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# BIOLOGY

## FOR QUEENSLAND

### AN AUSTRALIAN PERSPECTIVE

UNITS 3 & 4


LORRAINE HUXLEY

MARGARET WALTER

SERIES CONSULTANT
ROBYN FLEXMAN


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# CONTENTS

# CHAPTER 4

# FUNCTIONING ECOSYSTEMS

Living organisms are energy converters. Photosynthetic organisms convert radiant (light) energy to chemical energy. Heterotrophs obtain their energy from the chemical energy in the foods they eat as herbivores, carnivores or omnivores. Most heterotrophs do not digest all of the food they take in, so some chemical energy remains in the faeces that passes out of the body. All organisms lose some energy in the form of heat as they carry out life functions, and so must continually replenish their supplies of energy and food. The transfer of living matter through the ecosystem from producers through the various heterotrophs can be represented as energy-flow diagrams. As organisms eliminate waste matter or die, their organic chemicals are broken down, by decomposer organisms, into simple inorganic chemicals that are returned to the environment. During the conversion of complex to simple chemicals, chemical energy is also returned to the atmosphere as heat. Energy flows through an ecosystem while matter is recycled. Some species play a critical role in ecosystems, influencing the populations of all other species.

## OBJECTIVES

- → Sequence and explain the transfer and transformation of solar energy into biomass as it flows through biotic components of an ecosystem, including
  - – converting light to chemical energy
  - – producing biomass and interacting with components of the carbon cycle
- → Analyse and calculate energy transfer (food chains, webs and pyramids) and transformations within ecosystems, including
  - – loss of energy through radiation, reflection and absorption
  - – efficiencies of energy transfer from one trophic level to another
  - – biomass
- → Construct and analyse simple energy-flow diagrams illustrating the movement of energy through ecosystems, including the productivity (gross and net) of the various trophic levels
- → Describe the transfer and transformation of matter as it cycles through ecosystems (water, carbon and nitrogen)
- → Define keystone species and understand the critical role they play in maintaining the structure of a community
- → Analyse data (from an Australian ecosystem) to identify a keystone species and predict the outcome of removing the species from an ecosystem
- → Analyse data to identify species (including microorganisms) or populations occupying an ecological niche

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

## PRACTICALS

| | |
|---|---|
| SUGGESTED PRACTICAL | **4.1A** A simplified food chain in leaf litter |
| SUGGESTED PRACTICAL | **4.1B** Measuring biomass |



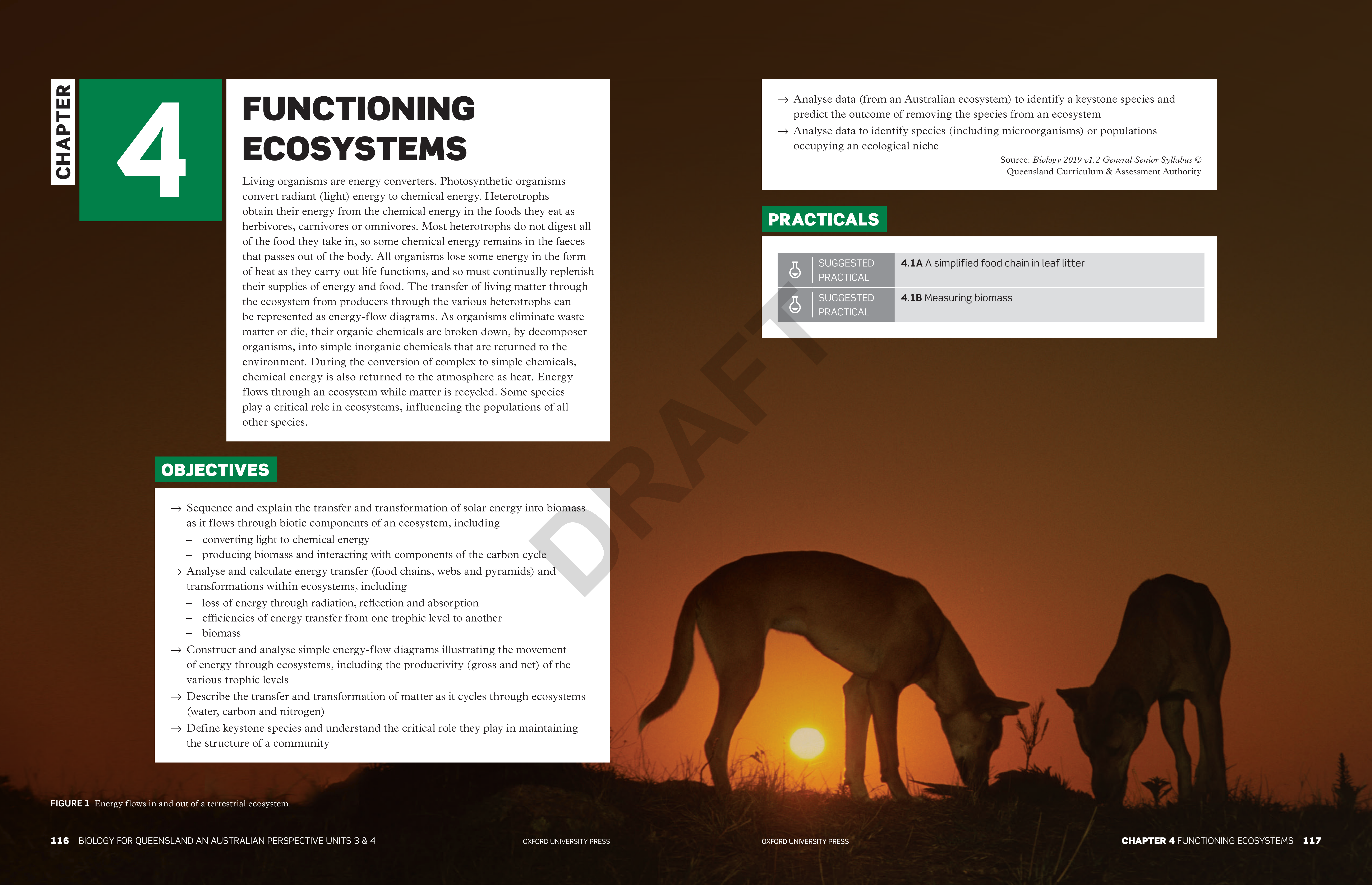

**FIGURE 1** Energy flows in and out of a terrestrial ecosystem.

# 4.1 Energy in ecosystems

**KEY IDEAS**

- Energy from the sun
- Energy flow through food chains
- Solar energy and photosynthesis
- Photosynthetic efficiency
- Productivity in an ecosystem
- Producers and energy
- Consumers and energy
- Decomposers and energy
- Trophic levels in a food chain
- Recycled matter
- Food webs and interlinking food chains

The energy that sustains the majority of living systems is solar energy. Some of the solar energy that radiates from the sun is reflected back into space by the atmosphere. The majority of the solar energy is absorbed by the Earth, with a small percentage (approximately 1%) absorbed by plants in the ecosystem.

Energy changes its form (is transformed) from solar light energy into chemical energy through the process of photosynthesis. The chemical energy is transferred from molecule to molecule in the biosphere before it is radiated into space as heat energy. The total amount of solar energy 'fixed' on Earth can determine the amount of chemical energy, and therefore the total amount of life. Only a small proportion of the total solar energy reaching the Earth's surface is transformed by photosynthesis into organic matter. Most solar energy is reflected back into space or absorbed by the Earth during the day and radiated back into the atmosphere at night. The patterns of flow of chemical energy can be tracked from molecule to molecule, and organism to organism in the biosphere.

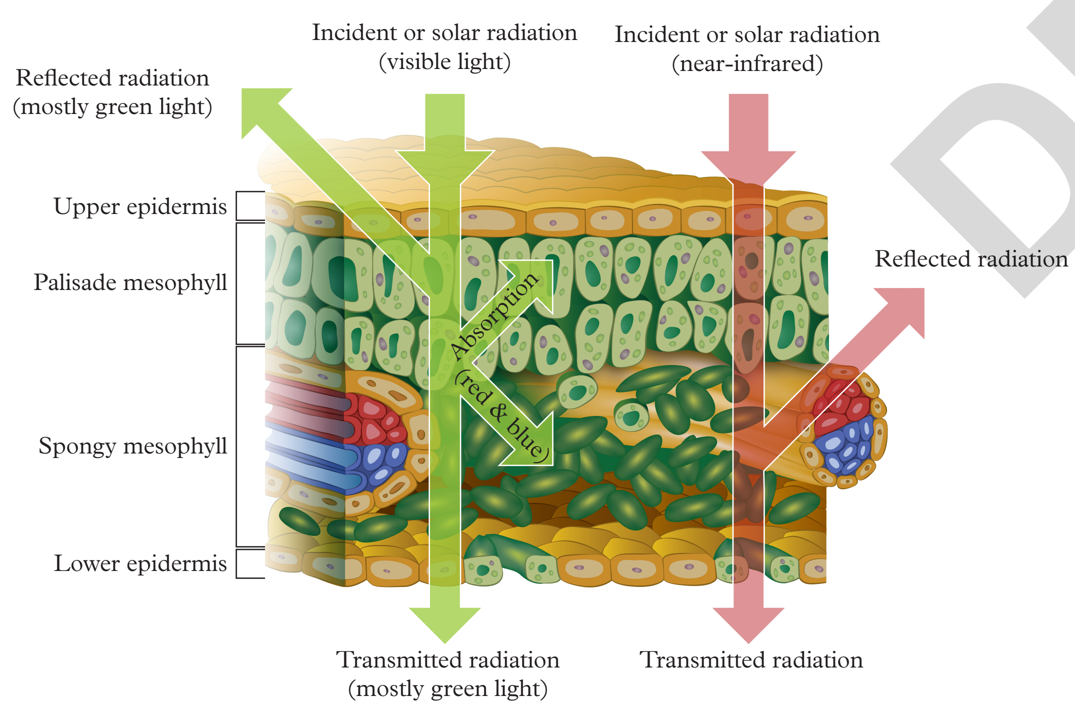


**FIGURE 1** Solar radiation is absorbed by the leaf of a plant and transformed into chemical energy through photosynthesis. This energy can be transferred to herbivores when the plant is eaten, or radiated into the atmosphere as thermal energy.





SUGGESTED PRACTICAL **4.1A** A simplified food chain in leaf litter
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SUGGESTED PRACTICAL **4.1B** Measuring biomass
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## Food chains

Autotrophs produce food (matter and chemical energy). The autotropic producers are eaten by other organisms, which in turn are eaten. The path that the food takes from organism to organism through the ecosystem is called a **food chain**. Because the food chain shows the direction of movement of matter and energy, the arrows show their direction of movement – from consumed to **consumer**.

On the basis of the way they obtain food, organisms can be categorised into three groups: producers, consumers and decomposers.

### Producers

Producers convert simple inorganic chemicals to complex organic molecules (molecules containing carbon and hydrogen together with other atoms). Most producers use solar radiation as an energy source. **Productivity** is measured by the amount of energy fixed within chemical compounds at each level in the ecosystem. In producers it can also be an indication of the amount the **biomass** (mass of all organic matter in an area) increases over a particular length of time. Photosynthesis is a chemical reaction. This means it is affected by the temperature of the environment. Higher temperatures cause the molecules to move faster, increasing the rate of photosynthesis and glucose production. Cold temperatures slow the rate that glucose is produced. The temperatures that determine the rate of photosynthesis change throughout the year because the production of glucose by plants and its conversion into other organic compounds (biomass) are influenced by season, latitude and altitude.

Productivity in producers is also influenced by other factors such as soil mineral availability and water. Although deserts may experience suitable temperatures for chemical reactions, there is little water present and as a consequence their productivity is low.

$$\text{carbon dioxide} + \text{water} \rightarrow \text{glucose} + \text{oxygen}$$

Plants and algae/phytoplankton also vary in their ability to convert light into chemical energy. This ability is the producer's **photosynthetic efficiency** – how effectively the producer in the ecosystem is able to produce glucose from sunlight. The total amount of organic matter in an ecosystem, which is produced as a result of photosynthesis or chemosynthesis, is called **gross primary production**. Not all of this energy can be used by the herbivore that eats the producer – some will be lost as heat and removed as waste products. The amount of energy the herbivore is able to gain when they eat the producer

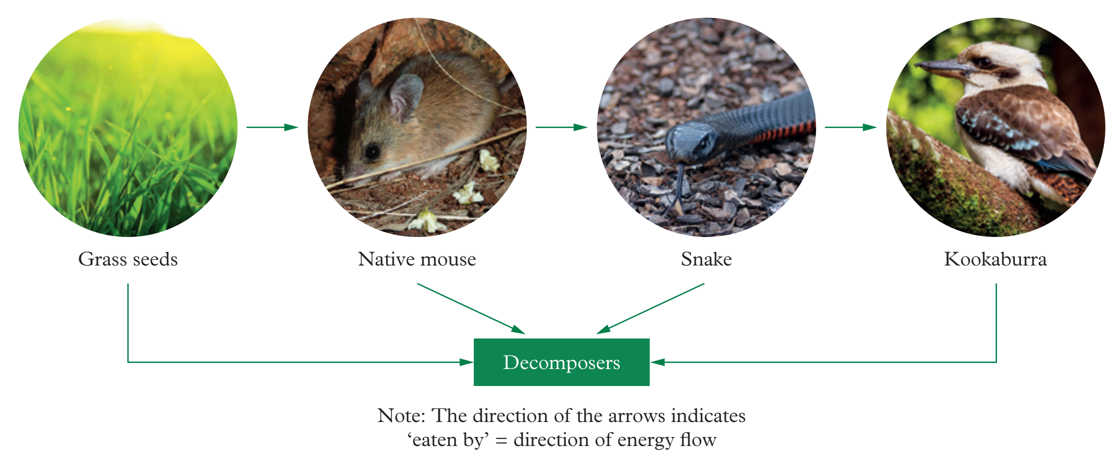


**FIGURE 2** A food chain

**food chain** simple linear arrangement of organisms showing the flow of matter and energy from one organism to another through feeding relationships

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

**productivity** amount of energy fixed in organic compounds; measured by increase of biomass per unit of time

**biomass** amount of organic matter in a system

**photosynthetic efficiency** the fraction of light energy that plants and algae convert into chemical energy during photosynthesis

**gross primary production** the total amount of organic matter in an ecosystem produced as a result of photosynthesis (after subtracting the energy it took to digest the plants) is called **net primary production**. The productivity can be measured for each level in an ecosystem. An example of this is secondary productivity, which is a measure of the amount of new tissue (biomass) generated by the growing herbivores in an ecosystem.

**net primary production**
amount of energy available for herbivores in an ecosystem

## Consumers

Consumers use food produced by other organisms as their energy source. First-order consumers are herbivores, which eat plant material. Second-order consumers are carnivores that eat herbivores. Third and higher-order consumers are carnivores that eat other carnivores. These carnivores may be predators (killing other animals for food), parasites (feeding on living organisms) or scavengers (eating animals they have not themselves killed). Some consumers – the omnivores – may be both a first-order consumer and a higher-order consumer simultaneously. Consumers that are **specialists** eat a limited range of things. Koalas, for example, only eat the young leaves of specific eucalypts. Other consumers, the **generalists**, eat a wide variety of food. A bandicoot is a generalist that eats insects, spiders, earthworms, berries, grass seeds, and young stems and roots.

**specialist feeder**
a heterotroph that can thrive only on a limited diet

**generalist feeder**
a heterotroph with a varied diet

## Decomposers and detritivores

All organisms eventually die and fall to the environmental substrate of any ecosystem. This mixture of dead plant parts, skin, undigested food and dead organisms is called the **detritus**. The detritus is broken down by two groups of organisms. Organisms that obtain their nutrients by ingesting and digesting the nutrients in the detritus internally (i.e. worms) are called **detritivores**. Other organisms, **decomposers** (bacteria, fungi and some protozoans), have external digestion and will often excrete enzymes to break down the nutrients before absorbing them directly into the cell. Since only a finite amount of matter is available in the biosphere, it is recycled.

**detritus**
organic debris from decomposing plants and animals

**detritivore**
an organism that feeds on detritus

**decomposer**
an organism (for example, bacteria and fungi) that utilises dead organisms or waste matter for its nutrient requirements, breaking down the complex organic molecules and releasing simple inorganic molecules back into the environment

**FIGURE 3** A bandicoot is a generalist, eating both animals and plants.





**FIGURE 4** Fungi are decomposers, breaking down dead material on the forest floor.

### Study tip

The terms decomposer and detritivore are often used interchangeably.

## Trophic levels

**Trophic** (feeding) **levels** describe the relative positions of producers and consumers in a food chain. A food chain shows a series of organisms existing in any ecosystem, through which energy is transferred. Each organism in the series feeds on, and therefore derives energy from, the preceding one. In turn it is consumed by the next organism along the food chain, passing on the energy it has stored in its cells and tissues.

**trophic level**
a feeding level in a food chain, e.g. producer, herbivore

## Energy transfer

There are very rarely more than six links in any food chain; usually there are only three to four. This is because energy is lost to the surrounding environment in the form of heat at each level of the food chain. It has been estimated that only 5 to 20% of the energy contained at one level of the food chain is transferred to the next level. For example, if 1000 units of energy is produced by grass through photosynthesis, and the energy transfer of grass is 10%, only 100 units of energy becomes incorporated into molecules of the grasshoppers. The other 900 units of energy will be used up in the energy-consuming activities of the grass, such as growing and flowering, which will release energy to the environment, either as heat or waste matter.

There is more energy stored in the lowest (producer) level of a food chain than in the third trophic level (consumers). Therefore, the closer a consumer is to the producer, the more energy is available to be transferred.

In most cases, higher-order consumers tend to be larger than lower-order consumers (particularly when they are carnivores). Food chains, therefore, generally have fewer members in each successive energy level. Because energy is released to the environment at each level, the number of levels in any food chain is limited. The energy released to the environment is eventually re-radiated into the atmosphere as heat. Energy is not recycled in an ecosystem, it flows through the ecosystem.

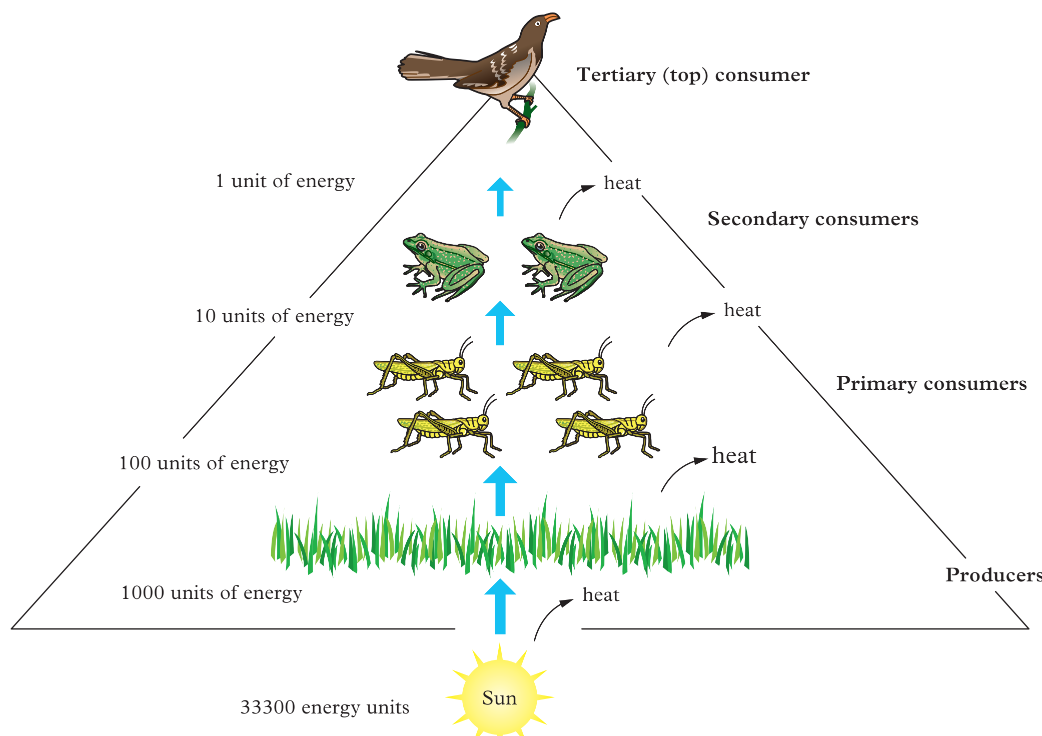


**FIGURE 5** The transfer of energy along a food chain is very inefficient.

## Food webs

A food chain is a simple linear series in which each organism is completely dependent on a single food source. However, more often, the range of plant species is sufficient enough for herbivores to have several alternative sources of food, and carnivores to prey upon a variety of animals. This can be represented by a diagram that contains a variety of food chains linked together (see Figure 6). This **food web** is a graphical representation of the many food chains that are interlinked to show the feeding relationships between organisms in an ecosystem.

**food web**
all the possible feeding relations in an ecosystem

In a complex food web there is greater stability, since most organisms have a variety of food sources to compensate for seasonal fluctuations.

All waste and dead materials are acted upon by decomposers. The organic debris may be totally consumed by the bacteria, fungi and small animals, releasing carbon dioxide, water and heat. Alternatively, the organic molecules may enter other complex food webs when scavenging organisms such as crabs utilise the remains of dead animals and in turn are eaten by fish such as mullet. Ultimately, however, decomposer organisms release nutrients back into the environment. This process is not always complete, and only partially broken-down products such as methane and alcohol may be released.

Ecosystems conform to the **law of conservation of matter and energy**, which states that matter and energy cannot be created or destroyed but can be changed to other forms.

**law of conservation of matter and energy**
matter and energy cannot be created or destroyed but can be changed to other forms

Although complex ecosystems (indicated by the variety of organisms at each trophic level, and therefore the types of feeding interactions) may contain changing population sizes, the same pattern of energy distribution is maintained in the system over very long periods of time.



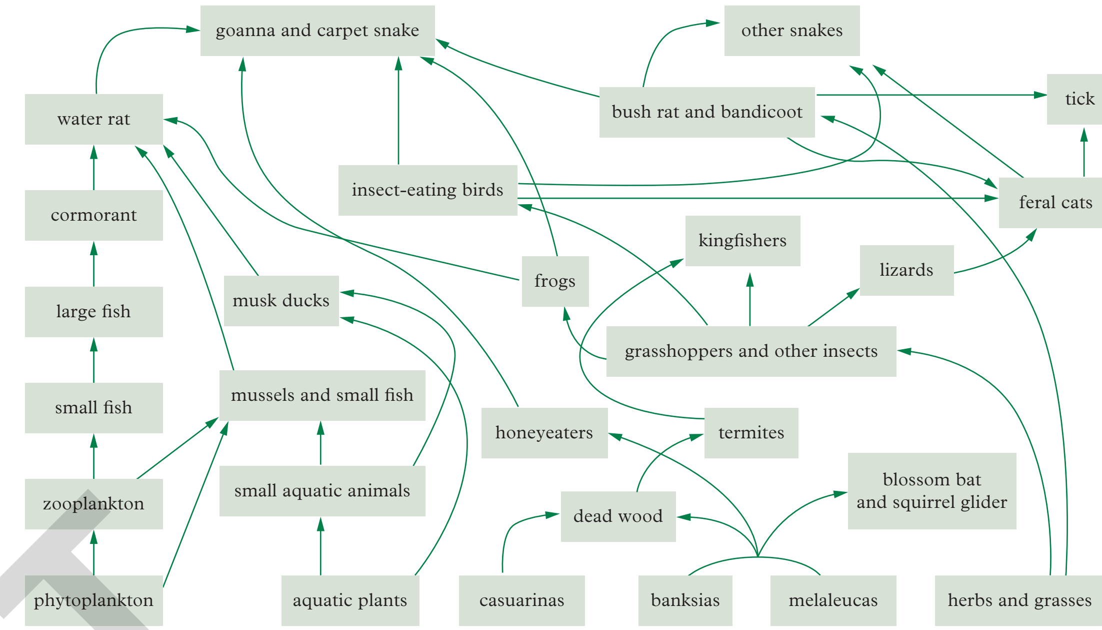


**FIGURE 6** A simplified food web of major organisms found on Moreton Island, Queensland. (The decomposers have been omitted from the food web for the sake of simplicity.)

### Study tip

Energy flows through an ecosystem while matter is recycled.

### CHECK YOUR LEARNING 4.1

**Describe and explain**

1 **Define** and give an example of a food chain.
2 **Explain** why simple food chains are rare in most ecosystems.
3 **Explain** why food chains usually do not have more than three or four trophic levels.

**Apply, analyse and interpret**

4 **Consider** the way energy and matter move through an ecosystem. **Determine** how they differ.
5 Several large geckoes are found in Australian rainforests: for example, the banded gecko, the chameleon gecko and the leaf-tailed gecko. They feed on insects and other small animals, which they encounter as they forage through the forest. These lizards blend into the general pattern of bark and leaves around them and are extremely difficult to observe when they are motionless. All geckoes are insectivorous, but will eat smaller lizards and sometimes frogs. They are nocturnal in habit.
   a **Identify** the position in the rainforest food web that a gecko would occupy.
   b **Discuss** abiotic requirements of these geckoes.
   c **Describe** an adaptation to the environment exhibited by the gecko.
   d In terms of diet, **determine** whether geckoes are specialists or generalists. **Consider** the effect this would have on their survival.

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4.1A A simplified food chain in leaf litter

» Suggested practical
4.1B Measuring biomass

# 4.2 Ecological pyramids

**KEY IDEAS**
+ Ecological pyramids
+ Standing crop

## Graphical representation of energy flow

**ecological pyramid** a model of the relationships between different organisms in a food chain

**pyramid of numbers** a model of the numbers of organisms at each trophic level of a food chain

**pyramid of biomass** a model of the amount of living matter transferred through a food chain

**pyramid of energy** a model of the amount of energy transferred through a food chain

The flow of energy through a food chain is often depicted by a graph representing the quantity at each trophic level. At each level, energy is lost to the ecosystem through movement and heat. A similar loss in biomass (a measure of the amount of organic matter in a system) occurs when the organisms excrete matter through sweat and faeces. Each trophic level is smaller than the level before. For this reason, diagrams showing these quantitative relationships nearly always take the form of a pyramid.

### Types of ecological pyramids

There are three types of **ecological pyramids**: a **pyramid of numbers**, showing the numbers of individual organisms at each level; a **pyramid of biomass**, based on the total dry mass of the organisms at each level; and a **pyramid of energy**, showing the productivity of the different trophic levels. Productivity is measured by the amount of energy that is fixed in chemical compounds or by the increase in biomass during a particular length of time.

The shape of any particular pyramid tells a great deal about the ecosystem it represents. In a pyramid of numbers for a grassland ecosystem (Figure 1), the primary producers (usually grasses) are small, so it takes a large quantity of primary producers to support the primary consumers (herbivores).

In a food chain in which the primary producers are large (for instance, trees), one primary producer may support many herbivores (Figure 2).

A pyramid of biomass for a grassland ecosystem (Figure 3) takes the form of an upright pyramid.



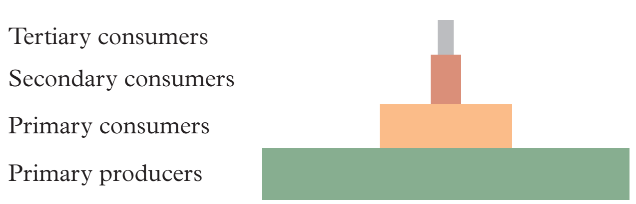


FIGURE 1 A pyramid of numbers – grassland ecosystem

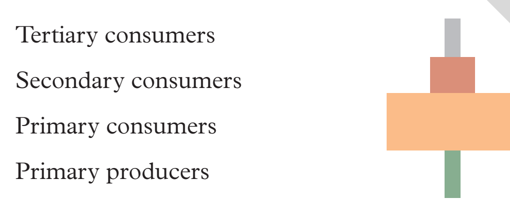


FIGURE 2 A pyramid of numbers – tree ecosystem

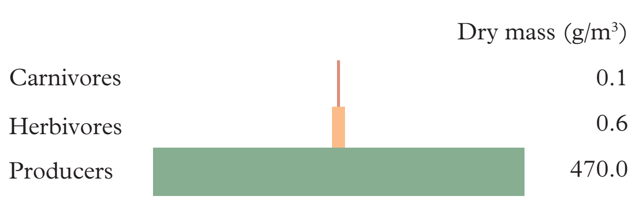


FIGURE 3 A pyramid of biomass – grassland ecosystem


FIGURE 4 A pyramid of biomass – ocean ecosystem



Inverted pyramids of biomass occur only when the producers and primary consumers are small. For example, in the ocean, the biomass of the phytoplankton is measured by the '**standing crop**', which is the biomass at any particular moment. Because the phytoplankton are able to rapidly reproduce, their biomass in a short time period may be smaller than the biomass of the zooplankton feeding upon them (Figure 4).

**standing crop** biomass of an organism at any particular moment

Energy pyramids show the productivity relationships of the trophic levels. This means they are an indication of the amount of chemical energy that is stored in a set time period. Because energy cannot be created in the food chain, the amount of energy will decrease at each trophic level, generating an upright pyramid shape only (similar to Figure 3).

## CHECK YOUR LEARNING 4.2

### Describe and explain

1 **Define** the terms 'biomass', 'productivity' and 'standing crop'.

2 **Describe** an 'ecological pyramid'.

3 **Identify** which of the pyramids in Figure 5 would best show the relative numbers of individuals in a food chain containing:

a sheep, sheep ticks and grass

b a tree, caterpillars and insectivorous birds

c trees, beetles and frogs.

### Apply, analyse and interpret

4 If an ecological pyramid is drawn for the food chains involving a large tree as the producer, different-shaped pyramids can be obtained depending on the parameter used (e.g. number of organisms, biomass, energy flow). Giving specific examples, **interpret** why the pyramids for the same food chain may differ.

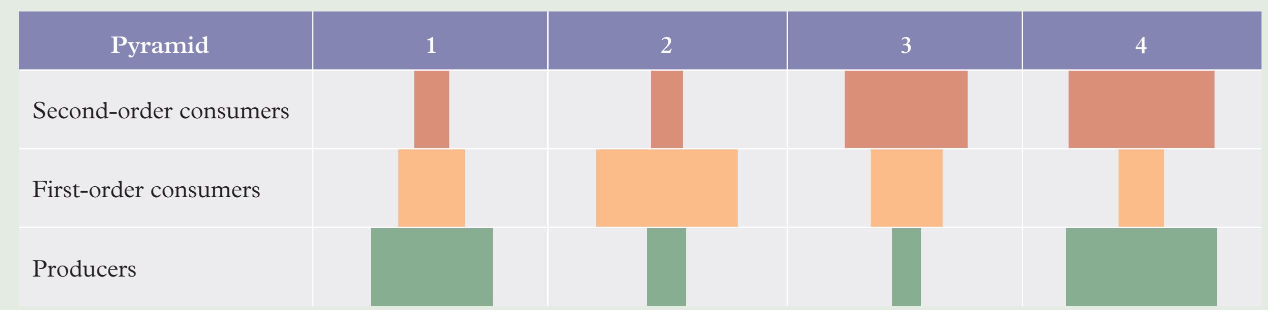


FIGURE 5 The number of individuals of different species is often indicated by means of a pyramid of numbers diagram.

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# 4.3 Biogeochemical cycles

**KEY IDEAS**

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

## General features

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

Biogeochemical cycles have two basic components: the **reservoir pool** and one or more **cycling pools**. The reservoir pool refers to a large, generally non-biological source of an element or a compound that has relatively little turnover. For example, a significant amount of carbon is pooled as fossils or in deep-sea sediments below the Earth's surface. The cycling pools are smaller, more active and are constantly exchanging their contents between the environment and organisms. Cycles in which the element is returned to the environment as rapidly as it is removed are said to be more perfect cycles.

Biogeochemical cycles are important because:

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

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

**biogeochemical cycles** circulation of chemical elements in the biosphere

**nutrient cycle** cycling of a particular element between biotic and abiotic ecosystem components

**reservoir pool** large abiotic component of a biogeochemical cycle in which matter is slowly exchanged with organisms

**cycling pool** small compartment of a biogeochemical cycle with active exchange of matter between organisms and the environment

**upwelling** upward movement of deep, cold water to replace warm surface water

**TABLE 1** Cycling of some major macronutrients

| Nutrients | Reservoir pool | Cycling pool |
|---|---|---|
| Water | Artesian, glacier, polar ice caps | Transpiration – evaporation – precipitation – uptake |
| Oxygen | Metal oxides | Photosynthesis – respiration |
| Carbon | Fossils, peat, coal, oil and gas, trees | Respiration – photosynthesis |
| Nitrogen | Deep-sea sediments | Nitrogen fixation – denitrification |
| Phosphorus | Phosphate rock, deep-sea sediments | Erosion – uptake – dephosphatising |



### CASE STUDY 4.3

#### Galapagos Islands

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

When ice periodically melts into the Southern Ocean, the water is cold and dense. As a result, this water sinks to the base of the Southern Ocean, sweeping up the nutrients (from dead organisms) stored as sediment on the ocean floor. These sediments (containing many essential minerals and nutrients) follow the current along the coasts of Chile and Peru, to the Galapagos Islands, where the current turns west. As a result of the upwelling, the many producers in the waters surrounding the islands are provided with a constant source of nutrition. As the seasons change, so too does the strength of the Humboldt Current. During the 'wet' season, warmer waters (from the Panama Current) arrive from the north. This current of warm water is less dense and doesn't carry as many nutrients from the ocean floor, slowing the growth of phytoplankton producers. As a consequence, the rest of the islands' food webs are affected.

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

## The phosphorus cycle

Phosphorus is a rare element on Earth but is an essential nutrient needed in the formation of bones, teeth, nucleic acids (DNA and RNA) and other molecules containing phosphorus. The principal reservoir for the cycle is phosphate rock formed in past geological time. Erosion by rainfall dissolves phosphate out of the rock, forming a phosphate pool in the soil of the ecosystem. However, a large amount of phosphate escapes via run-off into streams and the sea, before it is taken up by plants.

Many plants have adapted to growing in phosphate-poor soils. Some enter into a mutualistic relationship with fungal mycorrhizae. Others are able to extract and recycle the phosphate from their leaves before they are shed. These plants tend to grow more slowly than those from more fertile soils, avoiding the need for large amounts of phosphate at any particular time. The phosphate is transferred to animals when they eat the plants. When the animals excrete waste products or die, the phosphate is transformed into another form of phosphate by phosphate-cycling bacteria, ultimately entering the dissolved phosphate pool once more.

In the past, huge colonies of seabirds have played an important role in returning a substantial amount of phosphate to the land. Their food consisted of fish and other organisms near the shore, which were rich in phosphates that had washed down from the land. The seabirds' excreta, deposited at their breeding areas on islands and on coastlines, built up over time into large deposits of soluble phosphate (**guano**), which has been mined and used as fertiliser. The rate of mining, however, far outweighs the rate of guano formation.

**guano**
sedimentary rock, rich in phosphates, formed from the build-up of seabirds' excreta

Human exploitation of many islands and coastal areas has disturbed a large number of the seabird breeding grounds. Modern fishing and the removal of much marine life from the area has also depleted the phosphate levels. Underwater currents and geological subsidence carry the majority of phosphate compounds to deeper marine sediments, where they may remain locked for millions of years.

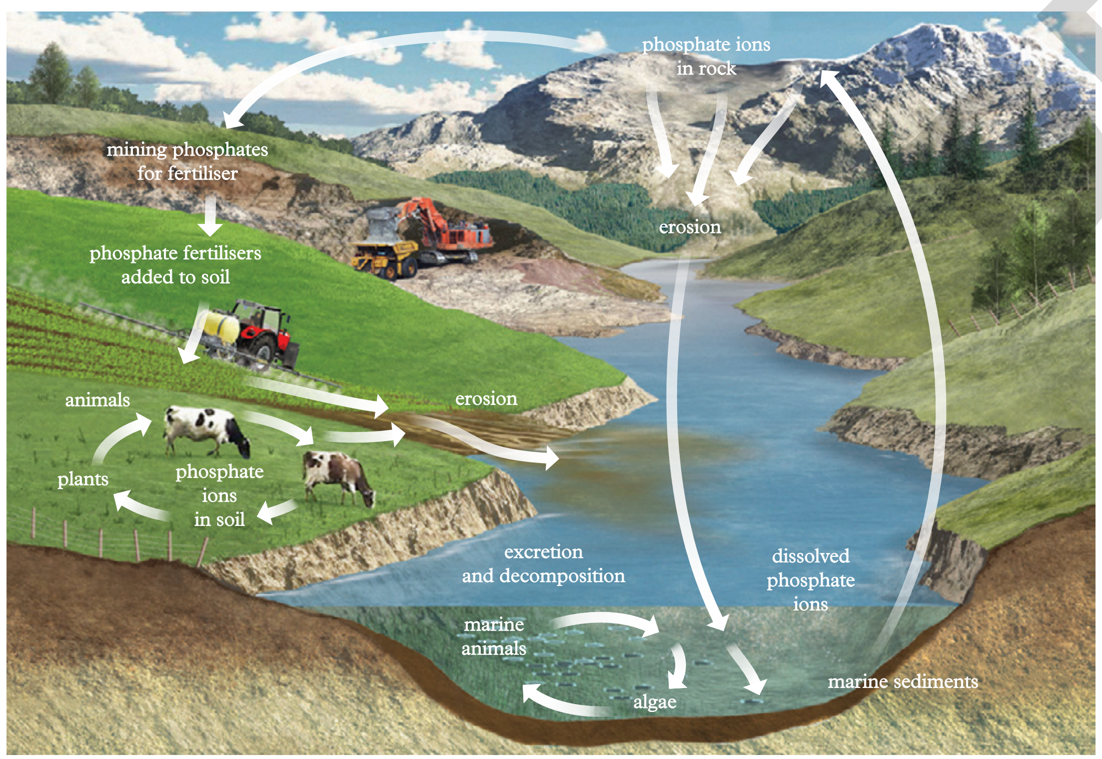


**FIGURE 2** The phosphorus cycle

## The water cycle

All living things need water. It is a requirement for all cells, a solvent in which many metabolic reactions take place, a reactant in a large number of chemical reactions and a habitat for marine life. The distribution of plants and animals in terrestrial environments is therefore closely linked to the availability of water.

About 98% of the water on Earth is found in oceans, rivers, lakes and wetlands. The remainder can be found frozen as permafrost, in groundwater, incorporated in the bodies of living things and as water vapour in the atmosphere. Solar energy powers the evaporation of water from the oceans and, to a minor extent, from freshwater environments, soil and organisms (for example, transpiration from plant leaves). The water vapour is carried by air currents into the atmosphere. When it meets cool air the water vapour condenses and forms clouds of liquid water droplets or ice. When the volume of water in the clouds reaches a critical level, it falls to the ground as precipitation (rain or snow).

Most rain falls on the oceans. That which falls on land is pulled by gravity back to the sea in the form of surface run-off, streams, rivers and lakes. Some of the water soaks into the soil, percolating down until it reaches a zone of saturation, the upper levels of which form a water table. This groundwater also moves towards the oceans. Much of the water taken up by plants from the soil returns to the atmosphere during transpiration. Similarly, a very small amount of water returns to the atmosphere as it evaporates from the gas exchange surfaces of terrestrial animals. The majority of water cycles from the oceans and returns back.

On land, the amount of rainfall is determined by the prevailing wind direction, temperature (which determines evaporation rate) and topography. Mountain ranges close to continental edges force vapour-laden air to higher altitudes where clouds form. The ocean sides of these ranges, therefore, have higher rainfall than the inland side. The further away from the ocean, the less rainfall will be experienced.

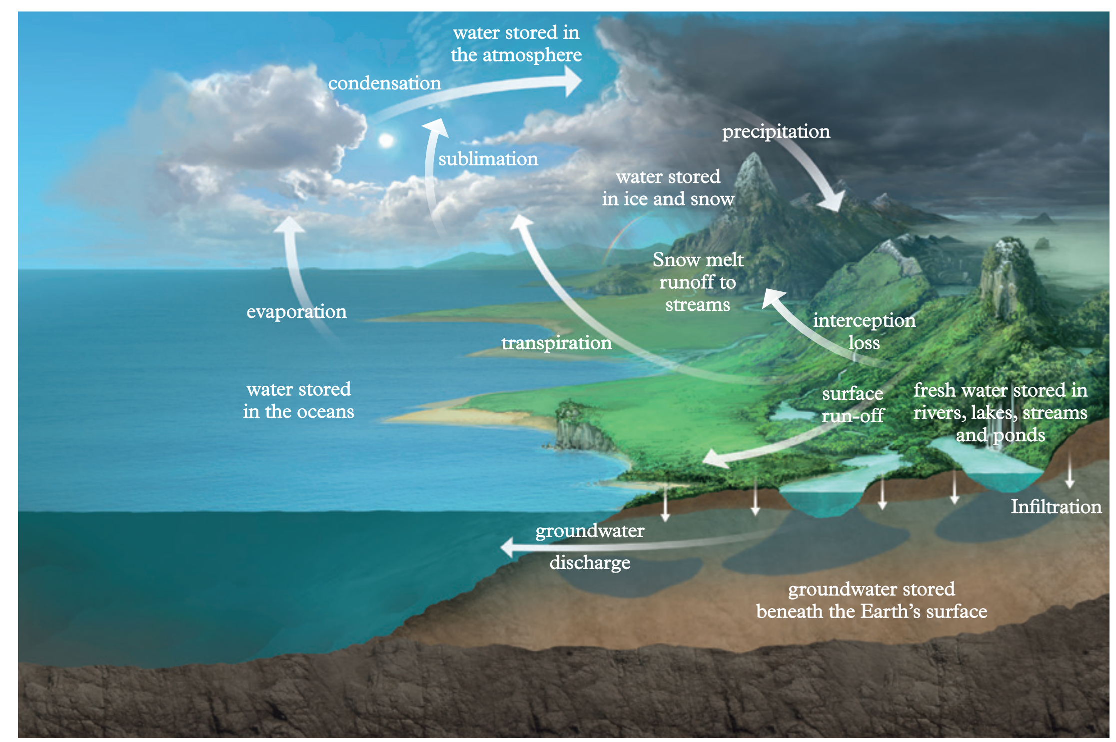


**FIGURE 3** The water cycle

## Oxygen and carbon cycles

The carbon and oxygen cycles are interwoven. Photosynthesis incorporates carbon from atmospheric carbon dioxide into complex organic molecules and oxygen is released. These compounds are broken down during cellular respiration, to release carbon dioxide and water back into the atmosphere. A large amount of carbon is tied up in living matter within food chains, and organic carbon is also contained in the dead bodies of plants and animals and in excretory waste. Detrital organisms and decomposers are responsible for the final release of carbon back into the environment.

Over geological time, carbon is locked in a reservoir pool as coal and oil and in the wood of trees. As humans exploit this fossil fuel in combustion processes, carbon is returned to the cycling pool.

## The nitrogen cycle

**nitrogen fixation**
conversion of atmospheric nitrogen to nitrate by bacteria and cyanobacteria

One of the most common gases in the atmosphere is nitrogen. As an essential component of amino acids, nitrogen limits the supply of food available in a food chain more than any other plant nutrient. **Nitrogen fixation** (conversion of atmospheric nitrogen, $N_2$, to soluble nitrate, $NO_3$) is an essential process for life on Earth and is carried out by chemosynthetic microorganisms in the soil and the roots of plants.

The best-known nitrogen-fixing organisms are bacteria. They transform the free nitrogen gas in the soil in metabolic reactions to release nitrates ($NO_3$), which are transferred to the plant to form proteins. The plant obtains the proteins necessary for life, while the bacteria receive protection and a supply of carbohydrates (from the plant's photosynthesis) for the synthesis of protein.

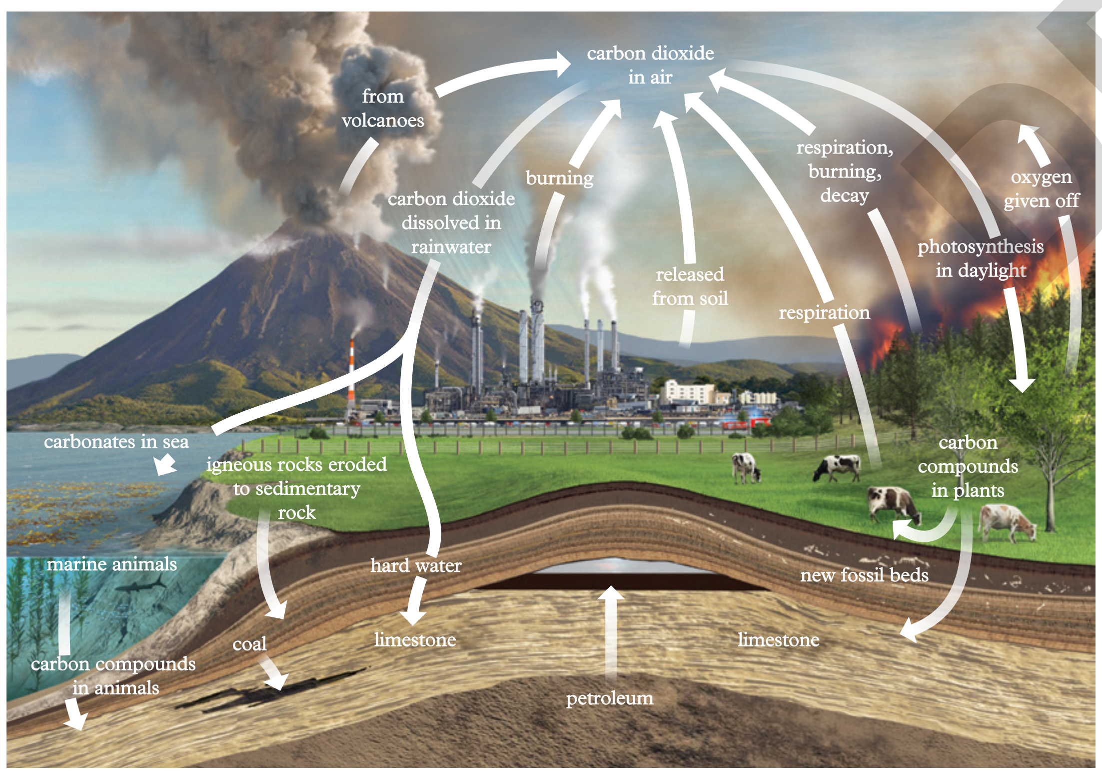


**FIGURE 4** A simplified carbon cycle





**nitrifying bacteria**
bacteria that convert ammonia to nitrite and nitrite to nitrate

Another important group of chemosynthetic organisms are **nitrifying bacteria**. These bacteria, such as *Nitrosomonas*, obtain energy by converting ammonia ($NH_3$) to nitrite ($NO_2$). Other nitrifying bacteria, *Nitrobacter*, convert nitrites to nitrates. Both forms of nitrogen can be absorbed and used by plants in the production of amino acids and proteins. These products are then available to animals as they pass from organism to organism in the food chain. The production of nitrites and nitrates releases energy, which is used by the bacteria to synthesise the organic compounds it needs.

**denitrifying bacteria**
bacteria that convert nitrate to nitrite, or atmospheric nitrogen or nitrite to ammonia

Bacteria that remove nitrate from the soil are called **denitrifying bacteria** and live in oxygen-depleted environments. By reducing nitrate to nitrite, ammonia or nitrogen, they liberate oxygen. The liberated oxygen is then utilised in aerobic respiration, and the released energy is used in the synthesis of organic compounds.

The cyclic conversion of gaseous nitrogen into nitrites and nitrates constitutes the nitrogen cycle.

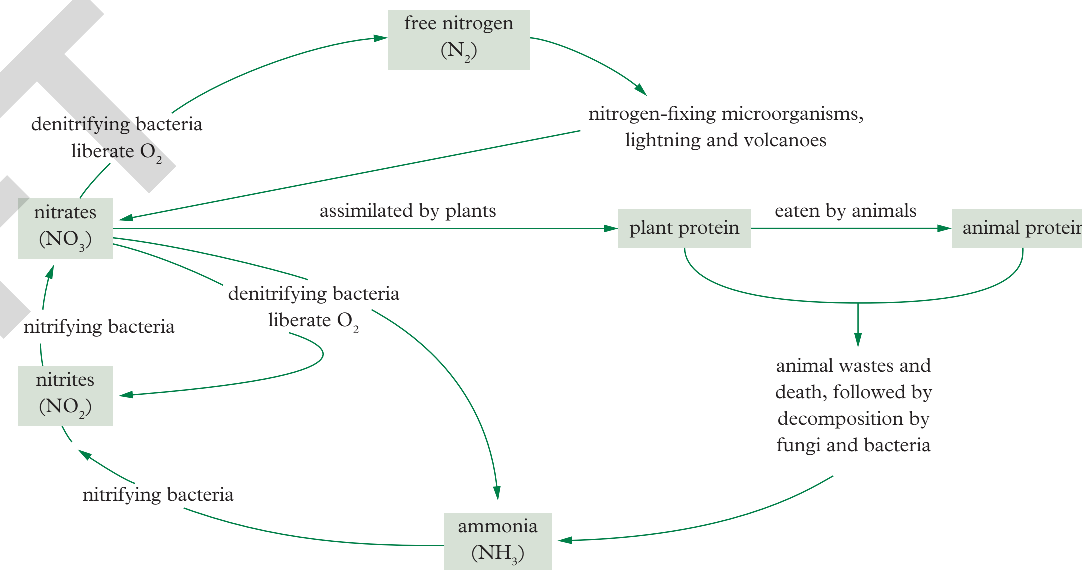


**FIGURE 5** A simplified flowchart of the nitrogen cycle

### CHECK YOUR LEARNING 4.3

#### Describe and explain

1 **Explain** why matter needs to be recycled in an ecosystem.

2 **Explain** why it is considered that the available phosphate reservoir pools of the world are being depleted.

#### Apply, analyse and interpret

3 Not all the carbon on Earth is being cycled continuously. **Determine** how carbon might be removed from the cycle for millions of years.

4 **Describe** the roles of reservoir and cycling pools using an example from one nutrient cycle.

Check your obook assess for these additional resources and more:

» Student book questions
Check your learning 4.3

» Weblink
The Humboldt Current

» Weblink
The deep carbon cycle

SCIENCE AS A HUMAN ENDEAVOUR

# 4.4 Keystone species

**KEY IDEAS**
- Keystone species
- Umbrella species
- Flagship species

**keystone species**
a species that has a disproportionately large effect on its environment relative to its abundance by maintaining local biodiversity within a community either by controlling populations of other species that would otherwise dominate the community or by providing critical resources

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

Keystone species are often only identified after an ecosystem has been impacted. Some indicating features of a keystone species include:
- The ability to eat a variety of organisms in the ecosystem. This allows them to keep all populations under control.
- Its influence on other organisms is out of proportion to its biomass or abundance.
- The negative effects of removal of such a species (intentionally or unintentionally) from an ecosystem.

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

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

**umbrella species**
species selected when making decisions about conservation because they are representative of other species, and protecting them indirectly protects other species in the same habitat

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

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

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






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

**flagship species**
a species chosen to raise support for biodiversity conservation in a chosen place or context

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

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

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

FIGURE 2 In a campaign to use recycled toilet paper, and so save trees, this appealing wombat was used as a flagship species.

## CHECK YOUR LEARNING 4.4

### Describe and explain

1 **Identify** an example of a keystone species that is:
  a a mutualist
  b an engineer
  c a carnivore.
2 **Explain** why most keystone carnivores are generalist feeders.

### Apply, analyse and interpret

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

Check your obook assess for these additional resources and more:
- » Student book questions Check your learning 4.4
- » Weblink Umbrella species
- » Weblink Flagship species

CHAPTER 4

# Review

## Chapter summary

4.1
- The majority of energy in ecosystems is generated from the sun.
- Energy flows through food chains.
- Solar energy is fixed as biomass in photosynthesis and is a measure of productivity.
- Photosynthetic efficiency is the fraction of sunlight plants convert into organic molecules during photosynthesis.
- Productivity is a measure of how much organic matter is generated at each trophic level in an ecosystem. It can be a gross measurement (the amount of energy captured) or net (the energy that is stored as cells and tissue).
- Producers use photosynthesis or chemosynthesis to generate organic molecules.
- Consumers gain their energy by eating other organisms.
- Decomposers and detritivores gain energy through consuming the detritus.
- The number of trophic levels in a food chain is limited.
- Matter is recycled.
- Food webs are a diagrammatic representation of interlinking food chains.

4.2
- Ecological pyramids represent organism numbers, biomass and energy at trophic levels.
- Standing crop is the amount of biomass available at a point in time.

4.3
- Elements are transferred and transformed between the biosphere and geosphere.
- The nutrient cycle is the pathway a particular element travels between the living and non-living components in an ecosystem.
- Elements can become trapped in reservoir pools for millions of years.
- Cycling pools rapidly recycle elements through the living and non-living components of an ecosystem.

4.4
- Keystone species are important in maintaining the balance of an ecosystem.
- Umbrella species ensure the protection of a wide range of other species.
- Flagship species can be used to promote conservation and wildlife management.



## Key terms

- biogeochemical cycles
- biomass
- consumer
- cycling pool
- decomposer
- denitrifying bacteria
- detritivore
- detritus
- ecological pyramid
- flagship species
- food chain
- food web
- generalist feeder
- gross primary production
- guano
- keystone species
- law of conservation of matter and energy
- net primary production
- nitrifying bacteria
- nitrogen fixation
- nutrient cycle
- photosynthetic efficiency
- productivity
- pyramid of biomass
- pyramid of energy
- pyramid of numbers
- reservoir pool
- specialist feeder
- standing crop
- trophic level
- umbrella species
- upwelling



## Revision questions

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

### Multiple choice

1 Decomposers are considered to be important within an ecosystem because:
**A** large quantities of dead plant and animal matter would not otherwise be consumed
**B** the dead plant and animal matter would otherwise harbour dangerous decay organisms
**C** they release nutrients, otherwise locked up in the dead matter, for the use of producers
**D** the food web of the community is a dynamic, continuously changing system

2 Gross primary production refers to:
**A** the amount of food available for carnivores in a food chain
**B** the rate at which solar energy is converted into chemical energy by autotrophs
**C** the amount of energy available to an organism for growth
**D** the amount of energy passed on to herbivores by producers

3 A study of an estuary showed that after a storm, large quantities of eelgrass were washed up along the shore line. With the aid of microorganisms, the eelgrass became broken down into small pieces and was consumed by beach worms. These worms were eaten by small fish, such as whiting, which in turn were eaten by large fish. Which of the following organisms has the greatest biomass?
**A** Eelgrass
**B** Beach worms
**C** Small fish
**D** Large fish

4 The standing crop of oceanic phytoplankton can be smaller than the biomass of zooplankton since:
**A** phytoplankton are larger than zooplankton
**B** the growth rate of phytoplankton is greater than that of zooplankton
**C** there are few zooplankton compared with phytoplankton
**D** zooplankton feed on a variety of organisms, including phytoplankton

5 A nutrient cycle describes:
**A** the pathway of a particular element between living and non-living parts of the ecosystem
**B** the study of chemical exchanges between different parts of the substrate
**C** how an organism utilises a particular element
**D** the pathway of a particular element in a food chain

6 Which of the following is a significant feature of a nutrient cycling pool?
**A** The formation of coal and oil from fossil organisms
**B** Evaporation and transpiration
**C** Underwater currents and geological settling
**D** Nitrifying bacteria reducing nitrates to nitrites to release oxygen

### Short answer

#### Describe and explain

★ 7 **Explain** why simple food chains are rare, and how food webs provide greater stability in ecosystems.

★ 8 **Describe** the roles of reservoir and cycling pools using an example from one nutrient cycle.

★ 9 **Explain** the meaning of an 'engineer' when related to keystone species.

★★ 10 Some species in an ecosystem are 'specialists' and some are 'generalists'. **Define** these two terms and explain which of the two types has greater survival potential.

#### Apply, analyse and interpret

★★ 11 Caves are frequently inhabited by bats, which go out at night to feed on flying insects and live inside the cave during the day, clinging to the rocky walls. On these cave walls are generally found small blood-sucking flies and bat bugs, which suck the blood of bats. The droppings of bats accumulate on the cave floor and form a suitable medium for certain fungi, particularly moulds. These moulds provide food for the cave crickets, which themselves are eaten by other insects, spiders and scorpions. These 'other insects' may also fall victim to the spiders.

a **Construct** a food web to show the relationships that exist in such a cave community.

b **Determine** what constitutes the boundary of such a community.

★★★ **12** *Frankia* are bacteria that can provide nitrogen to a plant. Trees in a forest plantation were treated in three different ways. The results are shown in Figure 1.

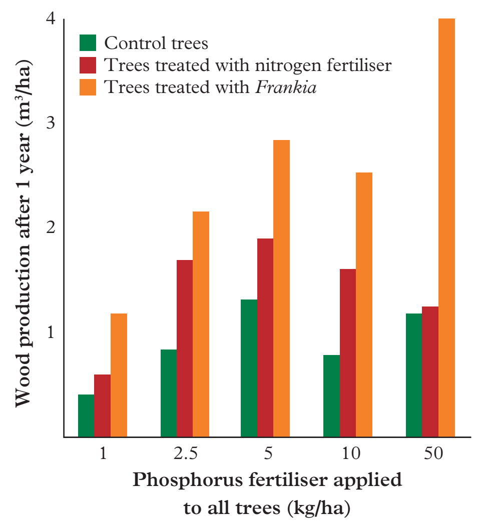


**FIGURE 1** Response of forest trees to phosphorus, nitrogen and *Frankia*

a **Distinguish** the experimental conditions of the 'control' trees from those of the other trees.

b **Explain** the rationale for the treatment of the 'control' trees.

c Using supporting evidence from the graph, **generate** a conclusion from these results.

★★★ **13** In an experiment investigating the rate of disappearance of leaf litter, uniform discs were cut from leaves, placed in nylon mesh bags and buried in newly cultivated pasture. The table shows the disappearance of the leaf discs from bags made from 7 mm and 0.5 mm mesh from June of one year to April of the next.

**TABLE 1** Leaf disc disappearances from June to April

| Month | Percentage (%) of leaf area remaining in bags of mesh size: | |
|---|---|---|
| | 7 mm | 0.5 mm |
| June | 100 | 100 |
| August | 81 | 94 |
| October | 30 | 91 |
| December | 13 | 66 |
| February | 9 | 62 |
| April | 6 | 60 |

a **Construct** a graph (on graph paper) of the data.

b **Describe** the effect of mesh size on the rate of disappearance of leaf litter between June and October. **Determine** causes for this.

c **Explain** the variation in the rate of disappearance of litter from the 0.5 mm mesh bags during the period of the experiment.

## Investigate, evaluate and communicate

★★ **14** Herbivores have generally been considered to have a negative impact on their plant prey. However, a controlled study of a natural community provides evidence to the contrary. The crustacean herbivore *Daphnia pulex* was fed on planktonic algae, and it was shown that the *Daphnia* had a stimulatory effect on the algal populations that approximately balanced its impact on algal mortality. **Predict**, with justification, mechanisms for the *Daphnia*-induced stimulation of algal growth.

★★ **15** Phytoplankton are the autotrophs of the ocean surfaces. In addition to being the major oxygen supply for Earth, many small animal plankton (zooplankton) feed on them. These two groups of organisms are the basis for most oceanic food webs. The biggest of all animals, the blue whale, depends entirely on plankton found in Antarctic seas and seals, penguins and other birds feed on small fish that eat the zooplankton. In recent years, krill (zooplankton) oil has become a popular remedy for arthritis and the krill themselves have become an important food for commercially reared prawns. Japanese and Russian ships are harvesting millions of tonnes of krill from these cold southern waters.

**Predict**, with reasons, the possible effects of this unnatural predation on stocks of krill on Antarctic ecosystems.

★★★ **16** For several decades after the Second World War, giant tritons (*Charonia tritonis*) were avidly removed from the Great Barrier Reef by shell collectors. This large, carnivorous mollusc is one of the few animals known to feed on the crown-of-thorns starfish (*Acanthaster planci*), which in turn feeds on coral polyps. By the 1960s the numbers of crown-of-thorns starfish had increased to such an extent that large sections of the reef were becoming bleached due to the death of the polyps. At that time, it was considered that the giant triton was a keystone species for the reef, maintaining the crown-of-thorns starfish populations at low, non-destructive levels. Further research indicated that the triton had never been common and so had little impact on the crown-of thorns starfish. In 2017, however, a breeding program for the giant triton was established for the purpose of releasing these molluscs onto the reef to control the crown-of-thorns starfish.

**Investigate** the possible causes for crown-of-thorns outbreaks. To what extent can you **determine** the impact of decreasing triton numbers on increases in crown-of-thorns populations? **Evaluate** the basis on which the triton breeding program for reef restoration is justified.

Write a fully justified response to whether or not the giant triton can be considered a keystone species for the Great Barrier Reef.

**FIGURE 2** Giant triton feeding on crown-of-thorns starfish

★★★ **17** **Design** an experiment to test whether the amount of leaf litter that accumulates in water-filled hollows depends on their depth. If the experiment showed a correlation between depth of hollow and amount of leaf litter, discuss the implications for the development of leaf litter food webs.

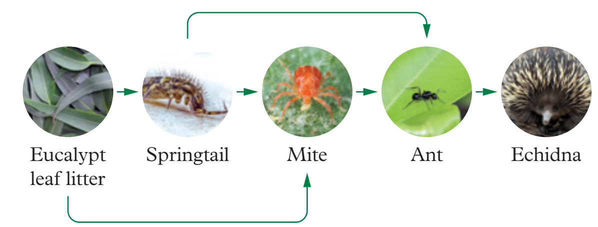


**FIGURE 3** A typical food chain for eucalypt woodland detritus



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