This chapter is designed to enable students to:

■ recognise how structural, physiological and behavioural features can contribute to the survival of organisms
■ recognise that a feature is adaptive in a specific set of environmental conditions
■ gain knowledge of particular adaptations that equip organisms for survival in various environmental conditions in Australia
■ understand that each organism has a tolerance range for every environmental factor and that beyond that range survival is at risk.
The Rule of Threes

The Rule of Threes provides a reasonable guideline for priority-setting for anyone lost in a harsh environment. The rule states:

- You can live for about 3 minutes without air. (Exceed that and a person is at risk of death from asphyxiation.)
- You can live for about 3 hours without shelter (in a harsh environment). (Exceed that and a person is at risk of death from exposure.)
- You can live for about 3 days without water (if you have shelter). (Exceed that and a person is at risk of death from dehydration.)
- You can live for about 3 weeks without food (if you have shelter and water). (Exceed that and a person is at risk of death from starvation.)

Leaving aside the immediate requirement for air (in fact, the oxygen in air), these times are guidelines only and will vary according to the severity of the conditions, as well as a person’s body weight, genetic factors and whether or not the person is already dehydrated.

The Rule of Threes is a useful rule-of-thumb for human survival in the harsh cold conditions of the high latitudes of the northern hemisphere. Teachers of basic skills for survival in a freezing wilderness may refer to the Rule of Threes because it stresses the priorities for survival. First priority — direct your focus and your energy into securing shelter; second priority — water; third priority — then, only after shelter and water are secured, worry about food. In the freezing cold of a northern hemisphere snowstorm, one challenge is to find shelter in order to avoid a drop in body temperature (hypothermia). In contrast, in the desert heat of the Australian outback in summer, the challenge is to find protection against the heat and avoid heat stroke (hyperthermia).

Regardless of whether people are challenged by the freezing tundra of Canada or in the desert heat of outback Australia, another essential for their short-term survival is water: prolonged dehydration can kill.

Food is a requirement for survival of heterotrophs (animals and fungi) but, in contrast to water, food is not necessary for short-term survival. In 1981, a number of political prisoners in Northern Ireland staged hunger strikes in protest against the presence of British military personnel in the region. Ten protestors who did take water, died after periods without food of between 46 and 73 days. The period of survival without food is influenced by a person’s health and stored energy reserves.

Bushfires are a serious threat to survival in fire-prone areas of Australia, especially the south-east sector of the country. The box on page xx relates to a tragic event during a bushfire in Victoria in 1998. Sadly, some firefighters died when a fierce bushfire suddenly changed direction.

In this chapter, we will look at a range of adaptations that contribute to the survival of animals and plants in a variety of environments. An adaptation is a genetically controlled structural, behavioural or physiological feature that enhances the survival of an organism in particular environmental conditions. It is important to note that the value of a feature as an adaptation exists in relation to a specific way of life and in a particular set of environmental conditions. In another set of environmental conditions and a different way of life, the same feature may be maladaptive. For example, freshwater fish extract dissolved oxygen from the water in which they live using their gills, the organ for gas exchange (see figure 5.2). Gills provide an efficient structure for extracting oxygen from water. However, if removed from the water, the fish gills are maladaptive. Without the buoyancy of water to support them, the feathery gill filaments collapse, and with no water flowing over them the fish cannot obtain oxygen and suffocates. Likewise, mammalian lungs are adapted for gas exchange with the air, but they are useless for extracting dissolved oxygen from water.
Adaptive features of an organism are innate, that is, built into its genetic makeup. Some adaptations reflect the Rule of Threes. For animals, survival depends on their structural, physiological and behavioural features that enable them to exploit the available resources of shelter, water and food in a particular environment. For plants, survival also depends on their structural, physiological and behavioural features that contribute to their success in accessing water and sunlight in their environments.

Tolerance range

The particular environmental conditions in which a particular species can successfully live and reproduce define its tolerance range. Every organism has a tolerance range for environmental factors such as temperature, desiccation, oxygen concentration, light intensity and ultraviolet exposure. A tolerance range identifies the variation within which organisms can survive. Figure 5.3 shows the tolerance range for a fish species in terms of water temperature. The extremes of this range are the tolerance limits for that environmental factor.
If an environmental factor has a value above or below the range of tolerance of an organism, that organism will not survive unless it can escape from, or somehow compensate for, the change. In some species migration is one such escape behaviour, while others retreat underground. Tolerance ranges differ between species and are influenced by structural, physiological and behavioural features of organisms. For example, the cold tolerance of various mammals is influenced by structural features such as fur density, shape of the body (see figure 5.4) and extent of insulating fat deposits, and by their behaviours, such as hibernating (‘coping-with-it’ strategy). In figure 5.4, can you identify which fox species is the Arctic fox (*Vulpes lagopus*) and which is the Simien Fox (*Canis simensis*)?

Any condition that approaches or exceeds the limits of tolerance for an organism is said to be a limiting factor for that organism. Terrestrial and aquatic environments can differ in their limiting factors. Table 5.1 shows environmental factors that influence which kinds of organism can survive in various habitats.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Limiting factor</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>floor of tropical rainforest</td>
<td>light intensity</td>
<td>Low light intensity limits the kinds of plants that can survive.</td>
</tr>
<tr>
<td>desert</td>
<td>water availability</td>
<td>Limited water supply means that only plants able to tolerate desiccation can survive.</td>
</tr>
<tr>
<td>littoral zone</td>
<td>desiccation</td>
<td>Exposure to air and sun limits the types of organism that survive.</td>
</tr>
<tr>
<td>polar region</td>
<td>temperature</td>
<td>Low temperatures limit the types of organism that are found.</td>
</tr>
<tr>
<td>stagnant pond</td>
<td>dissolved oxygen levels</td>
<td>Low dissolved oxygen levels limit the types of organism that can live there.</td>
</tr>
</tbody>
</table>

The structure and the physiology of plants and animals determine their tolerance range. For each organism, the limits of its tolerance ranges for various environmental factors are fixed, except for the occurrence of an enabling mutation.

The human species is the only organism that makes extensive use of technology to extend the limits of its natural tolerance range. As air-breathing mammals, we are not prevented from entering the watery world of the fish; technology such as scuba tanks enable us to do this. Technology enables people to survive in hostile environments on and beyond Earth, where conditions are outside the tolerance range of an unaided person. Equipment and hi-tech clothing enables a mountaineer to survive an ascent to the peak of one of the highest mountains on Earth (see figure 5.5a). An extremely sophisticated spacesuit enables an astronaut to leave the International Space Station, which is orbiting about 250 km above Earth, and install cables (see figure 5.5b).
FIGURE 5.5 (a) Andrew Lock is Australia’s most accomplished high-altitude mountaineer and the only member of the British Commonwealth to have climbed all 14 of the world’s 8000 metre plus mountains. Here he is ascending to the peak of Mt Annapurna, 8091 m above sea level, one of the world’s most dangerous climbs. You can find more information about Andrew’s ascent of the 14 peaks at http://andrew-lock.com/the-fourteen-8000ers. (b) Commander Barry Wilmore, a US astronaut, on a space walk from the International Space Station on 1 March 2015.

KEY IDEAS

- Adaptations are structural, physiological or behavioural features that enable an organism to survive and reproduce in particular environmental conditions.
- The tolerance range of an organism defines the range of environmental conditions in which a particular species can successfully live and reproduce.
- The human species uses technology to extend the limits of its natural tolerance range.

QUICK CHECK

1. What is meant when a structural feature of an organism is said to be ‘maladaptive’?
2. Give an example of a physical feature that could be labelled as ‘maladaptive’ and the conditions in which that label could be given.
3. Identify whether each of the following statements is true or false.
   a. Excluding technological support, survival is not possible beyond the extremes of an organism’s tolerance range.
   b. Adaptations are features that equip organisms to survive in all conditions.
   c. The extreme ends of a temperature tolerance range mark the tolerance limits of an organism for temperature.
   d. A behaviour that is learned is an example of an adaptation.

The desert environment

Australia is the driest inhabited continent on Earth and has been arid for millions of years. As vast areas of the continent dried out, ancestral species evolved over many generations. As a result of mutations, individuals of some species developed features that enhanced their survival in arid conditions and it was their offspring that had a greater chance of survival. Their descendants are the native plants and animals that live successfully in the vast desert regions and semi-arid areas of outback Australia. Today, much of inland Australia is covered by deserts, mainly sandy deserts with some stony deserts (see figure 5.6). Seventy per cent of Australia’s land surface is either arid (average annual rainfall of 250 mm or less) or semi-arid (average annual rainfall of 250 to 350 mm).
FIGURE 5.6 (a) Much of inland Australia is hot and arid and covered by deserts. This figure shows our 10 major deserts, ranging from the largest, the Great Victoria Desert, more than 400,000 km², to the smallest, the Pedirka, just over 1000 km².
(b) Most of these deserts are sandy deserts, such as the Simpson Desert, a large area of sand plains and dunes in central Australia. (c) Some areas are stony deserts, such as Sturt Stony desert, a rock-covered desolate area.
The environmental factors that dominate desert environments are temperature and aridity (absence of surface water).

The temperatures in Australian deserts in summer are very high. For example, the average daily maximum temperature for the month of February 2015 across much of inland Australia was in the range of 36 to 42 °C. For coastal Victoria, the figure was 24 to 27 °C (see figure 5.7a). The rainfall in central Australia in the same month was low, with most inland regions receiving rainfall of 0 to 25 mm. In contrast, in the same month a few coastal regions of eastern Australia received 600 to 800 mm of rain (see figure 5.7b). Because of the high temperatures of the desert areas, any small amounts of summer rain quickly evaporate and do not exist as free-standing water. In spite of the high temperatures and aridity of deserts, some plants and animals live successfully in these areas because they have adaptations that equip them for life in this environment.

![Figure 5.7](image)

**Figure 5.7** Much of inland Australia consists of large areas of arid, hot deserts. (a) Map showing the mean maximum temperature across Australia in February 2015. (The mean maximum temperature is the average daily maximum air temperature for the month.) (b) Map showing the rainfall in millimetres for the month of February 2015.

**Water is essential for life**

One of the key threats to survival in the arid Australian outback is dehydration. Water loss by an animal is normally compensated for by water gain so that, overall, over a period of time, water balance exists. That is:

\[
\text{water-in} = \text{water-out}
\]

OR

\[
\text{water gain} - \text{water loss} = 0
\]

In desert conditions, the water content of the body can become unbalanced if water loss exceeds water gain over an extended period, producing a state of dehydration. The more severe the dehydration and the faster it occurs, the more deadly the potential consequences.

Water is a remarkable substance with properties that are critical for living organisms (see the following feature).

In chapter 6 we will examine water balance and its regulation.
**Water: a special molecule**

Water has several special properties that enable it to play important roles in biological settings.

**Water molecules tend to stick together**

The tendency of water molecules (H₂O) to stick together can be expressed more scientifically as molecules having high cohesion. The cohesiveness is due to the fact that the oxygen end of a water molecule has a slight negative charge, while the hydrogen ends have a slight positive charge (see figure 5.8).

![Figure 5.8](image)

**FIGURE 5.8** A water molecule showing its arrangement of electrons (e⁻), two in the inner shell and six electrons in the outer shell. Each of the two hydrogen atoms shares its single electron with the oxygen atom. Oxygen is a larger atom than hydrogen and because of this the electrons are pulled toward oxygen and away from the hydrogen, resulting in a net negative charge for the oxygen end of a water molecule and a net positive charge for the hydrogen end.

Because of these slight positive and negative charges, water molecules are attracted to each other and stick together (in groups of up to 4 water molecules). This attractive force is known as **hydrogen bonding** (see figure 5.9). The cohesive nature of water is what makes it a versatile solvent for polar molecules (see next paragraph). The cohesive nature of water is one key factor that enables water columns in the xylem tissue of vascular plants to move at the top of trees.

**Water is a versatile solvent**

Water is the predominant solvent in living organisms. The chemical reactions that occur in cells involve the synthesis of complex molecules from simple ones and the breakdown of complex molecules. These chemical reactions occur in solution so that water, as a solvent, is necessary. Likewise, nutrients can only be absorbed from the alimentary canal into the bloodstream if they are in solution. How does water act as a solvent for hydrophilic or polar compounds? Let’s look at how water dissolves a hydrophilic solid, such as a crystal of common salt.

The top of figure 5.10 shows a crystal of common salt (NaCl) when it is first placed in water. At this stage, the salt crystal has not dissolved. However, after the salt comes into contact with the water, the salt dissociates (separates) into sodium ions (Na⁺) and chloride ions (Cl⁻) (see bottom of figure 5.10). Note that, in solution, the sodium ion (Na⁺) is surrounded by water molecules arranged with their oxygen atoms closest to the sodium ion. Check out the arrangement of water molecules that surround the chloride ion (Cl⁻). Which end of the water molecule is closer to this ion?

![Figure 5.9](image)

**FIGURE 5.9** (a) Each water molecule consists of one oxygen atom (O) joined to two hydrogen atoms (H) by a strong covalent bond. (b) Water molecules are attracted to each other because of the slight negative charge on the oxygen atom and the slight positive charge on each hydrogen atom. The attractive forces that hold water molecules together are called **hydrogen bonds**, shown here as short curved lines.
Each sodium ion and each chloride ion becomes surrounded by a shell of water molecules; this is possible because of the cohesive nature of water molecules. For the chloride ions, it is the positively charged side of the water molecules that surround them. In contrast, for the sodium ions, it is the negatively charged portion of the water molecules that surrounds them. These shells of water molecules separate the sodium ions from the chloride ions and, by removing the attraction between these ions, keep the salt in solution.

**Water resists temperature changes**

Resistance to temperature changes means that, relative to other compounds, more heat energy must be added to or removed from water to produce a given change in its temperature. This relatively greater resistance is because of the many hydrogen bonds that exist between water molecules in solution. (Remember, water molecules are cohesive!)

**Water has a relatively high specific heat capacity**

Specific heat capacity refers to the heat energy required to raise the temperature of a given mass of a substance by one degree. For example, the specific heat of liquid water is 4186 joules per kg per degree Celsius, while that of air is 1046 J. So, given the same input of heat energy, the temperature of a body of water changes far less than the temperature of the surrounding atmosphere.

Biologically, this means that large bodies of water provide relatively more stable thermal living conditions for the organisms that live in those environments in comparison with terrestrial organisms.

**Water has a high heat of vaporisation**

The heat of vaporisation refers to the input of heat energy required to convert a liquid to vapour (gas). For water, the heat of vaporisation of liquid water is 2260 kJ/kg; for comparison, that of petrol is about 600. The high heat of vaporisation of water is an important factor in cooling mammals exposed to heat stress.

The major mechanism for cooling in humans and other primates is the evaporation of sweat that is produced when the body starts to overheat. Not all mammalian species produce sweat in order to lose heat. Some species, such as dogs, use panting to cool themselves. Yet other species, such as kangaroos and wallabies, lick the fur and skin of their forearms and paws (see figure 5.11). Cooling in all these cases — sweating, panting and saliva spreading — is due to the evaporation of water from the sweat or the saliva on the skin or fur surface. The heat energy needed to evaporate the water is taken from warm blood in vessels close to the skin surface, cooling the blood. This blood then returns to the body core, cooling it.

Both the high heat of vaporisation and the high specific heat capacity of water were factors in preventing the deaths of the firefighters caught in a bushfire discussed in the box on page xxx.

(continued)
Water has a high heat of fusion

This refers to the heat that must be removed from liquid water to convert it to a solid (ice). For example, the heat of fusion of liquid water is 333 kJ/kg, while that of ethanol, another liquid, is 104 kJ/kg.

Solid water is less dense than liquid water

Density is a measure of the mass of a substance per unit volume (mass/volume). Most substances are more dense in their solid state than their liquid state. This is not the case for water; liquid water is more dense than solid water (ice) and, as a result, ice floats on water. An important consequence of this is that when small bodies of water such as ponds and lakes freeze in very cold climates ice forms at the surface. This ice acts as an insulating layer that assists in keeping the underlying water liquid. If ice were more dense than liquid water bodies of water would freeze in very cold weather from the bottom up, with deadly consequences for aquatic life (see figure 5.12).

Some density values are:
- liquid water = 1.00 g/cm³
- seawater = 1.02 g/cm³
- solid water (ice) = 0.93 g/cm³
- coconut oil = 0.93 g/cm³

Refer to figure 5.10 and see if you can explain why seawater is more dense than pure water. (Answer: Adding Na⁺ ions and Cl⁻ ions to the water increases the volume of the water. However, because the mass of the ions (Na⁺ = 23, Cl⁻ = 35) is greater than the mass of the water molecules (18), adding these ions to the water increases its mass by a greater factor, thus increasing its density).

To appreciate both the importance of water in living organisms and to understand how some animals can thrive in desert conditions, let us first look briefly at the water content of healthy adult people and their sources of water gain and water loss.

Water in the human body

Like all living organisms, the human body consists mainly of water. An average adult male consists of about 60 to 65 per cent water by weight, equivalent to about 45 litres. For an average adult female, the figure is about 50 to 55 per cent, corresponding to about 30 litres (see figure 5.13a). The values can vary according to a person’s age, state of health and weight. People with obesity, for example, have a lower percentage of water than those who are lean. The water content of the different tissues and organs of the human body varies from more than 80 per cent in the blood to about 10 per cent in adipose tissue (see figure 5.13b).
Figure 5.13  (a) Average percentage of body water in adult humans. Note the sex difference in the average percentage of total body weight that is composed of water. The average figure is lower for females because they have a higher percentage of fat. (b) Percentage water content of various human tissues and organs. Which tissues have the lowest water content? Do these data explain the difference between the average water content of adult males and females shown in part (a)?

Of the total water content of the body, most is contained within **intracellular fluid** (about two-thirds). This is the fluid *inside* the body cells, mainly the aqueous fluid of the cytosol. The remaining one-third of water is present as **extracellular fluid**; this is composed of **interstitial fluid**, which fills the spaces between cells and bathes their plasma membranes (about 26%), and **plasma**, the liquid portion of the blood (about 7%) (see figure 5.14a). The water content of the body is of course not just water: it contains dissolved solutes including proteins, sugars and minerals ions, such as sodium, potassium and chloride.

Figure 5.14  (a) Average distribution of the total water content of the body across the three ‘compartments’ in an adult human. In an average adult male weighing 70 kg, the total water of about 42 L is distributed as about 28 L of intracellular fluid within cells, about 11 L of interstitial fluid surrounding cells and about 3 L circulating in the blood plasma. (b) The body water compartments are separated but water can move between them. The cellular wall of the capillaries separates the plasma from the interstitial fluid. Plasma membranes of cells separate the interstitial fluid from the intracellular fluid.
Figure 5.15 shows the routes by which water is lost from and gained by the human body.

**Water Loss**

In people, as in other mammals, water is lost through several avenues. A healthy adult human loses water from:

- the kidneys in the urine
- the lungs in exhaled breath. When we breathe out, we lose water vapour from the lungs and its passages. Typically we do not notice this loss, so this loss is said to be **insensible water loss**. We can, however, see this water loss on a cold day when the warm water vapour in exhaled breath condenses into tiny water droplets on contact with the cold air outside (see figure 5.16)
- the gut in egested faeces
- the skin, in water lost via pores in the skin and as sweat secreted by sweat glands. The loss of water via pores in the skin is an example of insensible (not noticed) water loss, and is the loss of pure water. In contrast, sweat contains dissolved solutes. Note that sweating does not occur until the body is subjected to heat stress, but the insensible loss of water from the pores of the skin occurs all the time.

The total daily loss of water in a person in a temperate climate and in a non-exercising state is on average 2.5 L. Table 5.2 shows the proportion of this loss through the different avenues of water loss.

<table>
<thead>
<tr>
<th>Organ</th>
<th>Volume lost (L/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>kidneys</td>
<td>1.5</td>
</tr>
<tr>
<td>lungs</td>
<td>0.4</td>
</tr>
<tr>
<td>skin (via pores)</td>
<td>0.4</td>
</tr>
<tr>
<td>skin (from sweat glands)</td>
<td>0.0*</td>
</tr>
<tr>
<td>gut (via faeces)</td>
<td>0.2</td>
</tr>
</tbody>
</table>

*Sweating can be a major source of water loss, but sweating occurs only under conditions of heat stress.

Under changed conditions, water loss by a person can increase markedly, for example:

- Water loss from the skin is greatly increased when sweating occurs in response to an increase in core body temperature, such as during periods of vigorous exercise or during periods of exposure to high environmental temperatures. Sweating is initiated by the region of the hypothalamus of the brain in response to an increase in core body temperature. One study found that water loss from sweating can exceed 1.5 L per hour in persons working in very hot environmental conditions.
- Water loss from the gut is greatly increased when a person has severe diarrhoea or bouts of vomiting. In the case of diarrhoea caused by a cholera infection water loss can be fatal if medical treatment is not received (refer to chapter 1, p. xxx). This highlights the dangers of severe dehydration.
Water gain

Water is gained from two sources: one external and one internal (see below). The external sources of water gained by the human body are the aqueous fluids we drink and the water content of foods that we ingest (see table 5.3).

**TABLE 5.3 Water content of some fresh fruits and vegetables**

<table>
<thead>
<tr>
<th>Food item</th>
<th>Percentage water</th>
</tr>
</thead>
<tbody>
<tr>
<td>apple</td>
<td>84</td>
</tr>
<tr>
<td>banana</td>
<td>74</td>
</tr>
<tr>
<td>carrot</td>
<td>87</td>
</tr>
<tr>
<td>lettuce</td>
<td>96</td>
</tr>
<tr>
<td>orange</td>
<td>87</td>
</tr>
<tr>
<td>peas</td>
<td>79</td>
</tr>
<tr>
<td>watermelon</td>
<td>92</td>
</tr>
<tr>
<td>zucchini</td>
<td>95</td>
</tr>
</tbody>
</table>

*Source: Adapted from www2.ca.uky.edu/enri/pubs/enri129.pdf*

Water enters the gut from where it is rapidly absorbed into the blood circulatory system — within 5 minutes of drinking the fluid. Absorption of water occurs mainly in the small intestine and, to a lesser extent, in the colon of the large intestine. Water is then distributed via the blood stream throughout the body to the interstitial fluid and then to cells. (Passage of water into cells across the plasma membrane may occur either by osmosis or by facilitated diffusion through channel proteins known as aquaporins (refer to chapter 1, p. xx.)

The internal source of water is produced during aerobic cellular respiration. Recall the summary equation for aerobic respiration (refer to chapter 3, p. xxx):

\[
\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}
\]

Note that water is a product of aerobic respiration, and this water is called **metabolic water**. This water is produced in one of the last steps in aerobic respiration:

\[
O_2 + 4H^+ + 4e^- \rightarrow 2H_2O
\]

The volume of metabolic water produced each day is about 0.4 L. This amount is not sufficient for human survival, and must be supplemented by an intake of external water. One study identified that, on average, humans gain the water they need from fluids they drink (about 60%), from food they ingest (about 30%) and from metabolic water (about 10%).

**KEY IDEAS**

- Most of inland Australia is arid or semi-arid and is covered by sandy deserts.
- Water is essential for life and is a major component of the human body.
- In the human body, water is present in three ‘compartments’: plasma, interstitial fluid and intracellular fluid.
- For survival, water loss must be balanced by water gain.
- Water loss from the human body occurs through several channels, the main one being via the kidneys.
- Water gain by people is either external, from food and drink, or internal, from metabolic water.
Adaptations for survival: desert animals

In this section, we will look at some examples of adaptations that enable animals to survive and reproduce in a desert environment. The key environmental challenges of desert life are avoiding excessive water loss that can result in dehydration and avoiding overheating that can result in hyperthermia, both conditions being potentially deadly.

In the previous section we saw that people, like most mammals, replace most of the water that they lose by drinking liquid water. This is easy when access to clean piped water is available. In the desert, however, free-standing water is neither predictably nor reliably available. After an occasional heavy rain or storm, temporary creeks, transient lakes and small pools of water exist in the desert. For most of the time, however, creek beds are dry, lakes are dry salt-pans, and pools and puddles of water do not exist. This lack of free-standing water in the desert can persist for years, even decades. How is survival possible for animals and plants under these conditions?

Survival without drinking: the mulgara

Some mammals have features that equip them to survive in hot desert environments, including the ability to survive without drinking liquid water. Among them is the crest-tailed mulgara (*Dasycercus cristicauda*), a small native marsupial mammal that lives in sandy desert regions of central Australia (see figure 5.17). Mulgaras are carnivorous marsupials and their prey includes insects, scorpions and spiders. Like all mammals, mulgaras need water to egest their faeces, to excrete their wastes in urine and to cover evaporative loss of water vapour from their airways. How can they survive without drinking water? The mulgara achieves this by minimising its water loss to such an extent that it can meet all its water needs from the water content of its food and from metabolic water alone.

**FIGURE 5.17** (a) The crest-tailed mulgara survives in the hot and arid desert environments of central Australia. Here the mulgara is eating a locust that provides it with both nutrients and water. The mulgara can survive without an intake of liquid water. In addition to its food, what is the other important source of water gain for the mulgara? (b) Distribution of the crest-tailed mulgara.
Water-conserving features present in mulgaras include structural, physiological and behavioural adaptations. One structural and physiological adaptation is that mulgaras minimise water loss by producing very concentrated urine (nearly 4000 mOsm/L) compared to humans (1200 mOsm/L). This means that a mulgara can rid its body of nitrogenous wastes, in the form of urea, using far less water than a person. This is achieved by two measures relating to the function and structure of the nephrons of the kidney (refer to figure 4.45, p. xxx). These two measures are:

1. a reduction in glomerular filtration, meaning that less fluid leaves the blood and enters the kidney tubules
2. an increase in tubular reabsorption, meaning that more fluid is reabsorbed from the tubules and returned to the blood, particularly in the loop of Henle.

Studies have shown that a strong correlation exists between the structure of a kidney and its ability to concentrate urine. In particular, the efficiency of the kidney is associated with a thicker medulla such that kidneys with a thicker medulla can produce urine that is more concentrated than kidneys with a thinner medulla. A thicker medulla allows for longer kidney tubules, in particular for longer loops of Henle. These U-shaped loops are where the greatest concentration of the kidney filtrate occurs. Figure 5.18 shows a longitudinal section of a kidney with a relatively thick medulla.

The relative medullary thickness of a mammalian kidney (i.e. the thickness of medulla divided by kidney size) is positively correlated with the capacity of the kidney to concentrate the urine and so reduce water loss. The higher the relative medullary thickness, the higher the maximum concentration of the urine. In addition, the relative medullary thickness is greater in desert-dwelling mammals than in non-desert dwellers. Who do you think has kidneys with a thicker medulla: mulgaras or people?

Other structural and physiological adaptations include:

- Mulgaras produce very dry faeces and this means that they lose less water via their gut than animals that produce moist faeces.
- Mulgaras reduce insensible water loss from their airways by exhaling breath that is a few degrees cooler than the air they inhale. Warmer air holds more water than cooler air. The nasal passages allow outgoing breath to lose heat through the blood in the vessels in their nasal tissues, so that the air is cooled before it is breathed out. This conserves some water that would otherwise be lost as vapour if the exhaled breath were warmer.
- Mulgaras have few sweat glands so that the loss of water by sweating is minimised.

In summary, mulgaras minimise water loss through various structural and physiological adaptations. Because of this, mulgaras can obtain sufficient water for their needs from the water content of their food and from the metabolic water produced in aerobic respiration. If necessary, mulgaras can survive in the desert environment without drinking liquid water. Overall, mulgaras succeed in balancing their water loss and water gain, so that water-in equals water-out.
In addition, mulgaras exhibit adaptive behaviours that assist them to avoid overheating, for example:

- Mulgaras avoid the desert heat, particularly in summer, by sheltering during the day in their burrows and being active at night when conditions are cooler. This behaviour also assists in water conservation because sheltering in a humid burrow reduces the loss of water vapour from breathing and by diffusion from the skin. (For a person, the average daily loss from these channels is about 800 mL.)
- Mulgaras have their fat stores concentrated in their tail. Desert animals tend to store their body fat in a single location rather than having fat deposits spread under their skin and across the entire body surface. (The camel’s fat store is concentrated in its hump). A possible explanation is that body fat acts as an insulator and slows heat loss from the body.

**Survival without drinking: the tarrkawarra**

Let’s meet another water saver. The tarrkawarra, or spinifex hopping mouse (*Notomys alexis*), is a placental mammal that lives in sandy deserts in Australia (see figure 5.1 and 5.19). Because it can survive without drinking liquid water, the tarrkawarra can endure long periods of drought. Its kidney tubules reabsorb almost all the water from the kidney filtrate so that it produces highly concentrated and almost solid urine. In fact, tarrkawarras produce the most concentrated urine of any mammal. Their kidneys can produce urine with a concentration of 9370 mOsm/L.

Table 5.4 shows a comparison of the maximum concentrating abilities of the kidneys of various mammals. This table also shows the urine-to-plasma (U/P) ratio, that is, the concentration of electrolytes, such as sodium, potassium and chloride ions, in the plasma relative to that in the urine.

<table>
<thead>
<tr>
<th>Species</th>
<th>Max mOsm/L</th>
<th>Max U/P</th>
</tr>
</thead>
<tbody>
<tr>
<td>human</td>
<td>1200</td>
<td>4</td>
</tr>
<tr>
<td>dog</td>
<td>2500</td>
<td>7</td>
</tr>
<tr>
<td>camel</td>
<td>2800</td>
<td>8</td>
</tr>
<tr>
<td>rat</td>
<td>2900</td>
<td>9</td>
</tr>
<tr>
<td>sheep</td>
<td>3500</td>
<td>11</td>
</tr>
<tr>
<td>tarrkawarra</td>
<td>9000</td>
<td>25</td>
</tr>
</tbody>
</table>

The sources of water gain and water loss for the tarrkawarra are outlined in the following section, as well as the adaptations that enable the it to minimise its water loss so that water-in equals water-out. Achieving this water balance is essential for survival.
**Water balance in the tarrkawarra**

Water sources for the tarrkawarra are food, metabolic water and free-standing water. Water loss by the tarrkawarra can occur via the skin, faeces, exhaled air, urine and, in females only, milk.

**Water gained through food**

The main food for the tarrkawarra is dry seeds. The amount of water these contain depends on the humidity of the air in which the seeds are found. The relative humidity at night is greater than that during the day. The nocturnal habits of the tarrkawarra result in the animal collecting seeds at a time when the water content is likely to be at its highest. In addition, seed is stored in the burrows in which the tarrkawarra lives. The burrows are more than a metre deep, well insulated and have a relatively high humidity because animals huddle together there during the day. Seeds stored in burrows also have a greater water content than seeds collected from a plant. The tarrkawarra also eats green leafy shoots and insects when they are available but can gain weight on a diet containing dry seed only.

**Metabolic water**

When carbohydrate and fatty foods are oxidised in an animal’s body, the main end products are carbon dioxide and water. This oxidation water, or metabolic water, is used by the tarrkawarra. The tarrkawarra does drink free-standing water if it is available but can survive without it. Free-standing water sources may include dew that can appear after a cold night and rainwater (although rare). A summary of the sources of water for the tarrkawarra is shown in figure 5.20.

**Figure 5.20** An outline of how the tarrkawarra achieves water balance. For survival, water-in must balance water-out.
Water loss from the skin
Although a tarrkawarra has no sweat glands, some water is lost by diffusion through the skin. Evaporation from the skin occurs but this is minimised. During hot days, animals stay in their burrows huddled together. Air surrounding the group increases in humidity and has the effect of reducing water loss from the skin.

Water loss in faeces
Tarrkawarra faeces are very dry and little water is lost in this way.

Water loss in exhaled air
Air that moves from the lungs to the surrounding atmosphere is saturated with water vapour. This could result in significant water loss. In the tarrkawarra, a special heat exchange system in the nasal passages reduces that loss. The temperature of air entering the body is lower than body temperature and so nasal passages are cooled as air enters. Warm air exhaled from the lungs passes over these cooled areas and is also cooled. Exhaled air is at a lower temperature than body temperature. As the air is cooled, some of the water vapour from the lungs recondenses on the walls of the nasal passages. Hence, not all the water vapour that leaves the lungs leaves the body.

Water loss in urine
Mammals must produce urine to be able to excrete their nitrogenous waste: urea (see chapter 3, p. xxx). Oxidation of proteins results in urea that must be excreted. Tarrkawarras produce the most concentrated urine recorded for any mammal. Although some water loss occurs through the kidneys, it is clear that the kidneys are a significant site of water conservation in tarrkawarras.

Water loss in milk for the young
Female tarrkawarras, like all mammals, feed their young with milk. The loss of water through having to feed young is balanced to some extent by a mother drinking the urine her young produce. The water in urine is recycled. It has been estimated that a female who is feeding her young requires only one millilitre of water per day. This water for lactation is obtained from fresh green food, rainwater or dew. Although tarrkawarras live in very dry areas with little free-standing water, their structural, behavioural and physiological characteristics enable them to survive in harsh desert environments.

Surviving by dormancy
Frogs in the outback? Surely not!
Some frog species live in arid inland Australia. Frogs typically live in moist surroundings and need a body of water in which to reproduce. How do they survive long periods of drought in the inland? Some frog species that live near and breed in ephemeral waterholes respond in an amazing manner when the waterholes begin to dry out. The frogs burrow deeply into the soft mud at the bottom of their waterholes. Once underground at depths of up to 30 cm, the burrowing frogs, such as the trilling frog (*Neobatrachus centralis*) (see figure 5.21), make a chamber that they seal with a mucous secretion. The frogs then go into an inactive state known as dormancy in which breathing rates and heart rates are minimal and energy needs are greatly reduced. Their low energy requirements are met from their fat reserves. Read the account written by two explorers about burrowing frogs:

One day during the dry season we came to a small clay-pan bordered with withered shrubs…It looked about the most unlikely spot imaginable to search for frogs, as there was not a drop of surface water or anything moist within many miles…
The ground was as hard as a rock and we had to cut it away with a hatchet, but, sure enough, about a foot [30 cm] below the surface, we came upon a little spherical chamber, about three inches (76 mm) in diameter, in which lay a dirty yellow frog. Its body was shaped like an orange . . . with its head and legs drawn up so as to occupy as little room as possible. The walls of its burrow were moist and slimy . . . Since then we have found plenty of these frogs, all safely buried in hard ground.


The frogs remain buried and are protected from desiccation until the next rains come — this may be a wait of 1 or 2 years. The frogs come out of their dormant state only when soaking rains fall and soil moisture rises. Once activated, the frogs return to the surface to feed and breed in temporary pools. The completion of the life cycle is very fast. Within days of being laid, eggs undergo embryonic development, hatch and the resulting tadpoles metamorphose to produce small frogs. These new populations of frogs feed on larvae of crustaceans and insects that have also hatched from dormant eggs.

Other animal species survive extended periods of drought by sealing themselves off from the drying conditions. For example, the univalve (one-shell) freshwater mollusc (Coxiella striata) seals itself inside its shell by closing the shell opening with a hard lid (operculum). These inland molluscs must stay sealed tightly in their shells for months or years.

Surviving by moving around
Some species cope with drought by moving from affected areas to areas where conditions are more favourable. For example, banded stilts (Cladorhynchus leucocephalus) live near salt lakes in inland Australia and rely on these lakes for brine shrimps, which are their main food source (see figure 5.22). When one salt lake dries up, these birds simply fly to another salt lake.

Another species that moves widely throughout desert areas is the budgerigar (*Melopsittacus undulatus*). Flocks of these birds move to more favourable areas in search of food and water (see figure 5.23). In order to avoid the desert heat, they travel in the cooler periods of the day.

The strategy of moving quickly over large distances to seek out transient free-standing water in the arid outback of Australia is largely restricted to birds that are capable of flight. Many animal species and all plant species, however, cannot use a ‘get-up-and-go’ strategy in periods of drought.

**Surviving through offspring**

Survival can be viewed in terms of the successful survival of an individual organism that lives to reproduce on many occasions. Survival can also be considered from the point of view of survival of a species. Members of some species found in waterholes in the arid outback cannot survive long periods of drought. When the waterhole dries up, all the organisms die. Yet, these species are successful residents of the arid outback. How is this achieved?

Some species are unable to survive long dry periods and all members of the species die. In this case, the species survives through its offspring. This occurs in the case of crustacean species, such as fairy shrimps and shield shrimps. How?

When water is present in abundance, female shrimps produce eggs that are not drought resistant. As waterholes begin to dry out, fairy shrimps and shield shrimps (see figure 5.24) produce drought-resistant fertilised ‘eggs’. These eggs are in fact cysts and each contains a fully developed embryo encased in a hard protective shell. By the time the water has gone, all the adult shrimps are dead but the cysts they have left behind can withstand desiccation for long periods. These cysts are in a state of dormancy and can lie in the dust of dry waterholes for more than 20 years.
When the drought breaks and the waterholes temporarily refill, the cysts hatch. Within just a few days, the newly hatched shrimps mature and reproduce. This is necessary because the waterholes and puddles in which they live will soon dry out. Male shrimps die after mating. Females carries large numbers of tiny drought-resistant cysts in a brood sac on their underbodies. Before the pools and waterholes turn to mud and then to dust, the female shrimps release their cysts and then die. These dried-out dormant cysts will lie in the dust or be blown by the desert wind, and the next generation of shrimp will only emerge when the rains come, perhaps years later, and short-lived waterholes and pools reappear.

What about the camel?

Camels, both the dromedary (*Camelus dromedarius*) and the Bactrian camel (*C. bactrianus*) are known as ‘the ships of the desert’. Camels are large placentals mammals. They are not native to Australia but large feral herds of camels, mainly dromedaries, live in arid areas of Australia, being descendants of camels imported in the 1800s. What adaptations do camels possess that enable them to survive in a desert environment?

Structural features that enable camels to survive in desert conditions include:

- a double row of long eyelashes and slit-shaped nostrils that can be closed — both features protecting the camel from wind-borne sand particles (see figure 5.25)
- bony structures in their nasal passages that enable the water vapour in their outgoing breath to be absorbed; it is then exhaled as dry air
- oval shaped red blood cells; the oval shape enables them to continue circulating even when the viscosity (thickness) of the blood increases due to the camel becoming dehydrated and losing body water
- the inbuilt fat store in the hump, which can be metabolised for energy production if food is not available. The oxidation reaction involved is also a source of metabolic water for the camel.

Physiological adaptations that minimise water loss in camels include:

- the ability to produce concentrated urine because of efficient kidneys; the urine they do produce is released and runs down their legs and its evaporation cools them
- the ability to produce very dry faeces because of a long colon in their gut
- the ability to allow their body temperature to vary over a wide range, from 34 to 42 °C, depending on the external temperature (unlike other mammals that maintain their internal body temperature within a narrow range). When it is hot during the day, the camel’s body temperature rises. Sweating only comes into play when the camel’s body temperature reaches 42 °C. (This is an important water conservation measure because sweating involves significant water loss.) At night, when it is cooler, this body heat is lost and the camel’s body temperature falls.

Camels can lose up to 40 per cent of their body water, whereas an adult person can lose only 15 per cent. When water does become available, camels are able to drink large volumes of water — more than 100 litres in a day. This large intake of water, however, does not cause osmotic complications; for example, a camel’s red blood cells can swell to more than double their volume before they burst, while the red blood cells of other large mammals would burst before this.
KEY IDEAS

■ Native mammals of the Australian deserts show many structural, physiological and behavioural adaptations that equip them for living in arid Australia.
■ A range of adaptations may be seen in desert-dwelling marsupials that enable them to minimise water loss and, if necessary, survive without drinking water.
■ Other survival strategies seen in various animal species include becoming dormant, moving around and producing drought-resistant offspring.

QUICK CHECK

10 List three water-conserving adaptations that may be seen in the mulgara.
11 Which organism can produce the more concentrated urine: a person or a mulgara?
12 Identify two features relating to kidney function that enables desert-dwelling marsupials to produce very concentrated urine.
13 Give an example of an animal that survives the long periods of drought in the desert:
   a by becoming dormant
   b by moving around
   c by producing drought-resistant offspring.

Vegetation types of arid Australia

Figure 5.26 shows the distribution of the major vegetation types in Australia.
In terms of area, the dominant vegetation type in Australia is **hummock grassland**, which covers almost a quarter of the Australian land surface, including the sandy plains and dunes of the major deserts. Hummock grasslands are dominated by species of spinifex grasses (*Triodia* spp.) (see figure 5.27). Do not think about these grasslands in terms of the green grass of a front lawn or a suburban park. Spinifex grasses, such as buck spinifex (*Triodia basedowii*) are stiff, drought-resistant grasses.

![Hummock grasslands](image)

**FIGURE 5.27** Hummock grasslands are dominated by spinifex (*Triodia* spp.). These hummock grasslands cover much of the Australian sandy deserts. Note the typical hummock shape of the spinifex plant that gives these grasslands their name.

In terms of area covered, the next largest vegetation type is shrubland. Different kinds of shrubland exist. The kind of shrubland that is present in an area depends on rainfall and soil type, with each kind having a different dominant plant species. **Acacia shrublands** occur across the arid and semi-arid areas of Australia and are dominated by mulga (*Acacia aneura*) (see figure 5.28a). **Chenopod shrublands** occur in arid regions with salty soils and are dominated by saltbushes (*Atriplex* spp.) and bluebushes (*Maireana* spp.) (see figure 5.28b).

![Australian shrublands](image)

**FIGURE 5.28** Australian shrublands cover much of the continent. Included among them are (a) acacia shrublands, dominated by mulga and (b) chenopod shrublands, dominated by saltbushes and bluebushes.
Table 5.5 shows the pattern of distribution of the major vegetation types in Australia as determined by environmental physical factors of rainfall, temperature, evaporation rate, and mineral-nutrient levels (rich or poor) and salt levels of the soil (salinity).

<table>
<thead>
<tr>
<th>Vegetation type</th>
<th>Climate</th>
</tr>
</thead>
<tbody>
<tr>
<td>• hummock grasslands</td>
<td>arid: lowest and erratic rainfall, high evaporation rates, high temperature</td>
</tr>
<tr>
<td>• acacia shrublands</td>
<td>arid and semi-arid: low rainfall, high temperature, salty or alkaline soils</td>
</tr>
<tr>
<td>• chenopod shrublands</td>
<td>semi-arid: annual rainfall between 200 and 500 mm, clay soils</td>
</tr>
<tr>
<td>• tussock grasslands dominated by <em>Astrebla</em> spp.</td>
<td>tropical: summer monsoons and winter drought</td>
</tr>
<tr>
<td>• tropical grasslands dominated by <em>Sorghum</em> spp.</td>
<td></td>
</tr>
<tr>
<td>• mallee woodlands</td>
<td>temperate: intermediate rainfall, poor soil</td>
</tr>
<tr>
<td>• eucalypt forests</td>
<td>temperate: high rainfall, poor soil</td>
</tr>
<tr>
<td>• rainforests</td>
<td>tropical or temperate: high and reliable rainfall, rich soil</td>
</tr>
</tbody>
</table>

**Adaptations in desert plants**

Let’s look at how plants of the arid inland of Australia survive through structural and physiological adaptations that equip them to:
- maximise water uptake
- minimise water loss
- produce drought-resistant seeds.

**Maximising water uptake**

The part of a plant that takes up water is the root system. In arid areas of Australia, some trees growing along dry creek beds produce long, unbranched roots that penetrate to moist soil at or near the water table. Once moisture is reached, the major root branches and forms lateral roots. **Plants that produce these deep roots are called water tappers** and their major root can grow to depths of 30 m. The part of the root that is located in the upper dry soil is covered by a corky waterproof layer of cells that prevents water loss.

Other plants growing in arid regions develop extensive root systems that spread out horizontally, far beyond the tree canopy but just below the soil surface. In this case, the plant takes up water from an extensive area around it.

**Minimising water loss**

**Transpiration** is the loss of water vapour by evaporation from moist surfaces inside the plant (see figure 5.29). This loss of water vapour occurs through pores, known as **stomata** (singular: stoma), which are typically present on the lower surface of plant leaves (see figure 3.30). The higher the wind speed and the higher the temperature of the leaf, the greater the rate of water loss.

For a plant to reduce its water loss, the principal strategy is to reduce the loss of water vapour by transpiration through the stomata on its leaves. Transpiration cannot be stopped permanently because it is essential for the process of moving columns of water through xylem tissue, from where water is supplied to all cells of a plant (refer to chapter 4, p. xxx). Stomata are also the pores through which the carbon dioxide required for photosynthesis enters leaves and they must open to allow carbon dioxide to diffuse into the leaves.
Let’s explore how various adaptations of leaves, mainly structural, can reduce the water loss in plants.

**Presence of a thick cuticle**
Most water loss from plants occurs via their stomata, but some water is also lost directly across the surfaces of cells exposed to the external environment. This latter water loss is minimised by the presence of a waxy cuticle on the exposed upper surface of leaves (see figure 5.31). The cuticle is composed of a waterproof material called cutin. Plants that live in arid environments typically have leaves with thicker cuticles than those in non-arid regions.

**Figure 5.31** Transverse sections through leaves from two different species of plant: (a) *Eucalyptus globulus* and (b) waterlily (*Nymphaea* sp.). The two leaves are at the same magnification. Note the thick cuticle (arrow) of the Eucalyptus leaf and apparent lack of cuticle on the waterlily leaf. The thicker the cuticle, the less transpiration occurs.
Reduced number of stomata per unit of surface area
Fewer stomata per unit area of leaves means that water loss by transpiration is reduced.

Presence of sunken stomata
The rate of water loss of a leaf from its stomata is affected by several factors including the humidity of the air surrounding the stomata. Water vapour is lost from leaves via their stomata more rapidly when they are immediately surrounded by dry air than when they are surrounded by humid air. Why? The concentration gradient of water vapour from inside the leaf to outside is steeper in drier conditions relative to more humid conditions.

Another related factor that affects water loss by transpiration is wind speed. On a windless day, the loss of water by transpiration is low because the stomata are surrounded by a boundary of still air with a level of humidity similar to that inside the leaves. In contrast, on a windy day, the water vapour that transpires from leaves is immediately blown away so that more water vapour diffuses from the leaves. The windier the day, the higher the rate of transpiration.

Unlike ‘typical’ stomata that are situated at the leaf surface, sunken stomata are located in pits below the leaf surface. This position below the leaf surfaces creates a region of relatively higher humidity in the air space immediately surrounding the sunken stomata as compared with stomata at the leaf surface. The presence of sunken stomata reduces water loss by transpiration (see figure 5.32). Likewise, the presence of hairs on the upper surfaces of leaves and around the stomata would be expected to reduce the speed of airflow over leaves and contribute to a reduction in water loss.

Leaf colour, size and margins
Temperature is another factor that affects the rate of water loss by transpiration; lower temperatures mean less transpiration. Leaves of some shapes gather less heat from exposure to the sun than other shapes and so reduce water loss. Leaves with a small surface area reduce the area from which transpiration occurs.

- **Leaf colour.** Silver or glossy leaves reflect relatively more sunlight producing lower leaf temperatures.
- **Leaf shape.** Small, narrow or cylindrical leaves have a small surface area. When exposed to the sun, these leaves gather less heat than larger flat leaves and so stay cooler, minimising water loss (see figure 5.33).
Plants of the Australian genus *Hakea* show a variety of adaptations that enable the plants to minimise water loss. As well as cylindrical leaves, *Hakea* plants also have a thick cuticle on their leaf epidermal cells and have sunken stomata. Look at figure 5.34a. Note the cylindrical cross-section shape of the *Hakea* leaf and the position of some stomata (arrowed). Figure 5.34b shows the detail of a sunken stoma in a *Hakea* leaf.

- **Leaf margin.** Leaves are thinnest where their upper and lower surfaces meet, that is, at their margins. Plants lose more heat from thinner regions than from thicker regions. The larger the ratio of edge length to surface area of a leaf, the faster a leaf will be cooled. Cooler leaves have lower transpiration rates. Leaves with incised margins have a larger edge-length-to-surface-area ratio than leaves with entire margins. These leaves are thus cooler and so have a lower transpiration rate (see figure 5.35a).
- **Leaf orientation.** The orientation of leaves can influence leaf temperature (see figure 5.35b). Leaves with a vertical orientation have less exposure to sunshine and so gain less heat and are cooler. Cooler means less water loss.
Figure 5.35  (a) At left is a leaf with an indented margin and at right is a leaf with an entire margin. Which leaf will cool more quickly?  (b) Diagram showing how the orientation of leaves can affect the amount of heat gained when exposed to the sun. Which leaf orientation would be expected to gain more heat: vertical or horizontal?  (c) Vertically oriented leaves are common in Eucalyptus species.

Rolled-up leaves
Figure 5.36 shows a rolled-up leaf of marram grass (Ammophila arenaria). Although this is not an Australian species, some related species in Australia have the same characteristics. These leaves have a number of features to restrict water loss, including:
- hinge cells that lose turgor if water is lost and cause the leaf to curl inwards, creating a humid chamber for the stomata
- stomata on only one side of the leaf so that when the leaf curls, no stomata are directly exposed to the environment
- stomata located in ‘folds’ of the leaf so that they are shielded from air currents even when the leaf is unrolled
- a thickened cuticle on the surface that is exposed when the leaf curls.

Note the hairs on the upper epidermis of the leaf in figure 5.36b.

Figure 5.36 Transverse section of marram grass (Ammophila arenaria) at three different, increasing, magnifications.  (a) Water loss in hinge cells (marked by ‘’ ) causes the leaf to curl. Note the thickness of the cuticles on the upper surface (thin) and lower surface (thick).  (b) Note the vascular tissue, photosynthetic tissue, thickened sclerenchyma cells and hair cells.  (c) Can you identify stomata, photosynthetic tissue and hair cells in the upper epidermal layer?
No visible leaves
Various plants that survive in drought conditions have no visible leaves, for example, cacti, succulent plants that are member of the Cactaceae family and native to the Americas (see figure 5.37). Their leaves are reduced to spines and their stems are swollen with cells that contain water stores in their vacuoles. These plants have extensive shallow roots, thick cuticles on their surfaces and few stomata.

Leaves that aren’t leaves
Members of the genus *Acacia*, commonly called wattles, are widespread in Australian environments, including arid and semi-arid regions. Mulgas (*Acacia aneura*) are the dominant species in the acacia scrublands. As many *Acacia* species mature, their feathery leaves are replaced by their flattened leaf stalks. These flattened leaf stalks are known as phyllodes. Figure 5.38a shows a transitional state in which the feathery true leaves of an *Acacia* plant are starting to be replaced by leaf stalks that are gradually thickening. Phyllodes enable plants to survive in arid conditions because they provide a store of water in large parenchyma cells at their centre. In addition, phyllodes have fewer stomata than true leaves and so lose less water by transpiration.

Acacia species mature, their feathery leaves are replaced by their flattened leaf stalks. These flattened leaf stalks are known as phyllodes. Figure 5.38a shows a transitional state in which the feathery true leaves of an *Acacia* plant are starting to be replaced by leaf stalks that are gradually thickening. Phyllodes enable plants to survive in arid conditions because they provide a store of water in large parenchyma cells at their centre. In addition, phyllodes have fewer stomata than true leaves and so lose less water by transpiration.

Plants of the genus *Casuarina* and *Allocasuarina* show a different adaptation. These plants have what appear to be fine needle-like leaves, but in fact they are modified branches that function as leaves and are known as cladodes. The leaves are reduced to tiny scales that encircling each joint of the cladode (see figure 5.39). Cladodes have fewer stomata than true leaves and so lose less water by transpiration.
Shedding leaves
To minimise water loss, when plants become stressed in drought conditions, they may conserve water by dropping their leaves. This is a strategy that is seen in the bladder saltbush (Atriplex vesicularia). In conditions of severe drought this saltbush closes its stomata, drops its leaves and sheds its fine roots.

Producing drought-resistant seeds
Populations of some herbaceous flowering plants can survive in arid regions of Australia. These plants germinate from seeds, then flower and produce new seeds in a very short period. Plants that complete their life cycles in just two to three weeks are said to be ephemeral. Because they produce drought-resistant seeds, populations of ephemeral plants can survive in arid regions. The outer coats of the seeds of these plants contain a water-soluble chemical that inhibits seed germination. So, dry conditions = no germination. When heavy rains fall, this chemical is dissolved and the seeds germinate to produce seedlings. Shortly after, the new plants produce flowers in a synchronised display (see figure 5.40). The plants soon die, but not before they have produced seeds that will lie dormant until the next heavy rains.

As was seen in figure 5.40, local rainfall over a region of desert can transform areas of the red centre of Australia to a green centre. Some years, very heavy rains that fall hundreds of kilometres from the desert can reach the desert months later. This can occur with the monsoon rains that fall in Queensland and flow through rivers of the Channel Country, with the water spilling out over extensive floodplains (see figure 5.41). When this happens vast regions of the desert are transformed into watery habitats where fish and waterbirds breed.
FIGURE 5.41 A flooded river plain in the Simpson Desert. This water originated from torrential rainfall in western Queensland that eventually flowed into dry riverbeds in the desert, transforming the sandy plains to shallow lakes. (Image courtesy of Stan Sheldon)

On rare occasions, the water may reach as far south as Lake Eyre in South Australia. Normally, Lake Eyre is a dry saltpan but it sometimes becomes a giant lake and breeding ground for birds, including pelicans (see figure 5.42).

FIGURE 5.42 (a) Torrential rains in Queensland early in 2011 resulted in water flowing into Lake Eyre, transforming much of it into a shallow lake by August. This view of Lake Eyre (taken on 5 December 2011 from the International Space Station) shows water still present in some sections, including Belt Bay and Madigan Gulf. The green and pink colours are due to high densities of archaeas that thrive in these highly salty aquatic conditions. The bright white surface of Lake Eyre South (at lower right hand corner) shows that the water has already evaporated from there, returning it to its dry saltpan state. (b) Pelicans in large numbers breed on the shores and on mounds in Lake Eyre when it fills with water.

KEY IDEAS

- The arid and semi-arid areas of inland Australia are dominated by hummock grasslands, acacia shrublands and chenopods shrublands.
- Desert plants show a variety of adaptations to maximise water uptake and to reduce water loss.
- The major loss of water in plants occurs as water vapour lost by transpiration from the leaf stomata.
- Many adaptations exist in desert plants for reducing water loss from their leaves.
- Ephemeral plant species of desert regions produce drought-resistant seeds that germinate only after rain or flooding.
**QUICK CHECK**

14 What is the major avenue of water loss by plants?
15 Identify one example of an adaptation that enables a plant to conserve water by:
   a reducing water loss from cells at the leaf surface
   b reducing water loss from their leaf stomata
   c reducing the absorption of heat, thus staying cooler and reducing the rate of transpiration.
16 What is a phyllode?
17 How do phyllodes enable a plant to conserve water?
18 What feature prevents drought-resistant seeds from germinating before rain falls?

**The dominant plants**

Let us now have a closer look at three plants that are dominant species in the arid and semi-arid areas of Australia: the mulgas of the acacia shrublands, the saltbushes of the chenopod shrublands and the spinifexes of the hummock grasslands found in the major deserts.

**Mulgas: tree of the arid inland**

Acacia shrublands of arid inland Australia are dominated by mulga (*Acacia aneura*), which can exist either as trees or small shrubs (refer to figure 5.28a, p. xx). Mulga trees have many features or adaptations that equip them for survival in arid conditions (see figure 5.43).

**FIGURE 5.43** Some of the adaptations of the mulga tree. The vertical orientation of sparse foliage of mulga ensures that the little rain that falls is directed to the roots of the plant.

The root system of a mulga tree is concentrated around the base of the tree. When rain falls, it is caught by the upward-pointing leaves of this tree and funnelled down the branches to the centre of the tree. From there, the water falls to the ground around the trunk where the root system is most concentrated.
Mulga trees grow in regions where the rainfall is low and unreliable because they are drought resistant and can survive a year or more without water. In dry years, a mulga tree does not produce any flowers. If, however, heavy rains fall in the summer, a mulga produces flowers and, if rains occur in the following winter, seeds are formed. The seeds germinate to produce seedlings the following summer and require rain to survive. Notice that a pattern of rainfall over three seasons (summer-winter-summer) is required for a new generation of mulgas to be produced. This pattern of rainfall occurs during a La Niña event.

**Saltbushes (chenopods)**

Soils of some areas of the hot, arid inland contain high concentrations of salt. Many species of salt-tolerant plants live in this environment, such as species of saltbush (*Atriplex* spp.) (see figure 5.44) and bluebush (*Maireana* spp.). These plants are also drought resistant.

Saltbushes grow in soils that are too salty for many other plant species. They can survive because they excrete the dissolved salt that is taken up by their roots from cells in their leaves. As a result, the leaves of saltbushes are covered in fine salt crystals. As well as being an excretory product, these salt crystals reflect the sun’s heat and contribute to keeping the plants from overheating.

Saltbushes have structural adaptations to conserve water. Their leaves:

- have sunken stomata
- are covered in hairs
- are oriented so that they expose a minimal surface to the sun’s rays.

Saltbushes produce seeds that have high concentrations of salt in their outer coats and this salt prevents germination. Saltbush seeds germinate only after the salt has been washed out after heavy rainfall. As soon as the salt inhibition is removed, the seeds germinate and new seedlings quickly become established. The salt inhibition of germination means the next generation of saltbush plants appears in times of good rainfall when their chance of survival is maximised.

**Spinifexes of the hummock grasslands**

The leaves of spinifex plants contain high levels of silica grains, which makes them rigid and sharp-pointed (see figure 5.45). Spinifex hummocks provide shelter for desert animals: mammals such as the tarrkawarra and reptiles such as many species of lizard and snake. The only animals that use spinifex as a food source are termites that feed on the litter from dead plants.
Spinifex grasses show physical adaptations to desert conditions including:

- a deep root system that extends 3 m or more into the soil, maximising water uptake
- rolled-up leaves that
  - position the stomata inside the curved leaves, reducing their exposure to the wind, reducing the amount of water vapour lost by transpiration via the stomata
  - reduce the leaf area exposed to the sun, reducing the amount of heat absorbed and water loss
- roots that grow from the same nodes as the stems, meaning that each stem has its own supply of water and dissolved minerals
- seedlings that, under adverse conditions, can enter a dormant state, meaning that, rather than dying, the seedlings survive until favourable conditions return.

KEY IDEAS

- Mulgas, the dominant plant of the acacia shrublands of arid regions, show various adaptations to minimise water loss and maximise water uptake.
- Saltbushes of the chenopod shrublands show adaptations for minimising water loss and also for surviving in very salty soils.
- The spinifexes of the hummock grasslands of the deserts show adaptations to maximise water uptake and minimise water loss.

QUICK CHECK

19 Identify an adaptation that enables:
   a mulga shrubs to maximise water uptake
   b saltbushes to minimise heat absorbed
   c spinifexes to reduce water loss.

20 What feature enables saltbushes to survive in very salty soils?

Survival in the cold

To this point, the focus of this chapter has been on adaptations that enable the survival of Australian animals and plants in the arid and semi-arid regions of this country. Plants and animals also show adaptations that equip them for life in cold conditions on land and in water. Let us look briefly at a few examples.
Adaptations: animals in the cold

Ice can damage or kill

Processes that are essential for life include chemical reactions that take place between substances that are dissolved in liquid water, that is, in solution. These processes cannot take place in solid water (ice). If all the liquid water in a living organism were replaced by solid water, life would be destroyed. When ice forms, the solid water expands. If cells freeze, the expanding ice crystals rupture the cell membranes and kill the cells.

Many living things can exist on land in Antarctica or the Arctic. During winter, the air temperatures fall well below the freezing point of pure water. How do living things survive in these low temperatures? Organisms have special features or behaviours that enable them to survive extremely low temperatures.

Pure water freezes at 0°C, but water with dissolved material in it has a lower freezing point than this. For example, a very concentrated salt solution (280 g/L, or 4.8 M) starts to freeze only when the temperature falls to about −18°C. One strategy used by some living things to assist their survival in very low temperatures is to produce antifreeze substances. For example, some insects, fishes, frogs and turtles can survive in regions that have low temperatures during winter. These animals make antifreeze substances such as glycerol, amino acids and sugars, or mixtures of substances, at the start of the freezing season. These antifreeze substances are released into their body fluids. The presence of these dissolved substances lowers the freezing point of their body fluids to well below that of the surrounding water temperatures. This means that the body fluids of these organisms stay liquid.

Some frogs and toads burrow underground to avoid freezing temperatures. Birds and mammals living in Antarctica or the Arctic use another strategy to protect themselves from the damaging effects of low temperatures. Birds and mammals convert chemical energy present in their food into heat energy. This internal supply of heat keeps the body temperatures of these birds and mammals well above the freezing point of pure water. This heat is retained by excellent insulation; mammals have insulating layers of fat under the skin and thick fur, and birds have layers of feathers (see figure 5.46). Would you expect that these Antarctic animals would need to eat more or less than animals of comparable size living in temperate conditions?

**ODD FACT**

What is frostbite? At temperatures below freezing, body parts such as hands, feet, nose, chin and ears are at risk of damage from the cold. Sometimes just the skin freezes. In more severe cases, the skin and underlying tissues become frozen. If ice crystals form, the affected part of the body can be permanently damaged. Gangrene may result from damage to the blood supply. In this case, amputation of the frostbitten part may be necessary.

**FIGURE 5.46** Emperor penguins (*Aptenodytes forsteri*) are the largest of the penguin species, with adult birds more than 1m tall and weighing 40 kg. One of their survival mechanisms is to huddle in large groups. What is a possible advantage of this behaviour?
Burramys has a long sleep

The mountain pygmy possum, *Burramys parvus*, is the only Australian mammal that lives permanently in alpine regions. Its distribution is limited to two small areas (see figure 5.47), one in Kosciuszko National Park of New South Wales and the other near Mount Hotham in Victoria. *Burramys* has both behavioural and physiological features that enable it to survive the low winter temperatures of its alpine environment. It collects and hides seeds and fruits for use during winter. Unlike other pygmy possums, *Burramys* has no storage of fat in its tail. At low temperatures during winter, *Burramys* goes into a torpor that is equivalent to hibernation. When mammals hibernate, their heartbeat slows down considerably and their breathing rate drops. Body metabolism is significantly reduced and their body temperature drops. In captivity, *Burramys* can hibernate at about 6 °C and remains in that state for three to seven days at a time. Normal body temperature is around 36.1 °C and during hibernation drops to that of the environment. The body metabolism of *Burramys* in hibernation ranges between 0.6 per cent and 3.9 per cent of the normal metabolic rate of an active *Burramys* at 6 °C. Hibernation and the reduced metabolic rate for periods means that the amount of food required by an animal, overall, to survive in winter is reduced.

![Mountain pygmy possum](image)

**FIGURE 5.47** (a) Mountain pygmy possum, *Burramys parvus*, and (b) its distribution, limited to two small areas.

Adaptations: mammals in water

The time marine mammals can stay under water is determined by the amount of oxygen they are able to carry in their lungs or store in other body tissues. Mammals, such as elephant seals (*Mirounga leonine*) and sperm whales (*Physeter macrocephalus*), that dive to great depths are able to do so because they have special characteristics which increase their oxygen-carrying capacity. For example, they have a much higher concentration of red blood cells than many other mammals.

Whales and dolphins (order Cetacea) are mammals that spend their entire lives in water. Like all mammals, they are endothermic and they breathe air so must come to the surface every so often. The females give birth to young that they suckle on milk secreted by mammary glands.

Most land mammals have an insulating fur coat that assists in the regulation of the body temperature. Whales and dolphins rely on an insulating layer of fat or blubber below the skin. This layer may be up to 50 cm thick and can vary with the different seasons. Cetaceans maintain a stable body temperature of 36 to 37 °C in an environment that is usually less than 25 °C and may be as low as 10 °C. In addition to blubber under the skin, fat may also be deposited around organs and tissues such as the liver and muscles, and in bone in the form of oil. These deposits can make up to half of the body weight of an animal.
Countercurrent systems to warm blood

Whales and dolphins also maintain their body temperature by using a **countercurrent exchange system** (see figure 5.48). There is a fine network of vascular tissue within the fins, tail flukes and other appendages. An outgoing artery is paired with an incoming vein. Blood coming from the body core to the skin is warm. Blood flowing from the skin back to the body core has been cooled. In this countercurrent exchange system heat in the blood coming from the core flows to the blood returning from the skin. This warms the blood flowing from the skin and so prevents the venous blood from cooling the internal organs and muscles. At the same time, the blood moving out to the skin is cooled and so the loss of heat across the skin is reduced. This countercurrent system is also present in the feet, wings and bills of penguins.

Heat is readily lost from appendages such as hands and feet. Whales and dolphins have few protruding parts (fins and tail flukes). This means that they have a relatively small surface-area-to-volume ratio and heat loss across the skin is further minimised. These features enable large whales to live in the cold waters of the Antarctic Ocean.

Adaptations: Plants in the cold

Many plants survive in subzero temperatures without being damaged by these extremely low temperatures. Unlike animals, plants do not produce an ‘antifreeze’. They gradually become resistant to the potential danger of ice forming in their tissues as the temperature falls below 0 °C. How does this occur?

Remember that water is transported through plants in very fine xylem vessels and is subjected to a number of forces. These forces affect the way in which water behaves in plants in freezing temperatures. As the temperature surrounding the plant drops below freezing, ice forms suddenly in the spaces outside the living cells of the plant. The inside of the cells doesn’t freeze because the concentration of ions in the cytosol is greater than the concentration outside the cell. The cytosol has a lower freezing point.

Because ice has formed, the concentration of water inside the living cells is higher than the concentration outside and so water moves out of the cells. The ice crystals outside the cells grow (see figure 5.49). The movement of water out of the cells increases the ion concentration inside the cells and so lowers their freezing point even further. The living cells are then able to withstand further drops in the external temperature because the more concentrated cytosol acts as an antifreeze. The ice crystals grow between the cells and do not damage the cell membranes, which are pliable and bend under pressure of the ice.
Many species of trees are able to withstand extremely low temperatures before they are killed (see table 5.6). The temperatures at which the living tissue in a tree is killed influences the latitudes at which it can grow. Which tree in table 5.6 is most likely to be found in the northern latitudes of Canada? Note that as one travels further north (or south) from the equator at sea level, the average temperature falls. The higher the latitude, the lower the temperature.

**TABLE 5.6 Lethal temperatures for some trees**

<table>
<thead>
<tr>
<th>Species</th>
<th>Temperature (°C) at which killed</th>
</tr>
</thead>
<tbody>
<tr>
<td>redwood (<em>Sequoia sempervirens</em>)</td>
<td>−15</td>
</tr>
<tr>
<td>southern magnolia (<em>Magnolia grandiflora</em>)</td>
<td>−15 to −20</td>
</tr>
<tr>
<td>swamp chestnut oak (<em>Quercus michauxii</em>)</td>
<td>−20</td>
</tr>
<tr>
<td>American beech (<em>Fagus grandifolia</em>)</td>
<td>−41</td>
</tr>
<tr>
<td>sugar maple (<em>Acer saccharum</em>)</td>
<td>−42 to −43</td>
</tr>
<tr>
<td>black cottonwood (<em>Populus trichocarpa</em>)</td>
<td>−60</td>
</tr>
<tr>
<td>balsam fir (<em>Abies balsamea</em>)</td>
<td>−80</td>
</tr>
</tbody>
</table>

Ultimately, if there is an excessive drop in the surrounding temperature, ice crystals form inside the cells, which die and so the tree may die. It has been suggested that an excessive drop in temperature damages the protein molecules that form part of the cell membranes so that ions can leak out of the cell. Australia does not experience the sustained extremes of low temperatures found in many other countries and low temperature is rarely a limiting factor for plant growth. Growth of native plants in Australia is determined by whether a plant has the adaptations to survive the various altitude zones and their associated temperatures. Some plants, particularly exotic garden plants, may be killed or damaged by an unusually severe frost.

**KEY IDEAS**

- Adaptations of animals living in cold environments include the presence of insulating layers, the production of antifreeze compounds and the use of countercurrent exchange systems.
- Plants use different strategies to survive in subzero environments.

**QUICK CHECK**

21. What is the action of antifreeze substances?
22. When does ice crystal formation become lethal for plant cells?
23. In a countercurrent exchange system, in which direction does heat flow: from artery to veins or from veins to artery?

**Biomimicry**

*Biomimicry* (*bios* = life; *mimesis* = to imitate) is the practice of learning from and being inspired by nature’s best ideas to achieve technological advances, expressed in new designs, products and processes. The inspiration may be an observation of an energy-efficient action or structure in a plant or an animal, microscopic or macroscopic. It’s a case of watch and wonder.
A leader in the field has written about biomimicry in the following terms:

The core idea is that nature, imaginative by necessity, has already solved many of the problems we are grappling with... The conscious emulation of life’s genius is a survival strategy for the human race, a path to a sustainable future. The more our world looks and functions like the natural world, the more likely we are to endure on this home that is ours, but not ours alone.

Source: Interview with Janine Benyus, author Biomimicry Innovation from the World of Nature from http://futurepositive.synearth.net/2003/12/19

Biomimicry is based on the premise that biological evolution has been occurring for more than 3.6 billion years; in that time many biological designs and structures have evolved and been trialled in the living world, and the world around us is filled with survivors that exemplify successful biological designs and strategies. Biomimicry uses a ‘biology-to-design’ approach that starts with the study of a natural phenomenon, developing an understanding of how it works, and then applying that understanding to a human design challenge or problem.

**Burrs and Velcro**

A well-known example of biomimicry came not from the laboratory, but from a dog that walked through thick vegetation. In the early 1940s, a Swiss engineer went through the tedious process of removing burrs from the hair of his dog. He wondered why the burrs were so difficult to remove. Upon examination, he found that the projections on the burrs had tiny hooks at their ends. The inspiration was to recognise that this annoying feature of burrs could be applied to hold items other than burrs to dog hair together. This was the beginning of Velcro® (see figure 5.50).

![Burrs and Velcro](image)

**Lotus leaves and paint**

In the 1990s, German researchers used a scanning electron microscope to study the leaves of the lotus plant (*Nelumbo nucifera*). They found that the leaf surface was covered with microscopically tiny bumps and that water droplets fell off the leaves taking with them any dirt particles. The lotus leaf is in fact a self-cleaning structure. The concept of self-cleaning was patented and its first commercial application was a paint, marketed under the brand name Lotusan®, that mimics the rough lotus leaf (see figure 5.51). Other applications inspired by the self-cleaning and dirt-repellent properties of lotus leaves have been in camera lens coating and wallpapers.
Sharks and ships

Sharks are ocean predators that can move at speed in pursuit of their prey. Their skin appears smooth, however, the outer surface of a shark is covered by overlapping scales called denticles. These denticles have grooves running down their length (see figure 5.52). As the shark moves through water, the water is channelled by these grooves and moves across the shark’s skin surface more efficiently, with less drag than if the surface were smooth.

Marine designers and engineers are using shark-skin technology in the design of ships’ hulls to produce ships that move with less friction and drag that slow boats down. One claim is that the drag on boats with this technology is reduced by 67 per cent. In addition, the shark-skin technology makes it more difficult for marine organisms, such as barnacles and algae, to stick to the hulls of boats. This would mean that toxic cleaning chemicals would not need to be used to remove these organisms. What economic advantage might a reduction in drag produce for a commercial cargo ship? The use of shark-skin technology is also being explored in the aircraft industry. Tests are being carried out on the use of paints that have an imitation sharkskin pattern embossed into their surface.

A US company used shark-skin technology to design more efficient blades for wind turbines. They have produced blades that spin through the air more smoothly and with less drag.

Beetles and water bottles

A South Korean designer has produced a ‘Dew Bank Bottle’, inspired by the Namibian Beetle (Stenocara gracilipes) that collects moisture from ocean fog that drifts into the Namib desert each morning. The protective outer forewings (elytra) of the beetle are covered in tiny bumps that have hydrophilic (water-loving) tips and hydrophobic (water-repelling) sides. The beetle faces away from the incoming fog, arches its back, and tiny water droplets condense and run down grooves to the beetle’s mouth. The Dew Bank Bottle imitates the water collection technique of the beetle. Water vapour condenses on the rounded metal surface of the water bottle and is collected in the bottle.
The discipline of biomimicry is expanding as people, including designers, engineers, architects and scientists, look to the natural world for inspiration. Biomimicry is opening new fields for the development of new synthetic materials as people ‘think outside the box’. The gecko that can walk up walls and across ceilings raises possibilities for new materials for adhesion. The slippery glass-like inner surface of a pitcher plant raises possibilities for new materials for anti-adhesion. The structure of the compound eye of an insect raises possibilities for miniature motion detectors. The study of photosynthesis in plants raises possibilities for new ways of harnessing the energy of sunlight. The structure of mollusc shells raises possibilities for the design of new ceramics. The list is goes on.

**KEY IDEAS**

- Biomimicry is the practice of learning from and being inspired by nature’s best ideas to achieve technological advances, expressed in new designs, products and processes.
- Many examples of biomimicry exist.
- Biomimicry is a developing discipline that is increasingly affecting human life through the development of new designs and products.

**QUICK CHECK**

24. What was the biological structure that inspired the development of Velcro?
25. What is a denticle?
26. What performance improvements have flowed from shark-skin technology?
27. What is Lotus-Effect™ Technology?

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**Death in a bushfire**

The photograph in figure 5.53 appeared on the front page of *The Age* on Friday 4 September 1998. The caption read: ‘Twelve metres between life and death: two identical fire tankers — one burnt out, another unscathed — in the blackened bush near Linton.’ Five men survived in the tanker on the right of the photo, while five men died in the truck on the left.

Distance was not the important factor for the firefighters and trucks shown in the photograph. The truck containing the firefighters that survived had a reserve of water. Two of the crew huddled under a fire blanket in the cabin. The remaining three firefighters in the back of the unburnt truck turned small water hoses on themselves and then pointed them skywards so that water rained over the whole of their truck. Note the unburnt vegetation near the unburnt truck. This vegetation was also protected by the veil of water sprayed over the truck.

The men who perished in the fire were in a truck with no water. The change in fire direction happened so quickly there was no time for the men to get to the other truck. The fierceness of the fire, which is indicated by the complete absence of living vegetation near the burnt truck, meant that radiant heat would have been extreme and death inevitable for the unprotected. Water in the front truck was insufficient to protect the second truck. A key issue identified was that low-water-level warning devices should be installed in all Country Fire Authority tankers.

**FIGURE 5.53** One fire truck was burnt out and the other was unscathed in a serious bushfire in 1998.
Surviving a bushfire

Bushfires are an integral part of the Australian bush. The Black Saturday fires of 7 February 2009 caused the deaths of 173 Victorians. How can your chance of survival be increased if you are in such danger? Remember that, apart from the flames themselves, it is the level of radiant heat that kills.

**Make sure you are well clothed and take cover.** Wear protective clothing to reduce your exposure to radiant heat. Wear long pants and a long sleeved shirt or light pullover. Natural fibres such as light wool or close-weave cotton are best. Wear solid footwear, preferably leather, and cover your head with an appropriate hat. Remember — **cover up to survive** (see figure 5.54).

![Figure 5.54](image-url) **Radiant heat can kill. Remember, as soon as you become aware of a fire, cover up to survive.**

**Take cover inside your house.** You will be protected from the radiant heat. Shut windows and doors. This ensures your supply of oxygen and prevents embers from blowing into the house.

You run the risk of becoming dehydrated in a bushfire. Drink water often even if you don’t feel thirsty. Avoid alcohol and fizzy drinks.

**If caught on the road in a car DO NOT get out and run.** Stay in the car until the fire passes. Park the car with lights on and the engine running in a clear area away from vegetation, especially any that is dry. Close the windows and vents and get as low as you can within the car and cover yourself with a woollen blanket (see figure 5.55).

![Figure 5.55](image-url) **In the country and other fire-prone areas always carry woollen blankets in your car. They will help protect you from radiant heat.**

Radiant heat can be the killer. It can lead to heat exhaustion, heart failure and dehydration. Some people have died from asphyxiation (lack of oxygen) during a bushfire. Why do you think this occurs? Find out more information by going to the Country Fire Authority weblink for this chapter in your eBookPLUS.
Examine figure 5.56 and answer the following questions:

1. What relationship is illustrated in this graph?

2. a. The medulla of the kidney contains a particular part of the kidney nephron. What part of the nephron is this?
   b. As the medulla becomes thicker, what can happen to the loop of Henle?

3. a. You will be familiar with mammals such as pigs, dogs and cats, but you are unlikely to know much about jerboas (*Allactaga* spp.). However, based on the data in figure 5.56, what predictions might you make about:
   i. the environment in which jerboas survive
   ii. two structural adaptations that might be present in a jerboa.

   b. Do an online search for information about jerboas. Were your answers to part (a) correct?

4. Fish, like other vertebrates, have kidneys. Consider a freshwater fish and a saltwater fish. One of these fishes has kidney nephrons with long loops of Henle, while the nephrons in the other fish have almost no loops of Henle. Which fish has the long loops of Henle and which virtually lacks them? Briefly justify your decision.

---

**FIGURE 5.56** Relationship between thickness of medulla and maximal urea concentration

- Jerboa
- Dog
- Cat
- Human
- Pig

---

**Relative thickness of kidney medulla**

- Maximal urea concentration (mM/L)

- 0
- 100
- 200
- 300
- 400

- 1 3 5 7 9
Chapter review

Key words

acacia shrublands  adaptation  antifreeze chenopod shrublands  biomimicry  cladode  cohesion  countercurrent exchange system  cuticle  denticles  dormancy  drought-resistant seeds  ephemerol extracellular fluid  free-standing water  humidity  hummock grasslands  hydrogen bond  hydrogen bonding  hypothermia insensible water loss  insulating layers  intracellular fluid  interstitial fluid  limiting factor  loop of Henle  medullary thickness  metabolic water  mulgara  operculum  phyllode  plasma  rolled-up leaves  stomata  sunken stomata  transpiration  tolerance limit  tolerance range  water balance  water tappers

Questions

1 Making connections ➔ Use at least eight of the key words in this chapter and draw a concept map. You may use other words in drawing up your map.

2 Applying and communicating your understanding ➔ Explain how each of the following features assists a plant to survive in a very hot environment.
   (a) Desert plants generally have deeply penetrating root systems.
   (b) Succulent plants (that store water) have stomata that open only at night.
   (c) Some plants have special cells, called hinge cells, on the surface of their leaves that also has stomata. When hinge cells lose water, the leaf rolls up with the hinge cells on the inside of the rolled leaf.

3 Interpreting data and communicating ideas ➔ Many small animals that are solitary over summer tend to become social during winter and often construct nests under the snow. The temperature inside a communal nest of beavers was compared with the temperature of the outside air. The results are shown in figure 5.57.
   (a) What is the maximum difference between the temperature of the beaver nest and the temperature of the outside air?
   (b) Suggest what causes this difference in temperature.

4 Applying your understanding ➔ Look at figure 5.48 on page xxx. Assume a dolphin needed to lose heat. What changes would occur in the countercurrent exchange system to facilitate that loss?

5 Applying your understanding ➔ Identify a physiological characteristic that assists each of the following to maintain water balance:
   (a) humans (on a hot day)
   (b) sea birds
   (c) the tarrkawarra (Notomys alexis).

6 Applying your understanding in new contexts ➔ Air in the Antarctic is relatively dry. Antarctic explorers can become dehydrated relatively quickly. Explain the relationship between these statements. How can Antarctic explorers reduce the chance of dehydration?

7 Applying your understanding ➔
   (a) Explain why most stems and leaves on plants have a waterproof cuticle and yet roots do not.
   (b) When cuttings of plants are first potted, they have no roots and may wilt. Wilting is prevented if the pot is enclosed in a plastic bag and shaded from sunlight. Explain why this treatment prevents wilting.
8 You have been given the task of selecting plants for growth in a hot dry environment in a glasshouse.
(a) Identify five key features you would look for in the plants that you select?
(b) Briefly explain your choices.
(c) Would all of these features be expected to serve as adaptations if these same plants were to be grown in a low-light tropical rainforest?

9 Using skills of analysis ➔ Two closely related mammalian species differ in their range. One species, A, lives in a sandy desert, while the other, B, lives in a cool temperate grassland. Devise four relevant questions about structural, physiological or behavioural features of these mammals that will help you identify which species lives in which habitat, and give the answers to each question. (You cannot ask where each species lives!)

Show your questions and your answers by constructing a table along the following lines:

<table>
<thead>
<tr>
<th>Question</th>
<th>Species A</th>
<th>Species B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What is the comparative ear length of each species?</td>
<td>longer</td>
<td>shorter</td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Based on your answers to the questions you devise, which species lives in which habitat?

10 Applying knowledge in a new situation ➔ Figure 5.58 that shows an early (1790) illustration of an Australian plant. The description that accompanied this illustration reads as follows: ‘… the leaves which first appear on the seedling plant being pinnated, as is represented in the small figure on the plate, while those which afterwards come forth grow in whorls.’

(a) Note the small figure at the right side of the image. What does this illustrate?
(b) The illustration on the left side shows the foliage of the mature plant.
   (i) What change has occurred in the foliage as the plant ages?
   (ii) In the text quoted above, Curtis refers to structures that ‘grow in whorls.’ What is the correct biological term for these structures?
   (iii) How are the structures in part (ii) formed?
(c) This species of acacia grow in dry forests and sandy soils. What advantages might this feature confer on this plant?

11 Applying knowledge and understanding ➔ Suggest an explanation for, or comment on, each of the following observations.
(a) The young of tiny bats such as the bent-wing bat, Miniopterus australis, huddle very tightly together in large groups on the walls of caves where they live, rather than being widely separated.
(b) One plant species grows equally well in soils with a high salt content but a second plant species dies if the salt concentration in the soil exceeds a low value.
(c) Brown trout, Salmo trutta, are found in cold, fast-flowing mountain streams, but are absent from warm, sluggish waters.
(d) If placed in sea water, goldfish, Carassius auratus, will die.
(e) Desert mammals are typically active at night.
(f) A person who suffers from obesity has a lower body water content than a lean person.