes or channels. Cooler water flows into the bottom of the collector, gains heat and rises to an insulated storage tank. A transparent cover allows solar radiation to pass through yet reduces heat loss by protecting the absorber plate from wind and limiting the re-radiation of thermal energy. When there is insufficient solar radiation to maintain the water temperature, the storage tank may have a backup energy supply, such as gas, wood or electricity.

Higher temperatures, up to 200 °C, can be reached by evacuated tube collectors. These are similar to flat plate collectors except that the black absorber plate is held within a vacuum in a glass tube. This results in very little heat loss, allowing higher temperatures to be reached. Because the temperatures are above the boiling point of water, oil is usually used as a heat transfer fluid. These collectors are used in industrial processes.

Practical 14.3
Solar water heater

Aim

To design an efficient solar water heater.

Procedure

1. Design and construct a solar water heater. The capacity of your collector should be about 4 litres. In your design, take into account:
   - how to absorb solar energy while minimising heat losses from convection, conduction and radiation
   - the nature of the materials used in the construction
   - whether the colour of the materials is important
   - how to orient your solar collector.
2. Test the efficiency of your water heater by filling it with water and noting the temperature. Place the collector in sunlight for an hour and then record the temperature.
3. Calculate the efficiency of your solar collector.
   - Heat energy gained in joules (or energy output) = volume of water (mL) × 4.184 × temperature increase. What is the significance of the 4.184 figure?
   - Energy input from the Sun is 800 joules per second per square metre of collector area. Calculate the energy input for your water heater.
   - What is the efficiency of your collector?
4. Suggest some design improvements and trial them.
5. If you have access to a commercial solar water collector, carry out the same test and compare its efficiency with your solar water heater. Record your results and compare the efficiency.

Discussion

1. What factors did you take into account when you designed your solar water heater?
2. If you were to redesign your solar water heater, is there anything you would do differently? Explain.

Photovoltaic cells

A different approach to capturing and using solar energy is to convert solar energy into electricity, which is what happens in a solar or photovoltaic cell (Figure 14.10). Photovoltaic cells (PVs) are primarily made from silicon, which is a semiconductor. Semiconductors will conduct electricity only under certain conditions. In a photovoltaic cell, two types of impurities have been incorporated into the silicon to create those conditions.

One type of impurity (often arsenic or phosphorus) provides an excess of electrons over those needed for covalent bonding with the silicon. These extra electrons are free to participate in the conduction of electricity. Semiconductors such as these are called n-type, as they have an excess of electrons, which are negatively charged. The other form of impurity added to the silicon includes boron or aluminium, which have a shortage of outer, valence electrons. This is a p-type semiconductor.

Figure 14.10. Photovoltaic cells on a roof

When n-type and p-type silicon are in contact with one another, a p–n junction is formed. When a p–n junction is in the dark, and not exposed to light or solar energy, the excess electrons from the n-type silicon will drift across the junction and occupy spaces in the p-type silicon where there are electron shortages.

This creates positive charges on the n-type side of the junction (because it has lost electrons) and negative charges on the p-type side (because it has gained electrons). This produces an electric field across the junction (Figure 14.11).

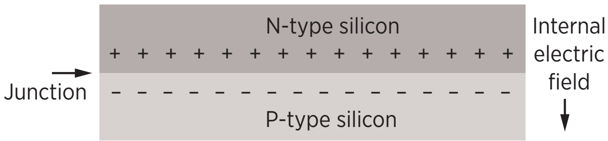


Figure 14.11. A p–n junction in the absence of solar energy

When solar energy hits the cell, enough energy is provided to move some of the extra electrons in the p-type silicon across the junction to the n-type silicon. If a wire is connected from the n-type to the p-type side of the junction, a current will flow; this current can be used to drive an external electrical device (Figure 14.12).

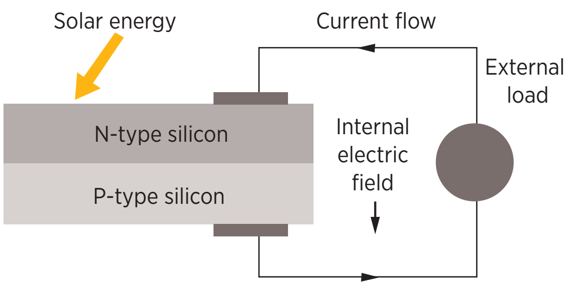


Figure 14.12. A representation of a photovoltaic cell

Solar cells are widely used in locations distant from the mains electricity supply. For example, they provide power for remote houses, external lighting, electric fences, weather stations and railway crossing signals. The power produced by the solar cells during the day is used to operate these devices and also used to charge batteries; the electricity stored in the batteries (potential energy) is made use of during the night or on cloudy days.

The current produced by a solar cell is direct current (DC). This can be used directly in some appliances, such as radios or lights, or it can be stored in batteries. Stored power from batteries, and DC directly from solar panels, can be converted into alternating current (AC) by an inverter. Alternating current is the form of electricity generated by conventional power stations and distributed to households and industry.

The cost to the consumer of generating electricity from photovoltaic cells has been quite high compared to the cost of electricity from conventional power stations. Some of this cost is offset by a reduction in electricity bills. This price disincentive has limited its use in general electricity production, although the government has provided rebates to reduce the cost and encourage uptake. The cost of the solar cells has been falling steadily over recent years, and they should contribute much more to electricity generation in the future.

Many houses in Melbourne are already using photovoltaic cells. These homes are connected to the electricity supply grid. They can provide power to the grid during daylight hours when their cells are active and electricity generation exceeds household requirements, and they can receive electricity from the grid at night and on overcast days.

Operating solar cells does not produce any pollution, but their manufacture requires significant amounts of energy and produces pollution. Sand mining for silicon can also have detrimental environmental effects. New methods are now being developed for the manufacture of cells that will reduce these environmental impacts. In theory, solar energy could supply much of Australia's energy needs – a high percentage of Germany's energy is now supplied by solar. The energy efficiency of photovoltaic cells ranges from 15% to 40%; as technology advances so too will the energy efficiency of these products.

Wind energy

Wind is another form of solar energy. Sunlight falls unevenly on Earth, heating the air unevenly. The warm air rises and cooler air moves in to replace it. This circulation of air from cool areas to warm areas produces winds. These processes operate at a local level, such as the cool sea breezes coming in over the land as it heats up. However, they also act on a global scale, with hot air rising at the equator and cooler air being drawn from the poles. This basic pattern is complicated by Earth's rotation, ocean currents and different land masses.

Of all the solar energy that falls on Earth, only 1–2% becomes wind energy. If we efficiently harnessed all of this wind energy and used it to generate electricity, it could produce 10 times more energy than humanity uses each year.

Wind turbines are used for mechanical tasks (such as pumping water) and to generate electricity. They come in two basic forms: those with a horizontal axis and those with a vertical axis. Wind turbines are made up of a propeller that spins when the wind is caught by the blades. The spinning blades drive a shaft connected to a mechanical device such as a water pump, or to an electric generator (Figure 14.13). A tail device is used on small horizontal-axis machines to swing the propeller into the wind. Larger machines may have motors to do this. Vertical axis machines do not need a direction controller as they catch wind coming from any direction.

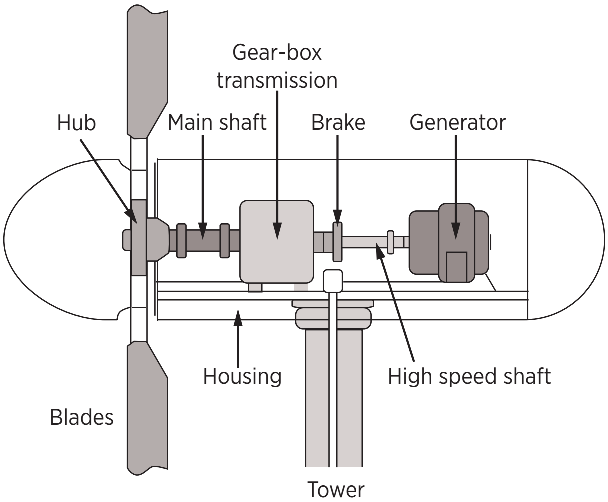


Figure 14.13. Horizontal-axis wind turbine

A thorough site analysis is required to determine whether or not it is appropriate to collect wind power on a given site. Electricity generation from wind power requires an unobstructed steady airflow.

Wind is used extensively for electricity generation in Germany, the United States, Denmark and Spain. Denmark leads the world in the proportion of its electricity (42%) being generated by wind turbines. Wind is a significant contributor to Australia's renewable energy supply, accounting for one-third of the country's renewable energy in 2015 (which was 4.9% of the electricity overall).

By the end of 2015, Australia's wind farms had a capacity of 4,187 megawatts (MW) of electricity from 2,062 turbines in 76 locations. Over half of Australia's wind energy is produced in South Australia. Victoria currently has 25 wind farms in operation (including in Codrington, Toora, Challicum Hills, Wonthaggi, Yambuk, Waubra, Cape Bridgewater/Cape Nelson and Hepburn) and others are being built or considered.

Hydro-electric power

The movement of water has been used to provide energy for humans for hundreds of years. Waterwheels on rivers were used to power grinding and milling machines. Advances in technology allowed the production of electricity from the flow of water: the first hydro-electric plant was commissioned in Wisconsin, USA, in 1882.

Hydro-electricity is produced by using water stored in dams. The stored water flows through a turbine that spins a shaft connected to an electric generator to produce electricity. The amount of electricity produced depends on the volume of water flowing through the turbine and the vertical distance the water falls. The gravitational potential energy of the water stored in the dam is converted into kinetic energy upon release, and this is converted into electrical energy in the generator. Hydro-electric plants are used mainly to supplement the electricity supply from other forms of power stations as they can be brought into and out of operation relatively quickly and easily. Hydro-electricity has a fairly high overall energy efficiency, with an average of 70%.

Hydro-electricity provides about 19% of the world's electricity production. In Australia, about 10% of the total electricity produced is hydro-electricity. Most of Australia's hydro-electric stations are located in areas with high rainfall and steep valleys that can be dammed easily. There is little potential for the expansion of hydro-electricity in Australia, as most of suitable sites have already been developed.

Hydro-electric power can be turned up and down quickly, and the system can store energy for several hours within the system.

Hydro-electricity is relatively clean because it emits virtually no particulate pollution, so it is often considered a ‘green’ energy source. However, it is does cause environmental and social impacts.

Hydro-electric power projects often displace human occupants when the initial dam is built and large areas of previously occupied land is flooded. In the 1960s, the town of Jindabyne, New South Wales, was relocated to its present location from a site now under the waters of Lake Jindabyne. This was to accommodate the construction of the Jindabyne Dam as part of the Snowy Mountain scheme.

Flooding to create dams has a major impact on wildlife habitats, and the storage, diversion and release of water disrupts natural environmental water flows, as has happened in the Snowy River, for example. The holding dams are filled with lakes and rivers, often diverted from their natural courses, to maintain water levels optimum for turning turbines. Released dam water is usually cold water from the bottom of the dam that disrupts the environmental conditions of aquatic species downstream.

Tidal power

The energy in the moving water of tides can also be used to produce electricity. Tidal power stations generate electricity in a similar way to hydro-electric power stations. A dam wall is built across the entrance to a bay or inlet, and moving water is passed through turbines to produce electricity. Typical hydro-electric schemes channel water in only one direction, out of the dam, but tidal power stations can use the incoming and outgoing (flood and ebb) tides to generate power. However, large volumes of water are needed to generate large amounts of power. Several major tidal power stations are currently operating around the world, including on the Rance River estuary in France, in Canada’s Bay of Fundy, Kislaya Guba in Russia and South Korea.

Tidal power is unlikely to contribute very much to the world’s electricity supply because few sites are suitable and they are expensive to build. They also cause massive disruption to the aquatic ecosystems where the stations are built.

Wave power

Waves can be used to provide energy. The amount of power a wave can produce is directly related to the height and period (time between successive wave fronts) of the wave. One of the devices that has been developed to generate electricity from waves involves a system of floats. These use the movement of the waves to compress air or lift a fluid to drive electricity generators. A number of offshore sites are suitable for wave power stations, but the devices can be damaged by salt water corrosion and storms.

Geothermal energy

Geothermal energy is heat energy that comes from deep within Earth. High pressures and temperatures deep within Earth constantly seek to escape to the surface. Areas of Earth’s surface where the crust is thin have high geothermal activity. In these areas, cracks and faults in the outermost layer of Earth allow heat from within Earth to come close to the surface. Water finding its way down these cracks is heated and can re-emerge at the surface as very hot water or steam in springs or geysers. New Zealand has examples of this kind of high-grade geothermal energy, and the steam is used to drive turbines to generate electricity. Heat from these sources can also be used for space heating and in industrial processes.

Water does not have to come to the surface as steam before it can be used. Portland, in western Victoria, is situated over the Otway Basin, which is a source of low-grade geothermal energy. Portland extracts its water supply from 1,400 m underground. The water comes to the surface at 60 °C and, in the past, was cooled before it could be used. Now, the heat is removed with heat exchangers and the heat is used to heat the public swimming pool complex and 14 buildings in Portland. Many new energy-efficient homes make use of geothermal energy to heat and cool their homes – in Iceland, 95% of buildings use this energy source for heating.

On a local scale, geothermal energy could be considered non-renewable because the removal of the steam or hot water will deplete the source.

However, on a global scale, the resource is so extensive that it can be considered renewable.

Geothermal energy is a clean source of energy, but there are some environmental considerations. One is local depletion of the resource, with the possibility of land subsidence if too much water is removed. Building the geothermal projects themselves can also damage ecosystems in the area. The scarcity of high-grade sources of geothermal energy and the costs associated with their development are likely to limit the use of geothermal energy within Australia. For example, using geothermal energy in Portland is economically feasible because energy had previously been used (and money spent) on cooling the water. Making use of the waste heat improved the efficiency of the system.

Biomass energy

Biomass simply refers to plant or animal material. Biomass energy is energy derived from material produced by living things. It includes waste from agricultural and forestry products, and industrial, human and animal wastes. Some forms of biomass can be used directly; for example, wood can be burnt for heating. Others can be used to produce fuels (biofuels) for transport or gas (biogas) for heating and generating electricity. All the energy in biomass originally comes from the Sun and the solar energy is converted into biomass through photosynthesis.

Biogas

Biogas is produced from the breakdown of plant and animal waste material in the absence of oxygen. The gas is a mixture of methane and carbon dioxide. It usually contains about 60% methane, which is a useful energy source. Biogas can be burnt in power furnaces, heaters and engines and even used to generate electricity.

China has about 24 million biogas digesters making use of anaerobic bacteria to convert animal and plant wastes into biogas. As well as producing energy, the residue from the biogas digesters is useful as a fertiliser.

Wood

Wood provides about 30% of the world's population with about 90% of the energy they need for heating and cooking. Wood is mainly used in developing countries, although it is used to some extent for heating homes in Australia.

One of the problems associated with burning wood is the often low efficiency of energy transfer from wood to usable heat. For example, about 90% of the heat produced in an open fireplace is wasted, and the smoke produced can lead to air pollution, especially particulates and polycyclic aromatic hydrocarbons. Closed slow-combustion heaters are more efficient than open fires and produce less pollution.

Using wood for energy at unsustainable rates can lead to deforestation, which in turn can lead to soil erosion and soil salting. In some developing countries, deforestation has reached the point where wood is no longer available to most of the population. Although wood is generally considered a renewable resource, it is clearly non-renewable in some places where it is being harvested at a rate higher than it is being replaced.

Ethanol

Ethanol is a biofuel and can be made from materials that contain sugars, starch or cellulose. It can be produced from sugar and grain crops by fermentation and distillation. Many countries are already blending ethanol with petrol to reduce their use of petroleum for transport. Blends of 5–80% ethanol with petrol are being demonstrated or introduced in Brazil, Canada, the USA and several European countries. In Australia, a blend of 10% ethanol with petrol (E10 fuel) is available and can be used in most cars.

Using ethanol may do little to reduce greenhouse gas emissions, depending on production methods. The combustion process of ethanol results in less tropospheric ozone being formed, but increases the emissions of aldehydes. Aldehydes are secondary pollutants that contribute to photochemical smog. Ethanol production is costly and, in some parts of the world, turning land over to the production of ethanol can conflict with food production.

Australia's vehicles currently use about 30,000 megalitres of motor fuel each year. To replace 1% of this with ethanol from crops we would need to double our current production of cereal crops and sugar cane or produce it from other forms of biomass, possibly on salt-affected land. On the other hand, each year we waste millions of tonnes of plant material that could be collected and used for energy production. Examples include wastes from logging and sawmilling and from food-processing industries.

Hydrogen power

As the reserves of high-density fossil fuels, such as petroleum and natural gas, become depleted, new sources of energy are being sought. One of those being investigated is hydrogen gas. Hydrogen is a very common element on Earth, making up about 90% of Earth's atoms and about 75% of its mass. However, very little hydrogen exists as hydrogen gas, which is present at only about one part per million in our atmosphere. Most of the hydrogen on Earth is bound up in compounds such as water (H_2O) or hydrocarbons such as methane (CH_4).

The combustion of hydrogen is an exothermic reaction; that is, it is a source of heat energy. In addition, hydrogen gas is very light, about one-eighth the density of natural gas, and it has an energy content per unit mass about three times that of natural gas. Another advantage of using hydrogen gas is that when it burns in air it combines with oxygen and forms water. The only other possible products of the combustion are some oxides of nitrogen that may form in the high-temperature region of the combustion. This virtually removes any air pollution problems. For these reasons, hydrogen gas is a very attractive proposition as an energy source.

One simple source of hydrogen gas is from the breakdown of water by electrolysis to release hydrogen and oxygen (Figure 14.14).

This establishes a fuel cycle through which hydrogen cycles in a way that is similar to the carbon, nitrogen and phosphorus cycles studied in Unit 1. Because hydrogen gas has to be produced from other sources, it is called a secondary fuel, unlike coal and natural gas, which can be used directly and are called primary fuels.

The problem with using hydrogen gas as a fuel is the question of how to generate it. Hydrogen gas is already in use in many industrial processes, where it is generated from the catalytic reaction of fossil fuel hydrocarbons, such as natural gas, with steam to form hydrogen and carbon dioxide. This is an expensive process and will not overcome the problems of dwindling fossil fuel reserves. Another approach is the electrolysis of water using electricity generated from fossil fuel power stations. Again, this is expensive and does not address the adverse environmental effects from the use of fossil fuels.

The ideal solution would be to generate the electricity needed for the electrolysis from renewable sources such as solar or wind. At present these processes are too costly, but further research may lead to the development of technology to allow this to happen economically.

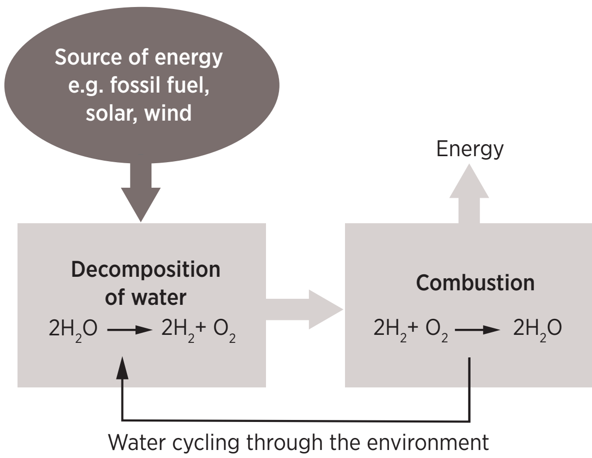


Figure 14.14. The hydrogen fuel cycle

Data analysis 14.2
Australia's use of renewable energy

Figure 14.15 shows Australian electricity generation from renewable sources from 1993–94 to 2018–19.

1. Using data from the graph, describe Australia's use of renewable energy sources from 2008–09 to 2018–19.
2. Identify the energy source that has shown the greatest increase in use in the past decade.
3. Describe two disadvantages of the use of each of the following energy sources for electricity generation in Australia:
   a) wind energy
   b) solar energy.

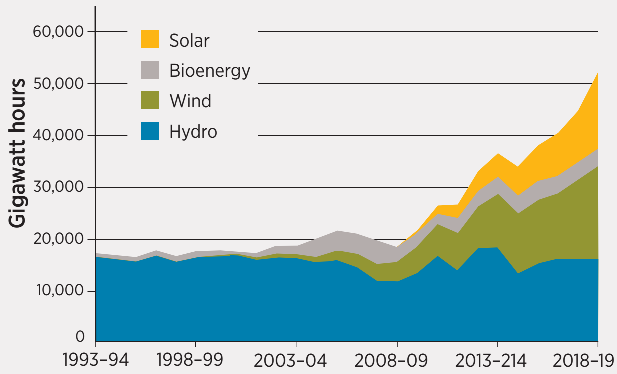


Figure 14.15. Energy generated from renewable sources in Australia

Critical and creative thinking 14.2

1. **Compare** and contrast the general advantages and disadvantages associated with renewable and non-renewable energy sources.
2. Using wood as a fuel to provide heat in a household is common and is considered a renewable form of energy, but it produces greenhouse gas emissions. **Explain** why wood is considered a renewable form of energy.
3. Complete the following table.

	Geothermal power	Hydro-electricity	Solar power	Tidal power	Wind power
Justify the classification of this resource as a renewable energy source.					
How is this energy source formed or harnessed?					
How is this energy source extracted, processed and distributed for use?					
What advantages are associated with extraction and use of this energy source?					
What disadvantages are associated with extraction and use of this energy source?					

CHAPTER

15

Sustainable energy use

15.1. Limits to fossil fuels

Changes in the rate of the use of fossil fuels over time and the concept of peak oil

Fossil fuel extraction and use have grown exponentially over the last couple of hundred years as societies around the world develop technologies and improve their standard of living. Against this ever-increasing demand, we must weigh up the limits of fossil fuels as a resource.

Fossil fuel depletion

Fossil fuels take hundreds of millions years to form within Earth but only days or months to extract from the ground in large quantities to power our activities. With Earth's population heading towards 8 billion people, our rate of extraction and use of fossil fuels is far greater than the rate that these fuels can be replenished.

Scientists agree that we will use up our fossil fuel reserves at some point in the future. There is, however, much debate about the timeframe within when this will occur. Estimates of when we will have used up all our fossil fuels range from the near future (for example, 2050) to only after hundreds or thousands of years. Factors that need to be considered in estimating fossil fuel depletion include future energy demands, technological advances in use and extraction methods, and estimates of remaining reserves.

Peak oil

Peak oil is the concept that the rate of oil extraction will reach a peak and then decline. This time of maximum oil production should not be confused with the time of oil depletion, when oil reserves are used up.

The concept of peak oil was introduced in 1956 by geophysicist M. King Hubbert, who accurately predicted that US oil production would peak between 1965 and 1970. The peak and subsequent decline was due to fewer new oil fields being discovered and output declining from existing oil fields to the stage where further oil production became uneconomic.

Hubbert also predicted that global oil production would peak between 1995 and 2000. He foresaw widespread economic consequences of the decline in oil production, including rapid increases in oil prices with resulting economic and political unrest.

The actual pattern of oil production has not followed his predictions because of a number of reasons, including new 'unconventional' oil sources being developed, the changing oil prices (affecting both consumption and the economic viability of extraction) and policies to move away from fossil fuel use (such as requiring more efficient car engines). Consequently, whether or not we will face peak oil soon is up for debate.

Nevertheless, many economists, environmentalists and petroleum industry experts believe that, because oil is a limited resource, we will hit peak oil some time soon – perhaps within a couple of years or maybe 20. In response, many governments are encouraging renewable energy and energy efficiency to reduce their economy's dependence on oil and move to a green economy.

15.2. Reducing the impacts of energy use

Energy efficiency calculations of single and multi-step conversions between different forms of energy, including potential, mechanical, kinetic, thermal, and chemical energy, to generate electricity

The implications of the first and second laws of thermodynamics in making energy choices

Sustainable use of energy requires that we think beyond sources of energy to also consider the impacts of energy use and the equity of energy availability.

We can reduce the impacts of our energy use in many ways; for example, we can modify our behaviour to reduce energy use by developing more energy-efficient technologies and by managing processes of energy extraction and use to minimise our impact on the environment.

Increasing energy efficiency

Energy efficiency is achieved by carrying out a particular operation, such as heating a house to a comfortable temperature, using less energy. For example, you might use a more efficient fuel or reduce heat loss by installing insulation, double-glazing or draught excluders.

Home heating accounts for about 15% of domestic energy use. Considerable energy savings can be made by increasing the energy efficiency of heating. The energy efficiency of different fuels, such as wood fire, gas or electricity, is affected by the number of energy conversions in the sequence between the original source of the energy and the final use. As we saw earlier, the amount of high-grade or usable energy available is reduced with each conversion step.

Electricity and natural gas are the most common sources of energy for heating in Australia. Figure 15.1 summarises the steps involved in converting the energy stored in coal to heat in the home. Energy is lost (converted into waste heat) at each of the five steps.

In contrast to using coal for heat, using natural gas involves only two energy conversions (Figure 15.2). Therefore, natural gas should be more energy efficient for space heating than electricity produced from coal (although electric heat pumps can improve the efficiency of electricity by a factor of two or three).

coal extraction ↗→ steam ↗→ kinetic energy of turbine (motion) ↗→ electricity ↗→
transmission ↗→ space heating

(↗ heat energy dissipated)

Figure 15.1. Steps in converting the energy stored in coal to heat in the home

natural gas extraction ↗→ distribution ↗→ space heating

(↗ heat energy dissipated)

Figure 15.2. Steps in converting the energy stored in natural gas to heat in the home

Energy transformations

Energy can usually only be detected when it changes from one form to another, for example, when a light bulb changes electrical energy into heat and light energy. Two laws govern these conversions as work is done.

First, energy is neither created nor destroyed; it is merely changed from one form to another. Consequently, the total quantity of energy in a system remains the same. This is known as the law of conservation of energy or the first law of thermodynamics.

The law of conservation of energy is sometimes referred to as the principle that there is no such thing as a free lunch, or you cannot get something from nothing. Take, for example, the combustion of petrol in a car engine. The chemical energy of the petrol is converted into heat and mechanical energy in the engine. The mechanical energy moves the car, and the heat produced is given off as a waste product from the exhaust and the engine itself. This heat is not useful and just contributes to heating the environment. The heat and mechanical energy produced are exactly equal to the chemical energy of the petrol used.

The other law concerned with energy conversion is the second law of thermodynamics, which can be expressed in several ways. One expression of the law states that when energy is converted from one form to another, some of it becomes degraded to a lower quality of energy. This degraded energy is less able to do work and in most conversions is released as heat. Our example of the car clearly demonstrates this.

These two laws are useful in understanding how efficient conversions are between different forms of energy. Energy efficiency is the ratio of energy input to a system to the useful energy output.

$$\text{Energy efficiency (\%)} = \frac{\text{useful energy output}}{\text{total energy output}} \times 100$$

Energy conversion is never 100% efficient. In a car, 80% of the energy of the petrol is lost as heat through the exhaust pipe and friction within the engine. The remaining 20% is converted into useful energy for turning the driveshaft, so the energy efficiency of this process is 20%. A car has further energy transformations as the mechanical energy of the driveshaft is converted into the movement of the car and further losses in friction within the transmission and between the tyres and the road. The energy efficiency of this process is 30%. Here we have a chain of energy conversions and we can calculate the overall energy efficiency by multiplying the individual efficiencies together.

20% of 30% = $0.2 \times 0.3 = 0.06$

As a percentage: $0.06 \times 100 = 6\%$

Thus, petrol is converted to movement of the car with an efficiency of 6%. This is still not the complete story as there have also been a number of energy transformations before the petrol is put into the fuel tank of the car. These include pumping the crude petroleum out of the ground, refining it and transporting it to the petrol station (Figure 15.3).

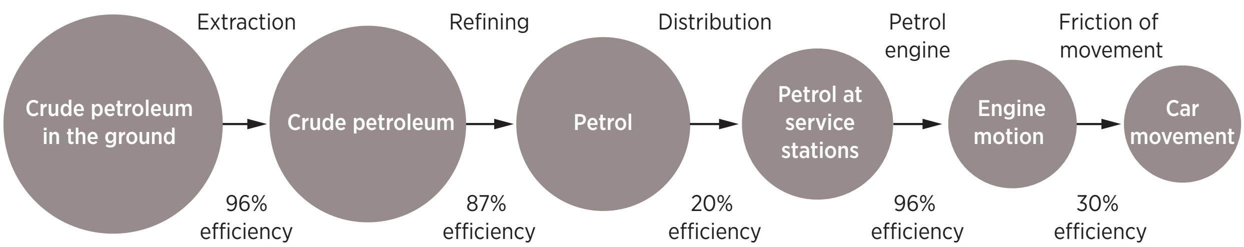


Figure 15.3. Energy efficiencies of the different stages of using petrol for transport

Implications of the laws of thermodynamics

The two laws of thermodynamics are important to bear in mind when we are assessing energy options for society. The first law of thermodynamics tells us that you can get no more energy out of a process than you put in. The second law shows that the amount of useful energy is reduced by conversions. Therefore, the amount of useful energy that can be obtained from any source (such as coal, oil or natural gas) is determined by the following relationship:

Useful energy = total energy in the resource − energy needed to obtain and process the energy (first law) − energy lost in obtaining and processing (second law)

The second law also tells us that any high-grade energy source cannot be used as such a high-grade energy source again. Once petrol is burnt in a car engine, its high-quality energy is lost forever. Therefore, our high-grade energy resources are continually being run down. Some renewable energy sources, such as solar energy, are high-grade sources of energy and will be able to replace fossil fuels, but they still need an input of energy to collect and concentrate them. The laws of thermodynamics and the fact that fossil fuels are a limited resource highlight the need for the development of renewable energy and energy conservation strategies. Some of these issues will be examined in the rest of this area of study.

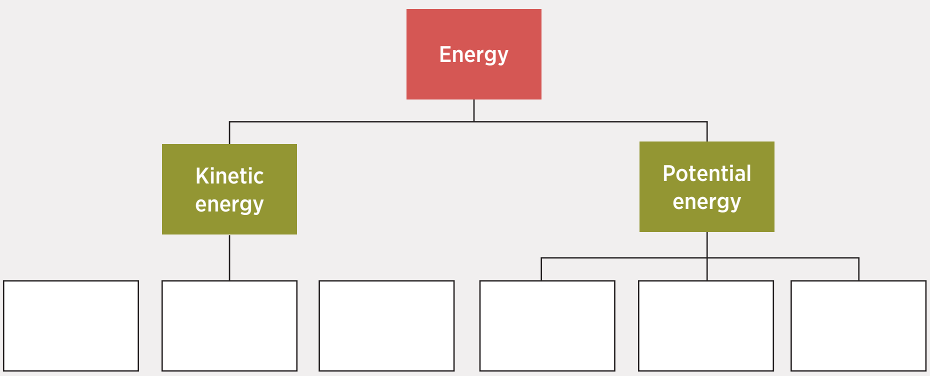
Critical and creative thinking 15.1

1. a) Complete the diagram below by categorising the following types of energy as either potential or kinetic: chemical energy, gravitational energy, electrical energy, wind energy, thermal energy, nuclear energy.

   b) With reference to the diagram, explain how you made the distinction between the types of energy that were classified as either kinetic or potential.

2. **Classify** the following according to their type of energy:

   a) a person running
   b) a car exhaust
   c) a stored body of water
   d) a stationary wind turbine
   e) carbohydrates
   f) powerlines
   g) a water turbine in action
   h) a lump of coal.



15.3. Rehabilitating mine sites

Mechanical and biological processes involved in rehabilitating sites from which energy has been sourced

It is also important to consider the environmental impacts of extracting our energy sources and how we can rehabilitate sites such as mines.

Land rehabilitation is the process of returning land to its former state after mining (such as for coal) has resulted in damage. Open-cut mines, for example, can span vast areas, destroying ecosystems and habitats and displacing species. While Australia has legislative requirements for mine operators to reduce environmental impacts, disruption cannot be avoided and operators are required to rehabilitate the land once a mine has closed.

There are three key modes of rehabilitation: mechanical, chemical and biological.

Mechanical rehabilitation involves physically moving components of a site to, from or within the site. This could be removing contaminated soils through excavation or replacing soil lost to the mining process.

Chemical rehabilitation involves ensuring the chemical properties of the mine site are returned to normal and safe levels equivalent to that of the pre-mine site. This may be as simple as applying fertiliser to newly deposited top soil or it may require elimination of harmful chemicals that were deposited due to the mining process.

Biological rehabilitation often involves replanting and reintroducing life to the mine site. It may also involve the use of biological processes (such as biogeochemical cycling done by bacteria) to help rehabilitate and stabilise a mine site.

All of these concepts are vital in ensuring that our energy consumption is sustainable, that we get to enjoy both the benefits of energy use and the natural environment, and that future generations and communities around the world also have the opportunity to share in these resources for years to come. Achieving a balance between the positive and negative aspects of energy extraction and consumption is vital for the long-term health of all the species found on Earth.

15.4. The potential for renewable energy in Australia

The extent to which different energy sources can supply current and projected base and peak load energy needs, and how these can be met at individual and societal levels

Electricity in Australia is generated mainly by coal-fired power stations. To genuinely reduce fossil fuel emissions, alternatives to fossil fuels must be found. Coal is what is known as a baseload fuel. This means coal is burnt continuously to provide constant and reliable energy outputs. Renewable energy sources are often criticised as not being reliable enough to provide baseload power. For example, wind energy is only produced when the turbines rotate, so if a turbine stops rotating it stops producing energy. In order to provide the necessary baseload power it is important to choose appropriate renewable energy sources. Currently the technology exists for biogas to be used as a baseload renewable energy, but the production capacity is small.

If Australia is to transition to renewable energy, significant investment is needed in technology and infrastructure. Research and development into thermal power plants, photovoltaic cells, wave power and geothermal power generation all show promising results in producing baseload power for reliable electricity.

Another possible strategy is to decentralise energy resources through storage. Rather than generating electricity at one central power plant and delivering it to homes through transmission lines, homes could generate their own electricity through photovoltaic cells and store the energy generated during the day in a battery to be used at night when solar baseload energy is not being produced.

Overall the cost of transitioning to renewable energy production is very high; however, when the cost of gas and coal extraction is factored in along with the cost of technology and infrastructure needed for carbon sequestration (if we continue to use fossil fuels) the cost of transitioning is significantly less. With the implementation of suitable government policies, there is no financial or technological reason why Australia cannot reduce fossil fuel use by 50% by 2040.

15.5. Building a sustainable energy future

Options for building a sustainable energy future that produces lower greenhouse gas emissions and supplies reliable and affordable energy services: improving resource efficiency; increasing the efficiency of energy conversion devices; replacing fossil fuels with non-fossil fuel energy sources; and reducing personal energy consumption

As the world's population increases, the need to supply energy to the growing population also increases because societies need energy for social and economic development as well as welfare and health. Renewable energy sources are becoming increasingly necessary to supply this demand in a sustainable way. Growing renewable energy markets offer opportunities including energy security, energy access, social and economic development, climate change mitigation and a reduction in environmental health effects of non-renewable energy sources. With these opportunities come challenges, but the challenges can be relatively easily overcome with the right government policies and technological innovation.

Using non-fossil energy sources

Hydro-electric power

Hydro-electric power is technically mature with a large power station in Australia, the Snowy Mountains Hydro-Electric Scheme.

Geothermal energy

Geothermal energy is usually converted into electrical energy by heating water to generate steam to turn turbines. This is a multi-step conversion, and therefore loses energy at each step making it as inefficient as coal, but it is a clean energy source.

As a form of energy generation the technologies needed are mature; however, they are often not located in areas where geothermal energy is close to the surface. To maximise this form of energy generation, new plants would need to be built where the geothermal energy is not too deep to extract.

Wind energy

Wind energy is emerging as a dominant global energy source because it is readily available and efficient in converting wind into electricity. In traditional coal-fired energy production, coal is burnt to heat water to generate steam to turn a turbine. With wind power there is no step between the energy source (wind) and turning the turbine. The Victorian State Government has invested heavily into wind energy over the past 5 years in response to the Victorian Renewable Energy Target. The Victorian renewable energy generation capacity is expected to exceed the minimum target of 6,341 MW. As of June 2019 there was 6,098 MW renewable energy installed – approximately 2,000 MW of that is wind power.

Biomass energy

Biomass energy is a versatile form of energy that can be used for transport (using biodiesel), electricity generation, cooking and heating. Biomass energy can use a variety of by-products from other industries such as wood from forestry and plant material (such as sugarcane waste) and animal dung from agriculture. Using waste material as biomass energy serves a dual purpose of waste reduction and energy generation, making it a versatile and sought after renewable energy source. Large-scale use of biomass energy would require huge amounts of land to produce the biomass, so it is more realistic to develop this sort of energy for small-scale community use.

Ocean energy (tide and wave)

Several wave energy projects have been planned in Australia, but to date there have been no significant advances. However, the many ocean energy generators around the world show that the concept is sound.

Increasing the efficiency of energy-conversion devices

Using energy more efficiently could greatly reduce the amount of energy used and, therefore, the greenhouse gas emissions affecting Earth's climate. To reduce emissions, governments and the scientific community have largely focused on energy supply options (renewables vs non-renewables). However, the International Energy Agency says that improvements in energy efficiency will provide the largest savings at the least cost.

Improving energy efficiency requires investigating the potential efficiency gains in each device in an energy network (Figure 15.4). Energy-conversion devices are those in which energy is converted from one form to another. For example, energy from a power station (electricity) is converted into a more useful form (light) by an energy-conversion device (lightbulb).

When considering the efficiency of devices, electricity is always used as the comparison because electricity is a high-quality form of energy. Electricity can be easily converted into mechanical energy which is another high-quality form of energy. Devices that convert one form of mechanical energy into another (gearbox) or electrical energy into mechanical energy (electric motor) have a similar energy efficiency.

However, when the input or output of energy of a device is heat, the energy value of the heat must be downgraded into its mechanical energy equivalent. This is why homes that are passively heated and cooled are particularly energy efficient. No heat–cool conversion device is needed, so the energy efficiency rate is high.

Reducing personal energy consumption

There are a number of ways that people can reduce their personal energy consumption to reduce greenhouse gas emissions. Turning off appliances such as televisions and computers rather than leaving them on standby can greatly reduce energy use, as can choosing energy-efficient appliances. Using heating sparely (for example, not setting thermostats over 21 °C) can also reduce greenhouse gas emissions.

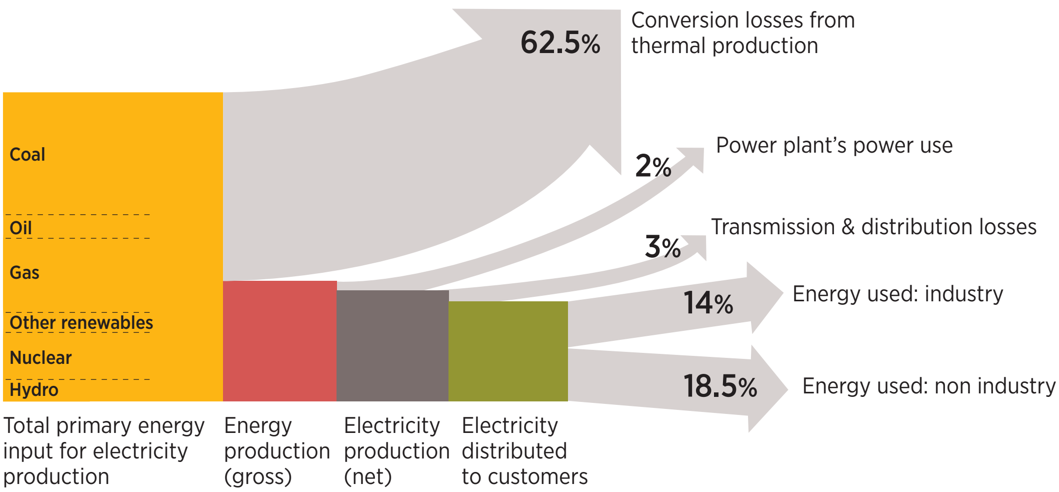


Figure 15.4. Only a small proportion of the energy in fuel sources for electricity production reaches end users

EXPLORING SCIENCE 3.
Satellites are giving us a commanding view of Earth's carbon cycle

Pep Canadell, CSIRO Scientist and Executive Director of the Global Carbon Project; Alex Held, Principal Research Scientist, CSIRO; Cathy Trudinger, Senior Research Scientist, CSIRO; Peter Rayner, Professional Fellow, University of Melbourne; Vanessa Haverd, Research Scientist, Carbon Water Observatory, CSIRO

This article was originally published in The Conversation, *13 October 2017. https://theconversation.com/satellites-are-giving-us-a-commanding-view-of-earths-carbon-cycle-85539*

The job of monitoring Earth's carbon cycle and humanity's carbon dioxide emissions is increasingly supported from above, thanks to the terabytes of data pouring down to Earth from satellites.

Five papers published in *Science* today [October 13 2017], provide data from NASA's Orbiting Carbon Observatory-2 (OCO-2) mission. They show Earth's carbon cycle in unprecedented detail, including the effects of fires in Southeast Asia, the growth rates of Amazonian forests, and the record-breaking rise in atmospheric carbon dioxide during the 2015–16 El Niño.

Another satellite study released two weeks ago revealed rapid biomass loss across the tropics, showing that we have been overlooking the largest sources of terrestrial carbon emissions. While we may worry about land clearing, twice as much biomass is being lost from tropical forests through degradation processes such as harvesting. The next step in our understanding of Earth's carbon dynamics will be to build sensors, satellites and computer models that can distinguish human activity from natural processes.

Can satellites see human-made emissions?

The idea of using satellites to keep track of our efforts to reduce fossil fuel emissions is enticing. Current satellites can't do it, but the next generation is aiming to support the monitoring at the level of countries, regions and cities.

Current satellite sensors can measure CO_2 levels in the atmosphere, but can't tell whether it is coming from the natural exchange of carbon with the land and oceans, or from human activities such as fossil fuel burning, cement production, and deforestation.

Likewise, satellites cannot distinguish between natural and human changes in leaf area cover (greenness), or the capacity of vegetation to absorb CO_2.

But as the spatial resolution of satellites increases, this will change. OCO-2 can see features as small as 3 km^2 while the previous purpose-built satellite GOSAT is limited to observing features no smaller than about 50 km^2.

As resolution improves, we will be able to better observe the elevated CO_2 concentrations over emissions hotspots such as large cities, bushfire regions in Africa and Australia, or even individual power plants and industrial leaks.

By combining these sensing techniques with computer models of the atmosphere, oceans and land, we will be able to separate out humanity's impact from natural processes.

For example, we have long known that atmospheric CO_2 concentration rises faster during an El Niño event, and that this is mainly due to changes on land. Only with the bird's-eye view afforded by the OCO-2 satellite could we see that each of the tropical continents reacted so differently during the recent big El Niño: fire emissions increased in Southeast Asia, carbon uptake by forests in Amazonia declined, and soil respiration in tropical Africa increased.

Similarly, we can now examine the processes behind the extraordinary greening of Earth over recent decades as CO_2 levels have climbed. Up to 50% of vegetated land is now greener than it was 30 years ago. The increasing human-driven CO_2 fertilisation effect on vegetation was estimated to be the dominant driver.

We now have satellites that can study this process at spatial resolutions of tens of metres – meaning we can also keep tabs on processes that undo this greening, such as deforestation.

What's in store

The coming decade will see the development of yet more space sensors and modelling tools to help us keep tabs on the carbon cycle.

GOSAT-2 will replace the current GOSAT, offering significantly improved resolution and more sensitive measurements of CO_2 and methane (CH_4), another important greenhouse gas.

Meanwhile, the GeoCarb satellite will be launched into a stationary orbit over the Americas to measure CO_2, CH_4 (largely from wetlands in the tropics), and carbon monoxide (from biomass burning). It will keep an eye out for any large leaks from the gas industry.

The BIOMASS and FLEX satellite missions will provide better global estimates of forest height and carbon density, and of plants' photosynthetic capacity, respectively.

Aboard the International Space Station, an instrument called GEDI will also estimate vegetation height and structure, and combined with ECOSTRESS will assess changes in above-ground biomass, carbon stocks and productivity.

In Australia, we are developing an atmospheric modelling system and a dynamic vegetation model able to ingest the latest generation of satellite and ground-base observations to map carbon sources and sinks over the entire continent.

Through the Terrestrial Ecosystem Research Network (TERN), we are preparing to take full advantage of these new missions, and help validate many of these space-borne estimates at TERN's Supersites and other key sampling plots.

With the wealth of information set to be generated by space sensors, as well as Earth-based observations and computer models, we are moving into an era when we will have an unprecedented ability to track humans' impact on our atmosphere, lands and oceans.

Students undertake a student-designed scientific investigation in either Unit 3 or Unit 4, or across both Units 3 and 4. The investigation involves the generation of primary data related to biodiversity, environmental management, climate change and/or energy use, and should be inspired by a contemporary environmental science challenge or issue. The investigation draws on knowledge and related key science skills developed across Units 3 and 4, and is undertaken by students in the laboratory and/or in the field.

When undertaking the investigation students are required to apply the key science skills to develop a question, state an aim, formulate a hypothesis and plan a course of action to answer the question, while complying with safety and ethical guidelines. Students then undertake a controlled experiment, correlational study or fieldwork to generate primary quantitative data, analyse and evaluate the data, identify limitations of data and methods, link experimental results to scientific ideas, discuss implications of the results, and draw a conclusion in response to the question. The presentation format for the investigation is a scientific poster constructed according to the structure outlined on pages 11 and 12 of the study guide. A logbook is maintained by students for record, assessment and authentication purposes.

Outcome 3

On completion of this unit the student should be able to design and conduct a scientific investigation related to biodiversity, environmental management, climate change and/or energy use, and present an aim, methodology and method, results, discussion and a conclusion in a scientific poster.

AREA OF STUDY 3

How is scientific inquiry used to investigate contemporary environmental challenges?

Key knowledge

Area	Section
Investigation design	
• environmental science concepts specific to the selected scientific investigation and their significance, including definitions of key terms	
• characteristics of the selected scientific methodology and method, and appropriateness of the use of independent, dependent and controlled variables in the selected scientific investigation	
• techniques of primary qualitative and quantitative data generation relevant to the selected scientific investigation	16.1
• the accuracy, precision, reproducibility, repeatability and validity of measurements	
• the health, safety and ethical guidelines relevant to the selected scientific investigation	
Scientific evidence	
• the nature of evidence that supports or refutes a hypothesis, model or theory	16.2
• ways of organising, analysing and evaluating primary data to identify patterns and relationships including sources of error and uncertainty	
• authentication of generated primary data through the use of a logbook	16.4
• assumptions and limitations of investigation methodology and/or data generation and/or analysis methods	16.3
Science communication	
• conventions of science communication: scientific terminology and representations, symbols, formulas, standard abbreviations and units of measurement	16.5, 16.6
• conventions of scientific poster presentation, including succinct communication of the selected scientific investigation, and acknowledgements and references	
• the key findings and implications of the selected scientific investigation	

CHAPTER

16

Evaluating evidence and communicating science

CASE STUDY 14.1
Chickens in fancy dinner suits

Invasive species have been an issue in Australia since early colonisers arrived and brought European animals to Australian shores. One of the most destructive of these was foxes, originally brought to Australia for the purpose of hunting. Foxes quickly multiplied and caused severe damage to Australian native fauna. Dr Patricia Corbett, as the head of the Middle Island – Maremma Penguin Project, knows only too well how damaging foxes can be.

This project was established in response to a local population of little penguins that resides on Middle Island, a small island just off the beach in Warrnambool, Victoria. After calling this island home for some time, a devastating event occurred that almost wiped out the entire colony. Between 2000 and 2005, foxes decimated the penguin population by swimming to the island during breeding season and killing large numbers of penguins. During this time the population decreased from 800 returning penguins to only four, which meant the colony was categorised as locally endangered.

Figure 16.1. Maremma dogs are guarding penguins on Middle Island. Credit: Warrnambool City Council CC BY 2.0

Terrestrial fox control, including baiting and catching, was well underway through the Warrnambool council, but this was not controlling the foxes. No one knew how to help these penguins until a third-year student at Deakin University was chatting with a local chicken farmer. The farmer, Alan ‘Swampy’ Marsh, was known as an eccentric character with some innovative ideas; he had for example been using Italian sheepdogs, maremmas, to protect his chickens from foxes. When the student told Swampy the issue they were having with foxes, he responded with the idea of trying out maremmas on the island; after all, “penguins are just chickens in fancy dinner suits”. This was the beginning of the Middle Island Project.

Figure 16.2. Little penguins.
Credit: JJ Harrison CC BY-SA 3.0

Figure 16.3. Maremma guardian dog Tula.
Credit: Warrnambool City Council CC BY 2.0

The very first maremma to be trialled on the island was the famous Oddball, who has been dubbed as the saviour of the penguins. However, she was only on the island for a trial period of four weeks to establish whether using maremmas was a viable option. Oddball proved that having dogs guarding the penguins was an effective method of deterring foxes, but she was too devoted to her human companions to be a permanent part of the program. Rather than continuing to use maremmas that were used to living on a farm, the program bought some puppies that could be trained from an early age to think of the island as their territory and the penguins as the animals they were guarding. Since becoming the head of the program, Corbett has been the main dog trainer and organiser of the dog's shifts.

Throughout the summer the dogs stay overnight on the island for five out of seven days, and throughout the winter they are taken to the beach to mark their scent each day. Over time, the foxes became smarter, and more management and new ideas were needed from Corbett and her team. This has led to increased monitoring of early arrivals of penguins and increased presence of the dogs, even when it seems impossible to access the island. Through increased monitoring and presence from the dogs, the penguin population has increased; the count in 2017 stood at 182 birds and continues to stay steady.

This program is one of a kind and paves the way for new research with maremmas and other dogs. An example close to the Middle Island Project is the restoration of the eastern barred bandicoots near Hamilton, Victoria. Maremmas are being trained to take care of the bandicoot territory while steering clear of the animals so that the bandicoots do not get scared (as dogs are predators). Corbett suggests that this is a new area of study in Australia that could be used for much more, including crop protection and the discovery of endangered or invasive species. It is an exciting area of research that holds a lot of potential for the future.

Figure 16.4. Middle Island.
Credit: philip.mallis CC BY-SA 2.0

Figure 16.5. Maremmas returning from Middle Island.
Credit: Warrnambool City Council CC BY 2.0

16.1. Primary and secondary data

Techniques of primary qualitative and quantitative data generation relevant to the selected scientific investigation

Primary data is data that is collected by the investigator themself from firsthand experiences through experiments or fieldwork. The advantages of using primary data are that the data is specific to the investigation and there should be no question as to the quality of the data because the investigator has control of the data collection. Also, it is possible to make note of, and obtain, any additional data and information during the study that may be of assistance when analysing and interpreting the results.

Secondary data has been collected by someone else in different studies, surveys or experiments. Secondary data can provide you with information to help you start your own investigation, and it also provides data for you to compare with your own findings. The advantage of using secondary data is that the research has already been done, but there is no guarantee that the data is of good quality. Also, unless stated in the research, it is hard to know if the secondary data was collected under comparable conditions to the data collected from primary sources.

Student activity 16.1
Primary and secondary data

Complete the table below to check your understanding of primary and secondary data.

Point for comparison	Primary data	Secondary data
Definition		
Main source		
Data time		
Level of control over data		
Collection time		
Specific to researcher needs		
Accuracy, reliability and validity		

Research project B.1
Topic and data sources

In this area of study, you will conduct an investigation, using secondary data, into how scientific endeavours have contributed to minimising human impacts on Earth's systems. Your teacher will explain the details of this task.

1. Decide what sort of topic you are going to investigate. Record the topic in your logbook.
2. Decide on the sources of secondary data that you will use. Record your ideas on secondary sources in your logbook.

16.2. Types of evidence

The nature of evidence that supports or refutes a hypothesis, model or theory

When gathering data for your report, you will have access to lots of information. Gathering a variety of information will make you informed, and the way that you think about and process this information will create good ideas, and therefore allow you to produce a high-quality report. However, not all information is evidence.

The *Cambridge Dictionary* defines **evidence** as “anything that helps to prove that something is or is not true”. Your ability to distinguish weak from strong evidence will depend on how critically you can analyse the data.

Using a variety of different sources of secondary data will help to validate your research. Different sources can include journals and periodicals, encyclopedias, textbooks, non-fiction books and the internet. Figure 16.6 shows you a guideline to determining whether evidence from different sources is weak or strong. The strongest evidence is good-quality scientific evidence (that is, evidence that has been generated by a large group or is supported by multiple sources).

The pyramid in Figure 16.6 shows the hierarchy of scientific evidence, from weakest at the base to strongest at the peak.

The pyramid shape demonstrates the amount of evidence you need at each level – a lot of weak evidence or a smaller amount of strong evidence.

Sources of evidence listed in the square in Figure 16.6, such as anecdotes and fake news websites, are all non-scientific. Unfortunately, a lot of information posted online is unscientific and written by people who don’t (or can’t) distinguish strong from weak evidence (even if they *think* they do).

To assess the quality of online data, first see who has published it. Look at the site’s url – a ‘.gov’ site will have reliable information, while a ‘.org’ site may be credible, depending on the organisation behind it. Many science publications are now found online, such as *Cosmos* magazine and *National Geographic*. Do your research: find internet sites that are run by science organisations, or literary organisations, not just a person or organisation who has created a page to voice their own agenda or opinion.

Your own beliefs or view can sway the evidence that you try to collect and the way you interpret evidence. It is important to be as objective as possible in collecting and analysing evidence.

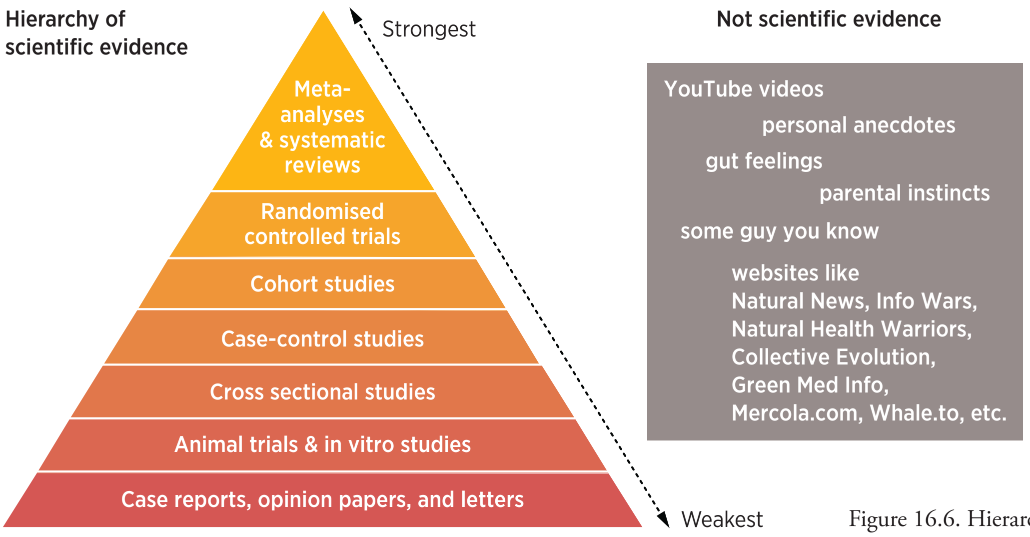


Figure 16.6. Hierarcy of scientific evidence

Research project B.2
Ensuring strong evidence

At this step in your investigation, it is important to ensure that you base your data on strong scientific evidence, rather than media-based opinions or weak evidence.

As you gather data for your investigation, ask yourself the following questions.

1. How do I distinguish between true and false information?
2. How am I going to determine if this evidence is from a credible source?

Student activity 16.2
Opinions and evidence

Complete the table below in your workbook by reading each idea in the first column. In the middle column you should write your current belief or opinion about the idea.

In the final column, outline the evidence you have to support your own current belief.

An example has been done for you for the first idea.

Idea	What do I currently believe?	Evidence for this belief
February 2020 recorded the hottest ever sea temperatures on record in the Great Barrier Reef (GBR) ecosystem	'True! I believe that sea temperatures are rising and the 2020 summer showed the hottest ever GBR recorded sea temp'	My teacher showed us a graph created by the Bureau of Meteorology. I have read an article on *The Conversation* about bleaching on the GBR
Animal agriculture is responsible for 91% of all Amazon rainforest destruction		
Climate change is contributing to the worst extinction event since the extinction of the dinosaurs 65 mya		
2.7 billion people live in areas that experience severe water scarcity issues		

16.3. Assessing evidence quality

Assumptions and limitations of investigation methodology and/or data generation and/or analysis methods

Scientific evidence comes from a variety of sources, including research findings and expert opinion. In Year 11 you learnt about how to ensure a scientific investigation is valid. Well-designed and carried out research based on scientific principles will minimise biases and take into account sources of error. Scientific papers published in peer-reviewed journals have been evaluated by other scientists to make sure they are scientifically rigorous and of high quality. The meta-analyses and systematic reviews that are at the top of the hierarchy of scientific evidence shown in Figure 16.6 look at lots of different published research studies on the same topic to see if their findings are consistent, and thus are extremely strong evidence.

People who are very skilled and experienced in their field can provide expert opinions based on their professional knowledge. However, experts should not give opinions on areas outside their expertise. For example a staff member from a zoo could provide expert options on animals in a zoo context, but could not give expert evidence on domestic pets.

Scientific evidence can also be affected by bias – either deliberate or accidental. An example of scientific bias is a researcher who deliberately removes data that does not support the study's hypothesis. Bias can also benefit certain groups. For example, if more research funding is granted to conservation studies of mammals than of insects, then insects may be less well managed. The case study below looks at unintentional errors and bias in the study of wolves that have led to a well-ingrained cultural misunderstanding of wolf behaviour.

CASE STUDY 16.2
Hierarchies in wolf packs

An example of scientific evidence that was accepted despite limited validity is that of the concept of 'alpha' wolves – a lead male and a lead female – in a wolf pack. Swiss animal behaviour scientist Rudolph Schenkel described the concept in an article he published in 1947 called 'Expression studies on wolves' based on his study of wolves during the 1930s and 1940s in the Zoo Basel, Switzerland. Schenkel described how the dominant male and female wolves in a pack constantly controlled the behaviour and reproduction of the other pack members, and he drew parallels with domestic dogs. He concluded that dogs and dog-like animals (such as wolves) that live in packs have a structured social hierarchy with the alpha male and female constantly competing against other pack members to maintain ultimate authority them.

Although Schenkel studied only captive wolves, his work became the foundation for more studies and more widely published results. Wildlife biologist Dave Mech used Schenkel's and other studies as the basis for his PhD research, again with captive wolves, this time in Isle Royale National Park in Michigan. In 1970 Mech published a book called *The wolf: the ecology and behaviour of an endangered species* in which he coined the term 'alpha wolf'.

Dave Mech is a highly respected expert in wolf behaviour and was the Chair of the IUCN Wolf Specialist Group from 1978 to 2013. This status meant that his research was widely accepted and underwent little scrutiny or questioning. But again, findings from captive animals were being extended to apply to all members of the species. Scientific research was being applied beyond the limitations of the study, even influencing how people trained domestic dogs.

It was not until 1999 that Mech and others corrected their misunderstanding of wolf pack structures.

In his article published in the *Canadian Journal of Zoology*, 'Alpha status, dominance and division of labor in wolf packs', Mech correctly describes wolf pack structure as observed in wild wolf populations. It turns out that wolves actually live in family structures: the parents are the dominant animals and the subordinate animals are the children. In contrast, the captive wolves from the initial studies were unrelated adults that lived together and therefore behaved in a way not found in wild packs. Mech has spent most of the rest of his career, and numerous published articles, debunking the idea of alpha males that his and others' research constructed.

Research project B.3
Validity of scientific research

When analysing scientific research for validity you can ask yourself the 'who','what', 'when' and 'why' questions.

- Who wrote, published or made the source?
  - Is the author's personal perspective obvious in the source?
  - Is the author a member of a particular group, religion or organisation?
- What type of source is it?
  - Was the source created at the time of the research or after?
- When was the source written, published or made?
  - How old is the source?
  - Is it written by the person who conducted the research or by another person afterwards?
  - Is the source a complete account of the research or does it partially describe the research?
- Why was the source written or published?
  - Was it produced to entertain, persuade or argue a point of view?
  - Does the creator have anything to gain for producing the source?
  - What other research might have been happening at the time that could have influenced the source?

Use the table below to assist in your decision-making and analysis of scientific sources to help construct your investigation.

Research topic:			
Hypothesis:			
Sources	**Pros and cons**	**Category of source**	**Reference**
Source 1			
Source 2			
etc.			

16.4. Organising data

Authentication of generated primary data through the use of a logbook

When you have found a source of information that you could use for your investigation, you need to take notes. Don't simply copy slabs of information from the source material. While you can quote from material to back up your statements, your investigation should be written in your own words. Record your notes in your logbook. A table is often a good way to to organise the data (see Table 16.1).

If you are investigating several ideas, then it's best to create a separate table for each idea. In the table, you will need to summarise the information (for example, in brief dot points) and record the source of the material so that it can be correctly referenced in a list at the end (see 16.8 'Referencing sources', p 197).

When you have collected data and information from a number of sources, you will need to go back through your notes to validate the information. If you find a number of different reputable sources have provided similar, if not the same, information, then it is safe to assume that the information is valid and would be good to use. If some information contradicts the rest, it does not mean that it is not valid; it may just mean that you will have to look for more sources to help validate this information if you want to use it in your investigation. The greater number of reputable sources you can find that provide the same or similar information, the more confidence you can have that the information is valid.

Table 16.1. Example of logbook table for collection of secondary data

Topic/concept:		
Source	**Notes**	**Validity**
1.		
2.		

16.5. Science communication

Conventions of science communication: scientific terminology and representations, symbols, formulas, standard abbreviations and units of measurement

A scientific research report should follow the general structure of:

- introduction – this first paragraph should introduce the topic, including why the topic is of importance
- body paragraphs – each paragraph should cover one main idea. If you are switching to another idea or concept, start a new paragraph. Avoid very long or very short paragraphs and make sure you are providing evidence for any statements being made
- conclusion – this should summarise main findings and also relate to the title of the investigation. It can also include any potential future research.

Scientific research should be written in an objective and unbiased style and should not switch between first- and third-person narrative. It is important to decide on the audience and the purpose of the presentation.

Is the audience going to be young children, teenagers, adults? Does the audience have a science background? Do they already know about the topic you are presenting? Is the investigation presenting the findings of an experiment or fieldwork? Is it an informative piece of writing? These questions will help decide the tone and level of language used in your presentation and also the way it is presented.

Through your recording of research notes in your logbook, you should have established the valid information you are going to include. It is now a matter of writing the notes you have taken into concise and coherent sentences and paragraphs. Make sure your information makes sense and it flows well from one lot of information to the next.

If you include diagrams, tables or graphs, refer to them in the text. For example: ‘Figure 16.7 shows that atmospheric carbon dioxide levels increased in the 50 years to 2010’ or ‘Atmospheric carbon dioxide levels increased in the 50 years to 2010 (Figure 16.7)’. Only include such visual elements in your report to validate and enhance the information you are providing, not simply as decoration.

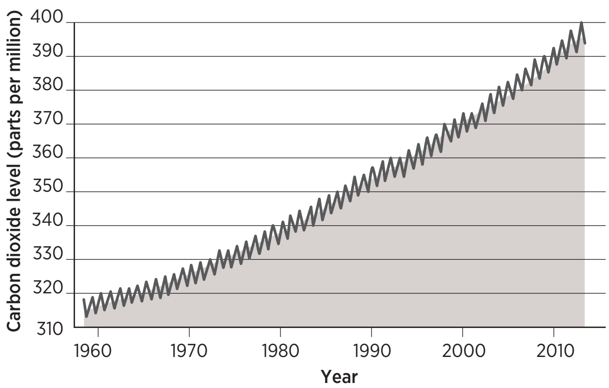


Figure 16.7. Monthly carbon dioxide levels

16.6. Representing data

As we have seen, data representations and models are commonly used in explaining weather patterns and systems all around the world.

Scientists use data modelling to predict and visualise large-scale changes to one aspect of the environment, such as weather patterns, sea level or forest distribution.

You may choose to present data models when explaining the science behind your chosen topic (see the example in Figure 16.8). Other data representations that you may choose to include are graphs or tables that you create yourself after analysing various sources of valid secondary data.

You may also choose to create an infographic display when organising large chunks of your secondary data. Infographics are visual representations of data that use graphs and images to convey a concept (see Figure 16.9). Creating an infographic may allow you to break down and simplify some of the information in your secondary data.

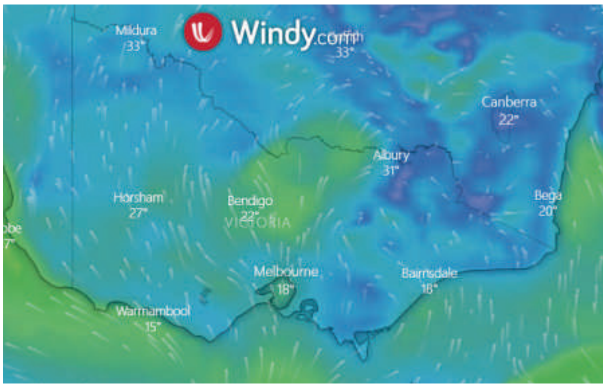


Figure 16.8. Websites like windy.com use data modelling to predict weather patterns. Credit: Screenshot from windy.com © OpenStreetMap contributors

When choosing how best to represent the data you collect, consider including appropriate visual aids to representation.

Finally, remember the advantages of presenting data in the form of scientific diagrams and drawings. Although you are analysing secondary data in this task, diagrams and photographs may be suitable representations of the information (see Figures 16.10 and 16.11).

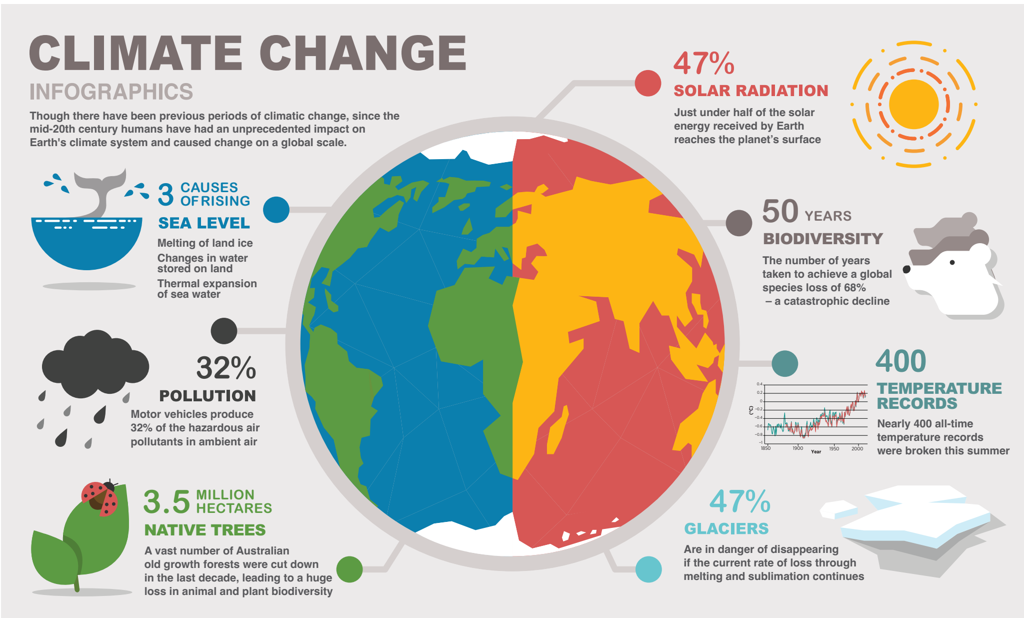


Figure 16.9. Infographics break down and simplify complicated messages into visually engaging bursts of knowledge

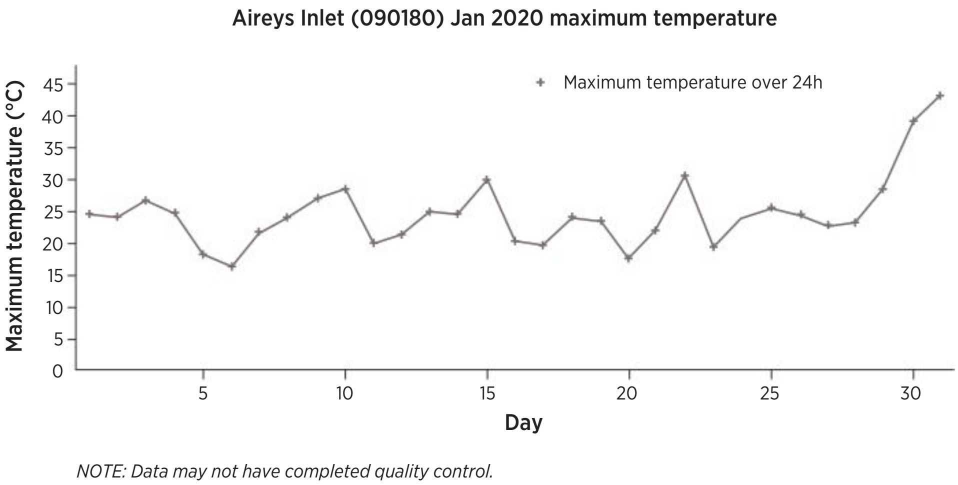


Figure 16.10. Graphs can allow us to organise large amounts of statistics or observations into easy-to-analyse information

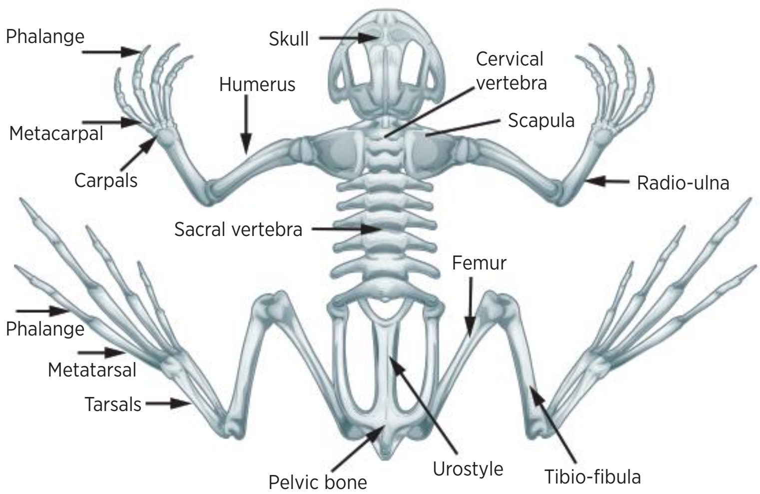


Figure 16.11. Scientific diagrams can be used to explain and display concepts even when you are analysing secondary data. Credit: designed by Freepik.com

16.7. Social, economic, legal and political considerations

Science as a human endeavour explains the nature of science, how science is shaped and how science shapes society; it serves to describe the intentions of science. By posing questions and investigating using evidence, science constructs the most robust theories to explain aspects of the natural world. These theories are not fixed and change as new evidence becomes available. New evidence can be generated by new technologies or new ways of thinking and doing – each of these helps society to advance. These technologies and new ways of thinking are influenced by the dominant society of the time. Remember that once people thought Earth was flat and that smelly air caused diseases. Cultural, legal, economic, political and ethical factors all shape the direction of scientific endeavour as a process.

Sociocultural

Sociocultural influences are those that are directed by the dominant social culture of the time and reflect the priorities of that culture. During the 1950s, 1960s and 1970s, humans made significant advance in space travel, culminating with the Moon landings. There were several reasons that science focused their energies on space during this time, including international competition and new technologies developed during the Second World War. More recently, advances in renewable energy technologies and environmental remediation reflect the dominant societal culture's awareness of global climate change.

Economic

Science has great economic value, including the ability to develop new technologies which then drive manufacturing, employment and economic growth. Technological advances have played a major role since the industrial revolution when products were first produced on a mass scale made possible by the invention of the steam engine. Development of modern technologies and development of modern cultures often go hand in hand. The economic impacts of scientific endeavour are not limited to the production of technologies but can be broadened out to other areas where science has posed questions and produced knowledge to assist in understanding. One example of this is in agriculture – by better understanding soil structure and microbial activity, farmers can produce higher yields with less harmful techniques.

Legal

The law has a large part to play in the advancement of science and science has a part to play in the application of the law. As science does not exist outside of cultural understandings, there is a need to regulate and monitor aspects of science that can influence the direction of a society. For example, biomedical advances such as genomics or engineered babies raise issues that are addressed by strong laws ensuring the integrity of human behaviour. In many aspects of society, human behaviour is regulated and enforced by legislation, such as the regulations controlling pollution. Legalisation is often shaped by the political party in power and reflects that party's agenda and priorities, including ethical concerns.

Ethics

Most formal scientific research is practised within established ethical guidelines, often set at a national level. Ethical guidelines in Australia cover treatment of animal and human research subjects as well as the ethical use of data collected from research subjects.

Student activity 16.3
Science as a human endeavour

By completing this activity, you will get a better understanding of the different aspects of science as a human endeavour. To complete the task you need to think about one issue from two different points of view: the dominant culture and a minority culture.

Choose an environmental science issue such as water pollution or the concept of peak phosphorus. With that issue in mind, answer the following questions from the two points of view.

1. Is the issue important today and will it still be in 20 years? Justify your response.
2. How did scientists come to generate their understanding of the issue?
3. What kind of experiments could have been conducted?
4. What ethical implications would have been considered in conducting these experiments?
5. Can you describe the use of the knowledge generated by studying the issue and how that knowledge can be used by various forms of society?
6. Is there a need to develop laws to regulate this issue in society? Justify your response.

16.8. Referencing sources

Conventions of scientific poster presentation, including succinct communication of the selected scientific investigation, and acknowledgements and references

All information that you collect from secondary sources should be referenced in your report. Both in-text citations and a reference list at the end of your report are an essential way of acknowledging the ideas of other people that you have included in your report.

Cite your secondary source in the text by including the author's name (or names) and the date of publication at the point where you have discussed their work in you own words. If you are using a direct quote from a secondary source, you must use quotation marks to show that the idea is someone else's exact words. Again, cite the original document and add the number of the page that the quote is taken from.

When compiling your reference list at the end of your report, remember to list each reference in alphabetical order, by name of author. If you use more than one source by the same author, then list these in order of their published date.

Some other hints for an appropriate reference list:

- Leave a full line between each reference.
- Make sure every in-text citation has a full reference listed at the end of your report, and that each reference in your list is cited somewhere in the report.
- Start your reference list on a new page at the end of your report.

As a general rule, scientific papers use Harvard -style referencing (also known as 'author–date' system), but some research fields tend to use other methods (for example, using footnotes or endnotes). Journals each decide their preferred way of setting out Harvard-style references.

Table 16.2 below shows some examples for both in-text citation and the end of report reference list.

Table 16.2. Examples of Harvard-style citation and referencing

Source type	In-text reference exemplar	End of text reference list format
Online article or web page	February 2020 showed the highest average monthly ocean temperatures on record on the Great Barrier Reef (Hughes and Pratchett, 2020).	**Author (s), date published, 'title of article', URL address (date accessed)** Hughes, T and Pratchett, M, 2020, 'We just spent two weeks surveying the Great Barrier Reef. What we saw was an utter tragedy', https://theconversation.com/we-just-spent-two-weeks-surveying-the-great-barrier-reef-what-we-saw-was-an-utter-tragedy-135197 (accessed 8 August 2020).
Book	Through interspecies association, trees gain benefit from taking part in the forest ecosystem, therefore increasing chances of survival (Suzuki and Grady, 2018).	**Author(s), date, *title of book*, publisher, location** Suzuki, D and Grady, W, 2018, *Tree: A Life Story*, Greystone Books Ltd, Vancouver.
Journal article (with more than three authors)	Molyneux et al. (2012) states that the country of Timor Leste is dominated by a central mountain ecosystem.	**Author(s) date, 'title of article', *journal title*, volume number, page number** Molyneux, N, Rangel da Cruz, G, Williams, RL, Anderson, R and Turner, NC, 2012, 'Climate change and population growth in Timor Leste: implications for food security', *Ambio,* vol. 41, pp. 832–840.

Both Microsoft Word and Google Docs have tools that can help you use the appropriate formatting to reference your work. The important part is ensuring that you are making it clear to your teacher that the ideas you have used are not your own. Plagiarism is a serious issue in VCE and learning how to cite your sources is a valuable skill.

Student activity 16.4
Citing a source

1. Create a table like Table 16.2 and reference the following sources:

a. this text book

b. an article from National Geographic website: https://www.nationalgeographic.com

c. a journal article.

EXPLORING SCIENCE 4
Drones, detection dogs, poo spotting: what's the best way to conduct Australia's Great Koala Count?

Romane H. Cristescu, Postdoc in Ecology, University of the Sunshine Coast; Celine Frere, Senior Lecturer, University of the Sunshine Coast; Desley Whisson, Senior Lecturer and Conservation Biologist, School of Life and Environmental Sciences, Deakin University

This article was originally published in The Conversation, *26 November 2020.* *https://theconversation.com/drones-detection-dogs-poo-spotting-whats-the-best-way-to-conduct-australias-great-koala-count-150634*

Federal environment minister Sussan Ley this week [23 November 2020] announced A$2 million for a national audit of Australia's koalas, as part of an A$18 million package to protect the vulnerable species.

The funding might seem like a lot – and, truth be told, it is more than most threatened species receive. But the national distribution of koalas is vast, so the funding equates to about A$1.40 to survey a square kilometre. That means the way koalas are counted in the audit must be carefully considered.

Koalas are notoriously difficult to detect, and counts so far have been fairly unreliable. That can make it hard to get an accurate picture of how koalas are faring, and to know where intensive conservation effort is needed – especially after devastating events such as last summer's bushfires.

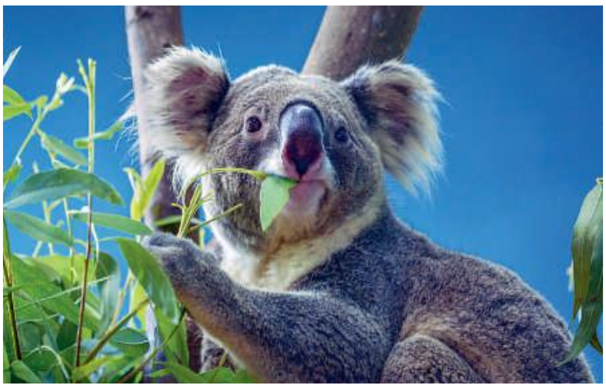


Figure 16.12. Environment Minister Sussan Ley has pledged $2 million for a national koala count

Figure 16.13. To date, estimates of koala numbers have been highly uncertain

Figure 16.14. Romane Cristescu with USC x IFAW detection dog Bear. Detection dogs have been trained to locate koala and their scats. Credit: Detection Dogs for Conservation

Figure 16.15. Everyday citizens can help with koala counting

Methods for counting koalas range from the traditional – people at ground level looking up into the trees – to the high-tech, such as heat-seeking drones. So let's look at each method, and how we can best get a handle on Australia's koala numbers.

Why we need to know koala numbers

Gathering data about species distribution and population size is crucial, because governments use it to assess a species' status and decide what protection it needs.

In announcing the funding, Ley said the new audit aims to fill data gaps, identify where koala habitat can be expanded, and establish an annual monitoring program.

So far, population estimates for koalas at the state and national level are rare and highly uncertain. For example, the last national koala count in 2012 estimated 33,000–153,000 in Queensland, 14,000–73,000 in NSW and 96,000–378,000 in the southern states.

This uncertainty can make it hard to detect changes in population trends quickly enough to do something about the threat, such as by limiting development or logging. However, the new audit can use methods not available in 2012, which should help with accuracy.

So how do you actually count koalas?

Finding a koala can be difficult. There may be few individuals spread over large areas. And koalas are well camouflaged and quiet, unless bellowing. Finally, they can sit high in the tree canopy.

In numerous research and management programs, we have observed that even the most experienced koala spotter may only see 20–80% of koalas present at a site, especially if the vegetation is thick or the terrain difficult to move through.

Making the job even harder, existing koala habitat maps can be highly inaccurate and miss unexpected hotspots. However, computer modelling using the latest methods, if carefully validated on the ground, can produce more accurate maps.

Traditional surveys involve multiple people independently searching the same area, and correcting counts based on the number of koalas each observer sees. This helps account for the difficulties in koala counting, but it's hard, slow and costly work.

Searching for koala scat (poo) also is a common method of determining koala habitat – wherever koalas spend time, they will leave scats. However, the small brown pellets are easily missed, and large surveys for scats are time consuming.

Detection dogs have been trained to locate koala scats: in one study, dogs were shown to be 150% more accurate and 20 times quicker than humans.

And because male koalas bellow during the breeding season, koalas can also be detected with acoustic surveys. Audio recorders are left at a survey sites and the recordings scanned for bellows to determine whether koalas are present.

Recently, heat-seeking drones have also been used to detect koalas. This method can be accurate and effective, especially in difficult terrain. We used them extensively to find surviving koalas after the 2019–20 bushfires.

Citizen scientists can also collect important data about koalas. Smartphone apps allow the community to report sightings around Australia, helping to build a picture of where koalas have been seen. However, these sightings are often limited to areas commonly traversed by people, such as in suburbia, near walking tracks and on private property.

Getting the koala count right

All these methods involve a complex mix of strengths and weaknesses, which means the audit will need input from koala ecologists if it's to be successful. Survey methods and sites must be chosen strategically to maximise the benefits of the funding.

Robust research data exists, but is patchy across the koala's entire range. The first step could include collating all current data, including community sightings, to determine where additional surveys are needed. This will allow for funding to be prioritised to fill data gaps.

It is promising that the announcement includes monitoring over the long term. This will help identify population trends and better understand the response of koalas to ongoing threats. It will also reveal whether actions to address koala threats are working.

Finally, while threats to koalas are generally well understood, they can vary between populations. So the audit should allow for 'threat mapping' – identifying threats and looking for ways to mitigate them.

Saving an iconic species

Last summer's bushfires highlighted how koalas, and other native species, are vulnerable to climate change. And the clearing of koala habitat continues, at times illegally.

Government inquiries and reviews have shown state and federal environment laws are not preventing the decline of koalas and other wildlife. The federal laws are still under review.

However, the new funding underpins an important step – accurate mapping of koalas and their habitat for protection and restoration. This is a crucial task in protecting the future of this iconic Australian species.

Figure 16.16. The koala count is critical to protecting the species

Sources

EEV has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication, and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

Credits for figure adaptations

Figure 2.1
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Figure 2.4
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Figure 2.6
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Figure 2.7
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Figure 3.4
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Figure 5.1
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Figure 8.4
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