Government of **Western Australia**
Department of **Water**

Waterway Ecology

looking after all our water needs

Department of Water
168 St Georges Terrace
Perth Western Australia 6000
Telephone: +61 8 6364 7600
Facsimile: +61 8 6364 7601
www.water.wa.gov.au

February 2010

ISBN 978-1-921736-19-3 (online)

ISSN 1449-5147 (online)

Acknowledgements

The Department of Water would like to thank the following for their contribution to this publication.

This document was produced by Nadia Beale of the Waterways Section, Department of Water. It is an adapted version of Chapter 7: Stream Ecology of the River Restoration Manual (Water and Rivers Commission, 2000) written by Kerry Trayler.

Many thanks to Kerry Trayler of the Swan River Trust and to staff of the Department of Water for their review and comments towards the production of this document. Special thanks to the Water Science Branch (Department of Water) for kindly contributing photographs and data and to Adrian Pinder of the Department of Environment and Conservation for contributing photographs.

For more information about this report, contact Department of Water +61 8 6364 7600.

Contents

The physical factors of the environment: climate, geology, **hydrology** and **landform**, all influence the plants and animals living in an **ecosystem**. In an undisturbed, natural environment these physical factors and the **biota** find a balance i.e. are stable. However, the system is dynamic and change to any one of the physical factors will cause changes to the numbers and diversity of **biota** in that **ecosystem** (Figure 1).

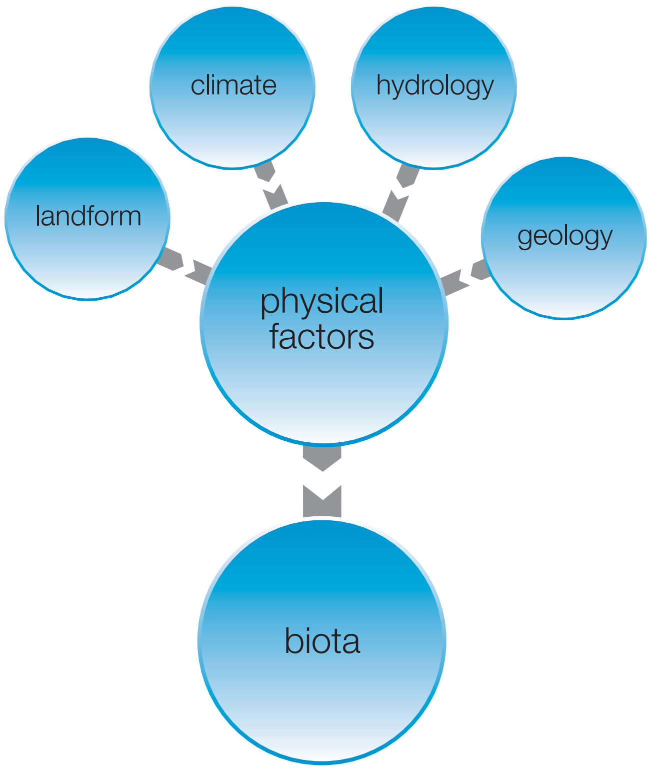

Figure 1 The physical factors of the environment influence the diversity and numbers of plants and animals living in an **ecosystem (biota).**

Aquatic environments, such as waterways, are complex **ecosystems** and are usually home to a variety of **biota**. The term 'waterway' refers to surface water bodies that includes rivers, streams, creeks, lakes, estuaries and their inlets. These can be seasonally or permanently inundated. It also includes **floodplains** and wetlands that overflow into rivers, as well as any lakes or swamps that are filled (mainly) by waterways rather than shallow groundwater.

Many waterways in Western Australia and their dependent **ecosystems** are becoming degraded or altered because the physical environment is changing as a result of human activities occurring within and along these systems, and from various land uses within the surrounding **catchments**, for example farming and urban development. These activities often change the landform and **hydrology** of the **catchments** which in turn affect the **biota** living in the **ecosystems**.

The effects of eroding foreshores and of invading weeds and feral animals, for example rabbits, foxes, and introduced fish species, are some of the more urgent problems that have been caused by the human impacts on waterways. Water quality is declining, with many waterways carrying excessive sediment and **nutrients**, and in some cases they are contaminated with chemicals and other pollutants. Many waterways in the south-west region of Western Australia are also affected by increasing salinity. These problems, together with the effects of other human activities, have serious consequences for the **ecology** (the relationships between organisms and their environment) of waterways.

Another major impact on waterways is climate change. In Western Australia this includes sea level rise, increases in temperature, increases in the frequency of extreme events, and changes in the pattern of rainfall across the state. Changes in rainfall, for example, will impact on the **hydrology** and water quality of our waterways. The potential impacts of these changes on the plant and animal communities living in our waterways requires extensive research and adds another complication to the task of effectively protecting Western Australia's waterways and their dependent **ecosystems**.

One way of reducing the effects of human impacts is to restore the health of waterways. Restoring the health of waterways primarily protects and conserves their **biodiversity** (the variety of organisms living within an area). It is, however, impossible to protect the **biodiversity** of waterway **ecosystems** without first protecting habitat and **ecosystem** processes (such as the flow of energy and **nutrients** within the **ecosystem**). It is, therefore, important to understand waterway **ecology**. This document provides an introduction to some of the important **ecosystem** processes that control the structure of plant and animal communities living within and along waterways. It also describes some of the human activities or pressures that threaten Western Australian aquatic **ecosystems**. Pressures resulting from climate change are not dealt with here.

Barlee Brook, a **tributary** of the Donnelly River in south-western Australia.
Source: Dr. Luke Pen, Water and Rivers Commission.

Waterway Ecology

Energy sources in waterways

In every waterway there are hundreds of species and thousands of individual plants and animals, or organisms. As with land (terrestrial) organisms, each individual organism in a waterway requires continual energy in order to survive, grow and reproduce. The energy they need is produced from the breakdown of complex **organic compounds** through an internal chemical process known as **respiration**.

Equation 1:

$$[CH_2O] + O_2 \rightarrow CO_2 + H_2O + \text{free energy}$$

sugars, oxygen → carbon dioxide, water

During **respiration, organic compounds** such as sugars are combined with oxygen and broken down into simpler compounds such as carbon dioxide and water. Energy is released in this process and is then available for body movement and other internal processes, such as regulating body temperature or preparing the body for reproduction.

The **organic compounds** that break down as part of **respiration** are obtained by the organism via one of two major pathways:

- **autotrophic** pathway
- **heterotrophic** pathway

Autotrophic pathway

autotroph
Greek: *autos* = self *trophe* = nourishment

Green plants are **autotrophs**. They are able to make their own organic compounds from simpler **inorganic compounds** that are available from air, soil and water. This is achieved through a process called **photosynthesis**; when exposed to light, green plants are able to convert carbon dioxide and water to simple organic sugars and oxygen. **Autotrophs** are known as primary producers.

Equation 2:

$$CO_2 + H_2O \xrightarrow[\text{chlorophyll -a}]{\text{light}} [CH_2O] + O_2$$

carbon dioxide, water → sugars, oxygen

Autotrophs in a waterway (Figure 2) include:

- submerged and emergent **macrophytes: macroalgae,** mosses, liverworts and flowering plants that are either rooted in the substratum (bed of the waterway) or free floating
- **periphytic algae:** microscopic plant communities living on the surface of submerged objects
- **phytoplankton:** microscopic plants or plankton that drift within the water column.

What is chlorophyll-a?

Greek: *chloros* = green   *phyllon* = leaf

Chlorophyll-a is a green pigment found in most plants and is required to convert the energy of sunlight into chemical energy (sugars). Some of the energy made by the plant will be broken down in **respiration** and used to maintain the plant (see Equation 1). The remainder of the energy can be used in combination with **nutrients** taken from the soil and water to make other substances required by the plant to grow and reproduce (e.g. cellulose, lipids, proteins, amino acids).

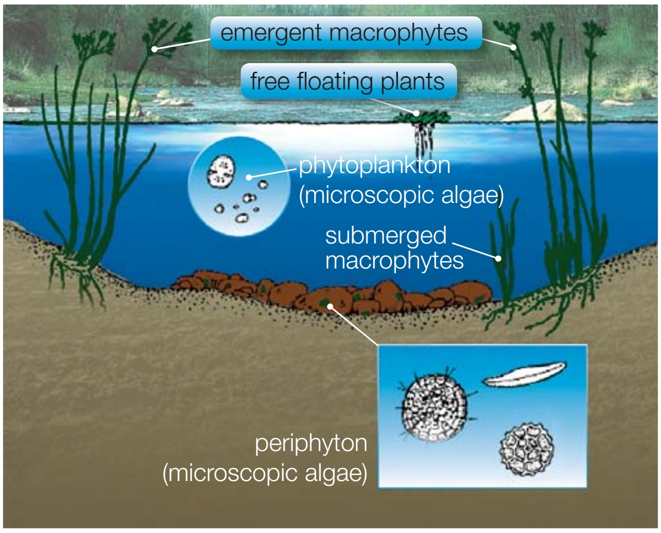

Figure 2 Autotrophs in a waterway.

Heterotrophic pathway

heterotroph

Greek: *heteros* = other   *trophe* = nourishment

Organisms that are not able to make their own **organic compounds** for **respiration** need to obtain **organic compounds** from elsewhere. Such organisms are consumers and are called **heterotrophs** (or first order consumers). **Organic compounds** made by **autotrophic** organisms are consumed by **heterotrophic** organisms. This can occur directly, whereby an **autotroph** (e.g. green plant) is eaten by a **herbivore** [L. *herba*, green crop; *vorare*, to devour] (e.g. some species of tadpoles) or indirectly, whereby plant material is broken down into dead or decomposing tissue known as **detritus** that is then eaten by a **detritivore** [Latin ***detritus***, rubbed off; *vorare*, to devour] (e.g. worms, amphipods).

Amphipods are bottom feeding **detritivores** but can also be found swimming in the water column.
Source: Department of Environment and Conservation.

Herbivores and **detritivores** are known as secondary producers because they use the energy from primary producers to grow and reproduce. However, not all of the energy from primary production is used for secondary production. Some energy from the primary producer is 'wasted' and left to decompose, some is lost by excretion (wastes from the animal) and some is lost in the process of maintaining the consumer via **respiration**.

Not all **heterotrophs** are **herbivores** and **detritivores**. Some **heterotrophic** organisms obtain their **organic compounds** and energy by consuming **herbivores** and **detritivores** and in turn they may be consumed themselves. These animals are called predatory **heterotrophs** (or second order consumers).

Heterotrophs in a waterway include aquatic insects, crustacea (including **zooplankton**), molluscs, fish, amphibians and waterbirds (Figure 3).

Communities of organisms in a waterway are mixtures of both **autotrophs** and **heterotrophs**. The dominance of **autotrophic** or **heterotrophic** pathways of energy transfer is dependent on whether conditions of light and **nutrient** availability favour primary production. A waterway or section of a waterway (a reach) is considered to be **autotrophic** when **photosynthesis** exceeds **respiration** within the waterway. If **respiration** exceeds **photosynthesis** then the system is defined as being heterotrophic. For example, upland waterways that flow through heavily shaded, forested areas are usually **heterotrophic** because **photosynthesis** is limited by light. Waterways that do not flow through dense forest (e.g. those in drier areas) receive a much greater input of energy through **photosynthesis**. Where **nutrient** input is not limited, **photosynthesis** may exceed **respiration** in these systems and the waterway may be considered **autotrophic**.

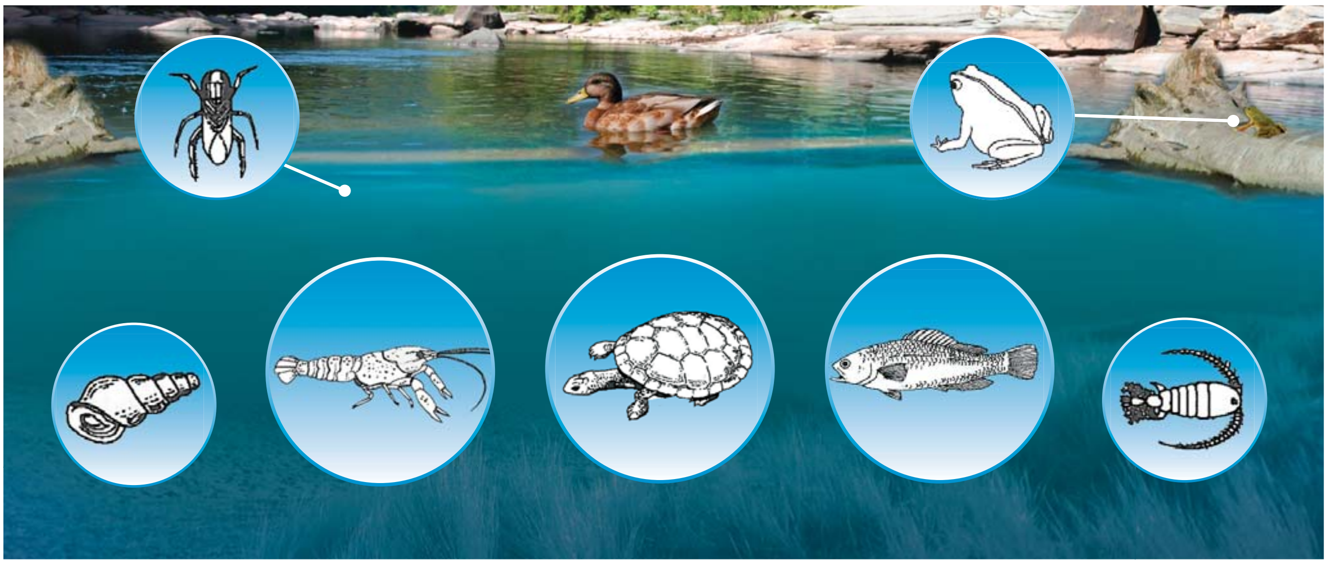

Figure 3 Heterotrophs in a waterway.

Food webs

The sequence of who eats who in an **ecosystem** is called a food chain. For example, in a waterway the **algae** is eaten by aquatic snails which are eaten by fish. The flow of energy along food chains is a fundamental process in an **ecosystem**. A food web is a number of food chains that link together due to some animals having a variety of organisms in their diet.

Each feeding level in a food web is called a **trophic level**. The **autotrophs** (primary producers) form the first **trophic level** and are at the base of the food web. The **heterotrophs** are at higher **trophic levels** and predatory **heterotrophs** are higher again.

Many **heterotrophs** living in waterways have evolved morphological (body form) adaptations and behavioural characteristics that allow them to consume particular types of food. This is particularly true of aquatic **macroinvertebrates**. For example, the net-spinning caddisfly larvae is a filtering-collector that spins silken nets between rocks to capture suspended food particles from the water column. Such animals play an important role in the trophic dynamics within waterways and, therefore, ecologists have divided aquatic **macroinvertebrates** into functional feeding groups (Table 1). Functional feeding groups are useful for describing the complex processing of **organic matter** within waterways.

Table 1 Feeding groups of aquatic macroinvertebrates.

Adapted from tables in Allan (1995); Merritt & Cummins (1996).

Functional Feeding Group	Food resource	Feeding Mechanism	Examples
Shredders	leaves and associated microbes	detritivores – chewing	some caddisfly larvae, stonefly juveniles, amphipods, isopods
	macrophytes	herbivores - chewing, mining	aquatic moth larvae
Gougers	woody material	detritivores - excavating, mining	some midge larvae, beetle larvae and caddisfly larvae
Filtering-collectors	suspended fine organic particles	detritivores - filtering apparatus	net spinning caddisfly larvae, blackfly larvae
Gathering-collectors	deposited fine organic particles	detritivores - browse surface deposits	many mayfly and midge larvae
Grazers	periphytic algae and associated microfauna	herbivores - scrape and rasp	some larval mayfly, caddisfly, limpets and snails
Macrophyte piercers	macrophytes	herbivores - piercing	some larval caddisfly
Predators	animal prey	biting / piercing	some larval stonefly, dragonfly, caddisfly, beetles and midge
Parasites	animal prey	internal parasites	nematodes (roundworms)

Both larval (A) and adult (B) diving beetles are predacious. *Source: Water Science Branch, Department of Water.*

Sources and processing of organic matter

In any reach of a waterway, the amount of **organic matter** present arises from either within the waterway (an **autochthonous** source) or outside of the waterway (an **allochthonous** source).

Autochthonous sources of **organic matter** form the basis of the grazing food chain in waterways (Figure 4). Primary production by **autotrophs** in a waterway, including **periphytic algae**, **macrophytes** and **phytoplankton**, represent important **autochthonous** sources of **organic matter** in a waterway.

Periphytic algae are consumed by grazers (e.g. aquatic snails) that scrape the surface of rocks and **macrophytes**. **Macrophytes** may be consumed by shredders (e.g. aquatic moth larvae), that chew or mine the living tissue, or piercers (e.g. some caddisflies) that suck out fluids from the living tissue. **Phytoplankton** may be consumed by herbivorous **zooplankton**.

autochthonous

Greek: *autos* = self   *chthon* = ground

allochthonous

Greek: *allos* = other   *chthon* = ground

Allochthonous sources of **organic matter** include: leaf litter, dead branches and fallen tree trunks (woody debris), and soil particles that fall or are washed into waterways with **runoff** from rain. These forms of non-living organic material form the basis of the detrital food chain within waterways. Non-living organic material takes three forms (Table 2):

- coarse particulate **organic matter**
- fine particulate **organic matter**
- dissolved **organic matter**

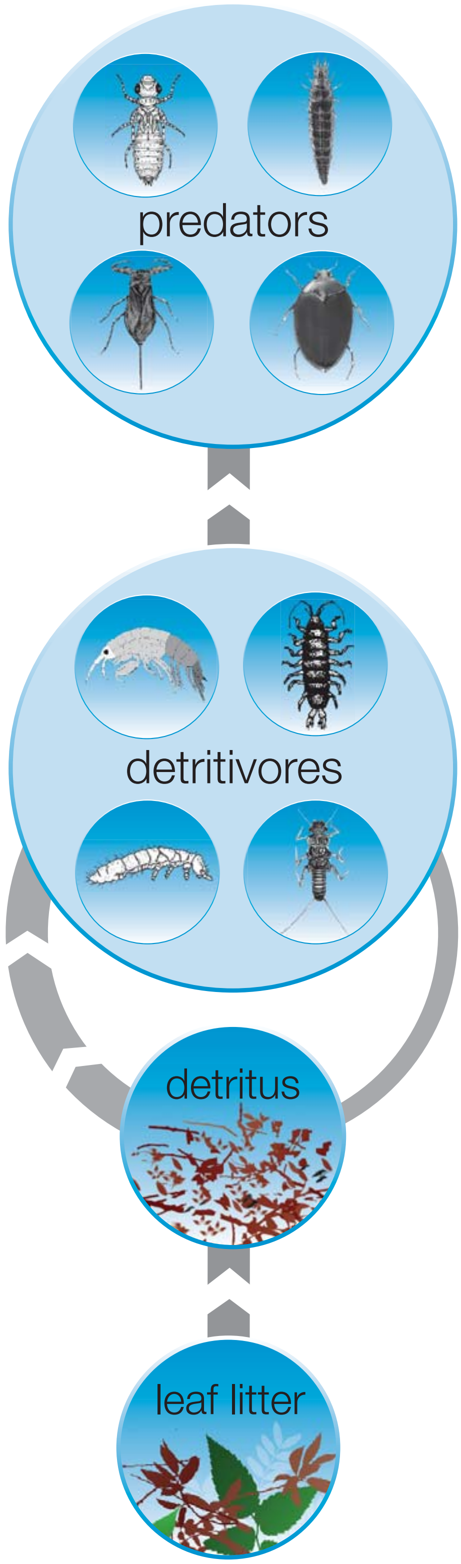

Figure 4 An example of a detrital food chain.

Coarse particulate **organic matter** (CPOM) arises from leaf material, woody debris or from decomposing **macrophytes** in the waterway. Some **macroinvertebrates** known as gougers (e.g. some midge larvae) assist in breaking down woody debris by burrowing into and feeding on the surface layers.

When leafy material enters a waterway it often come to rest in slow flowing areas. Some organic components are then leached out of the leaves, which are subsequently colonised by **microbes**, such as fungi and bacteria. **Macroinvertebrate** shredders (e.g. stoneflies, amphipods and isopods) are attracted to the gathered leaves and will consume them, obtaining nutrition from the leaves or from the **microbes** on the leaves. These shredders are sloppy feeders so small pieces of leaves are broken off and are transported downstream. These smaller leaf particles, combined with the waste generated by the shredders (faeces) and soil particles, are known collectively as fine particulate **organic matter** (FPOM).

Macroinvertebrates known as 'collectors' have particular body characteristics and behaviours that assist them in collecting FPOM as it moves through the waterway. Some collectors, known as collector-gatherers, feed on the FPOM that has come to rest in slow-moving areas. Collector-gathers include many midge and mayfly larvae. Other collectors, known as filtering-collectors are able to capture and feed on the FPOM that is in suspension within the water column. As well as the example of caddisflies that spin silken nets between rocks to capture suspended FPOM, other filtering-collectors, such as blackflies, possess specialised fan-like appendages that can filter FPOM from suspension.

Dissolved organic material (DOM) is the organic material that is leached from leaves and other debris, as well as from surface water and groundwater. Not all DOM is biologically available, but if it is, microorganisms such as bacteria can take it up which then contributes to their body mass. The **microbes** themselves enter the food web by being eaten by **protozoa**, that are in turn eaten by tiny consumer organisms such as **zooplankton**. Figure 5 illustrates the complexity of a typical food web in an aquatic **ecosystem** such as a waterway.

Table 2 Organic matter and its origin. Note that 1 μm = 0.001 mm.
Adapted from Allan (1995).

Type of organic matter	Size	Source within waterway	Source outside waterway
Coarse particulate	> 1 mm	dying macrophytes	leaf litter / woody debris
Fine particulate	0.5 μm - 1 mm	animal faeces	soil particulates, broken up leaf litter
Dissolved	< 0.5 μm	leached from leaves	surface water and groundwater

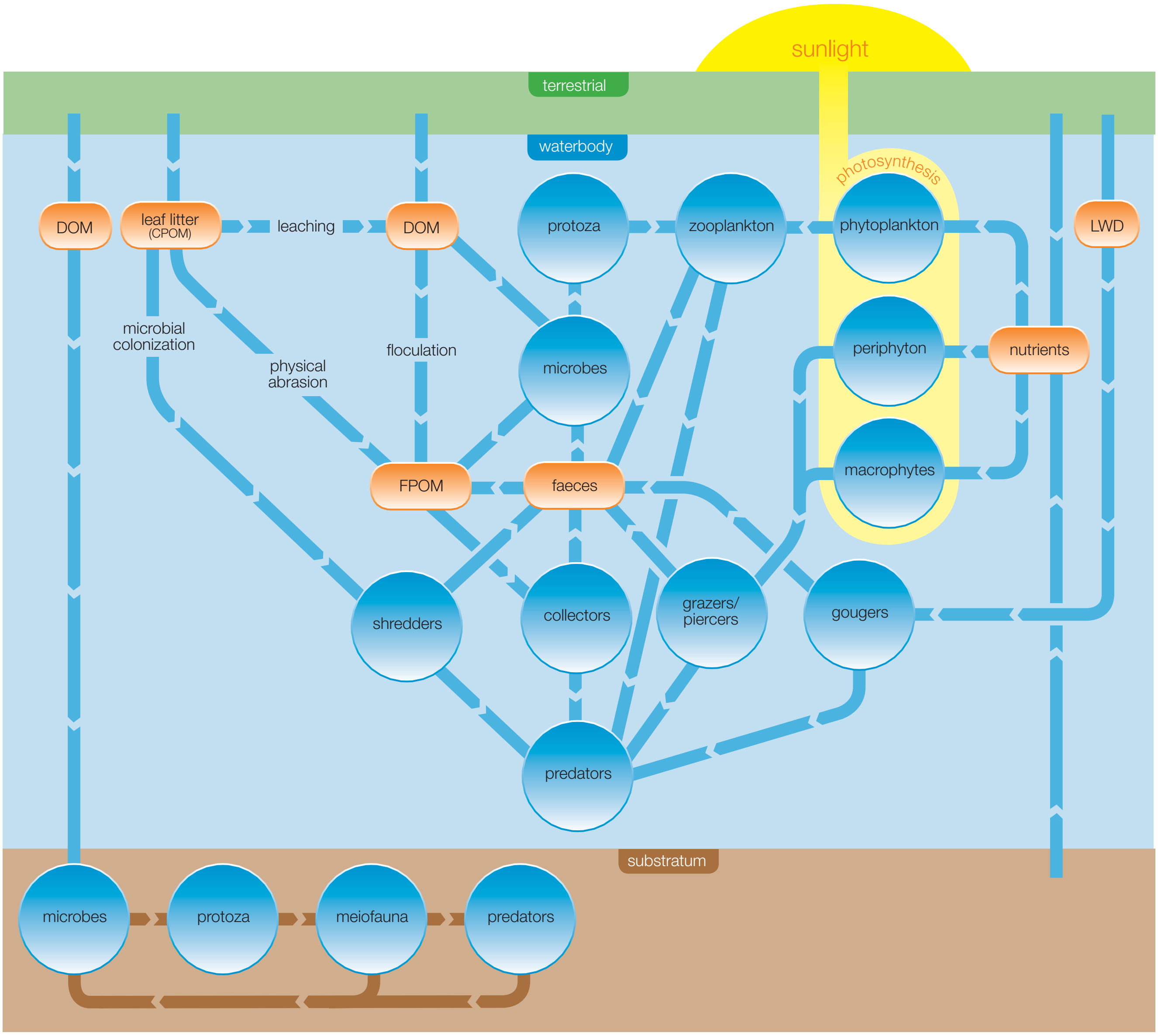

Figure 5 A typical food web in a waterway.

Waterway Ecology

Nutrients in waterways

Various **nutrients** (chemical compounds) are essential to plants and animals in order for them to make new organic material and grow. In waterways, **autotrophic** organisms may obtain their **nutrients** either through their roots or directly from the water column. **Heterotrophic** organisms obtain **nutrients**, as they do energy, through the consumption of other organisms.

Nutrients such as nitrogen and phosphorus are required in significant amounts in waterways and if insufficient levels are available, plant growth can become limited, which can effect the **productivity** of the **ecosystem**.

Nutrients are continually cycled through **ecosystems** from the physical environment (air, water, soil, rock) through the food web and then released back into the physical environment. For example, animals take in **nutrients** from their food and these **nutrients** are passed along the food chain and released as waste products back into the waterway (see **Nutrient** Spiralling).

In aquatic environments, **nutrients** occur in various chemical forms; as ions or dissolved gases. They may also be transformed into particulate forms by physical and chemical processes or by the metabolic activity of organisms.

Phosphorus cycling

Phosphorus exists in the aquatic environment in particulate and dissolved forms (Table 3). That is, it can be bound within living or dead organic material (particulate forms) or, through decomposition be released into the water column as phosphate ions (dissolved form). However, phosphorus is only available for uptake by plants and **algae** in its dissolved inorganic form (phosphate or PO_4^{3-}). Plants and **algae** utilise phosphorus in this form to promote growth. The phosphorus is then available to aquatic animals that consume the plants and **algae**. Eventually, phosphorus will find its way back to solution via animal waste or the death of plants and animals, and with the action of microbial organisms (Figure 6).

Table 3 Components of total phosphorus in waterways and its occurrence.

Component	Example of occurrence in a waterway
Dissolved inorganic phosphorus (DIP)	PO_4^{3-}
Dissolved organic phosphorus (DOP)	excretion by animals
Particulate inorganic phosphorus (PIP)	bound to clay particles/sediment
Particulate organic phosphorus (POP)	digested in algae

Dissolved inorganic phosphorus may also combine with particles of sediment. These particles may settle out of the water column and be deposited on the bed of the waterway. Under conditions of low oxygen concentrations, the phosphorus may be released from the sediment to become biologically available once more.

In agricultural areas, soil particles can be rich in phosphorus as a result of fertiliser application. During rainfall events phosphorus can be washed into waterways as a result of runoff and/or erosion of soil particles.

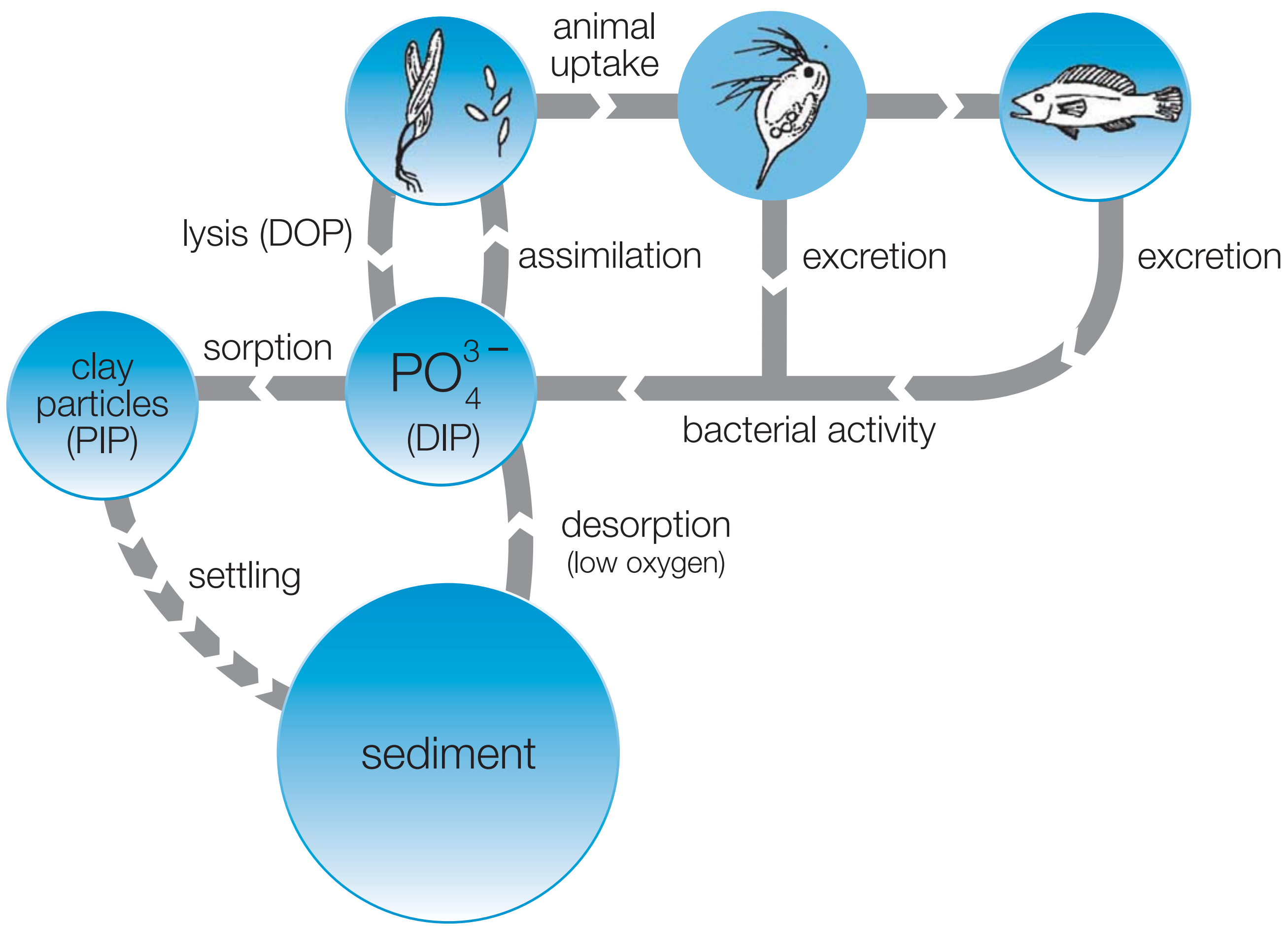

Figure 6 Components of the phosphorus cycle in aquatic environments.
PIP = Particulate Inorganic Phosphorus; POP = Particulate Organic Phosphorus; DOP = Dissolved Organic Phosphorus; DIP = Dissolved Inorganic Phosphorus.

Nitrogen cycling

Nitrogen is essential for all living things as it is needed for the manufacture of protein and amino acids (building blocks of protein). Nitrogen is the most plentiful gas in the atmosphere (approximately 78%) but plants and animals are unable to use it in this gaseous form. In aquatic environments, like phosphorus, nitrogen occurs in both dissolved and particulate forms but it also exists as a gas in solution (Table 4). Plants absorb ammonium ions (NH_4^+) and nitrate ions (NO_3^-) that are dissolved in water in the soil, through their roots and use them to make protein.

Table 4 Components of total nitrogen in waterways and its occurrence.

Components	Example of occurrence in a waterway
Dissolved inorganic nitrogen	NO_3^- (nitrate), NO_2^- (nitrite), NH_4^+ (ammonium)
Dissolved organic nitrogen	urea, amino acids, uric acid
Particulate organic nitrogen	digested in algae

The cycling of nitrogen in aquatic environments is complex and bacteria plays a central role in moving nitrogen into food chains (Figure 7). There are five important processes involved: assimilation; decomposition; nitrification; denitrification; and, nitrogen fixation.

Assimilation

Autotrophs such as bacteria and fungi take up nitrates and assimilate them within their cell structure as amino acid and protein. **Heterotrophs** obtain nitrogen through the consumption of those **autotrophs**.

Decomposition

Organic nitrogen, made available through excretion and decomposition is transformed back into its inorganic state (NH_4^+), principally through the action of bacteria and fungi.

Nitrification

Under **aerobic** (with oxygen) conditions, some nitrifying bacteria can oxidise ammonium (NH_4^+) to nitrite (NO_2^-) and nitrite to nitrate (NO_3^-). Nitrifying bacteria obtain energy through this process.

Denitrification

Under **anaerobic** (without oxygen) conditions, denitrifying bacteria utilise nitrate (NO_3^-) in order to obtain energy via **respiration**. In this process, some bacteria are able to reduce nitrate (NO_3^-) to nitrite (NO_2^-), whereas others are able to reduce nitrate to nitrogen (N_2), which is released as a gas.

Nitrogen fixation

Some bacteria and blue green **algae** (cyanobacteria) that have a special enzyme known as nitrogenase are able to break down nitrogen gas (N_2) into ammonium (NH_4^+) and incorporate the ammonium into bacterial **biomass** (living mass). This process is known as nitrogen fixation.

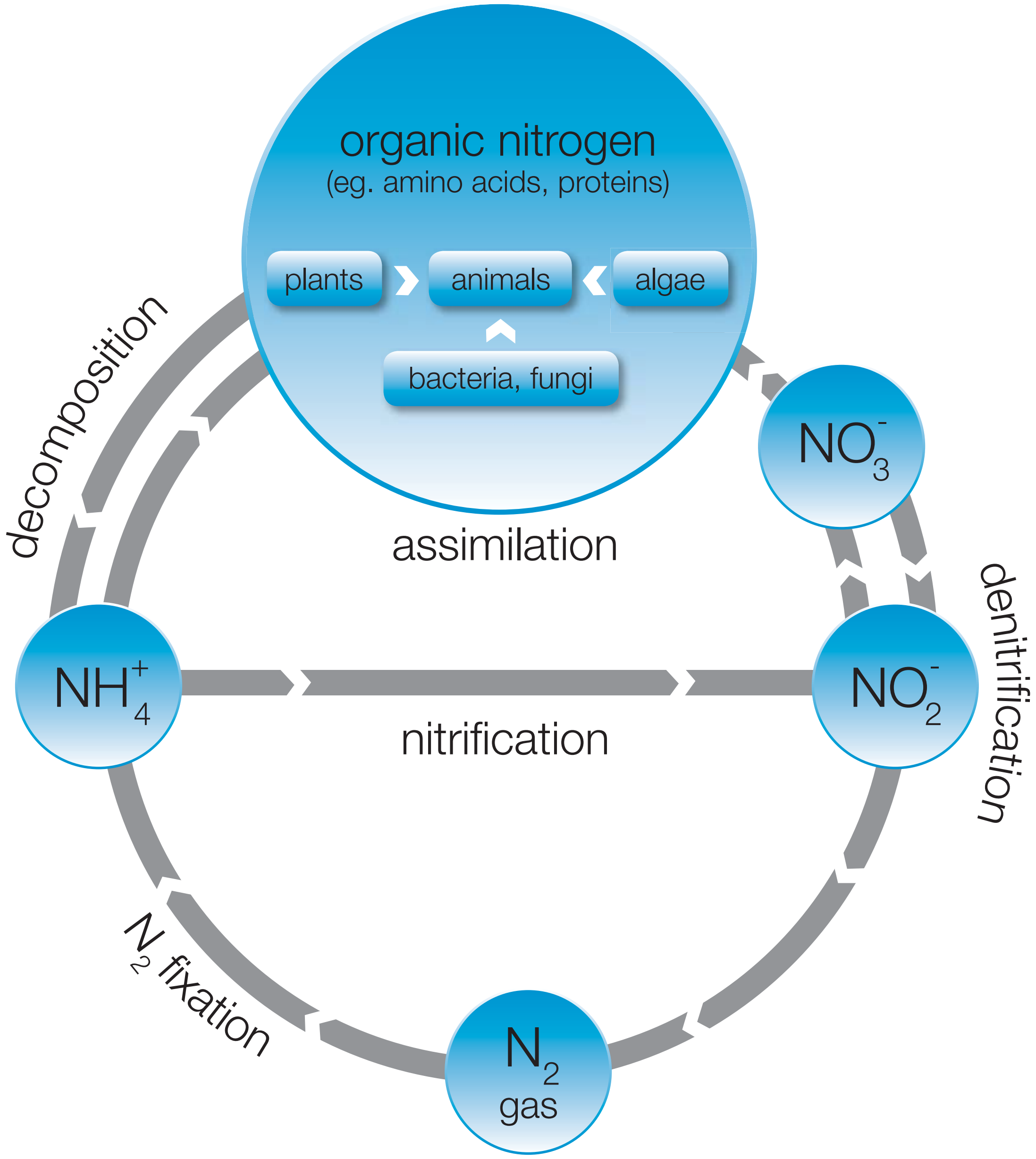

Figure 7 The cycling of nitrogen in an aquatic environment.

Nutrient spiralling

In aquatic environments, where water is not actively flowing, such as wetlands and swamps, **nutrients** are continually recycled through the **ecosystem** and are available for reuse in that same **ecosystem**. In flowing waterways, however, water actively flows downstream transporting dissolved **nutrients** and **nutrient** particles with it. The transported **nutrients** will settle at different locations downstream and this process is referred to as '**nutrient** spiralling'. The amount of **nutrients** that are retained at any one location is influenced by the amount of biological activity and the flow rate of the water. Systems with low amounts of biological activity and high flow rates tend to 'leak' more **nutrients** downstream than those with high amounts of biological activity and low flow rates. The amount of **nutrients** in a system may also influence how many **nutrients** are retained. That is, where a system has reached its capacity to recycle **nutrients**, surplus **nutrients** will be transported downstream. Where this occurs in excess, the receiving system, for example a downstream estuary, may become **eutrophic** (enriched with **nutrients**).

Trophic status

oligotrophic

Greek: *oligos* = little *trophé* = nourishment

eutrophic

Greek: *eu* = well *trophé* = nourishment

mesotrophic

Greek: *meso* = middle *trophé* = nourishment

The trophic status of a waterbody is determined by its **nutrient** content and **productivity**. **Productivity** is the rate at which **biomass** (living body mass) accumulates and it is measured as a dry or wet weight per unit of time. Waterbodies with low **nutrient** concentrations and low **productivity** are termed oligotrophic. Waterbodies that exhibit high nutrient concentration and high productivity are termed eutrophic. The mid range between these two states is termed mesotrophic. The transition between an oligotrophic system towards a eutrophic one is natural. As waterbodies age, they increasingly deposit both inorganic and organic material and, thereby, increase their **productivity**. This process is known as **eutrophication**.

Human activities, such as the use of fertiliser in agricultural and urban areas, can increase the rate of **eutrophication** of a waterbody through the input of excessive amounts of **nutrients** via **runoff**. Waterbodies in south-west Western Australia are thought to be prone to **eutrophication** (McComb & Davis, 1993). Sandy soils, such as those in the Swan Coastal Plain in Western Australia, have a poor ability to retain **nutrients** and so, when fertiliser is added to these soils, the **nutrients** make their way into waterways through shallow groundwater. Also, waterways in the south-west can have highly seasonal flows and most estuaries are poorly flushed.

Waterway Ecology

Habitats in waterways

A habitat can be thought of as an environment in which an organism is usually found. In every waterway, there are a variety of habitats. Different areas in the waterway have differing levels of light, shade, shelter, water depth and flow rates. Habitats can be very large or very small, ranging from the area under a stone or log to the entire waterway. Typical habitats in waterways include:

- submerged and emergent plants (e.g. water lilies)
- riffle zones (e.g. rocky rapids)
- sand
- large woody debris
- deep pools and the water's edge
- flooded zones

Submerged and emergent plants

Submerged or emergent plants that are floating and rooted plants provide an important habitat for invertebrate fauna. **Macroinvertebrates** may be feeding on the vegetation itself or upon the attached **algae**. Other **macroinvertebrates** (including some molluscs) attach or cling to the vegetation. From here they are able to obtain their food by filtering small particles from the water column.

Since many **macroinvertebrates** prefer submerged and emergent plants for their habitat, food resources in these areas are abundant for fish. The vegetation also provides shelter for fish, water birds and frogs in which they can escape predators and the harsh summer sun.

Riffle zones

Fast flowing areas, where the water is rippled or broken over rocks or logs are known as riffle zones. Riffle zones are often turbulent, well-aerated areas and are favoured by filter-feeding **macroinvertebrates** (e.g. blackfly larvae) that are able to use the water current for gathering food.

Sand

Sand is a poor habitat for **macroinvertebrates** because of its unstable and mobile nature. The invertebrates that inhabit sand are often burrowers with long thin bodies and thick body walls that enable them to withstand the abrasive action of sand, for example, oligochaetes (segmented worms).

Large Woody Debris

In sandy waterways, large woody debris, which is partly exposed or completely submerged under the water, provide a stable bed for **macroinvertebrates**. **Macroinvertebrates** are often more abundant, diverse and productive on woody debris than elsewhere in sandy waterways (Bilby & Likens, 1980). Some **macroinvertebrates**, such as caddisfly and midge larvae, are specifically adapted for inhabiting woody debris and have specialised mouthparts with which to gouge and tunnel into the wood.

Large woody debris provides secure roosting and preening sites as well as excellent viewing points for cormorants, herons and other birds to look for food. The woody debris also provides protection to fish from predatory birds and the fin-nipping habits of the introduced mosquitofish (*Gambusia* species). Native fish are more plentiful and diverse in waterways where woody debris is present (Beesely, 1996) and they can take advantage of the slower flowing water upstream of woody debris to escape the faster flow elsewhere in the waterway. Small pools created by woody debris are important habitats for fish, particularly during summer dry periods when many Western Australian waterways temporarily dry up. In these small pools, the woody debris also provides shade under which fish can escape the harsh summer sun.

Deep pools and the water's edge

Slower flowing areas within waterways such as deep pools and the water's edge are often the preferred habitat of species that are unable to cope with fast flow. Many of Western Australia's native fish species occur in these areas (Morgan *et al.*, 1996).

Suspended sediments often settle out in slower flowing waters. Where this occurs in shallow areas with abundant light, rooted plants are able to become established in waterways. **Macroinvertebrates** that live in the bed of waterways occur in slower flowing areas and are adapted to tolerate the sandy environment and lower oxygen levels that occur in these areas. Tiny planktonic plants and animals also typically inhabit slower flowing areas of waterways.

Deep pools are a particularly important habitat for aquatic animals during Western Australia's hot, dry summers when long sections of our waterways dry up. In these systems, permanent, deep pools provide a refuge for the aquatic animals that do not have physiological adaptations to tolerate drought. These animals are able to survive in the shrinking pools until flow begins again in winter and they can recolonise previously dry reaches of the waterway.

Boyagarra Pool, a 600 m stretch of the Avon River.

Flooded zones

Areas adjacent to waterways that are seasonally flooded are called **floodplains** and during high flows they provide an important habitat to small crustacea, wading birds, frogs and fish. For some species, the regular flooding of this zone is crucial to part of their life cycle. During winter, many native fish species migrate out from rivers and into annual creeks or the **floodplain** in order to reproduce in flooded vegetation (Morgan *et al*., 1998). Juvenile fishes then develop in these 'nursery' areas before moving downstream to more permanent waters.

Animal adaptations to water flow

The speed at which water flows in a waterway, and the turbulence created, presents special challenges to animals living in waterways and influences where they can live. Animals that live in fast-flowing areas often have specific body characteristics or behaviours that allow them to withstand the current and not be swept away. Most **macroinvertebrates** that occur in fast flowing areas are **benthic** (living on the bottom) and are often flattened or streamlined in shape. Others have suckers, hooks or use silk threads to enable them to remain within the flow. Lampreys, for example, have specialised mouthparts that allow them to sucker against rocks as they move against the flow during their upstream migration to reproduce. Other animals simply hide from the current in crevices, cracks and under rocks.

As mentioned previously, a large number of waterways in Western Australia dry up for part of each year. Many native aquatic animals are adapted to cope with these periods of drought and seek areas that are always wet, such as upland streams or deep pools within the waterway. Some species survive the dry period in moist habitats deep within the bed of the waterway, under moist leaf litter or in burrows made by freshwater crayfish. Other macroinvertebrates lay resistant eggs in the bed of the waterway so that when water flow returns, juveniles will hatch from the eggs and colonise the waterway.

Waterway Ecology

Impacts of human activities on waterways

The waterway **ecosystem** is evidently very complex; it involves intricate relationships and a natural balance between all of the living and non-living (physical) components. It is this balance that can become upset or altered when human activities occur along and within waterways. Human activities including: clearing of natural vegetation; stocking cattle near waterways; introducing feral animals and weeds; applying fertiliser to crops in the surrounding **catchment**; or, artificially altering the natural water regime, can cause a deterioration in the health of the waterway and the **ecosystems** that it supports.

Degradation of riparian vegetation

The area of vegetation along the banks of a waterway is called the riparian zone and is the most important feature around a waterway. **Riparian vegetation** plays an important role in the overall waterway **ecology**; the riparian zone delivers important **allochthonous** sources of energy to the food web; provides important habitat (for example, leaves provide surfaces for **macroinvertebrates** to live on and birds use the vegetation to nest in); acts as a habitat corridor (safe cover for the movement of animals between areas of habitat); and, also provides shade to waterways, which helps to reduce the extremes in temperatures.

There are a number of ways in which **riparian vegetation** may become degraded. These include: trampling by farm animals (e.g. cows, sheep) grazing near the waterway; damage from vehicle access; introduced and invasive weed species out-competing native vegetation; and, widespread clearing of vegetation for urban development or agriculture, for example.

Clearing **riparian vegetation** alters the amount of **allochthonous** material and sunlight available to a waterway **ecosystem** and this can dramatically influence the processes that occur in the waterway. For example, clearing **riparian vegetation** from shaded upland waterways may cause a shift in energy dynamics such that a waterway system moves from being **heterotrophic** to **autotrophic** with resulting changes in the species and total number of organisms inhabiting the waterway.

The removal of **riparian vegetation** results in habitat degradation for many species. By fragmenting the vegetation, animals can no longer move between areas of habitat under the safety of continuous vegetation (a habitat corridor). This can result in the isolation of species and inbreeding. In addition, remaining patches of vegetation are often too small to support the diversity of species that used to live there.

The roots of **riparian vegetation** provide stability to the banks of the waterway and enable resistance to the erosive power of the flowing water. When **riparian vegetation** is degraded, the soil along the banks of the waterway can more easily erode away and sediment will be transported downstream, which can negatively impact on the health of the waterway.

Sedimentation of waterways

Although sediment is a natural part of waterways, it can be damaging to the waterway **ecosystem** when it is present in excess. For example, a high load of sediment in the waterway can result in:

- altered waterway processes
- infilling pools
- altered vegetation and flow
- altered **macroinvertebrate** and fish communities

These issues are described in more detail below.

Altered waterway process: When large amounts of sediment are suspended in the water column, conditions become turbid (muddy) and light can not penetrate the water as easily. Since plants and **algae** living in waterways require light for **photosynthesis**, their growth rate will decline and this will alter the structure and function of plant and animal communities living in the waterway. Excess deposition of sediment may also slow the breakdown of leaf litter in waterways (Bunn, 1986); when sediment smothers leaves it reduces the availability of oxygen to the surface of the leaves. As a result, the leaves are not available to the **microbes** and **macroinvertebrates** that break leaves into finer particles. This influences the waterway **ecosystem** as the breakdown of leaf litter is very important to the **heterotrophic** pathway of energy transfer in aquatic **ecosystems**.

Infilling of pools: Pools in waterways often comprise areas of deep water and slow flow. It is natural for sediment to be deposited in pools and for the sediment to accumulate there until large floods scour it out. However, when upper reaches of a waterway are severely degraded, very large amounts of sediment may move downstream and flooding events capable of scouring the pools can be very rare. The infilling, and thus loss of pools with sediment, has serious consequences for the waterway **ecosystem**. For example, aquatic animals that relied on deep pools during the dry periods of the year can become locally extinct.

Altered vegetation and flow: Where sediment accumulates in shallow, slow-flowing areas of a waterway, it provides a base for aquatic plants to grow. Weeds, which readily invade new areas, may unfortunately out-compete native vegetation.

The colonisation of plants will slow the water flow across newly vegetated areas and cause further sediment to deposit there. These areas may become ‘islands’ within a waterway causing flow to divert around them which can then alter the shape of the waterway. The accumulation of sediment may also raise the bed and hence, reduce the waterways ability to carry high flows which can result in flooding.

Altered macroinvertebrate and fish communities: Aquatic **macroinvertebrates** are particularly vulnerable to deposited sediment because the composition of the bed of the waterway affects their movement, feeding, habitat and reproduction and so, is a major factor contributing to their distribution. The diversity of the **macroinvertebrate** community, generally reflects the health of a waterway. Typically, waterways subjected to increased sedimentation are less healthy and have a less diverse macroinvertebrate fauna. Macroinvertebrates, such as caddisflies, stoneflies and mayflies, which like to live in clean gravel beds become less abundant, while worms and midge larvae, which prefer finer sediment, typically become more abundant.

Sediment can obstruct aquatic macroinvertebrates' feeding appendages which increases the time and energy needed for them to collect sufficient food to survive.

Excess sediment may also influence the availability of food for fishes. Some fish, such as Gobies, feed on **algae**, while others have a diet of macroinvertebrates. Changes to the abundance and distribution of **algae** and macroinvertebrates as a result of increased sedimentation may indirectly influence fish populations as well. Fish may also have more difficulty finding food because of increased **turbidity** (muddiness). In addition, suspended sediment can be abrasive and cause damage to the gills of fish (Pen, 1999).

Pollution

Pollutants enter waterways through a range of land uses in the surrounding **catchment**, for example from industrial and agricultural wastewater. Pollution may include **nutrients** or chemicals such as pesticides, petroleum products or heavy metals. Many pollutants are toxic to plants and animals in waterways and can alter or influence animals' life cycles or even result in their death.

Some macroinvertebrates are more tolerant of pollutants than others. Consequently, pollution of a waterway can lead to a significant change in the macroinvertebrate community which in turn affects the health of that waterway.

When excessive amounts of **nutrients**, such as nitrogen and phosphorus, enter waterways, and under conditions of adequate light and temperature, the growth of **phytoplankton**, **macroalgae** and submerged **macrophytes** may be stimulated. Resulting algal blooms can de-oxygenate a waterbody and the consequential death and decay of the **algae** can produce toxins and stagnant conditions, which results in the loss of other aquatic organisms. The depletion of oxygen levels in the water occurs mainly at night when **photosynthesis** is not occurring and when the algal bloom dies off and decomposition occurs.

Salinisation

Widespread clearing of deep-rooted native vegetation and its replacement with shallow-rooted annual crops and pastures has altered the natural water regime in many regions of Western Australia. Shallow-rooted crops are unable to make use of the rainfall that creeps into the deep soils. As a result, more water enters the deep groundwater and the watertable rises. As this occurs, the groundwater brings with it large amounts of salt that has built up in the soil over thousands of years (Figure 8). When the saline groundwater reaches and evaporates at the land surface, the salt is concentrated causing what is known as secondary salinity. Salt enters waterways directly from the groundwater and when it rains, via run-off from the surface of the soil.

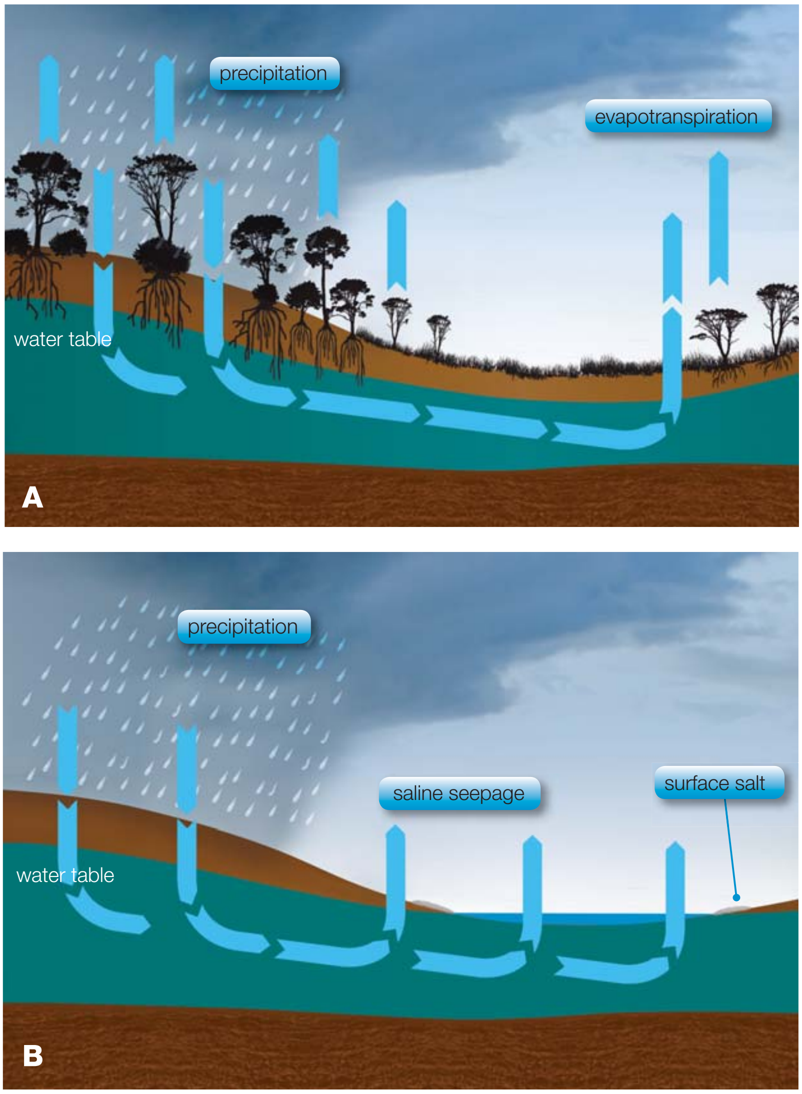

Figure 8 Clearing native vegetation can cause the water table to rise bringing with it large amounts of salt. A: Before clearing; B: After clearing.

Salinisation is a major threat facing our waterways. Salt intolerant riparian plant species are being lost and, thereby, waterway processes are being altered. Salinity is a major threat to the **biodiversity** of plants and animals in our waterways as many species can not survive in water that has even low levels of salt. For example, a decrease in the range of marron has been attributed to the increase of salinity in south-west waterways of Western Australia.

Acid saline water

Rising groundwater not only brings increased quantities of salt to the soil surface but it can also be acidic, often with high concentrations of dissolved trace metals (Degens and Shand, 2009). Groundwaters in some parts of the Wheatbelt region in Western Australia are very saline (saltier than seawater), very acidic with pH commonly between 3–4 (like weak vinegar), and, more critically, contain high concentrations of dissolved aluminium, iron and trace metals like lead, nickel, copper and zinc (Shand & Degens 2008). Most acidic groundwaters contain high concentrations of dissolved iron and so have the potential to become even more acidic (i.e. lower pH even more) on exposure to the air if they seep into lakes and creek-lines or are drained or pumped to the surface. The dissolved iron reacts with air much in the same way that rust forms, only unlike normal rusting of solid iron this reaction also releases acid into the water, with the effect of lowering pH.

When acidic groundwater finds its way into waterways, the risk to aquatic life is enormous. The acidification of waterways (including the sediments) can cause death for many aquatic species and can drastically reduce **biodiversity** in waterway **ecosystems**. Another major hazard to waterways is the associated transport and accumulation of trace elements in surface environments. This carries longer-term risks of accumulation in waterways, producing toxic effects on aquatic life and possible longer-term **bioaccumulation** through aquatic food chains.

Example data

The effect of water quality on the biodiversity of macroinvertebrates

Water quality (including **nutrient** levels, salinity and pH) and the number of macroinvertebrate families present were recorded in Spring 2008 for a site on each of the three different waterways in the south-west Western Australia. The total number of macroinvertebrate families were recorded as well as the number of pollution-sensitive **taxa** or EPT **taxa** (Emphemeroptera (mayflies), Plecopteran (stoneflies) and Tricopteran (caddisflies).

The table below shows that Site 1 had the best water quality (low **nutrient** levels, fresh water and neutral pH) and the highest number of macroinvertebrate families present while Site 3 had the lowest overall water quality (moderate to high **nutrient** levels, saline water and basic pH) and consequently, few number of macroinvertebrate families.

Please refer to *Water Facts 2 (2nd edition): Water quality and macroinvertebrates* (Water and Rivers Commission, 2001) for a description of animal classifications (i.e. Kingdom, Phyllum, Class, Order, Family, Genus, Species) and further information about macroinvertebrates, methods that can be used to sample them in the field and the effects of water quality on their biodiversity.

Note that in addition to water quality, there are several other factors that affect the biodiversity and abundance of macroinvertebrates in waterways (e.g. available habitat, water flow rate, type of substrate, amount of leaf litter entering the waterway).

Site	Total nitrogen concentration	Total phosphorus concentration	Salinity	pH	Total number of macroinvertebrate families	Number of EPT taxa
1	low	low	fresh	neutral	22	10
2	high	very high	fresh	neutral	16	3
3	high	moderate	saline	basic	8	0

Data provided by the Water Science Branch, Department of Water, Perth.

Introduced species

Humans have introduced many exotic plant and animal species to Western Australia, many of which are now considered as pests as they prey upon native animals. For example, foxes and cats prey upon native birds and mammals which are important parts of the waterway **ecosystem**. Rabbits which were also introduced can consume significant amounts of native vegetation and this has a detrimental effect to the waterway **ecosystem** by destabilising banks and increasing the potential for erosion. The species of plants that become re-established on the banks of waterways can be dominated by introduced plant species (weeds), which are introduced plants and often out-compete native plants.

Artificially changing the natural water regime

Artificially altering the natural water regime in waterways (e.g. extracting water for use in agriculture or building a dam in a waterway) can have serious consequences for the waterway **ecosystem**. Reductions in water flow can lead to: changes in the survival, growth and reproduction of organisms living in a waterway; invasion by exotic plant and animal species; and, altered water quality, which can all lead to modifications to the plant and animal communities associated with the waterway.

The damming and diversion of waterways influences the movement of organic material downstream and hence, will affect the process of **nutrient** spiralling, thereby affecting the structure and function of communities along the waterway. Dams also disrupt the migration of animals (e.g. native fish) between upstream and downstream areas of the waterway.

Reduced connectivity between the waterway and its **floodplain** may also occur as a result of changes to the natural water regime. This will have consequences for animals through the loss of important habitat for small crustacea, wading birds, frogs and fish. In addition, the disconnection of the **floodplain** may impact upon the **productivity** of large waterway systems that exchange **nutrients** and particulate material with the **floodplain** during flood events.

Conclusion

Having an understanding of waterway **ecology** in terms of: the array of organisms that inhabit the **ecosystem** and their habitat requirements; the sources and importance of energy flow within food webs; and, the **nutrient** requirements and cycling within the **ecosystem**, is important in order to respond to the pressures that human activities impose on these systems. It is essential that this knowledge is applied to the management of waterways in Western Australia to protect or restore their ecological health.

For more information on many of the topics introduced in this document, please refer to the *Water notes and Water facts* publications produced by the Department of Water. Go to <www.water.wa.gov.au> select *Looking after our waterways > Protecting > Water notes series* or *Water fact series.*

Waterway Ecology

Glossary

Aerobic
With oxygen; Organisms living or active only in the presence of free oxygen.

Algae
A diverse group of aquatic plants containing chlorophyll and other photosynthetic pigments. Many are microscopic (often being single cells) but some can be large, including the large seaweeds. They grow as single cells or aggregations of cells (colonies) (see Phytoplankton and Macroalgae).

Allochthonous
A source of organic matter that arises from outside of the waterway i.e. leaf litter, woody debris.

Anaerobic
Anoxic; without oxygen. Anaerobic organisms can or must live without oxygen.

Autotroph
Organisms that are able to make their own organic compounds from simpler inorganic compounds available from air, soil and water e.g. green plants. Also known as primary producers.

Autochthonous source
A source of organic matter that arises from within the waterway i.e. macrophytes, phytoplankton, periphyton

Benthic
Plants and animals that dwell on the sediment at the bottom of the waterbody.

Bioaccumulation
The accumulation of toxic substances (e.g. pesticides, chemicals) in an organism whereby the organism absorbs the substance at a greater rate than that at which the substance is lost.

Biodiversity
The variation of life forms within a given ecosystem. Biodiversity is often used as a measure of the health of biological systems

Biomass
The amount (weight) of living material (plants or animals).

Biota
All the plant and animal life of a particular region.

Catchment
The area of land which intercepts rainfall and contributes the collected water to surface water (waterways, wetlands) or groundwater.

Detritivore
Organisms that obtain nutrients by consuming detritus (decomposing organic matter). Also know as secondary producers.

Detritus
Organic material, including animal waste products and the remains of animals, plants and micro-organisms, together with the associated microbial community (bacteria and fungi).

Ecology
The study of the interrelationships between living organisms and their environment.

Ecosystem
A term used to describe a specific environment, e.g. waterway, to include all the biological, chemical and physical resources and the interrelationships and dependencies that occur between those resources.

Eutrophication
A natural process of accumulation of nutrients leading to increased aquatic plant growth in lakes, rivers, harbours and estuaries. Human activities contributing fertilisers and other high nutrient wastes can speed up the process, leading to algal blooms and deterioration in water quality.

Floodplain
The portion of a river valley next to the river channel which is or has been periodically covered with water during flooding.

Herbivores
Organisms that feed only on plants. Also know as secondary producers.

Heterotroph
Organisms that are not able to make their own organic compounds for respiration and so need to obtain organic compounds from elsewhere. i.e. herbivores, detritivores, predators. Also known as secondary producers.

Hydrology
The study of water, its properties, distribution and utilisation above, on and below the earth's surface.

Inorganic compound
An inorganic compound is any member of a large class of chemical compounds whose molecules do not contain carbon.

Landform/Landscape
The visual appearance of natural and human-made environments.

Macroalgae
Algae which can be seen by the unaided human eye in contrast to microscopic algae which must be studied under the microscope.

Macroinvertebrates
Invertebrates are animals without a backbone. Macroinvertebrates are big enough to be seen with the unaided human eye though they can be very small.

Macrophytes
A rooted aquatic plant that grows in or near water and is either emergent, submergent, or floating.

Microbes
Microscopic living organisms, including bacteria, protozoa and fungi.

Nutrients
Minerals dissolved in water, particularly inorganic compounds of nitrogen (nitrate and ammonia) and phosphorus (phosphate) which provide nutrition (food) for plant growth.

Organic compound
An organic compound is any member of a large class of chemical compounds whose molecules contain carbon.

Organic matter
Materials either of plant or animal origin which were once part of a living organism or produced by a living organism.

Periphytic algae
Floral communities living on the surface of submerged objects in most aquatic ecosystems.

Photosynthesis
Conversion of carbon dioxide and water to carbohydrates using light energy.

Phytoplankton
Microscopic free-floating or weakly mobile aquatic plants e.g. diatoms

Productivity
The rate at which biomass (living body mass) accumulates – measured as a dry or wet weight of biomass produced over a period of time. Productivity is used as a measure of the efficiency with which a biological system converts energy into growth.

Protozoa
Protozoa is a single celled organism.

Respiration
The process in which the chemical bonds of energy-rich molecules such as glucose are converted into energy usable for life processes.

Riparian vegetation
Vegetation growing along banks of waterways, including the brackish upstream reaches of an estuary.

Runoff
Water that flows over the surface from a catchment area, including waterways.

Taxon/taxa
A particular group of organisms of any taxonomic rank. For example, a phylum, a genus, or a species. Plural is taxa.

Tributary
A waterway such as a stream, creek or small river which flows into a larger waterway.

Trophic level
A particular feeding level occupied by a group of organisms in a food web. For example, the autotrophs (primary producers) form the first trophic level and are at the base of the food web while predators are at the top.

Turbidity
Muddiness or opaqueness of water due to suspended particles in the water causing a reduction in the transmission of light.

Zooplankton
Small or microscopic aquatic animals that float or drift in water.

Waterway Ecology

References

Allan, J. D. 1995. *Stream Ecology: Structure and Function of Running Waters*, Chapman and Hall, London.

Beesely, L. 1996, *The Ecological Importance of Large Woody Debris in the Sandy River Systems of the Swan Coastal Plain (Perth, Western Australia)*, Honours Thesis, University of Western Australia, Perth.

Bilby, R. E. and Likens, G.,E. 1980, Importance of organic debris dams in the structure and function of stream ecosystems. *Ecology* 61, 1107 - 1113.

Bunn, S.E. 1988, Processing of leaf litter in two northern jarrah forest streams, Western Australia II: The role of macroinvertebrates and the influence of soluble polyphenols and inorganic sediment. *Hydrobiologia* 162, 211-223.

Degens, B. and Shand, P. 2009. *Introduction to acidic saline groundwater in the WA Wheatbelt – characteristics, distribution, risks and management,* Department of Water, Perth.

McComb, A. J. and Davis, J. A. 1993, Eutrophic waters of southwestern Australia. *Fertiliser Research* 36, 105-114.

Merrit, R. W. and Cummins, K. W. 1996, *An Introduction to the Aquatic Insects of North America,* 3rd Edition, Kendall/Hunt, Iowa.

Morgan, D. L. Gill, H. S. and Potter, I. C. 1998, *Distribution, identification and biology of freshwater fishes in south-western Australia: Records of the Western Australian Museum,* Supplement No. 56, Western Australia.

Pen, L. 1999, *Managing our rivers: a guide to the nature and management of the streams of south-west Western Australia,* Water and Rivers Commission, Perth, Australia.

Shand, P. and Degens, B. 2008. *Avon catchment acid ground-water: geochemical risk assessment,* CRC-LEME Open File Report 191, CSIRO Exploration and Mining, Perth.

Water and Rivers Commission, 2000. *Chapter 7: Stream Ecology,* River Restoration Manual, Water and Rivers Commission, Perth.

Water and Rivers Commission, 2001 (2nd edition). *Water quality and macroinvertebrates,* Water Fact No. 2, Water and Rivers Commission, Perth.