Chapter 11: Regulation of water, salts and gases

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Water is essential to life

Water is the universal **solvent** and is essential to life.

A solvent is a substance in which another substance (known as a **solute**) dissolves.

Most salts and minerals in organisms are dissolved and broken into ions by water.

Organisms therefore contain an aqueous solution of ions, such as sodium and chlorine, ready for metabolic processes.

Metabolic reactions occur in a solution composed mainly of water. When the water content is too high or too low, metabolic reactions slow down, because the reactants travel too slowly to their reaction site.

Osmoregulation

Osmoregulation is the active regulation of an organism's water content.

It maintains the fluid balance (water gain and loss) and the concentration of electrolytes (ionic solutes, or salts in solution) and other solutes that will keep the fluids from becoming too diluted or too concentrated.

If the supply of water does not replace what is being lost, the relative concentrations of solutes and solvent in tissue fluids become difficult to regulate. Physiological functions are then affected.

Water

Methods of water gain and loss in animals

+ (gain)	− (loss)
Drinking	Sweating
Consuming food	Panting
	Rapid breathing
	Urination

Detecting changes in an organism's water level

Changes in the water level in the blood can be detected by receptor cells in the **hypothalamus** (called **osmoreceptors**).

The hypothalamus is a small region of the brain that plays a major role in detecting changes in the blood. In addition to detecting changes, the hypothalamus acts as a coordinating centre or modulator, receiving information and coordinating a response.

The hypothalamus alters the kidney membrane permeability to alter the concentration of the urine, allowing wastes in the form of solutes to be excreted while conserving water.

Water can move into and out of cells and organisms via osmosis. **Osmosis** is the passive diffusion of water across a membrane in response to a concentration gradient (osmotic pressure) caused by an imbalance of molecules on either side of the membrane.

Three types of extra-cellular solutions

Compared with the cellular contents, the surroundings are:	
Isotonic	when the surroundings are of equal concentration to the cellular contents, so that there is no net movement of water.
Hypertonic	when the surroundings have a higher solute concentration than the cellular environment.
Hypotonic	when the surroundings have a lower solute concentration than the cellular environment.

Kidneys

The kidneys are essential organs involved in maintaining a constant internal environment. They play an important role in osmoregulation.

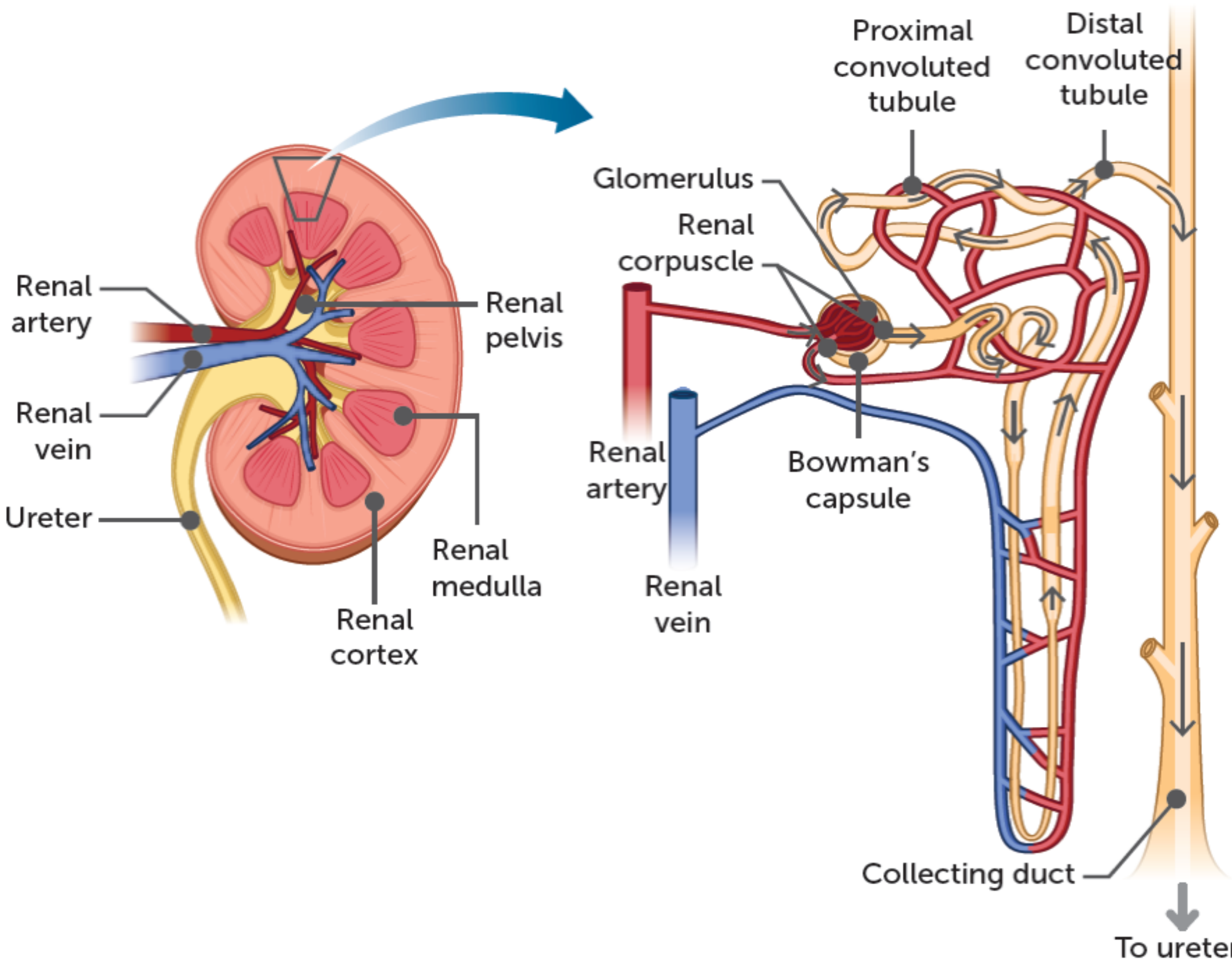
Their osmoregulatory function includes:

1 removal of nitrogenous wastes

2 regulation of water concentration in the blood

3 maintaining ion levels in the blood.

The left human kidney and nephron structures



Nitrogenous wastes

Excretion

Nitrogenous wastes are metabolic waste products that contain nitrogen; the result of the metabolic breakdown of proteins and nucleic acids.

Excretion is the removal of nitrogenous wastes.

In mammals, the nitrogenous waste urea is removed as part of a mixture known as urine.

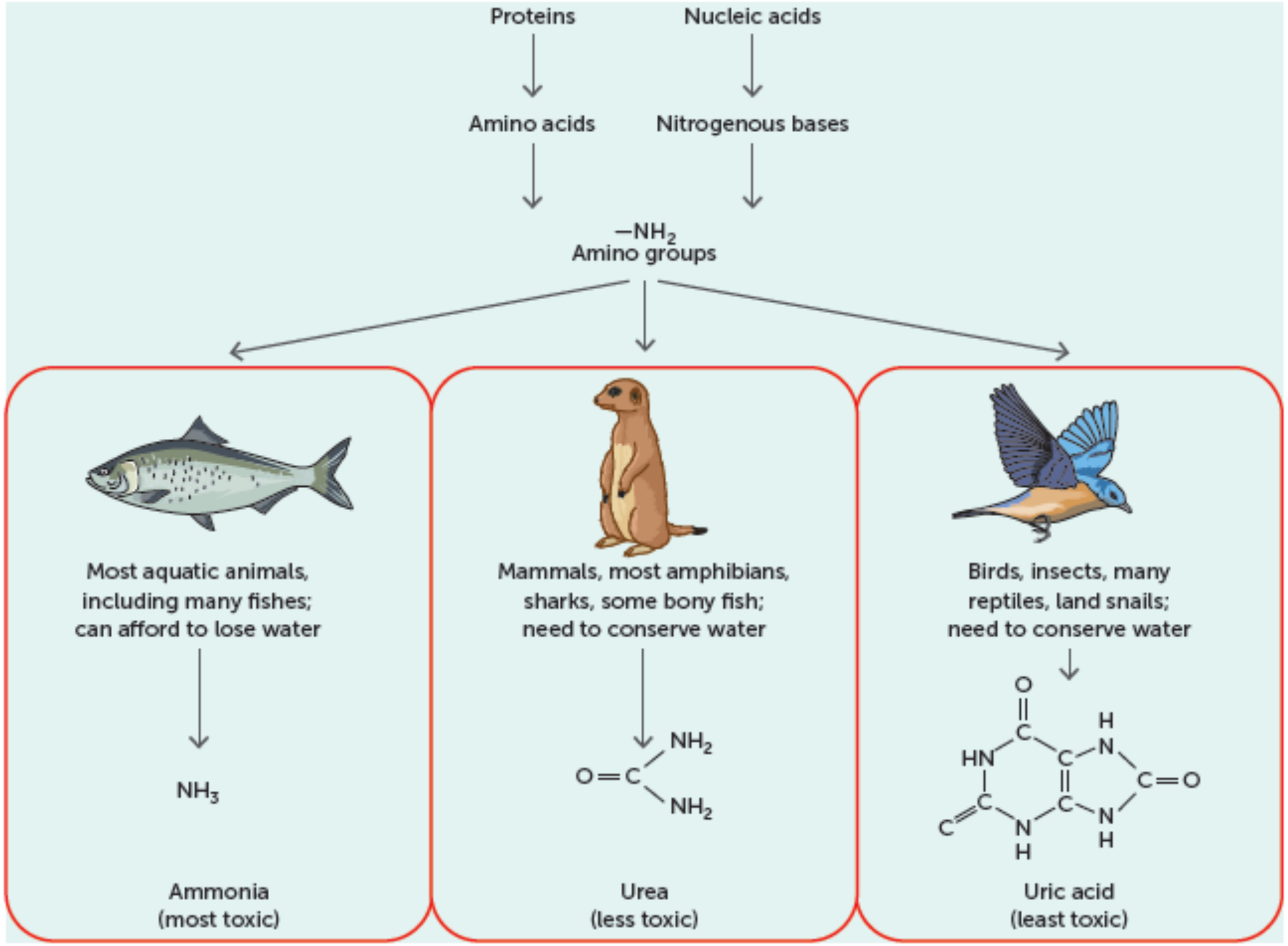
The elimination of nitrogenous wastes (formed from the breakdown of protein molecules and nucleic acids) is essential.

One such nitrogenous waste is **ammonia**, which is extremely toxic. A build-up of ammonia in cells can affect their pH severely.

Ammonia makes cell contents more basic, which can denature enzymes and compromise their function. This, in turn, can reduce metabolic activity.

Nitrogenous wastes

Three types of nitrogenous wastes and where they occur



How the kidneys regulate water balance

Antidiuretic hormone (ADH)

Maintenance of water balance in mammals is controlled by **antidiuretic hormone (ADH)**. *Diuresis* means ‘excessive urination’, so antidiuretic hormone reduces urine output.

ADH is produced by the hypothalamus and stored in the pituitary gland.

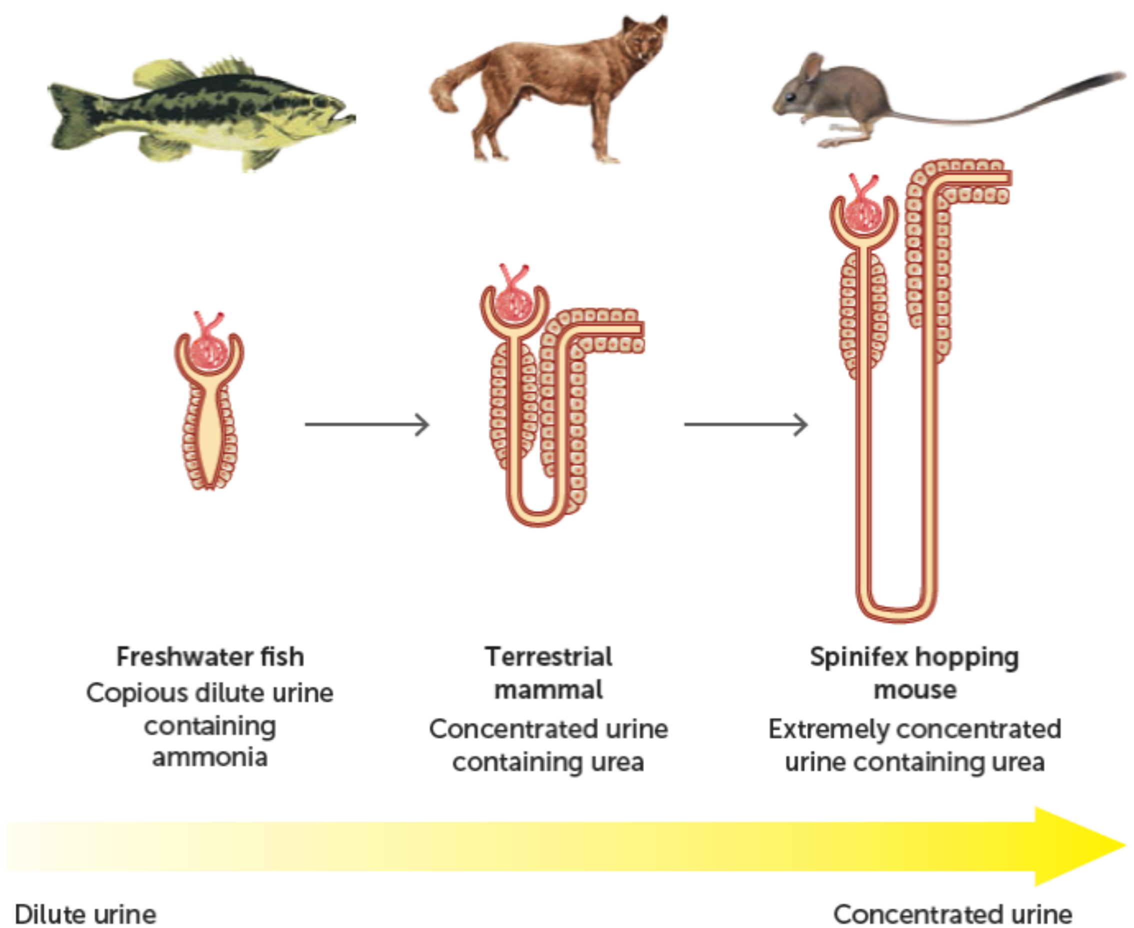
The way it reduces urine output is by acting on the collecting ducts of the kidney.

The main functions of the collecting ducts are reabsorption of water and carrying urine to the ureter, to be transported to the bladder.

ADH increases reabsorption of water in the collecting ducts.

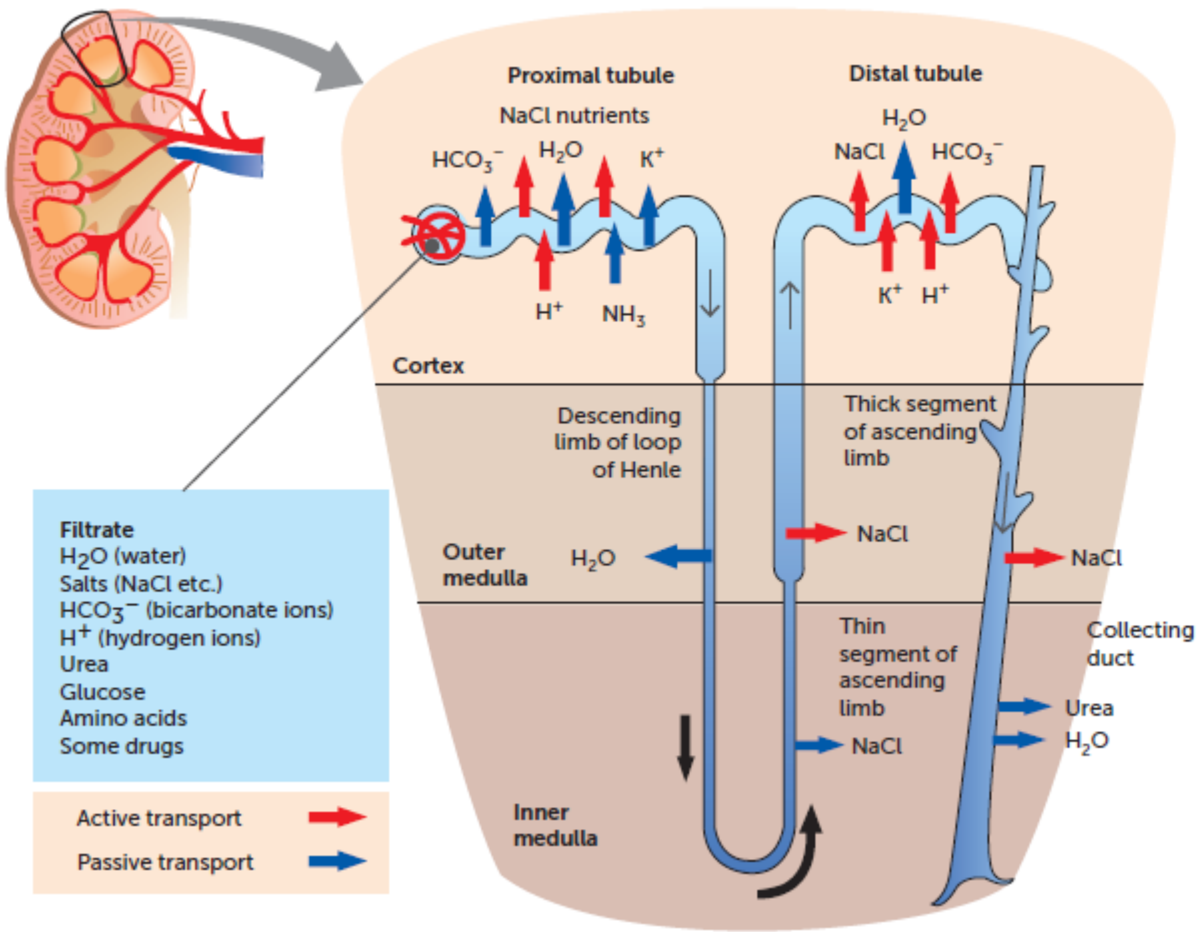
How the kidneys regulate water balance

Comparing loop of Henle lengths between different animals



The longer the loop of Henle, the more concentrated the urine and the more water saved.

Comparing loop of Henle lengths between different animals



Water is conserved when it is reabsorbed in the descending portion of the loop of Henle, as in this example of a mammalian kidney.

How the kidneys regulate water balance

Negative feedback loop for low water volume

Stimulus
Decrease in the blood water content below optimal range

↓

Receptor
Osmoreceptor cells in the hypothalamus detect the change in the blood water content and send a message to the coordinating centre.

↓

Coordinating centre (modulator)
The hypothalamus receives a message from the receptor, coordinates a response and sends a message to the effector.

↓

Effector
The pituitary gland releases ADH, which travels through the blood to the kidney nephrons, increasing the permeability of the collecting duct wall, increasing water reabsorption.

↓

Response
An increase in the blood water content, a lower volume of urine and a higher urine concentration

↓

Negative feedback
The blood water content returns to the normal/optimal value. The response counteracts the stimulus.

↓ (back to Stimulus)

Adaptations for maintaining water balance

Thermoregulation and osmoregulation are intricately bound with each other.

For many terrestrial organisms, a water supply is not always available.

Animals living in dry areas have a range of structural, physiological and behavioural adaptations for maintaining their water balance.

Adaptations for water balance

Structural features

The threat of dehydration is a major issue in Australian terrestrial (land) animals, so structural adaptations that reduce water loss are essential.

A waterproof or impermeable outer layer can reduce water loss.

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Example:

The scales of reptiles, the hair of mammals, the feathers of birds and the upper part of the epidermis contain keratin, a protein that hardens and waterproofs the body surface. The waterproof surface acts as a barrier, preventing water loss via osmosis or evaporation.

Adaptations for water balance

Physiological processes

Excreting nitrogenous waste as uric acid is effective in saving water.

Many terrestrial vertebrates slow down the production of urine by reducing the rate of glomerular filtration.

Example:

The Australian desert hopping mouse, *Notomys alexis*, can concentrate its urine more than any other known rodent. The longer the loop of Henle, the more concentrated the urine and the more water saved. The desert hopping mouse has a very long loop of Henle to maximise water conservation, and it is able to conserve water by producing a low volume of highly concentrated urine.

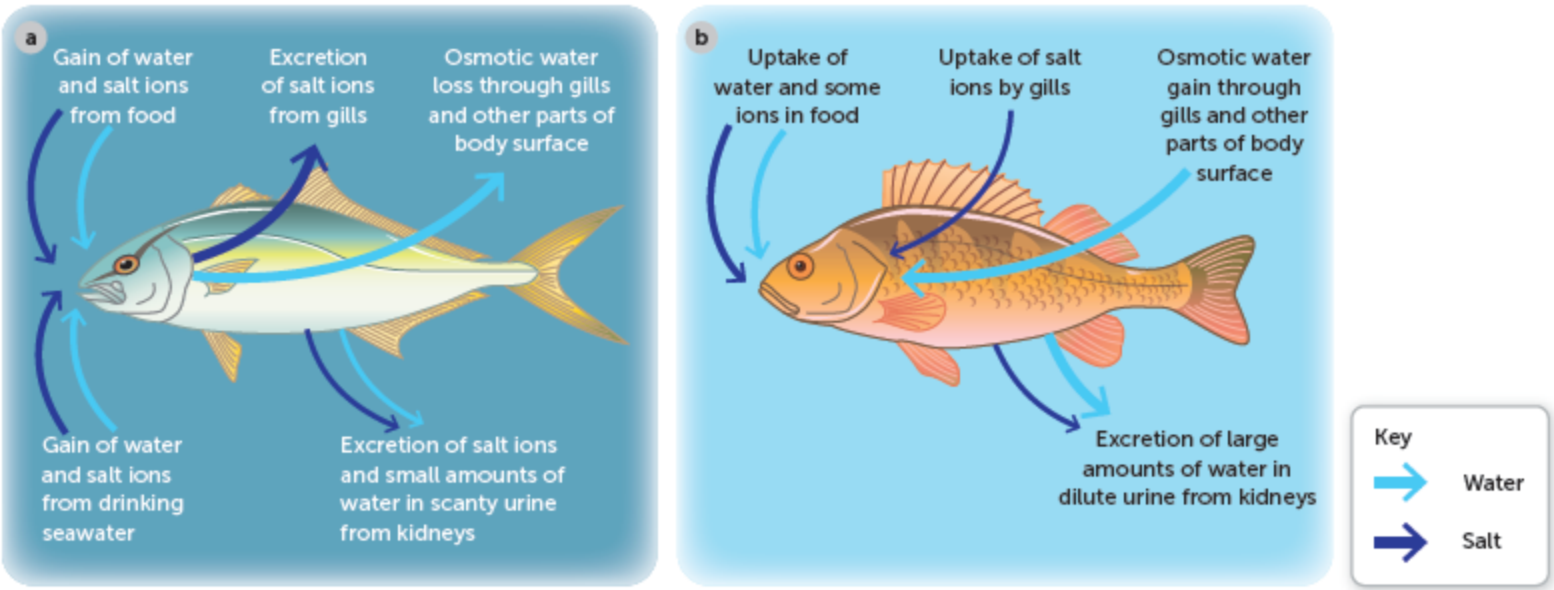
Adaptations for water balance

Physiological processes in marine and freshwater fish

Factor	Marine bony fish	Freshwater bony fish
Problems	Loses too much water via osmosis across skin. Gains too many salts via drinking seawater and eating food.	Gains too much water via osmosis across skin and when eating food containing water. Loses too many salts via diffusion and in urine.
Adaptations for water balance	1 Constantly drinking sea water. 2 Eating food containing water 3 High level of reabsorption in kidneys 4 Excretes a low volume of highly concentrated urine	1 Does not drink water. (Fish swim with mouth open so water passes by their gills for gas exchange, but they do not swallow.) 2 Low level of reabsorption in kidneys 3 Excrete high volumes of dilute urine
Adaptations for salt balance	1 Excretes highly concentrated urine, ridding the body of excess salts 2 Active transport of salts from salt-secreting cells in gills to the seawater	1 Gain salts when eating food 2 Active uptake of salts from seawater across gills

Adaptations for water balance

Physiological processes in marine and freshwater fish



Adaptations for water balance

Behavioural responses

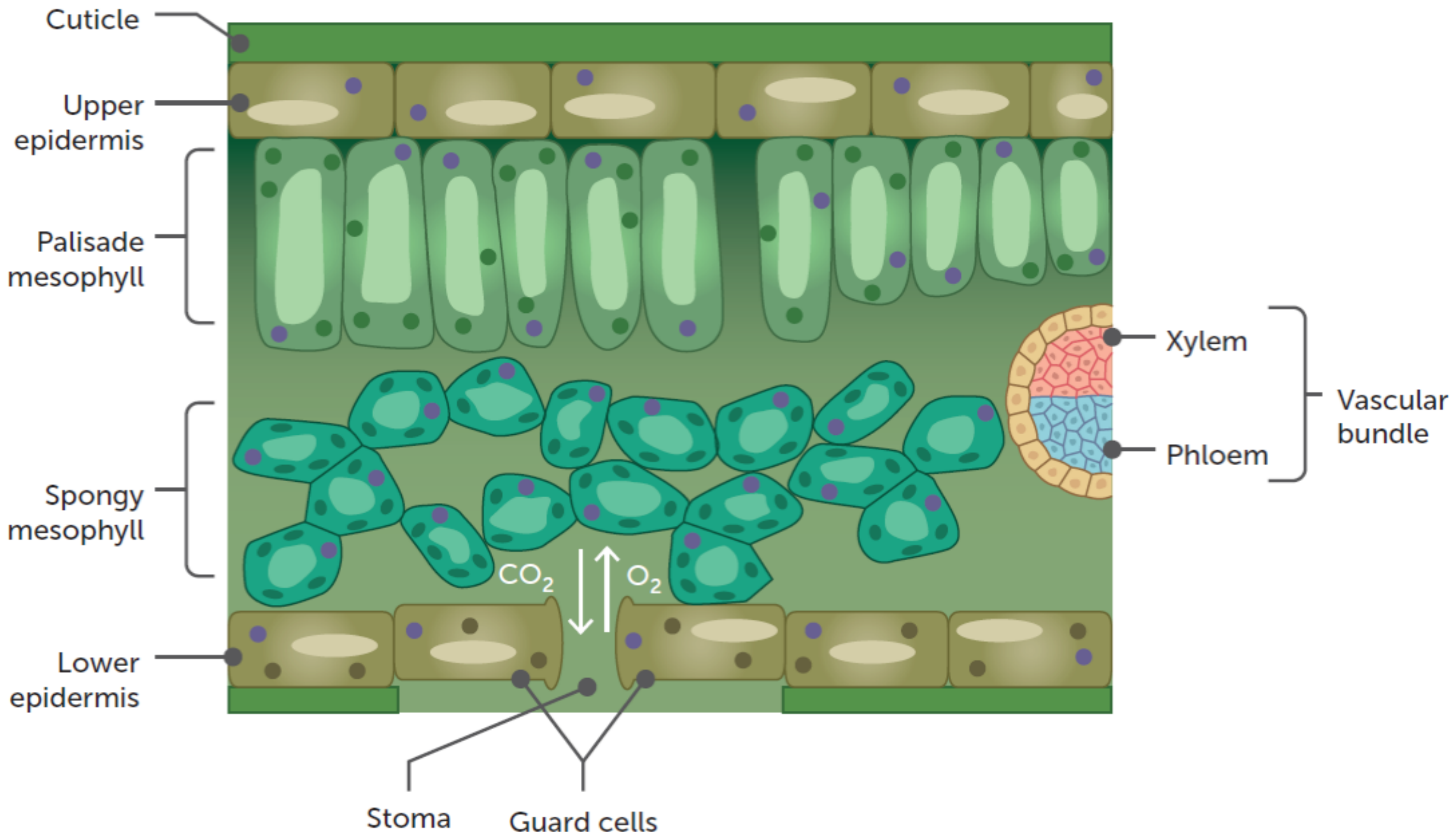
Desert animals have adaptations ranging from the production of highly concentrated urine to burrowing in the desert sands for several months at a time. Burrows have lower temperatures and higher humidity than the open air, so water loss is reduced.

Example:

The water-holding frog, *Litoria platycephala*, tucks itself into a water-conserving cocoon created from layers of skin. The frog's metabolic rate slows as it enters aestivation under the ground. Water is a product of some metabolic processes, so slowing down the metabolic rate can reduce water loss. The frog can survive in this way for many months.

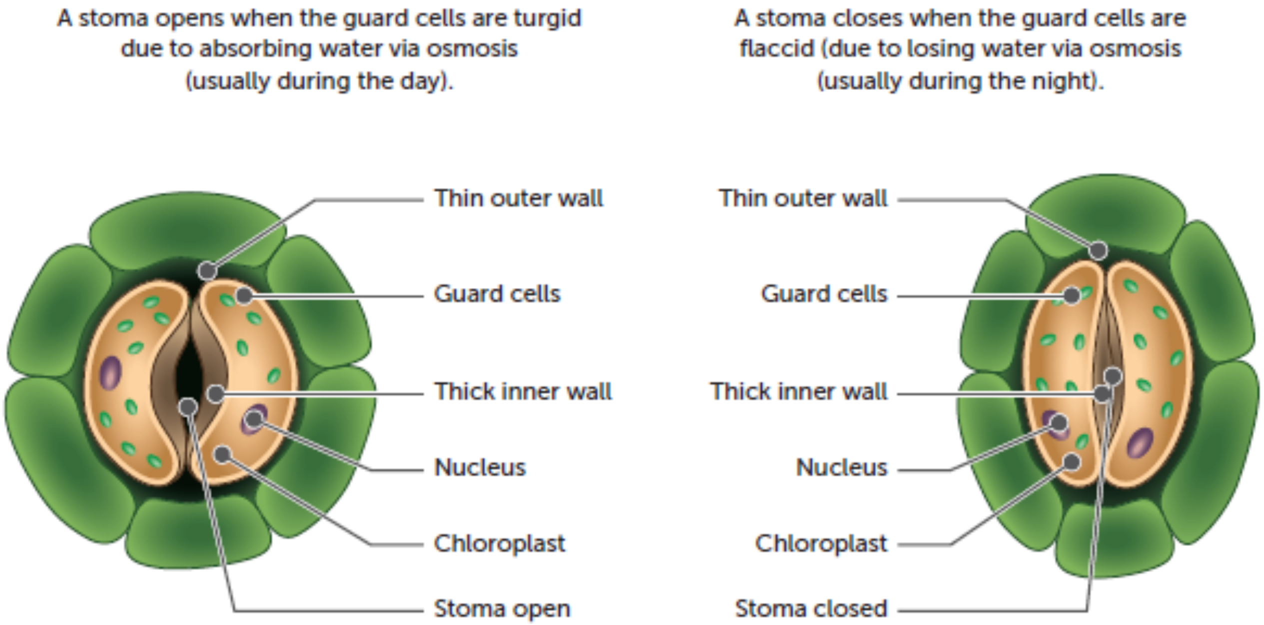
Plant transport structures and functions

In this leaf cross-section we can see that water loss is via stomata.



Plant transport structures and functions

In this diagram we compare open and closed stomata.



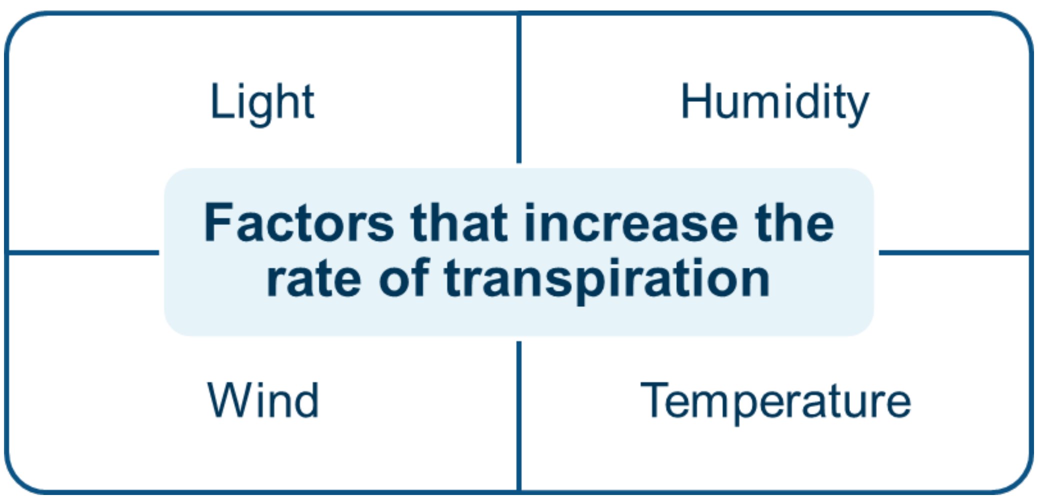
Plant osmoregulation

Transpiration in plants

Transpiration is the evaporative loss of water (in the form of water vapour) from plants, usually through small pores called **stomata** (singular: stoma) found on the surface of a plant, mostly on the underside of leaves.

Evaporation and diffusion out of the stoma occurs because of the concentration gradient of water vapour between the inside and outside of the leaf.

Water vapour moves down the concentration gradient, from an area of high water content to an area of relatively low water content.



The importance of transpiration

1. Transpiration supplies the photosynthetic process with the water it needs.

2. The evaporation of water from the mesophyll in the leaves that accompanies transpiration requires energy and therefore cools the leaves in the same way that sweating cools the skin of mammals. Heat energy is drawn out of the plant, into the water, then out into the external environment.

3. The transpiration stream is also necessary for distributing mineral salts throughout the plant.

Specialist plants

Adaptations for regulation of water, salts and gases

To regulate water and salt balance, and allow for gas exchange, specialist plants have a variety of adaptations.

Adaptations fall into the categories of structural (physical) or physiological (functional processes).

Gas exchange

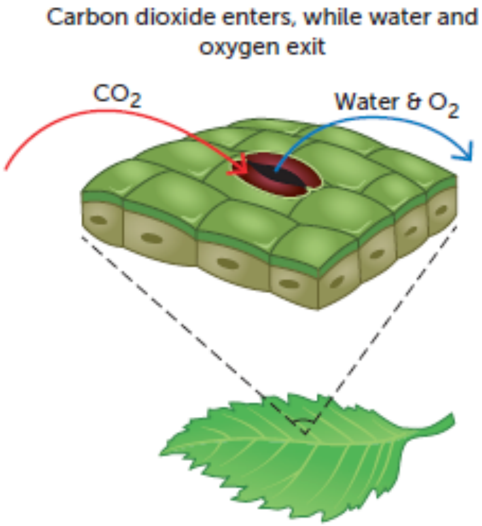
Gas exchange occurs through stomata, but only when they are open. They are usually open during the day, when sunlight is being used in the process of photosynthesis.

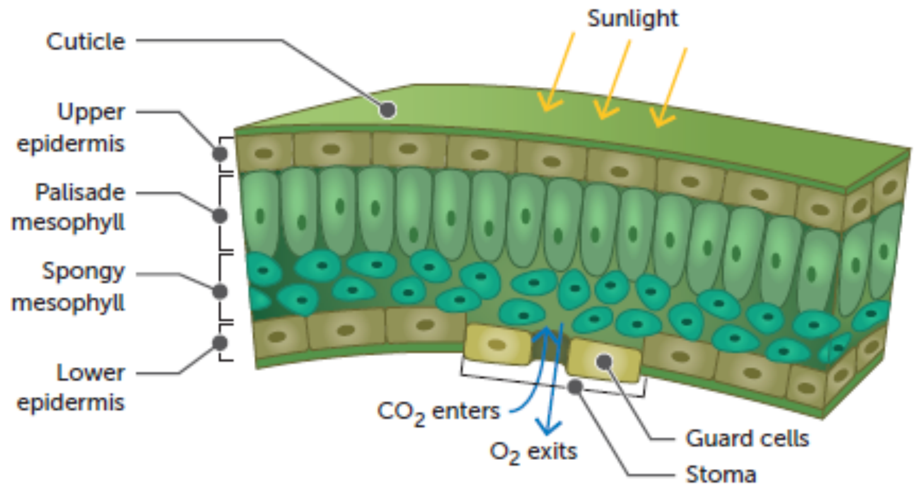
Stomatal opening and closing depends on changes in the **turgor** of the guard cells. Turgor is a force that results from the water pressure inside plant cells and it is maintained by osmosis.

When water flows into the guard cells by osmosis, their turgor increases and they expand. Due to the relatively inelastic inner walls of guard cells, they bend and draw away from each other, so the pore opens.

If the guard cells lose water, the opposite happens and the pore closes.

Gas exchange





Xerophytes

Xerophytes are plants adapted to live in arid environments. They have developed specialised features that minimise water loss, while allowing for gas exchange.

An environment is classified as arid if it is characterised by a severe lack of available water that hinders the growth of plant and animal life.

Xero is the Greek word for dry; hence the term xerophyte. Xerophytes may live in very hot places, such as the desert, where water is limited, or in areas of frozen land with no flowing water.

Xerophytes: problems

Water moves passively along a concentration gradient out of the plant and into the dry environment.

The rate of water loss by evaporation due to transpiration is very high. It is high because there is a relatively high concentration gradient between the inside and outside of the leaf.

Water vapour evaporates and diffuses more quickly in an arid environment compared with in a non-arid environment.

Plant cells can become flaccid, and plants can wilt, dry out and die when their water content falls below the plant's tolerance range.

Water is a requirement for photosynthesis, it is a medium for metabolic processes (chemical reactions), it is required for evaporative cooling, and it is needed for soil nutrients to dissolve into and be absorbed by a plant.

Xerophytes: adaptations

Xerophytes have a range of morphological (structural) and physiological adaptations that enable them to survive in an arid environment.

Structural:

- Thick waxy cuticle
- Small leaf surface area
- Sunken stomata
- Hairy stomata
- Rolled leaves
- Shallow spreading roots or long tap ro

Physiological:

- Stomata opening at night/reverse stomatal rhythm
- Storage of water in succulent tissues

Specialist plants

Halophytes

Halophytes are plants that live in environments of high soil salinity; that is, soil with a high salt concentration – places such as salt marshes and the mud flats of estuaries.

The amount of salt-affected land is increasing around Australia, and salt-tolerant plants can be studied to help scientists involved in agriculture, bioremediation and conservation.

Salt-tolerant terrestrial angiosperms are defined by CSIRO as plants that survive to complete their life cycle in at least 200 mM salt.

Halophytes: problems

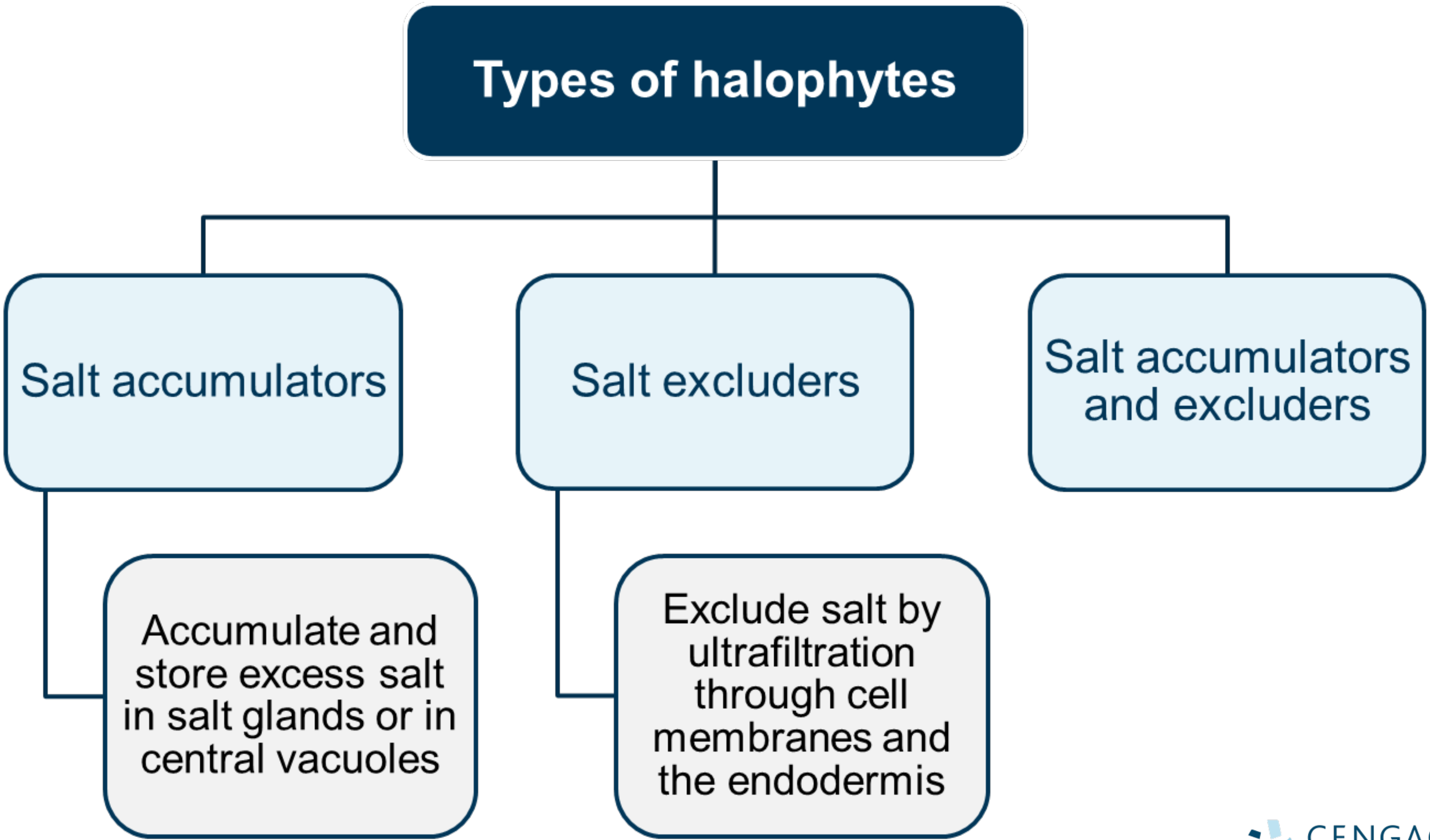
Water does not move into a plant if the plant's solute concentration is higher than the concentration outside.

Water will move out of the plant via osmosis passively along a concentration gradient. Halophytes will lose water, because the high salt concentration in the surrounding soils will draw water from plant tissue via osmosis.

Plant growth can be reduced, germination can be hindered, and plants can struggle with a water deficit as water is drawn out of them, which slows the rate of photosynthesis and productivity. High levels of salt ions can also lead to toxicity and cell death.

The salt concentration in the soil exceeds that in the root hairs. Therefore, water moves from the root hairs into the soil by osmosis until the two solutions are isotonic.

Halophytes: classifications



Halophytes: adaptations

Halophytes have a range of morphological (structural) and physiological adaptations that enable them to survive.

Structural:
- Aerial root systems called pneumatophores
- Filtration structures in roots
- Salt glands

Physiological:
- Concentrates and stores salts in vacuoles
- Accumulates salts in leaves or bark

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Halophytes: adaptations

Mangroves have developed methods of dealing with concentrations of salt that would kill or inhibit the growth of most other plants.