A guide to managing and restoring wetlands in Western Australia

Wetland ecology

In Chapter 2: **Understanding wetlands**

Version 1

Australian Government

Department of Environment and Conservation

Our environment, our future

Introduction to the guide

Western Australia's unique and diverse wetlands are rich in ecological and cultural values and form an integral part of the natural environment of the state. *A guide to managing and restoring wetlands in Western Australia* (the guide) provides information about the nature of WA's wetlands, and practical guidance on how to manage and restore them for nature conservation.

The focus of the guide is natural 'standing' wetlands that retain conservation value. Wetlands not addressed in this guide include waterways, estuaries, tidal and artificial wetlands.

The guide consists of multiple topics within five chapters. These topics are available in PDF format free of charge from the Western Australian Department of Environment and Conservation (DEC) website at www.dec.wa.gov.au/wetlandsguide.

The guide is a DEC initiative. Topics of the guide have predominantly been prepared by the department's Wetlands Section with input from reviewers and contributors from a wide range of fields and sectors. Through the guide and other initiatives, DEC seeks to assist individuals, groups and organisations to manage the state's wetlands for nature conservation.

The development of the guide has received funding from the Australian Government, the Government of Western Australia, DEC and the Department of Planning. It has received the support of the Western Australian Wetlands Coordinating Committee, the state's peak wetland conservation policy coordinating body.

For more information about the guide, including scope, purpose and target audience, please refer to the topic 'Introduction to the guide'.

DEC welcomes your feedback and suggestions on the guide. A publication feedback form is available from the DEC website at www.dec.wa.gov.au/wetlandsguide.

Contents of the guide

These topics are available in PDF format free of charge from the DEC website at www.dec.wa.gov.au/wetlandsguide.

'Wetland ecology' topic

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When specific reference is made to this topic, the recommended reference is: Department of Environment and Conservation (2012). 'Wetland ecology', in *A guide to managing and restoring wetlands in Western Australia*, Prepared by J Lawn and A Lam, Department of Environment and Conservation, Perth, Western Australia.

Contents

Before you begin

Before embarking on management and restoration investigations and activities, you must consider and address the legal requirements, safety considerations, cultural issues and the complexity of the ecological processes which occur in wetlands to ensure that any proposed actions are legal, safe and appropriate. For more guidance, see the topic 'Introduction to the guide'. Note that the collection of flora and fauna, even for conservation purposes, must be consistent with State laws, and is likely to require a license. More detail is provided in this topic.

Ecosystem: a community of interdependent organisms together with their non-living environment

Organism: any living thing

Introduction

Wetlands, by virtue of the presence of water, are distinctive **ecosystems** that are important for the life they sustain. The remarkable diversity of wetland types in Western Australia, from those that are seasonally waterlogged or intermittently inundated to those that are always inundated, mirrors the diverse and unique range of **organisms** they sustain. Some organisms rely entirely on these wetlands for their survival, including a range of wetland plants, fish, frogs, turtles, reptiles, birds, mammals, crustaceans, insects and other animals. Some rare plants, animals and other living things are known from as little as one or a handful of WA wetlands. At the other end of the spectrum, WA's wetlands provide sustenance and refuge for large populations of mammals, reptiles and birds that visit them at times in their life, including migratory birds that span continents to reach WA.

The diversity and wealth of life that WA wetlands directly and indirectly support is truly amazing, and forms an important part of Australia's rich biological diversity. Managing wetlands to sustain this life requires an understanding of the wetland ecology: the living things, and the relationships between these living things and with the non-living parts of the wetland. This topic provides an overview of the groups of organisms present in wetlands in WA and important ecological roles each group fulfil (Part 1), and what requirements these organisms have that explain why they are found where they are found (Part 2).

➤ More detailed descriptions of the physical factors (such as water, wind, light and temperature) and chemical factors (such as the availability and cycling of nutrients, carbon, salts and so on) that affect wetland organisms are provided in the topics 'Wetland hydrology' and 'Conditions in wetland waters' in Chapter 2.

- Introduced plant and animals are covered in the topics 'Wetland weeds' and 'Introduced and nuisance animals' in Chapter 3.
- Information on how to monitor plants and animals is provided in Chapter 4.

PART 1: WETLAND ORGANISMS

The plants, algae, bacteria, fungi and animals that inhabit or regularly visit WA's wetlands are outlined in this section. Although usually very inconspicuous, algae, bacteria and fungi are included because of their importance within wetland ecosystems. Although it is not always possible to see them or directly manage populations of these organisms, it is important to understand them and their role when managing and restoring wetlands.

extra information

A note on terminology used in this topic

Scientific names

In this topic, organisms are referred to by common names (for example 'human') and by their scientific names (for example '*Homo sapiens*').

Scientific names are assigned to living things in accordance with a long-standing naming system that groups them into 'kingdoms' of life. The original two kingdom system recognised only plants and animals. The six kingdom system is now widely used; this recognises the plant, animal, bacteria, fungi, protozoa and chromista kingdoms. Within each of these kingdoms, how closely related each life form is to one another, in terms of common ancestry, is reflected by whether they belong to the same taxonomic groups, starting with phylum and becoming more and more related if they belong to the same class, order, family and genus. Finally, within each genus are species, which are organisms capable of interbreeding and producing fertile offspring. The scientific name for the species is in Latin and in italics and in this topic it is often included along with the common name, for example: black swans, *Cygnus atratus.* Figure 1 shows the taxonomic groups that black swans belong to.

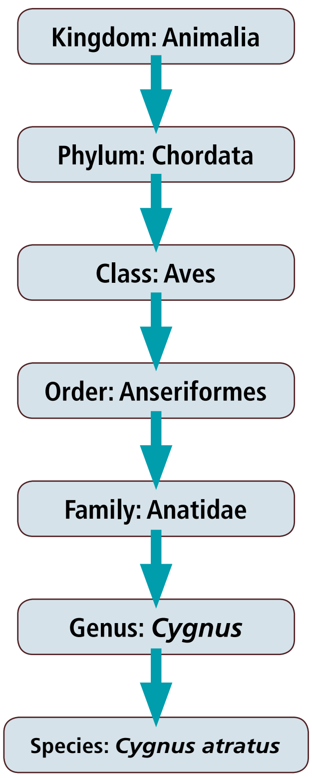

Figure 1. The taxonomic groups that the black swan (*Cygnus atratus*) belongs to.

extra information

The term taxon (plural 'taxa') is often used when referring to a specific type of organism or group of organisms. Depending on the context, this may be a species, genus or higher group.

For more information on the six kingdoms of life, see the Tree of Life website[1] or search under 'biological classification' on the Wikipedia website.

Threatened and priority wetland flora, fauna and communities

A number of wetland species are formally listed as 'threatened species' under the *Wildlife Conservation Act 1950* because they are under identifiable threat of extinction, are rare, or otherwise in need of special protection.

A relatively large proportion of wetland plants are threatened. As of 2011, forty-six of the 402 declared rare flora in WA occur in wetlands.[2] Additionally, a number of wetland plant taxa are listed as 'priority species'. Because of the large Western Australian flora, there are many species that are known from only a few collections, or a few sites, but which have not been adequately surveyed. Such flora may be rare or threatened, but cannot be considered for declaration as rare flora until targeted survey has been undertaken. These flora are included on a supplementary conservation list called the priority flora list. This list is dynamic—as new information comes to light the species' conservation status is reviewed and changes to the listing may result. Of the 2,704 priority species identified in 2011, [270] are known to occur in wetlands.[2] More information on these flora are provided in the topic 'Wetland vegetation and flora', also in Chapter 2 of this guide.

Listed threatened wetland fauna include the bilby, quokka, Australasian bittern, Australian painted snipe, fairy tern, western swamp tortoise, white-bellied frog, orange-bellied frog, sunset frog, western trout minnow, western mud minnow, Balston's pygmy perch, Cape Leeuwin freshwater snail, Minnivale trapdoor spider, Margaret River burrowing crayfish, Dunsborough burrowing crayfish, Walpole burrowing crayfish, megamouth bee and another native bee.[3]

Listed priority wetland fauna include rakali, quenda, western brush wallaby, the Nornalup frog, marbled toadlet, small toadlet, the black-striped minnow, the black bittern, little bittern, Carter's freshwater mussel, Poorginup Swamp watermite and Doeg's watermite.[4]

Similarly, a significant number of wetland communities are listed as threatened ecological communities (TECs). The Minister for Environment may list an ecological community (the sum of species within an ecosystem) as being threatened if the community is presumed to be totally destroyed, or is considered to be at risk of becoming totally destroyed. As of 2009, 316 threatened or priority ecological communities have been formally identified. Sixty-nine of these have been endorsed by the Environment Minister as follows: twenty-one as critically endangered, seventeen as endangered, twenty-eight as vulnerable, and three as presumed totally destroyed. Significantly, thirty-seven of Western Australia's sixty-nine[5] threatened ecological communities are wetland communities. These are listed in Appendix 1. Ecological communities with insufficient information available to be considered a TEC, or which are rare but not currently threatened, are placed on the priority list and referred to as priority ecological communities (PECs), of which there are five categories.

Lists of threatened flora, fauna and ecological communities are updated each year and are available on the DEC website: see the 'Threatened flora, fauna and ecological communities' webpage.[6] Information can also be accessed through the online mapping tool *NatureMap* (naturemap.dec.wa.gov.au) which can be used to produce maps, lists and reports of WA's flora and fauna diversity. It is constantly being updated or added to so the data is the most up-to-date available.

Other significant flora and fauna

Other significant wetland flora and fauna includes but are not necessarily limited to:

- species protected by international agreements or treaties such as migratory bird species[3]
- short range endemic species
- species with declining populations or declining distributions
- species at the extremes of their range
- isolated outlying populations
- undescribed species.

For more information regarding the protection of the state's flora, fauna and ecological communities, see the topic 'Wetland legislation and policy' in Chapter 5.

Wetland plants

Note

The following information is a very brief summary of the characteristics of Western Australia's wetland plants. A whole topic is dedicated to them: 'Wetland vegetation and flora', also in Chapter 2, while algae are included in this topic. For introduced wetland plants, see the 'Wetland weeds' topic in Chapter 3.

Wetland plants include all plant growth forms including trees, shrubs, sedges, ferns, herbs and grasses. There are a variety of Western Australian wetland trees, including paperbarks (*Melaleuca* species), eucalypts (*Eucalyptus* species), sheoaks (*Casuarina* species), and acacias (*Acacia* species). Shrubs, herbs and grasses are from a very broad range of families and genera. **Sedges** are common in Western Australia's wetlands. Sedges are members of the Cyperaceae, Centrolepidaceae, Hydatellaceae, Juncaginaceae, Restionaceae, Typhaceae and Xyridaceae families. The Restionaceae and Juncaceae are often called rushes while the Typhaceae are usually called bulrushes. Some grasses (Poaceae family) are known as reeds but only the tropical reed *Phragmites karka* is native to Western Australia. Other reed species, that is, other species in the genera *Phragmites* and *Arundo*, are not native to Western Australia.

Figure 2. Vegetation of a Kemerton wetland that is waterlogged in winter and spring and dry in summer and autumn (a dampland). Photo – J Lawn/DEC.

Wetland plants differ from dryland plants in their ability to grow in water, or alternatively in soils that are waterlogged either intermittently, seasonally or permanently. Wetland plants may be submerged or floating in water, or emergent from water or soil. It is a common misconception that only plants that grow in inundated areas are wetland plants, and that plants growing in areas that are only waterlogged or that are dry for a period (that is, seasonally or intermittently inundated) are dryland plants (Figure 2). It is also a common misperception that wetland plants always 'fringe' a waterbody. Wetlands that are completely vegetated throughout are common in Western Australia, and it is these wetlands that often have the greatest diversity of vegetation units and often flora.

Some plant species only grow in wetlands; these are called **obligate wetland plants**. Other plant species can grow in dryland ecosystems as well as wetlands; these are called **facultative plants**. Facultative and obligate wetland species are from a range of plant families.

More than 3,000 taxa in WA are thought to be wetland flora.[2] This is over 20 per cent of Western Australia's 12,500 flora. Some areas of the state, particularly the south-west, support a remarkable diversity of wetland plants, including a relatively large proportion

Sedge: tufted or spreading plant from the families Cyperaceae, Centrolepidaceae, Hydatellaceae, Juncaginaceae Restionaceae, Juncaceae, Typhaceae and Xyridaceae. In these plants the leaf sheath generally not split, there is usually no ligule, the leaf is not always flat and there is an extended internode below inflorescence. Some sedges are also known as rushes.

Obligate wetland plants: plants that are generally restricted to wetlands under natural conditions in a given setting

Facultative plants: plants that can occur in both wetlands and dryland in a given setting of locally and regionally **endemic** species. This is in keeping with the large proportion of endemic species in Australian ecosystems more generally, due partly to the continent's long geographic isolation.

It has been often reported that Australian freshwater wetlands display remarkably low levels of endemism, with many genera and some species being almost **cosmopolitan** (for example, Commonwealth of Australia[7]). There are many wetland flora which have a cosmopolitan distribution, occurring in wetlands worldwide. This is primarily because of the worldwide migration of waterbirds, carrying seeds and other propagules between habitats with similar environmental conditions. In WA these genera are more prevalent in large, permanently inundated wetlands (lakes). These wetland ecosystems often do not support such high levels of endemism as their dryland counterparts. However, in the broader context of all wetland types in WA, generalisations regarding endemism are inaccurate. For example, high levels of local and regional flora endemism are found in nearly all **perched** wetlands in the south-west, regardless of substrate (granite, clay, ironstone). The south-west is the world centre of diversity for a range of wetland-centred groups including the families Droseraceae, Restionaceae, Juncaginaceae, Centrolepidaceae[8] and Hydatellaceae and the samphire genus *Tecticornia*.[2]

Endemic: naturally occurring only in a restricted geographic area

Cosmopolitan: can be found almost anywhere in the world

Perched: not connected to groundwater

Vascular plants: plants with defined tubular transport systems. Non-vascular 'plants' include algae, liverworts and mosses.

New discoveries are still common across WA, in both remote and populated areas. The Southern Swan Coastal Plain Survey (1992–1994) alone resulted in ten plants new to science being recognised in the wetlands of the Pinjarra Plain east of Perth[9], including the swamp devil (*Eryngium pinnatifidum* subsp. *palustre*) (Figure 3). A range of wetland weeds also occur in WA.

Figure 3. The swamp devil (*Eryngium pinnatifidum* subsp. *palustre*) is one of ten plants new to science identified in a single study of the Pinjarra Plain east of Perth. Photo – B Keighery/OEPA. Images used with the permission of the Western Australian Herbarium, DEC. Accessed 21/06/2011.

A relatively large proportion of wetland plants are of conservation significance. Forty-six of the 402 declared rare flora in WA occur in wetlands, while 270 of the 2,704 priority species occur in wetlands.[2] Significantly, thirty-seven of Western Australia's sixty-nine threatened ecological communities are wetland communities; of these thirty-three are defined or reliant on **vascular plant** taxa.[2]

It is thought that the earliest vascular land plants on Earth were wetland plants, growing on the water's edge, some 410 million years ago.[10] Primitive flowering plants such as waterlilies are found in the Kimberley, and researchers have recently used DNA studies to discover that tiny wetland plants found in southern Western Australia—members of the Centrolepidaceae, Hydatellaceae and Juncaginaceae families—also have an ancient lineage, stemming from the time when Australia was part of the supercontinent Gondwana. They are thought to have some characteristics similar to those of waterlilies and conifers.[11]

A licence to take samples

Picking or harvesting of native plants on crown land in Western Australia is illegal unless authorised. This applies to conservation-related activities such as taking flora for the purposes of identification or inclusion in a herbarium. People who wish to take flora for scientific study, education, hobby, propagation or other non-commercial purposes must hold a Scientific or Other Prescribed Purposes Licence. Flora that is declared rare cannot be taken without written consent of the Minister for the Environment. For more information, see the flora licensing webpage on DEC's website.[12]

Rhizome: a horizontal, underground stem which bears roots and leaves and can usually persist, even if above-ground parts die back

The role of wetland plants

Providing food

Being an abundant resource in most wetlands, it is reasonable to assume that vascular wetland plants are an important food source. Yet although they do provide food for other organisms, their relative importance as a food source in wetlands is still the subject of research and debate, much of it based on studies conducted in the northern hemisphere.

Different plants and plant parts provide different resources. Many waterbirds in particular feed on grasses, the **rhizomes** of sedges and leaves of submerged plants (Figure 4). Kangaroos and wallabies enjoy grasses, shrubs and herbs, and while rakali are predominantly carnivorous, they also feed upon plant material. Pollen and nectar produced by a range of wetland plants is a food resource for a number of animals. For example, *Melaleuca* and *Barringtonia* species in north-western WA provide sustenance for the northern blossom bat *Macroglossus minimus*, which is a major pollinator of a number of plant species including within its range. Dead, submerged wood is of low nutritional value and is only eaten by a few specialised invertebrates. However, it tends to be coated by microorganisms including algae, bacteria, fungi and protozoans, which are a rich food source for invertebrates (small animals).[13]

Figure 4. Waterbirds such as Eurasian coots (*Fulica atra*) consume wetland plants. Photo – © W Eddy.

Some researchers propose that the consumption of living wetland plants is on par with that of terrestrial plants (such as Wetzel[14]). However, some attribute the majority of this consumption to terrestrial insects[15], concluding that vascular wetland plants contribute little to the food webs of many wetlands (although, in turn, it should be noted that fish of south-west WA have a higher reliance on terrestrial insects than fish of other regions of Australia[16]). Sophisticated analysis techniques, such as stable isotope analysis, appear to support the theory that wetland plants contribute little to the food webs of many wetlands. The reason put forward for the apparent lack of consumption of what can be a very abundant resource in wetlands is that many vascular wetland plants are too tough (due to **lignin**) or unpalatable (due to antiseptic **tannins**) for many wetland animals to consume (for example, Boulton and Brock[17], Chambers et al.[18]). In Australian wetlands, this is generally thought to be the case for fish, frogs, reptiles and mammals[19], with some invertebrates and waterbirds thought to be the main exceptions.[17],[19] High lignin content and polyphenolic concentration are common adaptations of plants in acidic, nutrient poor environments[13], such as many WA wetlands.

Many factors make this a complex field of study. In addition, studies differ as to whether they take into account only submerged plants or a broader range of wetland plants. Some differences are also attributable to regional variations in ecosystems. For example, in the northern hemisphere nutria (or coypu), muskrats, snow geese, voles, boars, capybaras, and some fish can consume significant amounts of wetland plants[14,20] and freezing of dead plant tissue during winter can break down tough plant cell walls and encourage herbivory.[13]

Species introduced to WA (weeds) vary in their palatability. *Typha orientalis* leaves are higher in structural carbohydrates than some other common wetland plants, making them particularly fibrous and not very palatable. Herbivory by invertebrates is said to be virtually unknown, although kangaroos do eat young shoots. In contrast, leaves from introduced **deciduous** species are soft and tend to easily decompose (Figure 5).[21]

Figure 5. Leaves of deciduous species tend to be softer and decompose easily. Photo – J Lawn.

Wetland plants are, indirectly, an important source of food once dead, as **detritus**[22,13], at which point they are consumed by detrital feeders such as midge (chironomid) larvae, crustaceans (ostracods, amphipods and isopods), worms (oligochaetes) and insects such as mayflies and caddisflies[18] and assimilated by fungi and bacteria. Some scientists take

Lignin: a material (a complex organic polymer) deposited in the cell walls of many plants, making them rigid and woody

Tannins: complex organic compounds (polyphenols) occurring in various plants

Deciduous: a plant that sheds its leaves annually

Detritus: organic material originating from living, or once living sources including plants, animals, fungi, algae and bacteria. This includes dead organisms, dead parts of organisms (e.g. leaves), exuded and excreted substances and products of feeding.

an alternative point of view, citing studies that provide little evidence that wetlands plants contribute significantly to aquatic food webs, either directly or indirectly.[17,15] A common view point is that the evidence to date indicates that algae serve as the primary base of wetland food webs, with a few exceptions such as heavily shaded forested wetlands.[15]

Providing habitat

Wetland plants are the dominant structure in many wetlands, and along with soil, sediment and the water column (if present), their surfaces, structures and microclimates create habitats for other organisms, both when alive and dead. For example:

- Wetland plants play a critical role in sheltering the adults, larvae and nymphs of wetland animals from predators. For example, dense understorey provides quenda with safe foraging and burrowing habitat; surface and partly submerged vegetation including hollow logs provide protection, feeding platforms, nesting areas and nesting material for rakali; vegetation and litter are important for reptiles, including lizards, snakes and nesting turtles; and submerged and emergent plant beds harbour very small aquatic animals and the larvae of a range of native fish from predators.
- Birds and bats roost and nest in wetland vegetation, including trees and tree hollows, shrubs, sedges and grass, and many birds use plant materials to form nests on the ground (Figure 6), in vegetation, or floating or anchored in water. Trees in water can provide bird chicks with refuge from foxes, cats and native predators.
- Microalgae, bacteria, fungi and very small animals live on plants and dead plant material such as logs, and sponges grow on submerged logs. These organisms play a very important role in wetlands and so, by extension, wetland plants are a critical part of most wetland ecosystems.
- Some frogs and many insects lay their eggs on submerged and emergent wetland vegetation (Figure 7).
- The larvae of aquatic weevils (a type of beetle) live on the inside of, and feed on, the air-filled stems of sedges.
- Some caddisfly larvae species (an important food source for fish) live in water, but build protective cases formed from plant material and spun with silk, which they live in until they change into adults.
- Many sediment-dwelling species can only live in the sediment within the rhizosphere, the area around the roots of plants that leak oxygen into sediment, making it habitable.

Figure 6. A red-necked avocet nest constructed from woody material. Photo – DEC.

Figure 7. The pupa case of a praying mantid constructed on a wetland plant at Lightning Swamp in the Perth suburb of Noranda. Photo – J. Lawn.

Figure 8. Wetland plants help to camouflage and stabilise this entrance. Photo – DEC.

Turbid: the cloudy appearance of water due to suspended material

Turbidity: the extent to which light is scattered and reflected by particles suspended or dissolved in the water column

Sediment pore water: water present in the spaces between wetland sediment grains at or just below the sediment surface. Also called interstitial waters.

Inorganic: compounds that are not organic (broadly, compounds that do not contain carbon)

Stabilising sediment

Wetland plants stabilise sediments by binding them with their roots. By creating areas of slow moving or still water where sediments drop out of the water column, plants help to maintain a wetland's shape and flow paths and reduce **turbid** conditions in wetland waters.

Rain, stormwater, channelised flows and wave energy erodes sediments in areas around wetlands as well as in wetlands themselves. Wetland plants moderate this. For example, powerful rainfall events can erode soil. Plant leaves intercept raindrops and reduce their erosive power, while roots and fallen plant litter bind soil, reducing the rate of erosion. Similarly, wave energy is baffled by plants. This is evident in wetlands with a body of water fringed by plants, where the plants along the water's margin considerably reduce wave power. The plants, particularly sedges, allow water to pass through them but water is slowed, energy dissipated and suspended particles in the water lose energy and drop, depositing sediment and organic matter in the substrate amongst the plants. By preventing erosion and settling out incoming material, intact vegetation reduces **turbidity** in wetland waters[18] and helps to build wetland sediments.

Moderating nutrient levels

Nutrients are needed by all living things. A reduction or increase in nutrients outside of the natural range of a wetland can disadvantage some species and favour others. Up to a certain point, plants help to moderate nutrient levels within wetlands. However if nutrient levels increase too much, many plants will also be disadvantaged by the altered nutrient regime. Algae tend to be favoured by these conditions and may out-compete plants, which may ultimately be lost from a wetland (for more information see the section 'Alternate stable states' in Part 2 of this topic).

Wetland plants tend to get most of their nitrogen and phosphorus, two key nutrients, from **sediment pore water** (also known as interstitial waters) rather than the water column. The concentration of nutrients in sediments is often much greater than that of the water column. Most aquatic plants have root 'hairs' or lateral root projections that increase their ability to take up nutrients from the sediment pore water.[14] Plants are able to take up nutrients if they are in an **inorganic** form that plants can use, known as '**bioavailable**' forms (under some circumstances they may be able to take up organic forms). When plants are consumed or decomposed, these nutrients are transferred to animals and other organisms. This allows a proportion of nutrients to cycle through wetlands instead of it all being locked away in the sediment.

Under low nutrient conditions, many wetland plant species form mutually beneficial relationships with fungi (known as mycorrhizae, described further in the 'Fungi' section) to enhance their growth.

On the other hand, in high nutrient conditions, some plants such as sedges and some submerged plants can act as nutrient 'sponges'. When nutrient availability is high, they are capable of taking up more nutrients than they need for current growth and storing them for future growth. The name of this process is '**luxury uptake**' (or luxury consumption). This is why harvesting sedge leaves is sometimes proposed as a way to remove excess nutrients from a wetland. They can also internally recycle nutrients by withdrawing them from senescing leaves and stems for use in new growth.[23] This recycling ability also allows them to survive in naturally low nutrient level conditions. Trees provide long-term storage of nutrients while herbs have shorter life cycles and their nutrients are returned to the system more rapidly.

Organisms living in the oxygenated root zones (the rhizosphere) of stands of sedges also take up nutrients, further increasing the nutrient buffering occurring in wetlands. Within these oxygenated pockets nutrient binding with iron or organic complexes in the sediment also occurs. This moderates **eutrophication**. In this way, healthy stands of sedges can help to reduce potentially harmful algal blooms.[18]

Some plants, such as duckweed (*Lemna*) absorb nutrients directly from the water via pendulant (suspended) roots. By shading the water column, they inhabit the growth of algae and submerged aquatic plants.

Building sediment

Plants help to build up the organic material of wetland sediments. As noted above, not all plant material within a wetland is consumed. A proportion falls to the wetland floor and is neither consumed nor fully decomposed. In wetlands that dry, most of this material will get consumed, but in permanently inundated wetlands the build up of wetland plant material over time can result in the development of sediment with high levels of organic matter, and ultimately the development of **peat** (the reason for this is outlined in the 'Bacteria' section).

The introduced species *Typha orientalis*, for example, will initially be rapidly decomposed, but the remaining leaf material can take up to eight years to completely break down.[21]

The sediment is habitat for a range of wetland species, and its composition (particularly the organic/mineral fraction) has a bearing on what species inhabit it and its water-holding capacity. Importantly, the sediment is also where many chemical reactions occur which govern nutrient and carbon cycles in wetlands, and the composition of the sediment strongly influences these reactions.

Influencing wetland hydrology

Wetland vegetation, like dryland vegetation, uses water and loses it to the atmosphere by the process of **transpiration**, leading to the loss of water from wetlands. The water lost to the atmosphere by emergent and floating wetland plants is reported to be greater than evaporation from an equivalent area of water.[14] On the other hand, dense growth of wetland plants can block flow paths, retaining more water in wetlands. Similarly shading of water can reduce the evaporation rate in a wetland.

Bioavailable: in a chemical form that can be used by organisms

Eutrophication: the nutrient enrichment of a water body, which can trigger prolific growth of plants, algae and cyanobacteria. May occur naturally over geologic time or may be human-induced

Peat: partially decayed organic matter, mainly of plant origin

Transpiration: the process in which water is absorbed by the root systems of plants, moves up through the plant, passes through pores (stomata) in the leaves and other plant parts, and then evaporates into the atmosphere as water vapour

Moderating light and temperature

The presence of wetland vegetation also moderates light and temperature. Some wetlands naturally have tea-coloured water due to staining with tannin, a dark-coloured chemical produced by plants. This tannin staining limits the amount of light that penetrates the water column, which in turn limits the activity of organisms in the water that need light in order to photosynthesise (such as submerged plants, cyanobacteria and algae) or to fix nitrogen (such as cyanobacteria). In this way, tannin staining is thought to play a role in keeping harmful algal and cyanobacterial blooms at bay, and in turn, moderating the populations of organisms that consume algae, such as midges and mosquitoes. Shading from vegetation also keeps wetland waters cool, and may contribute to controlling the populations of species which proliferate in warmer waters, such as some species of nuisance midges.[24]

Providing oxygen

One of the biggest challenges for organisms in wetlands is that oxygen can be limited in water. This affects organisms that inhabit waterlogged soil or water columns. While plants can help by generating oxygen during the day via the process of **photosynthesis**, they also use oxygen at night to **respire**.

Some wetland plants can store oxygen from photosynthesis in specialised air-filled spaces called **aerenchyma**. This allows them to pass oxygen from above-ground parts to their roots to allow them to live and grow. Some of the air leaks out of the roots into the surrounding soil, which is known as the **rhizosphere**, creating an oxygen-rich environment in the substrate. This creates an environment suitable for organisms that could not otherwise survive there[18], supporting high levels of microbial activity and facilitating many important chemical reactions.

Moderating toxic compounds

Wetland plants can reduce the levels of compounds such as ammonia and nitrite. In high concentrations ammonia is toxic to some animals including fish and frogs. Some plants can remove some metals in dissolved forms from the water column.[19]

Sources of information on wetland plants

- For detailed information on the state's wetland plants, and how to identify them, see the topic 'Wetland vegetation and flora' in Chapter 2.
- For information on the state's wetland weeds and how to control them, see the topic 'Wetland weeds' in Chapter 3.
- For information on how to revegetate wetlands, see the topic 'Managing wetland vegetation' in Chapter 3.
- For information on how to survey or monitor wetland vegetation, see 'Monitoring wetlands' in Chapter 4.

Photosynthesis: the process in which plants and some other organisms such as certain bacteria and algae capture energy from the sun and turn it into chemical energy in the form of carbohydrates. The process uses up carbon dioxide and water and produces oxygen.

Respiration: the process in which oxygen is taken up by a plant, animal or microbe, and carbon dioxide is released

Aerenchyma: interconnected air-filled spaces within plant tissue that transport air from plant parts above the water or saturated soils to the roots

Rhizosphere: the area of soil immediately surrounding plant roots, which is altered by their growth, respiration, exchange of nutrients etc

Wetland algae

Without algae, all freshwater bodies would be effectively dead.[25] Yet, as leading Australian algae researchers put it, 'algae have an image problem'.[26] Despite being a very important and dominant component of most wetland ecosystems, **algae** in wetlands are widely perceived as purely problem species.

Algae: a general term referring to the mostly photosynthetic, unicellular or simply constructed, non-vascular, plant-like organisms that are usually aquatic and reproduce without antheridia and oogonia that are jacketed by sterile cells derived from the reproductive cell primordium. It includes a number of divisions, many of which are only remotely related to one another[30]

While algae are found in virtually all habitats, the marine algae known as seaweed are probably the most well-known. Although all of WA's wetlands typically contain algae[27], it is a small number of problem species that tend to be the most well studied. There are approximately 2,800 species (and another 1,300 subspecies) of non-marine algae in Australia[28]; at least 12,000 marine, freshwater and terrestrial species in Australia, and world wide 27,000 species of algae are described.[25] Like vascular plants, there are some species that are widespread, and a large number that are restricted in their distribution and their habitat requirements. Knowledge of the taxonomy, ecology and distribution of most algae groups in Western Australia is still rudimentary. In particular, the north-west of the state is inadequately surveyed.[28] While studies confirm that a variety of algal species occur even in central Australia[29], the reality in Australia is that algal habitat is being destroyed or altered at a far greater rate than species are being discovered.[25] The *Wildlife Conservation Act 1950* allows for algae to be listed as rare, but the lack of comprehensive distributional data presents an impediment. Like vascular plant weeds, introduced algae can alter the ecology of a wetland. This is an important consideration in the developing industry of commercial algal production for biofuels, carotenoids, lipids, fatty acids, pharmaceuticals and pelletised stock fodder.

Algae vary significantly in size. **Macroalgae** is the term applied to multicellular algae that are individually visible to the unaided eye. **Microalgae** refer to single-celled algae visible under a microscope. 'Alga' is singular and 'algae' is plural.

extra information

Algae: more like friends than family

Algae are organisms that share a number of traits: most photosynthesise; have relatively simple physical structure, unlike vascular plants; and have similar reproductive characteristics. But despite these similarities, algae did not evolve from a common ancestor (unlike flowering plants, for example), instead deriving from a number of ancestral lineages, meaning many groups of algae are not closely related to one another.[30]

Some groups are thought to be related to vascular plants, in particular red and green algae, and are classified as belonging to the plant kingdom, and this is consistent with the traditional view of algae. On the other hand, many algae have traits that are traditionally considered characteristic of animals, such as being capable of motion (that is, they are **motile**). Dinoflagellates and euglenoids are two groups of algae that use whip-like appendages called flagella for locomotion (they are assigned to the protozoa kingdom).

Because the term algae relates to an artificial cluster of unrelated or distantly related groups of organisms[30], when reading literature it is important to understand which organisms are considered to be 'algae' for the purpose of that document. For example, cyanobacteria were previously known as 'blue-green algae', and because they function in a similar way to other organisms described

extra information

Algae: more like friends than family (cont'd)

as algae, they may be listed as either or both bacteria or algae in texts, scientific articles and studies. Similarly, dinoflagellates (Dinophyta) are treated as algae by some and not by others. Table 1 shows examples of groups that are treated as algae for the purposes of this publication.

Table 1: Examples of algae found in different kingdoms (source: adapted from DEC[31])

Kingdom of life	Groups within kingdoms, with algae in italics
Animals	Animals.
Plants	Angiosperms, conifers and cycads, ferns and fern allies, mosses, liverworts, hornworts, *green algae, red algae, glaucophytes*.
Chromista	*Diatoms, brown algae*
Protozoa	*Dinoflagellates*, excavata (*euglenoids*), rhizaria, amoeba, slime moulds.
Fungi	Fungi and lichen.
Bacteria	Cyanobacteria, archaea, bacteria.

Algae inhabit both inundated and waterlogged wetlands, with many species inhabiting saturated soils of waterlogged wetlands. Many species live in wetlands that are subject to periods of drying, by forming spores that can survive in dry conditions. This allows them to quickly recolonise a wetland upon wetting. Others rely on air, water or animals (for example, birds) to transfer **spores** from permanently inundated wetlands to those wetlands that dry out. Algae can be found free-floating in the water column (**phytoplankton**) and, typically to a much greater extent[14], attached to surfaces (collectively known as **periphyton**) including the surface layers of sediments (**benthos**) and to plants (**epiphyton**). Some single-celled algae form **colonies**. Species composition and abundance in a wetland is influenced by a wide range of factors including water regime, nutrient regime, salinity and pH, and seasonal trends are often observable.[14,32] Some species inhabit freshwater wetlands, others saline wetlands, while other algal species can tolerate fluctuating salinities.[33] Coloured wetlands tend to be **desmid**-rich habitats[25] and most types of green algae are not common in saline wetlands.[32]

Like plants, algae are able to photosynthesise, but they can get the nutrients they need directly from the water column.[34] Because they produce energy from this process they are a nutritious food source for many other wetland species[15], both when alive and following their death, and are referred to as **primary producers**. Their role as producers is critically important in wetland ecosystems, particularly the productive and palatable periphytic and planktonic algae, while floating beds of filamentous green macroalgae called metaphyton are thought to be less important.[15] Most frog larvae are considered to feed on algae (algivores).[15] Other algivores include bacteria, microcrustaceans and rotifers.

In addition to being important primary producers, algae can significantly influence the physical conditions in wetlands; even microalgae are a force to be reckoned with in sufficient numbers. When conditions are right, including sufficient sunlight and nutrients,

Spore: a reproductive structure that is adapted for dispersal and surviving for extended periods of time in unfavourable conditions

Phytoplankton: aquatic organisms that photosynthesise and which float or are suspended in water, drifting with water movements and generally having minimal ability to control their location, such as algae

Plankton: aquatic organisms floating or suspended in the water that drift with water movements, generally having minimal ability to control their location, such as phytoplankton (photosynthetic plankton including algae and cyanobacteria) and zooplankton (animals)

Periphyton: organisms such as bacteria, fungi, algae and invertebrates that are attached to underwater surfaces including sediment, rocks, logs and plants

Benthic: the substrate of a wetland; the organisms inhabiting it are known as benthos

Epiphyton: organisms such as bacteria, algae and plants that grow attached to plants

Colony (algal): a closely associated cluster of cells, joined together or enclosed within a common sheath or mucilage.[26] A colony may incorporate thousands of cells.[17]

Desmid: a member of the Desmidialies (Zygnemophyceae) within the Division Chlorophyta (green algae)

Primary producers: organisms which produce food (by photosynthesis or chemosynthesis) rapid and excessive growth of algae can lead to densities sufficient to be identified as an **algal bloom** (the density of algae required to be identified as a bloom is outlined in *Algal blooms*[35]). The natural balance of life in the wetland can be significantly affected. For example, blooms can shade submerged plants and populations of other algae species to the extent that they cannot get enough sunlight to photosynthesise, and they can weaken and die. Algal blooms can also shade out threatened benthic microbial communities, with catastrophic consequences (see 'Bacteria' for more information). They can also favour algae consumers, such as the crustacean *Daphnia*, which increase in population in response to greater food resources. Some algal species are toxic and can be harmful to people and animals to come into contact with or to ingest, either directly or via the consumption of shellfish or fish. For example, about thirty species of dinoflagellates produce powerful nerve toxins (neurotoxins). However reports of toxic algae are almost exclusively cyanobacteria, commonly called blue-green algae. These organisms are a special group of bacteria (division Cyanophyta), discussed in the 'Bacteria' section later in this topic.

When conditions become unsuitable for the algae (for example, once they consume all of the nutrients in the water column), the algal blooms collapse and the decomposition process depletes the water column of oxygen. This can lead to many changes in a wetland ranging from noxious smells (due to the proliferation of certain bacteria) to the death of fish and other organisms from a lack of oxygen, to **botulism** in birds. Crusting of algae on the surface of lake beds and seedlings can also inhibit plant germination by smothering emerging seedlings. This occurred at Lake Toolibin between 1986 and1992, contributing to the death of *Casuarina obesa* seedlings.[36] Yet not all blooms are bad: for some species a bloom may, in fact, be a part of its natural cycle[37] (in fact, Captain Cook recorded an algal bloom in 1770![35]), and may not impact upon a wetland system to the extent described above. The distinction is that human activities are increasing the frequency, duration and magnitude of algal blooms.[38] Some wetlands, such as Yangebup Lake in Perth's southern suburbs, are now afflicted by algal blooms almost year-round.[39] The excellent local guide, *Scum book*[37], identifies common 'blooming' species as well as those that are typically only found in patches in undisturbed wetlands. Blooms typically comprise only one or two species.

➤ For additional detail on the prevention and management of algal blooms, see the topic 'Water quality' in Chapter 3.

➤ For more information on botulism, see the topic 'Water quality' in Chapter 3.

Macroalgae

Some types of macroalgae form mats of long, green, multi-celled thread or strands known as **filaments** that may be attached to sediment, plants and other surfaces, in the water column and at the water's surface (Figure 9). Filamentous algae that occur in Western Australian wetlands include the red algae *Compsogon* and green algae including *Spirogyra, Enteromorpha, Cladophora, Zygnema, Mougeotia, Oedogonium, Sirogonium*. Many filamentous algae bloom in nutrient-enriched waters, but there are notable exceptions including *Zygnema, Mougeotia* and *Oedogonium*.[37]

The main type of macroalgae attached to wetland sediments are the **charophytes**, a group of green algae of the Characeae family.[17] The charophytes, chiefly the genera *Chara, Nitella* and *Lamprothamnium* are very beneficial to wetlands (outlined under the heading 'The role of charophytes'). Superficially they look more like submerged flowering plants (such as some species of *Myriophyllum*), with stem-like and leaf-like parts, than other types of algae (Figure 10). Charophytes are amongst the most complex of algae; they are, in fact, close relatives of vascular plants. In many text books and studies they are grouped with submerged plants, often included in the term 'submerged macrophytes'.

Algal bloom: the rapid, excessive growth of algae, generally caused by high nutrient levels and favourable conditions

Botulism: a paralytic disease caused by ingestion or exposure to a toxin produced by the bacterium *Clostridium botulinum*

Filament: cells in a linear series, usually abutting one another, creating threads or strands

Charophytes: green algae of the Characeae family; complex algae that superficially look like submerged flowering plants

Figure 9. Algae at Lake Goollelal, Kingsley, in Perth's northern suburbs.

Annual: a plant that completes its life cycle within a single growing season (from germination to flowering, seed production and death of vegetative parts)

Perennial: a plant that normally completes its life cycle in two or more growing seasons (from germination to flowering, seed production and death of vegetative parts)

Precipitate: cause a substance to be deposited in solid form from a solution

Stonewort: a term applied to *Chara* species that precipitate and deposit calcium carbonate on their surfaces

Marl: fine-grained calcareous material (often the biologically-precipitated calcium carbonate remains of charophyte algae)[17]

Species richness: the total number of species (in a defined area)

They occur in a wide range of intermittently, seasonally and permanently inundated wetlands including those with fresh, brackish, saline and turbid water, and across a broad phosphorous regime.[33] Charophytes include both **annuals** and **perennials**. Chara is typically found in alkaline wetlands while *Nitella* is typically found in wetlands with mildly acidic conditions, although there are exceptions[40], while *Lamprothamnium* is found in brackish to saline waters.[41] Although many charophytes are considered cosmopolitan species, current research indicates there are many endemic species in Australia, for example, Australia is home to a large number of endemic species of *Nitella*.[42] Although charophytes need free water for phases of their life, the spores of charophytes can be found in dry wetlands, surviving for many years until the right conditions for germination occur. Charophytes have root-like structures known as 'rhizoids' but are able to absorb nutrients such as phosphorous equally from all parts of the plant.[14]

Figure 10. ***Chara*** species can look similar to many aquatic plants. Photo – J Chambers/ Murdoch University.

Some *Chara* **precipitate** calcium carbonate ($CaCO_3$) from wetland water and deposit it onto their surfaces, becoming encrusted with it to the extent that they are known as **stoneworts** and when they die, a plant-like stone may remain, or it may desiccate to create a 'carpet fibre' look. The precipitate contributes to wetland sediment. In some wetlands, it creates marl[17], a material often mined from wetlands.

Macroalgae are thought to absorb nutrients through their foliage rather than from their rhizoidal (root-like) structures.[14]

In *Algae of Australia: Introduction*[33], it is reported that the few studies of macroalgal **species richness** in Australian wetlands suggest that, similarly to vascular wetland vegetation patterns, wetlands that are not permanently inundated tend to have a higher macroalgal species richness. Wetlands that experience perturbations in water quantity (for example, drought and inundation) on an intermediate scale can be expected to have a higher diversity than wetlands that are not subject to these events.

Diatomite, diatomaceous earth: siliceous deposits made up of the sedimentary build up of diatom shells (frustules)30

Microalgae

Microalgae are tiny single-celled organisms, and a microscope is needed to see individuals. However when they occur in high concentrations in the water column or form a scum on a wetland's surface they can be very visible! Single-celled (or unicellular) algae are extremely simple life forms. Cells are the basic unit of life; the smallest unit of life to be classified as a living thing. Yet microalgae are vitally important food sources in wetlands. The concentration of microalgae in a water column is often gauged by measuring the concentration of chlorophyll *a.* Chlorophyll *a* is a green pigment used by plants, algae and cyanobacteria to photosynthesise.

➤ For more information on measuring the concentration of microalgae, see 'Wetland monitoring' in Chapter 4.

There is a diverse range of microscopic algae in wetlands. Microalgae include green algae (Chlorophyta), diatoms (Bacillariophyta), euglenoids or flagellates (Euglenophyta), cryptophytes (Chryptophyta), dinoflagellates (Dinophyta) and golden algae (Chrysophyta).[30,17,37,43] They may be planktonic, benthic or periphytic. Different conditions favour different species.

Periphytic microalgae tend to live in close association with bacteria, with each supplying the other with compounds needed for survival. Microalgae are also important components of benthic microbial communities. Bacteria, algae and other organisms, collectively make up these communities. They are responsible for creating structures such as living mats known as benthic mats or microbial mats, and fascinating 'living rocks' known variously as microbialites, stromatolites and thrombolites. These are described in more detail under the heading 'Bacteria'.

Diatoms are a group of single-celled algae with intricately patterned glass-like cell walls made of silica, belonging to the class Bacillariophyceae (Figure 11). Wetland diatoms have a marine ancestry. Diatoms are typically present in WA's wetlands, and they are thought to be very similar to in the eastern states[44] and elsewhere in the world. They form the majority of free-floating algae (phytoplankton) in wetlands[45] but are also commonly attached to sediment and plant surfaces. There is evidence that land uses that influence pH, salinity and phosphorus levels are a determinant of which diatom communities will be present in a wetland. However even hypersaline, acidic Wheatbelt wetlands have been found to support tolerant diatom species such as *Navicula minuscula* var. *muralis* and *Pinnularia divergentissa* var. *subrostrata*.[44] When diatoms die, their siliceous cases are deposited on the sediment and build up, sometimes forming **diatomaceous earth** (also known as **diatomite**). Over time these individual skeletons can deposit in such volumes that they form vast layers, as has occurred at Lake Gnangara north of Perth. Diatomaceous earth has many commercial uses including abrasives, polishes and even in toothpaste. Large deposits are often mined, as was the case at Lake Gnangara in the 1940s, where several hundred tonnes was dredged.[45] Due to the persistence of diatomite in wetlands over extremely long time periods, it is often used by researchers (palaeolimnologists) to interpret historic conditions in wetlands and surrounds. At Lake Monger, for example, the marine diatom cells buried deep in the sediment confirm the area was previously under the ocean.[35]

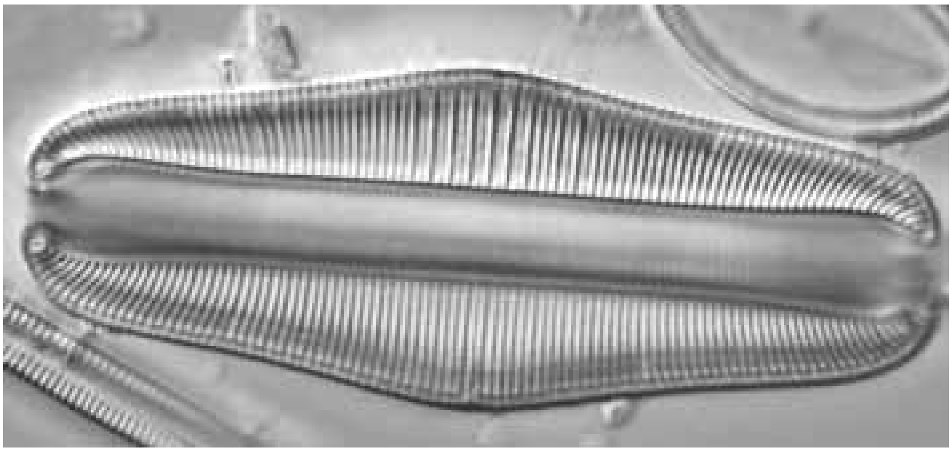

Figure 11. ***Rhopalodia gibba***, a diatom that is common in wetlands. Photo – courtesy of Monash University.

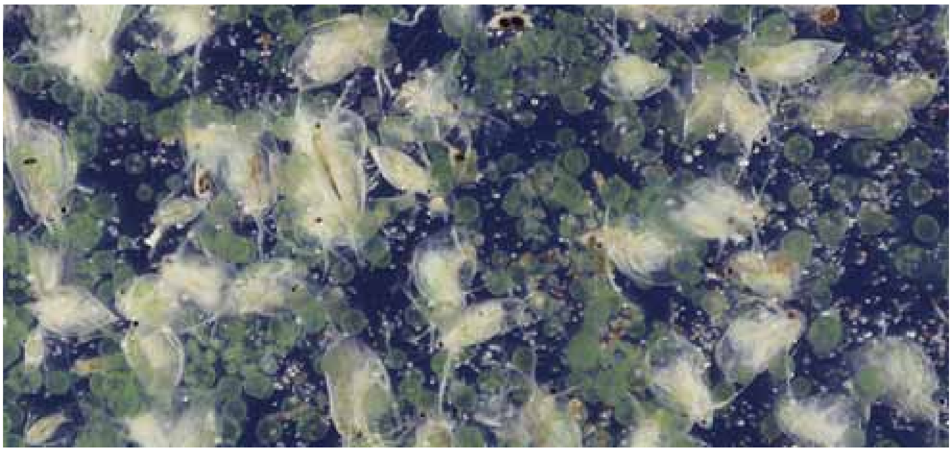

Figure 12. The green alga *Volvox*, with the water flea, *Daphnia*, in a water sample from Jualbup Lake, Shenton Park. Photo – J Davis.

extra information

Didymo: an alarming invasive alga

The freshwater diatom *Didymosphenia geminata,* commonly known as 'didymo' and 'rock snot', is an invasive algae species from the northern hemisphere. It could have devastating effects if it is introduced into Australia because it can completely alter ecosystems. It has been spread to many parts of the world, including New Zealand. It takes only one diatom in a single drop of water for the alga to spread between waterways.[46] The Tasmanian government has adopted the 'check, clean, dry' campaign to educate people to minimise the risk of introducing didymo to Tasmania via fishing gear or other equipment. For more information, or to report possible sightings, contact the Australian Quarantine and Inspection Service.

Pink Lake near Esperance gets its pink waters from *Dunaliella salina*, a green alga that accumulates pigments (carotenoids) that give it a red colour, and when abundant, give water a pink or red colour. *Dunaliella salina* is responsible for most of the primary production in hypersaline environments worldwide.[47] However over the past ten years the wetland's pink colouring has faded. This is due to a number of processes that are changing the water chemistry of the wetland, leading to declining salinity and nutrient enrichment, resulting in changes to the dominance of organisms in the wetland, including a decline in *D. salina*. The Department of Environment and Conservation is working with local landholders to minimise water quality changes in the wetland. A number of other WA wetlands also support considerable densities of *D. salina* including Lake Hillier on Middle Island, on the Recherche Archipelago off the south coast, and Hutt Lagoon, northeast of Port Gregory. In fact, Hutt Lagoon contains the world's largest microalgae production plant, a 250 hectare series of artificial ponds used to farm *Dunaliella salina*. This microalga gives Hutt Lagoon its colouring (Figure 13) and is used to produce beta-carotene, a source of vitamin A used in vitamin supplements, and a food-colouring agent used in products such as margarine, noodles and soft drinks.[10]

Figure 13. The waters of Hutt Lagoon, coloured pink by the alga ***Dunalliela salina***.
Photo – S Kern/DEC.

The role of algae

Algae have a significant role in the functioning and productivity of wetlands.[33]

- Algal photosynthesis a significant source of primary productivity[33], with phytoplankton and periphyton in particular forming the base of many wetland food chains[25], providing a valuable food source for algivores including bacteria and other microbes; and animals such as tadpoles, invertebrates including crustaceans such as cladocerans and copepods, molluscs such as mussels and birds such as black swans (*Cygnus atratus*).
- Both macro and microalgae help to make wetland environments suitable for a range of organisms by adding oxygen to (oxygenating) wetlands by photosynthesis, a process which creates oxygen as a by-product.
- Algae provide habitat, with macroalgal surfaces inhabited by smaller algae and other epiphytic organisms, and providing other organisms with refuge from predators and shade and shelter from unfavourable conditions.
- Diatoms develop diatomaceous wetland soils, which can significantly influence wetland water chemistry and hydrology, and can be used to interpret environmental conditions in much earlier time periods.
- Benthic communities formed between algae, bacteria and other organisms are ecologically significant components of some WA wetlands (outlined in the 'Bacteria' section below).

The role of charophytes

Charophytes are important in wetlands because they:

- are often pioneer colonisers of shallow waters of recently inundated wetlands.[48]
- inhabit niche areas including deeper waters of clear-water lakes that are too dark for flowering plants.
- keep the water clear of sediments by rooting into and stabilising sediment and, in dense populations, creating areas of slow-moving or still water where sediments drop out of the water column (with studies suggesting this function is provided by charophytes even more effectively than plants.[33])
- trap nutrients and minerals in a gelatinous mucilage, removing it from the water column.[37] Their high biomass means that they accumulate and retain large concentrations of nutrients for long periods due to their slow rate of decomposition.[49]
- provide habitat for insects, crustaceans, fish and other animals at various life stages, as well as smaller algae (such as diatoms[50]), especially in saline systems.
- provide an important food source for some invertebrates and birds. *Lamprothamnium* is an important primary producer in saline wetlands. It can grow in water with up to twice the salinity of sea water and is a food source for waterbirds, including black swans.[33] For example, at Lake Pollard south of Mandurah, growth of extensive areas of *Lamprothamnium papulosum* in summer months has been linked to the influx of black swans (*Cygnus atratus*), with numbers of grazing swans as high as 3000 in a single month.[51]
- potentially purify the water column and sediments of heavy metals. Research undertaken in Capel in WA's south-west suggests that some species, such as *Nitella congesta*, hyper-accumulate metals.[52]
- potentially provide an indicator of a wetland's water quality in respect of nutrients, although species may disappear due to other factors such as alteration of wetland water regime.
- develop wetland soils via the precipitation of calcium carbonate, which contributes to wetland sediment. In some wetlands, it creates marl[17], a material often mined from wetlands.
- potentially help to control nuisance insect populations. Several species of *Chara* have been found to have sulphur-releasing compounds that are thought to be harmful to mosquito larvae.[14]

Sources of more information on wetland algae

The following resources provide more information on wetland algae:

- *Scumbook: a guide to common algae and aquatic plants in wetlands and estuaries of south-western Australia*[37]
- *Freshwater algae in Australia: a guide to conspicuous genera*[26]
- *Australian Freshwater Algae*[53] website – provides a key, pictures, census, guides on how to collect and examine freshwater algae, and links to a number of other algae-related websites
- *Algal blooms (Water Facts series)*[35]
- *Waterplants in Australia: A field guide*[40] for information on charophytes

- *Algae of Australia: introduction*[30]
- *A phytoplankton methods manual for Australian freshwaters*[54]
- *Algaebase*[55]
- *Charophytes* journal and website www.charophytes.com

extra information

Identifying algae

The WA Herbarium provides a public reference herbarium, a public access collection of typical specimens of all known vascular plant species in the State. It is used widely by consultants, researchers and the public to help identify wildflowers and other vascular plants. The WA Herbarium and associated regional herbaria do not specialise in the identification of algae (including charophytes) and do not maintain algae collections. Various private industry and university specialists provide identification services, for example, the algae and seagrass research group at Murdoch University. A number of the references cited above provide information on the collection, storage, preservation and identification of algae. A guide to the collection of charophyte specimens for identification purposes is provided by www.charophytes.com.

Bacteria

Although invisible to the unaided eye, bacteria are nutrient recyclers and primary producers vital to wetland function and they are an important part of the food web. They are single-celled microscopic organisms that are neither plants nor animals, and, along with other very small organisms, are often referred to as **microbes**. At 0.3 to 0.6 microns in length[17], powerful microscopes are needed to study bacteria (one micron is one thousandth of a millimetre and the symbol for the unit of measurement is 'µm'). Bacteria are now usually identified using DNA analysis. Bacteria (and viruses) are the most abundant organisms in wetlands and occur in the water column (bacterioplankton), attached to surfaces such as plants, logs and animals (periphyton) and in the sediment (benthos). It was not until the 1970s that new techniques to count bacteria shed light on their abundance.[17] Bacteria can be dispersed by animals such as birds, as well as on winds and via dust storms as 'bioaerosols'.

Some bacteria are able to photosynthesise while others get nutrition from **organic** matter. These bacteria don't ingest food in the way animals do, nor do they have digestive tracts to consume food. Instead, they secrete chemicals to the outside of their cells ('extracellular enzymes') to decompose the adjacent material and break it into smaller materials. They can then transport these smaller materials into the cell and use the carbon and energy they contain. So, rather than eating and digesting food, bacteria are said to 'assimilate' carbon and other nutrients. Similarly, bacteria don't breathe, and don't have lungs or complex respiratory systems. They are so small and consist of only one cell, meaning that gas can diffuse into and out of their bodies.

Bacteria are not unique to wetland environments; they provide nutrient recycling and are a food source in all environments. However, particularly in inundated wetlands, the way in which bacteria overcome the lack of oxygen has a defining role in how wetlands function. Many do not require oxygen to survive, allowing them to inhabit **anoxic** (oxygen-poor) conditions in all areas of the wetland, but particularly the sediment. These are often called '**anaerobic** bacteria' and rather than using oxygen, they are capable of

Microbe: an organism that can be seen only with the help of a microscope for example, bacteria, some algae (also referred to as microorganisms)

Organic: compounds containing carbon and chiefly or ultimately of biological origin

Anoxic: deficiency or absence of oxygen

Anaerobic: without air (organisms that live in these conditions are anaerobes)

anaerobic respiration. **Aerobic** bacteria are also plentiful, floating in water and present in the **biofilm** found on all underwater surfaces: in or on wetland sediment and its rhizosphere, or on surfaces such as rocks and vegetation.[17] Some bacteria are also able to inhabit extreme environments, including extremely saline conditions (halobacteria), extremely high temperatures (thermophiles) and extremely acidic conditions (acidophiles).

Oxygen is required by the majority of living organisms. Bacteria that do not require oxygen instead use other materials in order to extract what they need from organic matter. These materials include metals in the case of iron-reducing and manganese-reducing bacteria, nitrate in the case of denitrifiers, and sulfate in the case of sulfate-reducing bacteria.[22] The conditions in a wetland will dictate which type of bacteria will predominate. Some, such as denitrifying bacteria, preferentially use oxygen when it is available then switch to nitrate when it is not. Methanogens are those bacteria present in anaerobic zones of freshwater wetlands that are responsible for breaking down organic matter that remains once other bacteria have extracted what they can from it. They are known as such because they produce methane (not to be confused with methanotrophs, which use methane). In saline wetlands, where sulfate is more abundant, sulfate-reducing bacteria are much more abundant than methanogens. When these bacteria are very active, they can be noticeable, especially when the sediment is disturbed, because their activity produces hydrogen sulfide (a gas also emitted by rotten eggs) giving off a characteristic odour.

This diverse use and manipulation of chemical compounds in wetlands means that bacteria have significant ecological roles, distinct from that of plants, animals, algae and fungi. Although microscopic, the cumulative effect of a population of bacteria in a wetland can have a significant effect on the chemical conditions in the wetland, which in turn affects all other organisms inhabiting it.

Bacteria populations can fluctuate in wetlands that wet and dry. Anaerobic bacteria such as sulphate-reducing bacteria and methanogens die when exposed to oxygen[22]; in wetlands that follow a wetting and drying pattern a large proportion of these bacteria die during the drying phase.[56] However, in wetlands that are only inundated seasonally or intermittently, deeper sediments may still remain anoxic for long periods and thus support anaerobic bacteria.

One particular bacterium, *Clostridium botulinum*, produces a potent nerve toxin that, if ingested or wounds are exposed to it, can make birds and mammals including humans very sick, and can be fatal. This form of bacterial poisoning is known as botulism, and more specifically avian botulism in bird populations. One outbreak at Toolibin Lake in 1993 caused the death of 450 birds.[57] Inhabiting soil and sediments, it can occur throughout WA at any time of the year. Temperature, oxygen and a suitable energy source are thought to be the factors that determine whether an outbreak of *C. botulinum* will occur. In wetlands, warm weather and anoxic conditions are optimal conditions for an outbreak. This is why avian botulism is commonly associated with algal or cyanobacterial blooms. The spores of *C. botulinum* can lie dormant for many years, germinating and multiplying when conditions are right.[58] Sick native birds should be reported to the Wildcare Helpline on 08 9474 9055, which operates 24 hours a day.

➤ For more information on botulism, refer to the topic 'Water quality' in Chapter 3.

Cyanobacteria

Cyanobacteria is one of the groups of bacteria (specifically, a phylum) that, like plants, are able to photosynthesise. They are a large and varied group of bacteria that were formerly known as **blue-green algae**. Cyanobacteria are an ancient form of life, at least three billion years old, and are thought to have been the first oxygen-producing organisms. Their activity is thought to have produced the oxygen-rich atmosphere which

Anaerobic respiration: respiration without oxygen (O_2). Respiration is the process by which organisms convert the energy stored in molecules into a useable form. In most organisms, respiration requires oxygen, which is why breathing by animals is referred to as respiration. However, some bacteria are capable of anaerobic respiration, in which other inorganic molecules (such as sulfur, metal ions, methane or hydrogen) are used instead of oxygen

Aerobic: an oxygenated environment (organisms living or occurring only in the presence of oxygen are aerobes)

Biofilm: bacteria, microalgae, fungi and unicellular microorganisms enmeshed in a hydrated mucopolysaccharide secretion that sequesters ions and isolates microorganisms from the water column.[14] May be present on living and non-living surfaces and substrates.

Cyanobacteria: a large and varied group of bacteria which are able to photosynthesise

Blue-green algae: an older term for cyanobacteria today's life forms are adapted to, increasing it from about 1 per cent to about 21 per cent.[59] In effect, humans are alive today because of cyanobacteria.

Many cyanobacteria also have the ability to secure their own nitrogen by 'fixing' atmospheric nitrogen (some other bacteria also have this ability but generally fix less nitrogen than cyanobacteria). This gives them a competitive advantage over plants and algae that rely on the nitrogen available to them in the soil or water column. Nitrogen fixation by cyanobacteria can be an important source of nitrogen for the wetland, and as such can influence productivity, particularly when phosphorus is also available.

The cells of cyanobacteria are much smaller than algal cells.[37] Some species appear as a scum on the water surface of wetlands, including *Anabaena*, *Nodularia* and *Oscillatoria* (although long filaments are visible under a microscope). Other species such as *Microcystis* also float at the surface but are colonial (a closely associated cluster of cells, joined together or enclosed within a common sheath or mucilage), with clumps of cells visible under the microscope. Others again inhabit sediment. Not all cyanobacteria blooms are blue or blue-green; *Oscillatoria* form brown scum and *Trichodesmium* pinkish scums, leading to it being known as 'red tide'.[37] *Cylindrospermopsis* on the other hand occurs throughout the water column, and may colour it brown or red.[37]

These cyanobacteria may proliferate in wetlands with high nutrient levels, causing water to become toxic to come into contact with or to ingest.[17] At a certain density, this proliferation is classified as a **cyanobacterial bloom** (the density required to be identified as a bloom is outlined in *Algal blooms*[35]) (Figure 14). Although cyanobacteria are found in almost any environment, ranging from hot springs to Antarctic soils, known toxic members mostly inhabit water and can occupy wetlands that range from fresh water to saline. Cyanobacterial blooms can cause severe illness and death in animals, including fish kills and cattle deaths. In humans, cyanobacterial toxins can cause nerve and liver damage, gastroenteritis and severe skin and eye irritations. For this reason, protective clothing should be worn and extreme caution should always be taken when sampling waters and when conducting associated management activities, even in what appears to be cyanobacteria-free wetlands. Damage caused by cyanobacteria blooms are estimated to cost $200 million yearly in Australia, and blooms are predicted to worsen with climate change.[60] However, they are not new, with anecdotal evidence to suggest that Aboriginal people were aware of toxic outbreaks in wetlands before European settlement.[35,60]

Cyanobacterial bloom: the rapid, excessive growth of cyanobacteria, generally caused by high nutrient levels and favourable conditions

Figure 14. A cyanobacterial bloom at North Lake, in Perth's southern suburbs. Photo – J Davis.

Cyanobacteria can use gas-filled bags, known as vacuoles, to stay buoyant in the area of the water column with optimal light and nutrients in order to photosynthesise. The sugar-heavy cells then sink following photosynthesis. However, in optimal conditions, the water surface can be densely populated, meaning that the cells on the surface cannot sink, and the cells below them cannot rise. The surface cells die due to prolonged UV exposure, creating the toxins and leading to a loss of oxygen in the wetland.[60]

It is thought that part of the reason why these blooms can occur is that cyanobacteria may be unpalatable to zooplankton.[61,14] During blooms, cyanobacteria can also suppress population growth of algae by releasing allelopathic compounds[14] (chemicals that inhibit other species). They can also have a competitive advantage over algae when conditions are still. Planktonic algae tend to be heavier than water and use water turbulence to stay suspended in the water column. In contrast, cyanobacteria use gas vacuoles to remain in the optimal zone of light and nutrients. This is why artificially mixing the water column, referred to as thermal destratification, is thought to be one of the ways to tackle serious cyanobacteria blooms.

Cyanobacteria produce resistant spores when a wetland dries.[17] Upon wetting the wetland is repopulated by a new generation of cyanobacteria from this propagule bank.

Cyanobacteria are an important part of the microbial communities that form microbial mats and stromatolites in a number of Western Australian wetlands (described below in more detail).

The role of bacteria

Decomposing and recycling materials

Particularly in very productive wetlands, the organic matter produced within the wetland and transported in from the surrounding catchment would build up rapidly, in some circumstances to the point where the basin would fill completely and then cease to exist as a wetland, if not for the action of bacteria and fungi.[14] Bacteria, along with fungi, play an important role in the **decomposition** of organic matter in wetlands[61]

Their reason for doing so is to gain energy and nutrients. They secrete chemicals (extracellular enzymes) to break down organic matter present in large, fine or dissolved forms in and on the soil and the water. This organic matter, commonly referred to as detritus, comes from a variety of plant, animal and microbial sources including dead organisms, substances exuded by algae, animal excretion and feeding and microbial decomposition. Depending on the substance, it may be decomposed relatively easily or fairly resistant to decomposition. Many terrestrial plants and sedges, for example, have a lot of structural material (that is, cellulose and lignin), and this tissue and humic substances from it are relatively resistant to decomposition and tend to accumulate in wetlands.

In the process of decomposing organic matter, nutrients are released and returned back into circulation in wetlands in **inorganic** forms, which are the favoured forms of nutrients that plants and algae can use for growth and survival. This is one reason why text books talk about almost all nutrient-cycling processes in wetlands being 'mediated' by bacteria.[22] This is covered in more detail below.

Providing food

It has been known for a long time that many bacteria decompose detritus in order to obtain energy and in doing so liberate nutrients, but until the 1980s it was not suspected that bacteria were in fact eaten by other single-celled organisms, including rotifers, which are tiny microscopic animals; protozoans, which are organisms that are neither plants nor animals (also sometimes called protists), such as small flagellates and ciliates,

Decomposition: the *chemical* breakdown of organic material mediated by bacteria and fungi, while 'degradation' refers to its *physical* breakdown.[22,17] Also known as mineralisation.

Inorganic: compounds that are not organic (broadly, compounds that do not contain carbon) that occur in abundance in aquatic and damp environments; and a range of larger bactivorous animals such as chironomids (midges) and mussels.[17,22] It is now widely accepted that bacteria are an extremely nutritious food source, forming a vital food source for organisms further up the food chain.[17] Only bacteria are able to assimilate carbon when it is the form of dissolved organic carbon, which is the most abundant form in wetlands.[22] This makes bacteria essential in wetlands because carbon is needed for growth and survival of all life in wetlands. Much of the nutritious value of detritus, such as dead leaves, is not in the detritus itself, but rather in its coating of microbes that are decomposing it, that provides an energy-rich food source. This concept of the 'microbial loop' has revolutionised understanding of how energy cycles through wetlands.

Affecting nitrogen availability in wetlands

Nitrogen is a nutrient, meaning it is essential for living things. Bacteria are responsible for three key processes that have a significant effect on nitrogen availability in wetlands.

Firstly, some bacteria mediate a process known as *denitrification*, which reduces overall nitrogen levels in wetlands by converting nitrate to gaseous nitrogen, leading to its export from the wetland to the atmosphere. Denitrification occurs under anoxic conditions, however, it is much more prevalent in wetlands that wet and dry[22], because it is then coupled with the process of nitrification (production of nitrate) during the dry, aerobic phase. It is largely the result of the microbes and conditions within wetland sediments. This export of nitrogen is a contributing factor to the typically lower nutrient levels of these wetlands.

A second set of processes, known as *dissimilatory nitrate reduction to ammonium and nitrate-nitrite respiration*, retain nitrogen in a wetland. The nitrogen is retained in the form of ammonium and nitrite respectively, forms that are readily taken up by plants and algae. These typically take place in wetlands that hold water permanently and again are driven by the bacteria (anaerobic, aerobic and facultative) and conditions within wetland sediments.

Figure 15. The floating water fern ***Azolla filiculoides*** is a host to the cyanobacterium ***Anabaena azollae***, which provides it with nitrogen in return. (a) and (b) green and red varieties of ***A. filiculoides***; (c) in a Kemerton wetland. Photos – C Prideaux/DEC.

Finally, some bacteria are able to 'fix' atmospheric nitrogen under oxygenated conditions. They effectively import nitrogen into wetlands. Well-developed cyanobacteria mats are able to fix relatively high amounts of nitrogen, for example.[34] Some also have **symbiotic** partnerships with plants, including *Azolla* and some species of *Casuarina*. The floating water fern Azolla is fed nitrogen fixed from the air by its partner, the cyanobacterium *Anabaena azollae* (Figure 15). The cyanobacterium can meet the fern's total nitrogen requirements (in fact, it will continue to fix nitrogen even if the fern assimilates ammonium or nitrate from the water). Unlike many other cyanobacteria, this one is not toxic. This relationship plays a major role in fertilising rice fields in Asia, so much so that as much as a quarter of the total human nitrogen consumption is obtained from the *Azolla-Anabaena* source assimilated by rice.[14] Tropical wetlands are responsible for two-thirds of the biological fixation of nitrogen on Earth.[34]

Symbiosis: a relationship in which dissimilar organisms live in close association, and which is mutually beneficial to both organisms

Bioremediation: the use of microorganisms to break down environmental pollutants

Benthic microbial communities: bottom-dwelling communities of microbes (living on the wetland sediments)

➤ For more information on microbial processes and the nitrogen cycle, see the topic 'Conditions in wetland waters' in Chapter 2.

Affecting phosphorous availability in wetlands

Phosphorus, like nitrogen, is a nutrient required by living organisms. Bacteria can make phosphorus available to other organisms in wetlands, through the process of decomposition which releases phosphorus from detritus in phosphate, a bioavailable form of phosphorus.

Bacteria are also responsible for the release of phosphorus from sediments into the water column in the form of phosphate. This happens under anoxic conditions in wetlands with low levels of calcium carbonate.

➤ For additional detail on microbial processes and the phosphorus cycle, see the topic 'Conditions in wetland waters' in Chapter 2.

Altering the toxicity of metals, hydrocarbons and pesticides in wetlands

Sometimes called 'nature's janitors', bacteria are capable of degrading complex chlorinated solvents, diesel fuel, hydrocarbons and pesticides under certain conditions[22] and so are the focus of many **bioremediation** studies. They can also alter the toxicity of heavy metals in aquatic systems. For instance, the hydrogen sulfide produced by bacteria in anoxic environments can react with a range of metals, making them insoluble and therefore biologically inactive. Other bacteria and fungi can produce organic compounds (such as citric, oxalic and humic acid) which can bind metal ions and render them inactive, and still others bind toxic metal ions to their cell walls, or within extracellular slimes, thereby removing them from the water column.[62] This prevents them from being toxic to other organisms. However, bacteria are not a simple solution for wetland pollution; and in some circumstances, they may increase toxicity of pollutants. For example, some evidence suggests that the solubility, toxicity and availability of mercury may be increased by sulfate-reducing bacteria in estuarine wetlands.[22]

Creating benthic mats and other microbial structures

Benthic mats

Some types of cyanobacteria are dominant parts of microbial communities that create living mats on the surface of wetland sediments. These dense living mats are often visible as pink or purple mats, and vary in characteristics from rubbery, cohesive mats, such as those found in Pink Lake in Esperance, to loosely mucilaginous mats, or thin films, as can be found in the Yarra Yarra salt lake system of the northern agricultural region.[63] These mats are often called microbial mats, benthic mats or sometimes algal mats. They are created by cyanobacteria and other types of bacteria, algae and other organisms, collectively known as **benthic microbial communities** (BMCs) and include both the organisms themselves as well as non-living material. For example, at Lake Clifton the mat has been found to be composed of two species of cyanobacteria and fifteen species of diatoms (a type of algae) embedded in a matrix formed by mucilage secretion of the organisms.

Conditions suitable for the establishment and survival of BMCs are variable, but permanently inundated, high salinity, low nutrient wetland conditions are favoured.[64] Upon wetting, some wetlands are initially dominated by BMCs but over time become phytoplankton dominated, while others, such as Lake Coogee, retain mats over time as do those at Rottnest (Government House Lake, Herschell Lake and Serpentine Lake).[59] They grow very slowly; a footprint in a mat may last hundreds of years.[59] Higher species diversity and thicker, cohesive mats are typical in wetlands that hold surface water for sustained periods. Lake Thetis in Cervantes contains a variety of much less cohesive BMCs, each producing a distinctive mat. These include crenulate mats, nodular mats, filamentous mats, flocculent mats and diatomaceous mats (Figure 16); flocculent mats are thought to be 50–60 centimetres thick.[65] BMCs have also been recorded from Lake Cowan, Lake McLeod and Salmon Swamp (on Rottnest Island).[66]

Figure 16. Benthic microbial mats are visible (a) in the shallows of Lake Thetis in the forefront of the rock-like thrombolites and (b) in closer detail. Photos – W Chow/DEC.

Benthic microbial mats can significantly influence the ecology of some wetlands. They are often the predominant primary producers. In the Yalgorup Lakes, the BMC is thought to be the main source of food for thousands of migrating and local birds.[51] They also produce oxygen; often visible as bubbles beading the mat in the middle of the day when photosynthesis is highest.[67] In fact, their photosynthetic activity can supersaturate the bottom waters with dissolved oxygen.[68] In many permanently inundated saline wetlands, a thick mat of BMCs may reduce or almost stop water exchange between groundwater and surface water.[69] This means that the wetland waters become increasingly saline over time, as the surface water evaporates and is not diluted by an inflow of fresher (although still saline) groundwater. In Lake Clifton where the mat is 1 centimetre thick the inflowing groundwater can be intercepted and calcium removed.[51]

A change in conditions, such as secondary salinisation, may promote the loss of plants and an increasing dominance of BMCs in a wetland. In this situation, invertebrates, amphibians, reptiles and waterbirds reliant on plant-dominated wetland ecosystems may be lost.[70]

However, if conditions do not favour BMCs they can easily be outcompeted by submerged plants and charophytes, and they have low resistance to physical disturbance.[64]

Stromatolites and thrombolites

Mats are one type of microbial structure; the other types, **stromatolites** and **thrombolites**, are structures formed by the microbial communities by precipitating calcium carbonate (the key component of limestone) out from wetland water. These structures often look like stone domes, reaching up to 1 metre in diameter (Figure 17 and Figure 18). Their plain exterior belies the fact that they are representatives of ecological communities that have existed for three-quarters of the Earth's existence[59], known to have existed 3.5 billion years ago, while other early life forms did not develop in the Earth's ocean until 635 million years before present.

They house a complex assemblage of other bacteria and algae, as well as other aquatic fauna. Worldwide, these structures are limited to very few locations, predominantly Bermuda, the Bahamas and WA.71 WA contains the oldest microbialite fossils, at 3.5 billion years.[59] The state also contains the greatest number and most varied occurrences of living microbialites in the world59, including both marine (stromatolite) and wetland (thrombolites) occurrences, and a number of fossil sites including one just north of Kalgoorlie. Perhaps the best known microbialites in Western Australia occur at Hamelin Pool, Shark Bay.

Living and fossilised thrombolites in the south west of the state occur at Pink Lake in Esperance, Lake Clifton, Pamelup Pond at Lake Preston in Yalgorup; Government House Lake in Rottnest Island; Lake Thetis in Cervantes, Lake Richmond in Rockingham and Lake Walyungup southwest of Rockingham.[72,59] Each of these constitutes a distinct and very significant community in terms of history, structure, and morphology.[73] The extensive 'reef' of thrombolites at Lake Clifton provide a home for the microbial association itself, as well as a range of other organisms. Twenty-five species of aquatic animals were found inhabiting the thrombolites at Lake Clifton, including crustaceans and worms.[73]

It is thought that light and fresh water rich in calcium carbonate and low in nutrients is required for the survival of these thrombolitic communities. Despite having existed in wetlands for thousands of years, these internationally significant biological wonders are showing a decline in condition. A worldwide decline 1,000 million years ago is attributable to increased nutrients associated with plant and animal evolution. However, the recent decline in modern communities is the result of human activity within their catchments. The communities at Lake Thetis, Lake Clifton and Lake Richmond are now listed as threatened ecological communities by both the state and Australian governments and interim recovery plans are in place for the latter two (for more information see the 'Threatened ecological communities' webpage of DEC's website[6]).

Figure 17. Incredible structures: thrombolites of Lake Clifton, within the Peel-Yalgorup wetland system near Mandurah. Photos - M Forbes/DEC.

Figure 18. Incredible structures: thrombolites of Lake Thetis, Cervantes. Photo – R Jenkins/ robertjenkinsphotography.

Creating crusts on wetland soils

In arid and semi-arid regions, dense plant growth is limited by the hot, dry conditions and variable rainfall. In wetlands and their surrounding drylands, large open spaces between plants often have a hard crust of soil a few millimetres thick, which is actually constructed by living organisms binding together soil particles to form biological soil crusts. Biological soil crusts can be formed by cyanobacteria, algae, lichens, fungi and bryophytes (that is, mosses, hornworts and liverworts). The crust stabilises the soil, protecting it from blowing or washing away, as well as retaining moisture and adding nutrients to the soil. The retained moisture can be essential for the survival of animals such as burrowing frogs. Biological soil crusts are common at the edges of many salt lakes in Australian inland regions, and are critical to the maintenance of wetland condition in these fragile systems.[74] They are also often present on the wetland bed once a salt lake has dried, containing the drought-surviving spores, seeds and eggs of organisms which spring to life when the wetland is next inundated.[17]

Producing sulfide that generates potential acid sulfate soils

Under anaerobic conditions, sulfate-reducing bacteria produce sulfide which can react with iron present in the sediment to form iron sulfides, most commonly pyrite.[22] When these soils are exposed to air, the sulfides are oxidised, creating sulfuric acid.[75] The resulting acid can dramatically alter the chemistry of the area, releasing other substances, including heavy metals, from the soil and into the surrounding environment. Significant areas of Western Australia, including a large number of wetlands, contain either potential or actual acid sulfate soils.

➤ For more information on sulfur cycles, see the topic ‘Conditions in wetland waters’ in Chapter 2. For more information about the cause and management of acid sulfate soils, see the topic ‘Water quality’ in Chapter 3.

Sources of more information on wetland bacteria

Stromatolites[59] provides an account of stromatolites, focussing on Western Australian occurrences.

Ecology of freshwater and estuarine wetlands[76] contains an excellent, though relatively advanced chapter on bacteria by Paul I. Boon: 'Chapter 5: Biogeochemistry and bacterial ecology of hydrologically dynamic wetlands'.

The chapter 'Benthic microbial communities of Australian salt lakes' by J. Bauld, in the book *Limnology in Australia*.[66]

The chapter 'Bacterial biodiversity in wetlands' by Paul I. Boon in the book *Biodiversity in wetlands: assessment, function and conservation*.[77]

extra information

Identifying bacteria

Bacteria are not typically monitored in wetlands, with the exception being cyanobacteria and those species that are indicators of faecal pollution (for example, from septic tanks and overflowing sewage pumping stations). Sometimes the activity of bacteria are obvious; the activity of sulfate-reducing bacteria produces hydrogen sulfide, a gas also emitted by rotten eggs, giving a characteristic odour sometimes noticeable in inundated saline wetlands, especially when the sediment is disturbed. Where warranted, biofilms can be sampled; specialists can measure the algal and microbial biodiversity of a biofilm and the functions it is performing, such as nutrient recycling, oxygen production or food production for bugs. The potential for in-depth bacteria studies to provide information about the state of a wetland has been highlighted[61], but due to the expertise needed it is unlikely to be a feasible option in the majority of cases.

Fungi

Fungi are multi-celled organisms that are neither plants nor animals (fungi is the plural, fungus singular). Fungi include an extremely wide range of organisms including macrofungi such as mushrooms, toadstools, puffballs, coral fungi, earthstars and truffles, and an even broader range of microfungi.

Fungi occur in most environments, however, some fungi species are much more prevalent in wetlands than other areas, such as certain species of macrofungi that fruit most abundantly on paperbark (*Melaleuca*) trees, and the predominantly microscopic aquatic fungi, which rely on free water for some part of their life cycle. The total number of fungi worldwide is estimated at between one and half to five million species. While the number of fungi species that occur in Western Australia is not known, it is estimated to be approximately 140,000 species.[78] Six hundred species of macrofungi have been recorded in the Perth region alone to date.[78] The Perth Urban Bushland Fungi Project has significantly increased the knowledge of this region. More than sixty urban bushlands have been surveyed and 600 fungi species recorded, of which forty are new records for Western Australia and several are new to science. Among their discoveries, participants of the Perth Urban Bushland Fungi Project found the first Perth occurrence of a fascinating mushroom: the volvate cortinar, *Cortinarius phalarus*. This mushroom was found at Forrestdale Lake growing under a thick layer of *Astartea* shrubs with an overstorey of *Eucalyptus rudis* and *Melaleuca preissiana*, with which it is considered likely to form a mycorrhizal partnership (explained below). This mushroom is a member of a small group also found in South America, giving rise to the theory that it is a relic from the time when what is now Australia and South America were part of the Gondwanan supercontinent (between 510 and 180 million years ago).[78]

Although fungi are not plants, they are considered to be plants for the purposes of the *Wildlife Conservation Act 1950*. This means that a flora license is required to collect fungi. For more information see the flora licensing webpage of the DEC website.[12]

Saprotroph: an organism that absorbs soluble organic nutrients from inanimate objects (e.g. from dead plant or animal matter, from dung etc)

The role of fungi

Although much research is still needed to understand the diversity and role of fungi in WA's wetlands, their role in a range of processes provide some insight into their importance in the function of wetland ecosystems. For example, truffle fungi are a favoured food of quendas and a range of soil-dwelling animals. Quendas return the favour by ingesting and then dispersing truffle spores in other locations in their dung.

Decomposing materials

Unlike plants which can secure energy from the sun through photosynthesis, many fungi gain their energy by decomposing organic materials.[17] Litter, dung, wood and dead organisms are all decomposed by these **saprotrophic** fungi. Their ability to decompose major plant components—particularly lignin and cellulose (the major components of plant cell walls)—means that we are not buried in debris (Figure 19).

Figure 19. Fungi decompose organic materials.

Recycling nutrients

The decomposition of dead materials also means that carbon and nutrients such as phosphorus, nitrogen, sulphur and copper are recycled, and bioavailable for plants, which is extremely important given the state's infertile soils.[79] Fungal networks capture soil nutrients, help prevent leaching, and retain nutrients in a plant available form. The importance of these functions has led scientists to conclude that 'it is difficult to conceive of any bar the simplest ecosystem surviving in the complete absence of fungi'.[31]

Supporting wetland plants

Many fungi form a close association with plants in which both parties benefit from an exchange of nutrients and sugars. This relationship is known as **mycorrhiza** and the roots of these plants are referred to as mycorrhizal roots. These fungi-plant roots are connected to networks of microscopic thread-like structures developed by the fungi known as hyphae or mycelia, which explore and exploit a far greater area of the soil than 'uninfected' roots alone. These networks take up nutrients, such as phosphorus, and transport the nutrients back to the plant. Two main types of mycorrhiza occur: endomycorrhiza, where the fungi penetrate the plant's cell wall, and ectomycorrhiza, where the fungi are external to the plant cells. Endomycorrhiza are formed mainly by microfungi and can be present in permanently flooded soils, while ectomycorrhiza are formed by many macrofungi and appear to be sensitive to inundation.[80]

Mycorrhiza: a symbiotic association between a fungus and the roots of a plant, from which both fungus and plant usually benefit

Lichen: a composite organism consisting of a fungus and a cyanobacterium or alga living in symbiotic association

Studies worldwide show that a large number of wetland plants are partnered with mycorrhizal fungi[14,81] and WA is no exception—including but not limited to *Melaleuca, Astartea, Isoetes, Cotula, Viminaria, Myriophyllum, Nymphoides, Nymphaea, Pericalymma, Livistona, Pandanus, Ruppia* and *Eucalyptus*.[82] In recent decades there has been developments in the understanding of mycorrhizal associations with sedges, and the major role they play in phosphorus dynamics.[81]

The significance of these beneficial plant-fungi partnerships needs to be considered when planning wetland revegetation. Research has found that healthy natural woodlands have a greater diversity of native fungi than degraded woodlands or revegetated agricultural lands, and that most native fungi are not self re-establishing in degraded or cultivated land, at least in the short to medium term.[79]

It has also been proposed that these fungi have a protective role for some plants rooted in soils with high metal concentrations. Similarly the truffle fungi that are the favoured food of quendas and other animals are mycorrhizal.

Stabilising soil and creating soil crusts

Networks of fungi hyphae (mycelia) stabilise soil. **Lichens** are associations between fungi and cyanobacteria or algae. Usually the partners comprising a lichen are unable to live apart. Lichens help form biological soil crusts along with algae, bryophytes (that is, mosses, hornworts and liverworts) and stand-alone fungi and cyanobacteria. These biological soils crusts stabilise and protect the soil in arid and semi-arid regions, where dense plant growth is limited by the hot, dry conditions and variable rainfall. In wetlands and their surrounding drylands, large open spaces between plants often have a hard crust of soil a few millimetres thick, which is actually constructed by living organisms binding together soil particles to form biological soil crusts. The crust stabilises the soil, protecting it from blowing or washing away, as well as retaining moisture and adding nutrients to the soil. The retained moisture can be essential for the survival of animals such as burrowing frogs. Biological soil crusts are common at the edges of many salt lakes in Australian inland regions, and are critical to the maintenance of wetland condition in these fragile systems.[74] They are also often present on the wetland bed once a salt lake has dried, containing the drought-surviving spores, seeds and eggs of organisms which spring to life when the wetland is next inundated.[17]

Providing food and habitat

Fungi are an important food source for many animals. Notably, fungi form an important part of the diet of a number of mammals including the quenda, bilby and western bush rat.

The hyphal networks (mycelia) of fungi provide nutrients for myriads of microorganisms and soil fauna. Fruit bodies of macrofungi provided habitat and food for many invertebrates, particularly during the cooler/wetter months.

Moderating populations

Some fungi are pathogenic, that is, they derive energy from living organisms by invading and often killing them. A notable example is the chytrid fungus *Batrachochytrium dendrobatidis*, which infects frogs with the chytridiomycosis disease, which has decimated many frog populations. Aquatic fungi are typically microscopic and predominantly saprotrophic or pathogenic, or both.

Sources of information on wetland fungi

Key databases

NatureMap is a collaborative website of DEC and the Western Australian Museum, available at naturemap.dec.wa.gov.au. It presents the most comprehensive and authoritative source of information on the distribution of Western Australia's flora and fauna. *NatureMap* is an interactive tool designed to provide users with comprehensive and up to date information on plants, animals, fungi and other groups of biodiversity. It can be used to produce maps, lists and reports of WA's flora and fauna diversity.

Key websites

Perth Urban Bushland Fungi www.fungiperth.org.au

Fungibank www.fungibank.csiro.au

Fungimap www.rbg.vic.gov.au/fungimap

Fungigroup, Western Australian Naturalists Club www.wanats.iinet.net.au/fungigroup.html

Mycorrhizal associations: the web resource www.mycorrhizas.info

Key literature

The field guide *Fungi of the Perth region and beyond: a self-managed field book*[83] available from the Perth Urban Bushland Fungi website www.fungiperth.org.au

Working with mycorrhizas in forestry and agriculture[84] available from http://aciar.gov.au/publication/mn032

Animals

Sources of information on wetland animals

Key databases

NatureMap is a collaborative website of DEC and the Western Australian Museum, available at naturemap.dec.wa.gov.au. It presents the most comprehensive and authoritative source of information on the distribution of Western Australia's flora and fauna. *NatureMap* is an interactive tool designed to provide users with comprehensive and up to date information on plants, animals, fungi and other groups of biodiversity. It can be used to produce maps, lists and reports of WA's flora and fauna diversity.

WetlandBase is an interactive database by DEC, with web hosting by the Department of Agriculture and Food WA, available via http://spatial.agric.wa.gov.au/wetlands. *WetlandBase* provides a comprehensive online resource of information and data about Western Australian wetlands. It provides spatial data, such as wetland mapping, and point data, such as water chemistry, waterbirds, aquatic invertebrates and vegetation sampling results. DEC is preparing an alternative to *WetlandBase*, scheduled for release in 2013, that will continue to make this data publicly available.

Freshwater fish distribution in Western Australia database is a spatial dataset by the Department of Fisheries, available at http://freshwater.fish.wa.gov.au. It is an interactive online tool that enables users to search all available information on the distribution of native and introduced freshwater fish and crustaceans in Western Australia. The dataset also contains historical records of freshwater fish collected in WA. It is constantly updated with new records of native and feral fish distribution provided by Department of Fisheries researchers, universities and other agencies.

Key websites

DEC's online library catalogue: www.dec.wa.gov.au/content/view/123/2122/

The Australian Museum: www.australianmuseum.net.au

DEC's biological surveys: www.dec.wa.gov.au/content/category/41/834/1814/

Animal conservation research: www.dec.wa.gov.au/content/category/41/829/1813/

Legislation relating to the protection of native animals: www.dec.wa.gov.au/content/section/43/1979/

The Australian Faunal Directory[85] provides information and a comprehensive list of references on mammals.

Environmental impact assessment reports prepared under the *Environmental Protection Act 1986* generally include fauna investigations on local fauna: www.epa.wa.gov.au

Key literature

Note: field guides to particular groups of animals are listed in text.

Fauna of Australia[86] (multiple volumes, available online).

A biodiversity audit of Western Australia's 53 biogeographical subregions in 2002[87]

A biodiversity survey of the Western Australian agricultural zone[88]

A biodiversity survey of the Pilbara region of Western Australia, 2002 – 2007[89] and the associated database (available at http://science.dec.wa.gov.au/projects/pilbaradb/).

Surveying fauna

A licence from the Department of Environment and Conservation is required if native fauna is to be caught or interfered with in any way. Catch and release surveys should not be undertaken without instruction from DEC. For more information, see the 'Fauna licensing' webpage of the DEC website.[90] A licence from the Department of Fisheries is required to survey fish.

Reporting fauna

Sick or orphaned native animals should be reported to the Wildcare Helpline on 08 9474 9055, which operates 24 hours a day.

Opportunistic native fauna sightings can be reported to DEC using the fauna report form available from the 'Standard report forms' webpage of DEC's website.[91] The report form is used for recording observations of threatened or priority fauna species but it may also be used to record unusual observations of common fauna (for example, where an animal is found outside of its usual range, such as a specimen washed up on a beach after a storm, or a migratory bird etc). Survey observations are to be submitted to the fauna survey database as per the conditions of the licence to take/collect fauna.

Introduced animals can be reported to the Pest and Disease Information Service, Department of Agriculture, phone number 1800 084 881; introduced fish, crayfish and other aquatic species to the FISHWATCH service, Department of Fisheries, phone number 1800 815 507.

Animals: vertebrates

Vertebrates are animals with backbones, including fish, frogs, reptiles, birds and mammals. Some live all or most of their life at wetlands but many are wetland visitors, such as dingos, emus and kangaroos. The following is a summary of vertebrate animals that are known to inhabit or often make use of Western Australian wetlands. This list is certainly not exhaustive. This is, in part, because we still do not have a comprehensive understanding of the habitat use of many species, particularly those of remote or under-surveyed areas of the state. Additionally, biologists may identify a species as occurring in 'moist habitats' or 'riparian habitats' without specifying whether these are in wetlands.

Fish

Native fish species in inland waters of Western Australia are few, and they tend to be more prevalent in waterways than in wetlands. In a global context, Australia is considered to be depauperate (deficient) of freshwater fish, with less than 200 species. This is thought to be because of the relative scarcity of rivers and the seasonal nature of inland waters. In particular, the freshwater fish of south-western Australia is considered to be far more depauperate than that of south-eastern Australia, attributable to the long isolation of south-west WA, a long history of aridity, and an extremely low level of primary productivity.[92] No fish species have been recorded from the Great Sandy, Gibson or Great Victoria Deserts.[92]

The Kimberley supports at least forty-nine species of freshwater fish.[93] Researchers consider it likely that there will be future discoveries. The Kimberley is an endemic hotspot for freshwater fishes, with around forty per cent of the species found nowhere else. It is encouraging that there are currently no introduced fishes found in any major catchments of the Kimberley; however there are records of eastern mosquitofish (*Gambusia holbrooki*) from Cape Leveque and redclaw crayfish (*Cherax quadquicarinatus*) within the Ord River basin.[94]

The Pilbara region supports thirteen native species of freshwater fish, including two that are restricted to caves.[95] Five of these are endemic, with the rest also occurring in the Kimberley. Four introduced species are also present. Importantly, they are presently restricted to the southern half of the Pilbara Drainage Division, with no records of them north of the Lyndon River.[94]

With only eleven native freshwater fish species, the south-western region of Western Australia has a remarkably small number of freshwater fish. Notwithstanding this, they are considered a unique assemblage of freshwater fishes. Nine are endemic, meaning the south-west region has the highest percentage of endemic fishes in Australia, that is, over 80 per cent of the freshwater fish are found nowhere else on Earth.[96] This is thought to be due to the long period of isolation (approximately 15 million years). They are small bodied, generally less than 140 millimetres with the exception of the freshwater cobbler *Tandanus bostocki*. They are all well adapted to life in the variable aquatic environment of the south-west, which is characterised by a long dry summer and a cool wet winter. Research indicates that the south-west freshwater fishes have a higher reliance on terrestrial insects than fishes in other regions of Australia.[16] Inundated vegetation is thought to be important habitat for the larvae of the salamanderfish, black-stripe minnow, western mud minnow and Balston's pygmy perch (Figure 20).[92] Acidic (pH 3.9–6.0), tannin-stained waters are important for Balston's pygmy perch.[97]

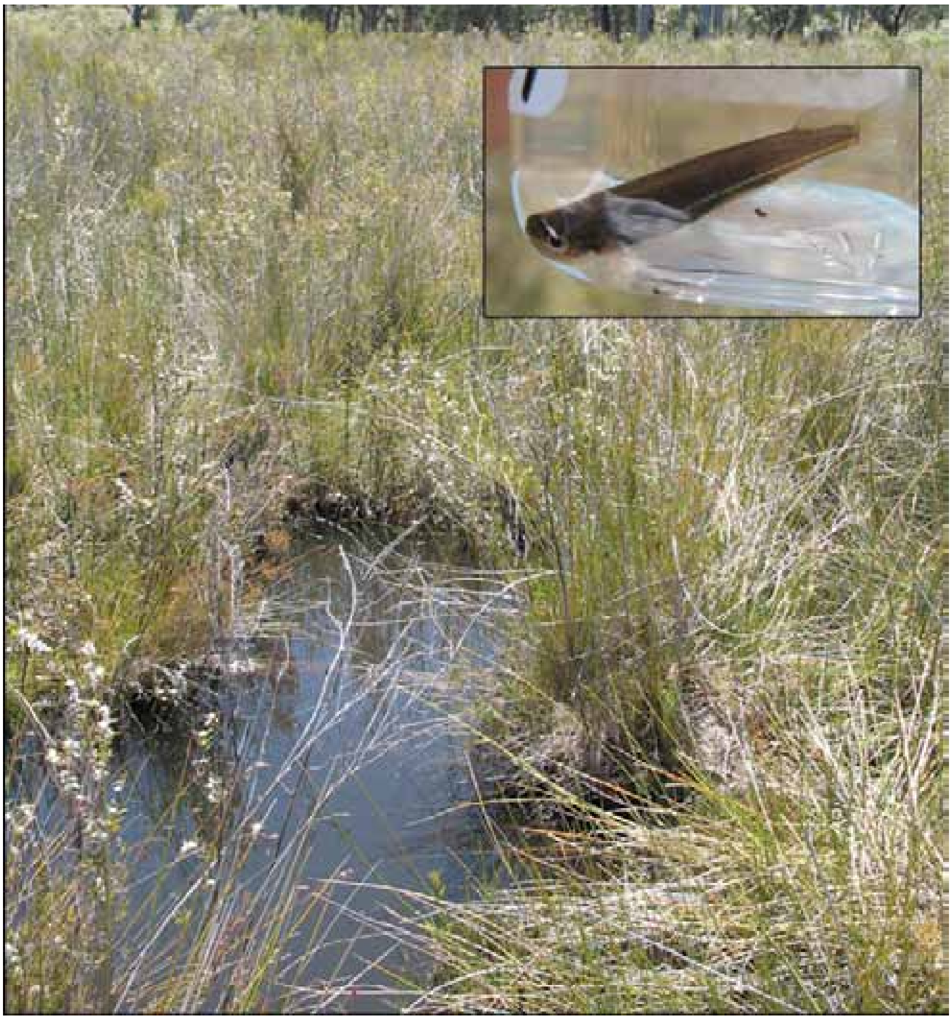

Figure 20. Inundated vegetation is important habitat for native fish in WA's wetlands, such as this western mud minnow, *Galaxiella munda,* found during water sampling in a densely vegetated wetland east of Margaret River. Photos – M Bastow/DEC.

In 2009–2010, a study by the Department of Fisheries found native fish in only fifty of 114 wetlands surveyed in the south west and Midwest.[98] Concern has been expressed that native fish habitat in the southwest is being lost due to development and altered regime (drying) of wetlands. Introduced fish are also implicated; 66 per cent of wetlands in the study were found to contain introduced species and only 9 per cent of the sites were populated exclusively with native freshwater fish. Previous studies (for example, Morgan et al. 1998[92] and Morgan et al. 2004[94]) show similar trends.

Aestivation: a state of dormancy that occurs in some animals to survive a period when conditions are hot and dry

The conservation status of WA's wetland fish is as follows:

- Threatened: western trout minnow *Galaxias truttaceus hesperius*
  western mud minnow *Galaxiella munda*
  Balston's pygmy perch *Nannatherina balstoni*[99]
- Priority three: black-stripe minnow *Galaxiella nigrostriata*

case study

Figure 21. The incredible salamanderfish, which reaches a maximum size of 5 centimetres (male) and 8 centimetres (female).[103] Photo – G Allen/Freshwater Fish Group and Fish Health Unit, Centre for Fish and Fisheries Research, Murdoch University.

Fish mystery solved by a water truck

Most fish inhabit permanent water sources or move to permanent water sources during the dry season. The salamanderfish *Lepidogalaxias salamandroides*, and the black-stripe minnow *Galaxiella nigrostriata* do not, puzzling researchers as to how they survive the hot, dry summers of the southwest.

The salamanderfish is of ancient lineage, described as looking a little like a "dark grub with fins and tail" (Figure 21). Its mystery appearance and disappearance from wetlands every year was solved by freshwater fish research Gerald Allen, co-author of *Field guide to the freshwater fishes of Australia*.[101] He borrowed a water truck one hot summer to flood a dried-up hole. He recalls "It was amazing. Within 10 or 15 minutes the pool was virtually teeming with fish".[102]

By following the dropping groundwater table down into the moist sandy soil and **aestivating** during the dry season, the salamanderfish and the black-stripe minnow display an extraordinary adaptation to the conditions of the south west. It is thought that there are only twenty four species worldwide that share this life cycle![104] Because the salamanderfish and black stripe minnow are reliant on the underlying substrate to remain waterlogged, the drying climate of the south west poses a major threat to the remaining populations, which have already contracted (considerably, in the case of the black-stripe minnow which is mostly confined to the Scott Coastal Plain). Burning of sediment poses another key threat.

Research into the ecology of the black-stripe minnow is shedding light on their habitat and diet preferences, aestivation requirements and population genetic structure. One investigation is looking at their burrowing capability as well as the commonly cited theory that the minnows inhabit the burrows of the koonac crayfish, *Cherax preissii*.[105,106]

A recovery plan is in place for the western trout minnow.[100] For more information, see the 'Recovery planning and implementation' webpage of the DEC website.

➤ For more information, see the following resources on freshwater fish:

- The *Field guide to the freshwater fishes of Australia*[101] provides photos and information to help guide identification.
- Introduced fish in WA's wetlands and their management is outlined in the topic 'Introduced and nuisance animals' in Chapter 3 of this guide.
- The website of the Freshwater Fish Group and Fish Health Unit, Centre for Fish and Fisheries Research, Murdoch University (http://freshwaterfishgroup-fishhealthunit.yolasite.com/) provides excellent information.
- The Department of Fisheries website www.fish.wa.gov.au provides information and the spatial dataset *Freshwater fish distribution in Western Australia database*, available from http://freshwater.fish.wa.gov.au/.
- An excellent film, *Native freshwater fishes of south-western Australia*[107], is available for viewing from the Envfusion films website: www.envfusion.com.au/Portfolio.htm

Amphibian: the class of animals to which frogs, toads and salamanders belong. They live on land but develop by a larval phase (tadpoles) in water.

Frogs

The ancestors of amphibians crawled from the water over 370 million years ago and were the first vertebrates to colonise the land.[108] Most are still dependent on water to complete their life cycle giving rise to the term '**amphibian**' meaning 'two lives' - one in water and one on land. Other present-day amphibians occur on other continents, including toads, salamanders, newts and caecilians.

There are about 216 frog species in Australia, with eighty-one known to occur in WA.[109] Over time, additional new species of frogs are being identified in WA. With over forty species, the Kimberley is home to the greatest diversity of frogs in the state, and is

Figure 22. Frog spawn in waterlogged soil of a wetland, in a depression created by animal pad. The lack of a protective shell renders frog eggs susceptible to pollutants and altered water quality. Photo – J Lawn.

considered to be a centre of frog endemism in Australia.[110] The south-west boasts thirty species[109] and the arid zone home to more than twelve. There are three threatened species of frog, all from the south-west. The cane toad *Bufo marinus* is the only introduced frog in WA.

Spawn: eggs surrounded by jelly; generally applied to a group of eggs

Wetlands are essential habitat for many of WA's frogs. As amphibians, the vast majority need water to breed, to keep eggs moist and to provide habitat for tadpoles.[111] There are exceptions, with the young of some species developing entirely within the egg, and upon hatching are miniatures of the adults, rather than tadpoles. Eggs are typically produced in a clump, referred to as **spawn**, kept together by the jelly encasing each egg. Wetland spawning sites include floating, submerged or at the bottom of open water, in 'foam rafts' on the water, on vegetation above water, in shallow depressions or a burrow in waterlogged soil (Figure 22), and in depressions or channels in peat. Adults of many species can travel significant distances from wetlands. In Perth, the moaning frog *Heleioporus eyrie* (Figure 23) and the pobblebonk *Limnodynastes dorsalis* rely on wetlands to breed but as adults are entirely terrestrial, living up to 4 kilometres from water.

Figure 23. The moaning frog, *Heleioporus eyrie*, breeds in wetlands in south-western Australia. Photo – C Mykytiuk/WWF.

All Kimberley species are known to breed in the wet season (November–March).[112] Arid zone frogs breed when water becomes available, typically following infrequent storms, especially when cyclones travel south from the Timor Sea during the wet season (November–March). The tadpoles complete development rapidly as ponds do not last long in the arid zone. The only exception is the northern sandhill frog (*Arenophryne rotunda*) near Shark Bay, which breeds in winter and spring and has direct-developing young (no tadpole stage). In the south-west, most species breed for a period between autumn and spring but there are exceptions, such as the motorbike frog (*Litoria moorei*), which breeds well into summer[112], and others, such as plonking frog (*Neobatrachus wilsmorei*) and the shoemaker frog (*Neobatrachus sutor*) which breed in response to summer rains.[112]

Frog species vary widely in their adult habitat requirements. Some frogs can live their adult lives in dryland habitats, seeking moisture from below ground or under surfaces, for example, the turtle frog (*Myobatrachus goldii*).[109] Some species, such as the moaning frog (*H. eyrei*), burrow into soil during the day in summer and forage at night to avoid dessication.[112] WA is considered to be rich in burrowing frogs by Australian standards, with burrowing being an important survival strategy employed by a large proportion of WA's frogs: over 70 per cent of Kimberley frogs, close to 75 per cent of arid region frogs, and over 60 per cent of south west frogs.[113] Some burrow extremely deep, such as the aptly named desert spadefoot, *Notaden nichollsi*, which can burrow to 1 metre.[112] Some, such as the water holding frog *Cyclorana platycephala* absorb large quantities of water through their skin and store it in their tissues and particularly in the bladder where it can be reabsorbed later.[114]

Frogs play a key role in many food webs, both as predators and as prey. Frogs are an essential part of the diets of many animals including snakes and birds.[114] Frogs are carnivores, and mostly eat insects and arthropods. Some eat other frogs, lizards and small mammals. Most tadpoles are considered to feed on algae (algivores).[15]

Amphibians are experiencing an unprecedented decline worldwide, with more than a third of species considered to be at risk of extinction. The decline in frogs has significant implications for food webs of wetland and dryland ecosystems globally. More than half of Australia's frog species are threatened by a disease called chytrid fungus *Batrachochytrium dendrobatidis*, which infects frogs with the chytridiomycosis disease.

Frogs are particularly good indicators of changes to water chemistry because they breathe primarily through their moist, semi-permeable skin, which is a poor barrier to pollutants, and their eggs lack a protective shell. Both of these factors make them highly susceptible to pollutants in the water and to changes in water chemistry. Frogs seem to be most vulnerable to pollutants when they are in the egg and tadpole stages.[114] Only limited information is available about the tolerances of frogs to salinity in Western Australian wetlands, however, anecdotal information suggests that frog declines are associated with an increase in salinity.[115] The effect of increased salinity on populations of the spotted burrowing frog (*Heleioporus albopunctatus*) has been investigated in the inland south-west agricultural area, and there is some indication that there may be a decline in its numbers correlated with salinisation of its habitats, possibly related to the effect of salinity on eggs and tadpoles. If this is the case, it is likely that other frog species in the region are also vulnerable.[116]

Much loved by children and adults alike for their charismatic tadpole and adult forms and their calls, native frogs are fantastic icon species for wetlands. Creating frog ponds is a popular way to interact with frogs, but moving tadpoles around can spread diseases and move frogs out of their natural range. The Alcoa Frog Watch website[112] facilitates a tadpole exchange program and provides tips on how to minimise potential adverse effects of moving frogs.

The conservation status of WA's frogs is as follows:

- Threatened: white-bellied frog *Geocrinia alba*
  yellow-bellied frog *Geocrinia vitellina*
  sunset frog *Spicospina flammocaerulea*[99]

Note: recovery plans are in place for each of these species. For more information, see the 'Recovery planning and implementation' webpage of the DEC website.[117]

- Priority one: marbled toadlet *Uperoleia marmorata*
  small toadlet *Uperoleia minima*

- Priority four: Nornalup frog *Geocrinia lutea*[4]

➤ Frog resources include:

- *Field Guide to Frogs of Western Australia*[109]
- the Alcoa Frog Watch website[112]
- the CD *Frog calls of southwest Australia*, available from the Western Australian Museum; for more information see the Alcoa Frog Watch website
- the Frogs Australia Network website[114]
- the website www.frogwatch.org.au, designed to provide information about frogs from across Northern Australia, including the Kimberly region. *The Northern Australian Frogs Database System* can be accessed from this website.
- the topic 'Monitoring wetlands' in Chapter 4, which provides a guide to monitoring frogs.

Reptiles

Western Australia's wetland reptiles include lizards, snakes, turtles and crocodiles.

Crocodiles

Crocodiles are an ancient group of reptiles who are well-adapted adapted to the warmer waters of northern Western Australia. They are of importance in Aboriginal culture, featuring in the rock art and stories of the traditional owners of the Kimberley. Freshwater crocodiles, *Crocodylus johnstoni*, and estuarine crocodiles, *Crocodylus porosus*, inhabit rivers and also some wetlands south to Exmouth. Freshwater crocodiles inhabit freshwater wetlands and occasionally tidal areas, with track marks indicating they can walk considerable distances at the end of the wet season in search of a dry season refuge.[118] During the dry season the crocodiles may lie dormant in areas where the water dries up, sheltering in burrows among the roots of trees fringing waterbodies or in shelters dug into creek banks. Adult crocodiles are the top of the food chain of many wetlands, feeding mainly on insects and fish, as well as crustaceans, spiders, frogs, turtles, lizards, snakes, birds and mammals. Although estuarine crocodiles are known as 'salties', they inhabit both freshwater and saline wetlands. Growing up to seven metres, this iconic species of the Kimberley is the largest reptile on earth. They feed on fish, waterbirds and occasionally large land mammals such as humans and wallabies.

Freshwater crocodiles excavate a hole in soil and lay 70 millimetre eggs in late August to early September, incubating them for three months. About three weeks before egg-laying starts the female begins excavating a number of 'test' holes at night, usually in a sandbank within 10 metres of water. In areas where there are limited suitable nesting sites, many females may choose the same area, resulting in a number of nests being accidentally dug up.[118] Estuarine crocodiles construct a nest of vegetation and soil and lay 85 millimetre eggs during the wet season from November to April, also incubating the eggs for three months.

Young crocodiles are often taken as food by birds of prey, goannas, dingoes and adult crocodiles. A study of freshwater crocodile nest egg predation at Lake Argyle found that dingoes were responsible for most predation.[119] Adult crocodiles have few predators besides other crocodiles, however the cane toad *Bufo marinus* is considered a threat to freshwater crocodiles after the discovery of many dead crocodiles with toads in their stomachs.[118]

Historically, unregulated commercial hunting for meat and skins drove the saltwater crocodile to the brink of extinction in WA while the numbers of freshwater crocodiles were considerably reduced in some areas. Today crocodiles are legally farmed for meat and skins but are not hunted in the wild. Farmed crocodile meat has been approved for human consumption in Western Australia since 1989 and crocodile meat products for human consumption are sold within Australia and exported overseas.[120]

Conservation status: Crocodiles have special protection under schedule 4 of the *Wildlife Conservation (Specially Protected Fauna) Notice 2010 (2)* as 'other specially protected fauna'.[3]

➤ For more information on crocodiles, see:

- DEC webpage 'Crocodile management in WA'[121]
- *Australian Crocodiles: a natural history*[122]; and
- The relevant chapters of *Fauna of Australia Volume 2A amphibia and reptilia*.[123]

Turtles

Western Australia supports seven of the twenty-six described species of Australian freshwater turtles (a number are yet to be described).[124,125] All of Western Australia's freshwater turtles live in water for the duration of their lives; feeding, courting and mating underwater. They emerge to bask in the sun to raise their body temperature (thermoregulation) and lay their eggs on land. Hatchlings are preyed upon by many other animals, for example, crayfish such as koonacs (*Cherax preissii*) and introduced yabbies (*Cherax destructor*) predate upon oblong turtles.[126] Foxes, cats and birds are known predators of adult turtles.

Figure 24. A turtle saved from the wheels of a four-wheel drive vehicle, Jurien Bay. Photo – A Shanahan/DEC.

Kuchling's long-necked turtle, *Chelodina kuchlingi*, is found in a very small area of north-east Kimberley, east of Kalumburu. The Kimberley is also home to the sandstone snake-necked turtle, *Chelodina burrungandjii, Elseya dentata* and *Emydura victoriae*, which occurs west across to the Fitzroy drainage.[125] *Chelodina kuchlingi* and *C. burrungandjii* are carnivorous while *E. dentata* and *E. victoriae* are omnivorous, eating a lot of plants, and fruit and algae, respectively.

The flat-shelled turtle, *Chelodina steindachneri*, is very hardy, inhabiting the most arid region of any Australian turtle. It inhabits seasonally and intermittently inundated wetlands from the Pilbara to the Midwest extending into the desert. When surface water dries up, it digs holes under vegetation surrounding wetlands and aestivates for periods up to years, until the next heavy rains arrive, or it undertakes lengthy overland migration to find surface water. It is adapted to hot, dry conditions, employing a range of techniques to survive including storing water in the urinary bladder. It is carnivorous, eating a variety of food such as fish, tadpoles, insects, frogs, small crayfish, freshwater prawns and carrion. Hatchlings have been known to eat aquatic plants, insects and mosquito larvae.

The oblong turtle (*Chelodina colliei,* formerly *C. oblonga*) is endemic to the south-west of WA, occurring from Hill River in the Midwest region to the Fitzgerald River on the south coast, and extending east into the Avon Wheatbelt. Also known as the long-necked turtle, it withdraws its long neck in a sideways motion into a groove in its shell, like all other turtles in the genera *Chelodina*. It is carnivorous, eating a variety of food such as fish, tadpoles, insects, frogs, small crayfish, freshwater prawns and carrion. Hatchlings have been known to eat aquatic plants, insects and mosquito larvae. It usually occurs in permanently inundated wetlands, but it is known to aestivate in mud or under leaves or logs for five to six months or migrate to nearby water during dry periods.[124] Recent research indicates that turtles are only likely to successfully aestivate or migrate if they are in good health. In urban environments such as Perth, where it is common, inadequate wetland buffers and poor management of humans, pets and introduced predators in and around wetlands take a serious toll on populations of the oblong turtle. Added to this is the tendency of well-meaning humans to thwart the migration and egg-laying processes, which can involve the females travelling considerable distances from the water to reach nesting sites, typically between September and January: *'It is a tough life for those turtles inhabiting lakes surrounded by busy roads and manicured lawns with little lakeside vegetation remaining…[but] during the warmer months, female turtles are best left alone to fulfil their motherhood duties. Imagine hauling yourself around for a considerable distance with a tummy full of eggs looking for a good egglaying site only to be returned to the water to start the journey all over again.'* - Bush *et al.*, 2007.[127] Interestingly, a study of two Perth wetlands found a preference amongst the oblong turtles for laying eggs on the southern aspect of these wetlands.[128] Hatchlings emerge at different times at different wetlands.

The species is known to tolerate estuarine level salinities if it has access to fresh water for breeding and long-term health.[129] It does not possess a salt excretory gland (J Giles 2009, pers. comm.).The habitat of the oblong turtle is likely to have contracted considerably with the widespread secondary salinisation of Wheatbelt wetlands.

Lastly, human poaching, including for the illegal pet and restaurant trade, has been implicated as the cause of population declines at some wetlands. In 2003, more than twenty females were poached from Lake Joondalup in an attempt to smuggle them out of the country, of which only four survived.[130]

For all these reasons, oblong turtles are assigned the status 'near threatened' by the IUCN, meaning that the species is close to qualifying for 'vulnerable' status (which applies to taxon facing a high risk of extinction in the wild in the medium-term future).[131] To assist with its conservation, people can record their observations of oblong turtles on the ClimateWatch website (www.climatewatch.org.au) or via Turtle Watch, which is run out of four environment centres in the Perth metropolitan region: Cockburn Wetlands Education Centre, Canning River Eco Education Centre, South East Regional Centre for Urban Landcare and Herdsman Lake Wildlife Centre.

Western swamp turtles (*Pseudemydura umbrina*) are considered Australia's most endangered reptiles. Their habitat has been cleared for agriculture, urbanisation and for extraction of clay for brick and tile manufacture. The remaining populations are now protected in two seasonally inundated wetlands in Ellenbrook Nature Reserve and Twin Swamps Nature Reserve in Bullsbrook, north of Perth.[127] Attempts to broaden their distribution are being progressed with translocations to other sites north of Perth. At a tiny 15 centimetres, the tortoises are vulnerable to predation by foxes, cats, dogs, rats and ravens. They are also reliant on rainfall to survive and reproduce successfully, so without intervention, successive dry years pose a considerable threat to the populations. Perth Zoo runs a breeding program for the tortoise with 700 successfully reared since 1989 and 500 returned to the wild. The Friends of the Western Swamp Tortoise actively support and promote the management of the turtles. It is carnivorous, eating a variety of food such as fish, tadpoles, insects, frogs, small crayfish, freshwater prawns and carrion. Hatchlings have been known to eat aquatic plants, insects and mosquito larvae.

The red-eared slider is the only introduced turtle in WA, where known occurrences in Perth wetlands have been removed. It is one of the top 100 'World's Worst' invaders as determined by the International Union for the Conservation of Nature and is considered a major threat to biodiversity. In Australia, they compete with native turtles for food, nesting areas and basking sites; and by eating hatchlings and carrying diseases that can infect native turtles.

The conservation status of WA's turtles is as follows:

- Threatened: western swamp tortoise *Pseudemydura umbrina*[3]

A recovery plan is in place for the western swamp tortoise. For more information, see the 'Recovery planning and implementation' webpage of the DEC website[117]

➤ For more information on turtles, see:

- *Australian freshwater turtles*[132]
- 'Management of the long-necked tortoise *Chelodina oblonga*' in *Managing your bushland*[129]
- The Friends of the Western Swamp Tortoise website www.westernswamptortoise.com[133]
- Perth Zoo and its website www.perthzoo.wa.gov.au

Lizards

While lizards are widespread in dryland habitats, wetlands may form part of the habitat of many species. Some lizards specialise in wetland habitats, such as the saltpan ground dragons, *Ctenophorus salinarum*, which are found amongst the glare, wind and salt of salt lakes of inland WA[127,88] and the painted ground dragon, which occurs in samphire of salt lakes of far south-eastern WA. The long-snouted water dragons (*Lophognathus longirostris*) are found in areas close to water from the Murchison to the Midwest. The purple arid dtella *Gehyra purpurascens* are a tree-climbing gecko that perch on trees in damp areas such as claypans in arid Western Australia.[127] The water monitor, *Varanus mertensi*, is a semi-aquatic monitor seldom seen far from water in the Kimberley. It is an accomplished climber and a strong swimmer. It mostly feeds on fish and frogs, but will also eat insects and small terrestrial vertebrates. It has an excellent sense of smell and may dig up prey when foraging, including freshwater turtle eggs. Mortalities from ingesting cane toads, *Bufo marinus*, have been recorded.

A number of skinks prefer cool, damp wetland habitats, such as the western glossy swamp skink (*Egernia luctuosa*) which is found in dense wetland vegetation from Perth to Albany. They are perfectly adapted for their wetland habitat; they can dive into shallow water and swim with ease, and have been reported sheltering down abandoned crayfish burrows.[127] Researchers have identified a dramatic decline in numbers of western glossy swamp skink in the Perth metropolitan region, and attribute this to the destruction of wetland habitats.[134] The south-western cool skink (*Acritoscincus trilineatum*) prefers thick vegetation and moist conditions between Gingin and Israelite Bay, including wetland habitats. Apparently the loud rustling noises often heard coming from leaf litter and dense vegetation of wetlands can often be attributed the south-western cool skink, despite its small size.[135] The loss of leaf litter associated with the vegetation decline is likely to impact upon this and other skinks.[136]

A number of mulch skinks inhabit wetlands. The south-western mulch skink, *Hemiergis gracilipes*, occurs in wetlands from Bunbury and Collie south to near Albany.[127] The two-toed mulch skink *Hemiergis quadrilineata* occurs in wetlands from Jurien south to Busselton. It inhabits leaf litter and forages for small prey such as termites and ants. The four-toed mulch skink *Hemiergis peronii peronii* occurs in wetlands of the south coast. The southern five-toed mulch skink, *Hemiergis initialis initialis,* prefers moist areas of the Darling Range and the south-eastern Wheatbelt.

Snakes

There are more than one hundred species of snake found in Western Australia and its oceans.[137] While most of WA's snakes are terrestrial, many do use or inhabit wetlands and some are aquatic (Figure 25). These are described below (estuarine and mangrove snakes are not included). Wetlands also indirectly support terrestrial snake populations because frogs and other wetland animals are an important part of the diet of many snake species.

Figure 25. An unidentified snake species in the water at Lake Hayward in the suburb of Preston Beach, south of Perth. Photo – Wetlands Section/DEC.

Northern Western Australia is home to a number of aquatic snakes that inhabit wetlands. The freshwater snake (also known as the 'Keelback') *Tropidonophis mairii* is a semi-aquatic snake that inhabits freshwater wetlands in the Kimberley, south to Kununurra. They may be seen basking on the surface of open, still water[137] and have the ability to remain submerged for 20 to 30 minutes.[138] They mainly feed on adult frogs (Figure 26), but also eat frog eggs, tadpoles, small fish and reptiles. It is reported that they can feed on cane toads, *Bufo marinus*, without ill-effect.[138]

Figure 26. A frog poses a hearty, if somewhat resistant, meal for this individual of the species known as the freshwater snake *Tropidonophis mairii*, which in WA can be found in the Kimberley, south to Kununurra. Photo – G Calvert/James Cook University.

The green tree snake *Dendrelaphis punctulatus* occurs in the Kimberly south to Lake Argyle. While they are at home in pandans and in trees as their name suggests, they are also excellent swimmers.[137] The threatened Pilbara olive python *Morelia olivacea barroni* are found close to[139] and in water.

The wetlands of the south-west (Gingin–Israelite Bay) are habitat of one of the world's most deadliest snakes, the tiger snake, *Notechis scutatus*. They are commonly observed amongst wetland vegetation, in animal burrows, under large boulders, in standing dead trees, and in water, being accomplished swimmers and readily searching underwater, where they can stay under for at least nine minutes.[140] Being relatively cold tolerant, they commonly emerge at night to prey on frogs[140], which make up the bulk of their diet, along with lizards, mammals, young birds, turtles and fish.[141] Tiger snakes mate in summer and bear live young in autumn. They are dangerously venomous, resulting in the second highest number of fatal bites by Australian snakes, after the brown snake group.[127] They display extreme colour and size variation, but get their name from the yellow stripes visible on some individuals.

Much more elusive is the large-eyed sedge snake, *Elapognathus minor*, which extends from Busselton to Two Peoples Bay. They inhabit wetlands dominated by sedges, tussocks and dense heath.[141] The related crowned snake, *Elapognathus coronatus*, also inhabits wetlands, and occurs mainly near the coast from Muchea to the Great Australian Bight.[127]

➤ A number of excellent guides to the reptiles of Western Australia are available. These include:

- *A complete guide to reptiles of Australia*[124]
- *Snakes of Western Australia*[137]
- *Reptiles and frogs in the bush: southwestern Australia*[127]
- *A guide to the reptiles and frogs of the Perth region*[141]
- *Lizards of Western Australia. 1. Skinks*[137]
- *Guide to the wildlife of the Perth region*[135]

Birds

Birds are usually the most visible of wetland animals, and can often be seen roosting, foraging and nesting even in urban wetlands. WA's wetlands provide habitat for a wealth of birds, too numerous to discuss here in any detail. Almost five hundred and fifty bird species are recorded from Western Australia, with sixteen occurring exclusively in the state.[142] Wetlands provide either important or sole habitat for a significant proportion of these, from a diverse range of bird groups including, but not limited to, quails, ducks, geese, swans, grebes, darters, pelicans, cormorants, herons, egrets, bitterns, ibis, spoonbills, storks, birds of prey, kingfishers, cranes, waterhens, button-quails, shorebirds, terns, scrub-birds, wrens, honeyeaters, robins, babblers, fantails, warblers, mistletoebirds, finches and pipits. Wetlands also provide an important drinking water source for birds such as Carnaby's cockatoo and emus (*Dromaius novaehollandiae*), which inhabit a wide range of habitats but remain within 20 kilometres of drinking water, favouring flats where fresh vegetation grows after rain.[143] Researchers estimate that approximately 150 waterbird species make use of WA wetlands.[144]

The importance of wetlands as habitat for many of the state's birds is reflected in the number of Important Bird Areas[145] (IBAs) that are wetlands. Similarly, two out of the nine criteria used to assess whether wetlands are listed as internationally significant under the Ramsar convention relates to waterbird habitat. Forrestdale and Thomsons Lakes, Lake Gore, Toolibin Lake, the Lake Warden system, Lakes Argyle and Kununurra, the Muir-Byenup system and the Peel-Yalgorup system are Ramsar sites in WA that meet one or both of these criteria.

Different wetland types provide different resources for wetland birds (Figure 27). Seasonally inundated wetlands, for example, are important bird habitat, with small, poorly defined wetlands inundated for a few months accounting for more than half of the breeding by ducks.[146] Saline wetlands, in particular, support an abundance of waterbirds.

Figure 27. The striking pink-eared duck, *Malacorhynchus membranaceus*, prefers shallow intermittently and seasonally inundated wetlands. Photo – S Halse/DEC.

A large proportion of birds that use wetlands are mobile[147], travelling between wetlands, waterways, estuaries and dryland and creating biological networks and connectivity between them. Bird species that are relatively sedentary, living locally for the duration of their life, are known as residents. Even residents may use one or more wetlands within a territory. They may visit several wetlands in a day, using each wetland for different purposes.[27] For example, they may feed at a saline wetland, drink at a freshwater wetland and roost at a third wetland.

Waterbirds are mobile and typically use many wetlands in a lifetime. Episodic migration between breeding territory in the south-west in winter and the north in the wet season is common. Movements of Australian waterbirds are considered to be largely unpredictable and complex.[38] Partial migration (where only part of the population migrates) south from the Kimberley during the dry season is undertaken by a number of wetland bird species, including the white-necked heron (Figure 28), plumed whistling duck and brolga.[147] The arid zone is an important nursery for waterbirds. Lake Gregory, Fortescue Marsh and Mandora Marsh in the north together support over a million waterbirds during the late dry season in some years and are important breeding sites for some species.[146] Irregular movement beyond the normal breeding range of a species also occurs in wetland bird populations. These irruptions are often a reflection of rainfall patterns. Many wetland birds can respond to rainfall by dispersing quickly and widely, and then contracting to

Figure 28. The white-faced heron, *Ardea novahollandiae*, occurs in many areas of WA. Photo – J Lawn/DEC.

a small number of sites during dry times.[146] Nomadism, where individuals of a species regularly move away from the breeding range to take advantage of favourable conditions to feed or breed, also occurs in many wetland birds. These include the Australian white ibis, straw-necked ibis, red-necked avocet, banded stilt, black-winged stilt and the black-tailed native-hen, to name a few.[147]

Some migratory shorebirds travel between continents, flying thousands of kilometres to reach Western Australian wetlands. These fly south from Asia or Alaska stopping first at the north-west tidal flats and then on to the wetlands and estuaries of southern Australia.[148] More than fifty million migratory waterbirds from fifty-four species[149] use the East Asian–Australasian **flyway**, which extends from the Russian Far East and Alaska in the north to Australia and New Zealand in the south, and incorporates eastern Asia and parts of south Asia (Figure 29). These birds make an annual round trip of up to 25,000 kilometres. Important WA wetland sites already recognised along this route include Lake MacLeod, Lake Cooloongup, Lake Gregory, Forrestdale Lake, Lake Preston, Thomsons Lake and Camballin. Beaches and waterways are also very important habitat, including Roebuck Bay, Eighty-Mile Beach and parts of the Swan River.

Flyway: a geographic region that supports a group of populations of migratory waterbirds throughout their annual cycle. Up to nine flyways are recognised worldwide.

Propagule: a unit or a piece of an organism that facilitates the organisms' reproduction. Plant propagules primarily include seeds, spores and plant parts capable of growing into new plants. Invertebrate propagules are usually eggs or, in the case of sponges, gemmules. Protist propagules are usually cysts. Bacteria and algae propagules are usually spores.

Figure 29. The East Asian–Australasian flyway. Image – © East Asian–Australasian flyway Partnership.[149]

Mobile birds can transport materials, nutrients and energy into and out of wetlands. In particular, they move **propagules** to and from wetlands[150] on their bodies (for example, stuck to feathers), in their gut, and in faeces. Long-distance dispersal by birds helps to explain major disjunctions (separations) between populations of a species, such as many sedge species. They can also transport adults; small animals such as water mites can hitch a ride while some, such as snails, may actually be ingested and survive inside a bird gut for hours before being excreted many kilometres away. In boom times, large populations can import significant amounts of nutrients into wetlands, via faeces.

Birds are often at the top of many wetland food chains. There are birds that eat almost every conceivable type of food in wetlands, including plants, fish, frogs, tortoises, small mammals such as mice, insects, gilgies, lizards, worms, leeches, snails, slugs, algae and other birds. Food is sourced from vegetation, water, the soil and soil litter, and organisms caught in flight. Colonies of breeding waterbirds may range some distance from wetlands to feed. Farmers sometimes consider them important in pest control in crops and pasture because they eat caterpillars, crickets and grasshoppers.[17] They can also reduce nuisance midge and mosquito populations. Bird diets range from extremely specialised to more generalist. For example, blue-billed ducks (*Oxyura australis*) are thought to rely on larvae of midges for about 25 per cent of their food[152], as well as caddis flies, dragonflies, flies and water beetle larvae. They may also eat the seeds, buds, stems, leaves and fruit of a wide variety of plants.[142] A waterbird's beak is usually a good guide to its preferred foods.

➤ For more information on inferring diet from bill morphology, see the feeding ecology information on Birds Australia's website www.birdlife.org.au/all-about-birds/australias-birds/biology-ecology

extra information

International agreements and treaties for the protection of migratory birds

Listed migratory species are those animals that migrate to Australia and its external territories, or pass through or over Australian waters during their annual migrations. Migratory species include species of birds, reptiles and mammals (such as whales).

The Australian Government maintains a list of migratory species, available online.[151,3] It includes those listed in the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention), China-Australia Migratory Bird Agreement (CAMBA), the Japan-Australia Migratory Bird Agreement (JAMBA) and the Republic of Korea-Australia Migratory Bird Agreement (RoKAMBA).

All species on the list of migratory species are 'matters of national environmental significance' under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. This means that any action that has, will have, or is likely to have, a significant impact on a listed migratory species will require referral to the Commonwealth Environment Minister and undergo an environmental assessment process.

For more information, see the topic 'Legislation and policy' in Chapter 5.

Similarly, birds make use of most wetland habitats to feed, nest and roost. Trees and tree hollows, shrubs, sedges and grass on land and in water are nesting sites for various species, as well as floating structures on water. A number of species nest on the ground, while the rainbow bee-eater (*Merops ornatus*) tunnels into sandy soil to nest underground. Caves and old rabbit burrows are also used by species including the Australian shelduck (*Tadorna tadornoides*).[152] Loss of wetland plants can have a major impact on many birds. For example, the whistling kite *Haliastur sphenurus* has suffered a major decline in population in many urban areas because of the loss of woodlands of flooded gum, *Eucalyptus rudis*, and the paperbark, *Melaleuca preissiana*, which are used for breeding.[134] Similarly, the Swan Coastal Plain Wetlands Study found that generally the wetland with the most complex vegetation structure had the most birds.[153,154] However, birds are not always a good indicator of the health of a wetland; the same study indicated that birds are often very abundant at nutrient enriched wetlands.

Waterbirds digging and probing wetland soils seeking underground plant parts (rhizomes) or wetland invertebrates mix air or oxygenated water into the sediment[155], and may also temporarily increase turbidity. In open water, diving waterbirds increase mixing and oxygenation of the water column, as does walking and probing in the shallows. Plants may be pollinated by nectar-feeding birds (this is less relevant to aquatic species).

The conservation status of WA's wetland birds is:

- Threatened: Australasian bittern *Botaurus poiciloptilus*
  Australian painted snipe *Rostratula benghalensis australis*
  fairy tern *Sterna nereis nereis* [3]
- Priority three: black bittern *Ixobrychus flavicollis australis*
- Priority four: little bittern *Ixobrychus minutus*[4]

➤ A number of excellent guides to the birds of Western Australia are available. These include:

- *The Michael Morcombe eguide to Australian birds*.[156] This application includes both images and recordings available for Apple iPhone and iTouch and Android phones and doesn't need internet access to function.
- *Handbook of Western Australian Birds* Volumes I and II[147,157]
- *Field guide to Australian birds*[158]
- *Field guide to the birds of Australia* 7th edition[159]
- *The Slater field guide to Australian birds*[160]

➤ Birdlife Australia (formerly Birds Australia and Bird Observation and Conservation Australia) have produced a number of resources, including:

- Guides, lists and other WA-specific resources, available online: www.birdlife.org.au/locations/birdlife-western-australia/bird-guides-wa
- *The Atlas of Australian Birds*, a database documenting the distribution and relative abundance of Australia's birds across the continent. It is available at www.birdata.com.au.
- *The state of Australia's birds 2004*[146], which provides a water-focussed overview of factors affecting birds, and in particular, birds that rely on wetland and waterway habitats.
- *Australia's important bird areas: key sites for bird conservation*[145]

➤ For more information on migratory birds, see:

- the Global Flyway Network at www.globalflywaynetwork.com.au
- Partnership for the East Asian–Australasian flyway: www.eaaflyway.net
- the International Waders Study Group at www.waderstudygroup.org
- Shorebirds 2020 at www.shorebirds.org.au
- DEC has published a number of reports and data detailing long-term monitoring of birds in south-west WA. For more information, see the 'Wetlands data' webpage on DEC's website[161]. Reports and publication links are provided.

Mammals

Mammals are warm-blooded vertebrates that suckle their young and have hair. Most mammals live a dryland existence, visiting wetlands because of the rich food sources they provide. A range of mammals including kangaroos and wallabies visit wetlands to graze and drink, while others such as dingoes drink and hunt for a variety of animals.

Relatively few of the mammals that inhabit WA rely solely on wetlands for survival. Of WA's 141 mammal species, the rakali is the sole mammal dependent on wetlands, waterways and coasts. A number of other mammals which use wetlands heavily include the quenda, the quokka, the western brush wallaby, the yellow-footed antechinus, bilbies and at least five species of bat. As with most of Western Australia's mammals, the populations of all of these species have been seriously impacted by clearing, habitat fragmentation, changes in fire and hydrological regimes and the introduction of cats, foxes and other predators and competitors. A number of these species are threatened, and this is stated below alongside their name. The Tanami desert populations of the rufous hare-wallaby (*Lagorchestes hirsutus*) inhabited salt lakes, but are now extinct.[162] While kangaroos do not rely solely on wetland habitats, they are included here because of their important role in wetlands.

- *The mammals of Australia* 3rd edition[162] is a comprehensive text on Australian mammals. More species-specific resources are listed below.

Rakali (*Hydromys chrysogaster*)

Rakali, also known as water rats, have been present in Australia for at least four million years.[163] They are variously described as iconic, cryptic, fascinating and 'our other platypus'. They require permanent water and are highly adapted to a semi-aquatic life. They have a broad muzzle, partially webbed hind feet, thick water-repellent fur and large, muscular white-tipped tail (Figure 30).[164] In WA water rats occur predominantly along the coast from Moore River in the Midwest region across to the Fitzgerald River National Park on the south coast, with isolated coastal populations in the Pilbara and Kimberley across to the Northern Territory. They depend on waterways and wetlands with fresh or brackish water and, on the Pilbara coastline and offshore islands, marine environments.[165] They live in dens or burrows hidden amongst vegetation alongside water, with a round entrance around 15 centimetres in diameter.[166] Steep banks are often a favoured location for burrows and nesting sometimes occurs in logs. They are typically nocturnal, being most active around sunset and sunrise, although they may be seen during the day. They predominantly hunt in water, with reports suggesting that they favour water less than 2 metres deep[167], but it is also thought that they forage in vegetated areas and occasionally climb trees in search of food.[168] A top-order predator, they mainly seek out large aquatic insects, fish, crustaceans and mussels from the water column, although frogs, lizards, young turtles, small mammals, fresh carrion, and birds are occasionally eaten.[165,17] Middens of food remains, such as crayfish and mussel shells, can signal their presence. Although predominantly carnivorous, they will also eat plants when other food is scarce. Rakali have significant home ranges; in Two Peoples Bay, in the South Coast region, they were found to be between 7 and 10 hectares. They also show preference for habitat with intact vegetation, better water quality and habitat complexity.[169] Rakali litters are between one and seven offspring, with three being average.[167]

Figure 30. (a) Rakali are cryptic mammals adapted to semi-aquatic lives; (b) occurring in low numbers across WA's western and northern coastal areas. Photo – R Jenkins © Australian Museum.

(a)

(b)

During the 1930s and 1940s they were heavily hunted for their fur, until the practice was put to an end by protective legislation. Although the populations increased as a result, they have been slow to recover, and are thought to be once again in severe decline in south-west Western Australia, caused by loss of habitat; fragmentation and degradation of habitat via clearing, drying of suitable habitat, salinisation, acidification and potentially increasing turbidity; predation and competition with introduced species and by drowning in illegal marron and gilgie nets[163] (Figure 31). A 2009 study of thirty-nine wetlands in the Perth metropolitan region found evidence of rakali at only seven.[167] There have been many local extinctions on the Swan Coastal Plain (Jurien Bay – Dunsborough). Genetic studies are being undertaken to understand the relationships between populations, remote cameras are being employed to learn more about these very shy creatures. However there are still significant gaps in knowledge of their ecology.

Figure 31. A rakali found drowned in an illegally set opera house trap near Thompson Bridge, Roleystone on the Canning River in 2011. Photo – courtesy of P Mutton.

Conservation status: priority four[4]

➤ The following resources provide information on rakali:

- The Australian Platypus Conservancy website (www.platypus.asn.au/the_australian_water_rat.html);
- Journal articles including DEC[165]; Atkinson[168]; Smart[167].

Western bush rat (*Rattus fuscipes*)

Western bush rats, like water rats, are native rodents. They are seldom seen in their native habitat, which extends along the mid west coast to the south coast. They prefer dense vegetation and are common in wetlands and waterways and for this reason are sometimes referred to as the 'western swamp rat'. Fungi are a dominant part of their winter diet, along with fibrous stems and leaves of specific grasses and lilies, and in spring and summer fruits and seed are important.[162] They help to disperse fungi by ingesting and excreting fungal spores.

Conservation status: not listed as either a threatened or priority species.

➤ It can be tricky to distinguish between the western bush rat, the black rat and common mouse. 'Rodents – the good and the bad'[164] is a handy one-page guide to native and introduced rodents.

Quenda (*Isoodon obsesulus*)

Quendas or southern brown bandicoots are common in dense vegetation of wetlands of the south-west. They prey on insects, earthworms, plants[170] and fungi; and a tell-tale sign of their foraging is cone-shaped diggings. Being marsupials, they have a pouch. They live in nests, generally a slight bowl-shaped hollow constructed from grass, twigs and other plant material, under dense bush. If the nest gets saturated with surface water in winter they will move to drier areas to nest. They have large territories; for example, 2–7 hectares for an adult male. A study on the Darling Scarp east of the Swan Coastal Plain found that males travelled up to 800 metres in a night, and females 295 metres. They occur from Guilderton north of Perth inland to Hyden and east to Esperance.[171] In 1994, Perth Airport was recorded as having one of the most extensive and abundant populations of the quenda of any bushland remnant of the Swan Coastal Plain.[134] Both their distribution and their numbers are thought to have declined substantially since European settlement.[172] The results of a survey of quenda throughout greater Perth (Lancelin to Harvey, including the Perth Hills) by DEC in spring 2012 will be compared with an earlier 1984 survey to see how numbers have changed over the past thirty years.[173] Changes in their distribution and abundance have implications for species that prey on them as well as those they eat. Truffle fungi are a favoured food of quendas, which by ingesting truffles help to disperse truffle spores across their territories in their dung.

Figure 32. The quenda is an iconic wetland species of south west WA. Photo – B Glossop.

Conservation status: priority five.[4]

➤ The Wildlife Note *Encouraging quendas*[172], and the pamphlet *Living with quendas*[174] are good sources of information for landholders.

Quokka (*Setonix brachyurus*)

Quokkas need to live near permanent fresh water, and are therefore restricted to land near freshwater wetlands. They were once common throughout the south-west of WA, where they favoured swamps and coastal thickets.[139] Quokkas are now restricted to Rottnest and Bald Islands and a few isolated populations located predominantly in densely vegetated wetlands and creeks from Gingin to Albany.[139,171] In the northern Jarrah forest, quokkas are closely associated with the wetland plant *Taxandria linearifolia* and the presence of a complex structural mosaic as a result of the fire history. A reduction in the number of wetlands supporting this complex habitat mosaic and/or increasing distances between patches of suitable habitat are thought to have contributed to the decline in the number of populations at this northern limit.[162]

Conservation status: declared threatened fauna.[99]

Note: a recovery plan for quokkas is being drafted. For more information, see the 'Recovery planning and implementation' webpage of the DEC website.[117]

Western brush wallaby (*Macropus irma*)

The western brush wallaby lives in open forest or woodland in the south-west, but particularly favours open, seasonally wet flats with low grasses and open scrubby thickets, appearing to manage without free water.[162]

Conservation status: priority four.[4]

Figure 33. Open, seasonally wet flats with low grasses are favoured by the western brush wallaby for grazing. Photo – B & B Wells/DEC.

Kangaroos (grey, *Macropus fuliginosus* and red, *Macropus rufus*)

Kangaroos have large home ranges that can include wetlands. While they do not rely solely on wetlands, kangaroos can have a significant influence on them, because they are widespread across WA with the exception of the far north-east, abundant in many areas, and able to exert significant grazing pressure on a wetland. They will visit wetlands to graze, and where surface water is present, to drink. Red kangaroos (*Macropus rufus*) drink about every four to ten days in summer from available water sources and in the dry season they are found within 10–20 kilometres of a water point, often aggregating in moist or wet areas where short green pasture is available.[162] Kangaroos can create trails through wetland vegetation, import nutrients via droppings, and import and export seeds in their droppings and on their coats.

Conservation status: not listed as either a threatened or priority species.

Yellow-footed antechinus or mardo (*Antechinus flavipes*)

The yellow-footed antechinus is a very small (mouse-size), nocturnal marsupial that in WA is found only in the south-western corner. It exists in a broad spectrum of habitats, although the dense vegetation of wetlands and waterways are favoured.[134] In urban environments it is known to pilfer from the kitchen and build nests inside television sets and lounge chairs.[162] It has a varied diet including insects, flowers, nectar, small birds and house mice. The yellow-footed antechinus has declined markedly around Perth.[134]

Conservation status: not listed as either a threatened or priority species.

Bilbies (*Macrotis lagotis*)

Bilbies occur in the southern Kimberley and Pilbara, where salt lakes form part of their habitat.[175] They eat insects and their larvae, seeds, bulbs, fruit and fungi. They construct impressive burrows up to 1.8 metres deep and 3 metres long where they remain during the day. Bilbies can shift rapidly in response to changing food availability.[162]

Conservation status: declared threatened fauna.[99]

Figure 34. Salt lakes are used by hardy bilbies. Photo – B & B Wells/DEC.

Western ringtail possum (*Pseudocheirus occidentalis*)

The Western ringtail possum inhabits peppermint (*Agonis flexuosa*) tuart (*Eucalyptus gomphocephala*), jarrah (*E. marginata*), wandoo (*E. wandoo*) and marri (*Corymbia calophylla*) habitats, and is also known to also nest in rushes and blackberry thickets.[162]

Conservation status: declared threatened fauna.[99]

Bats (including flying foxes)

Bats are an important part of the Western Australian environment, with more than twenty species recorded, and a distribution across many areas of the state, particularly the Kimberley and Pilbara. Bats use a variety of habitats, and a number are known to use wetlands for foraging or camping. These include the echolocating, insect-eating microbats (of the suborder Microchiroptera) and the fruit and nectar-eating bats (of the suborder Megachiroptera). Species that forage at wetlands include the northern long-eared bat *Nyctophilus arnhemensis*, which eats mainly beetles, bugs, crickets and spiders; and the little north-western mastiff bat *Mormopterus loriae cobourgiana*. Many species catch their prey in flight, for example, by flying over wetland water to catch flying insects such as mosquitoes. The large-footed myotis *Myotis macropus* is adept at this technique, raking the surface of the water with sharp, curved claws to catch aquatic insects and small fish and excelling at downward spiralling flight as they search for flying insects.[162] They roost close to freshwater and make use of wetland trees such as *Pandanus* spp. Camps of other species can also be found in wetlands, including those of the northern blossom bat *Macroglossus minimus*; black flying fox *Pteropus alecto*; and the little red flying fox *Pteropus scapulatus*.[162] Some, such as the "small but characteristically feisty"[162]

Figure 35. The little broad-nosed bat *Scotorepens greyii* is just one of many bat species that use wetlands in WA. Photo – G Little © Australian Museum.

little broad-nosed bat *Scotorepens greyii* (Figure 35) skim over the water surface to drink.[176] Many species are not often sighted because they are nocturnal. The northern blossom bat is a major pollinator of a number of plant species including *Melaleuca* and *Barringtonia* species within its range in north-western WA. A high proportion of Australian bats are threatened with extinction. The main causes of decline in bats have been identified and include habitat clearing, disturbance of roosts, forest harvesting and the collapse, closure or re-working of old mines.

Conservation status of the above bats is as follows:

Priority one: little north-western mastiff bat, *Mormopterus loriae cobourgiana*.[99]

➤ *The action plan for Australian bats* reviews the conservation status of 90 taxa of Australian bats.

- A key to bat families and genera is provided in *A field guide to the mammals of Australia*.[177]
- The article, 'Capturing the call of the bat' in *LANDSCOPE* Volume 26 No. 4 outlines advances in bat monitoring.

The role of vertebrates

Transporting life, energy and nutrients and pollinating plants

Vertebrates are mobile, and some travel between wetlands, creating biological connectivity between them. They can be responsible for the transport of materials, nutrients and energy into and out of wetlands, and can also act as a means of transport for the import and export of propagules to and from wetlands. All vertebrates contribute nutrients and energy to wetlands in form of faeces. Kangaroos and emus eat plant material, often ingesting seeds that are deposited in faecal matter at other wetlands. Similarly, quendas, bilbies and western bush rats disperse fungal spores. As top-order predators, rakali and crocodiles are ecosystem regulators. Waterbirds are the ultimate wetland travellers, typically using many wetlands in a lifetime. They move between regions and continents, flying hundreds or even thousands of kilometres to reach a wetland when it fills. A waterbird can visit several wetlands in a day, using each wetland for different purposes.[27] They act as modes of transport between wetlands for the propagules of wetland algae, plants, animals and other life forms.[150] Bats such as the northern blossom bat *Macroglossus minimus* can also be major pollinators. Vertebrate pollination of aquatic plants appears to be rare compared to invertebrate pollination. However some shrub species that grow in waterlogged land may be pollinated by vertebrate visitors to wetlands such as nectar-feeding birds, possums and bats.

Mixing and oxygenating sediments

Digging by vertebrates disturbs wetland soils and sediments, a process often referred to as bioturbation. This physical soil turnover, oxygenation of soil, leaf litter disturbance and burial, movement of fungal spores and creation of fertile bare areas are all critical components of soil ecosystem processes provided by native vertebrate species in balance with the landscape. In inundated mud, digging and probing by waterbirds seeking rhizomes or wetland invertebrates mixes oxygenated water into the sediment[155], and may also temporarily increase turbidity. Activity of waterbirds diving and walking in the open water zone also increases mixing and oxygenation of the water column. Digging in soil by vertebrates such as bush rats, burrowing frogs and rakali also provides a pathway for aeration of the soil. Research undertaken at Lake Martin, Yalgorup National Park, found that an individual quenda can displace more than 3 cubic metres of soil per year–about the same size as a small spa.[178] Disturbance created by larger vertebrates such as kangaroos and emus may create spaces in the soil and vegetation and in doing so, create opportunities for colonisation by plants. In comparison, large, hoofed introduced species including camels, pigs, goats, horses and cows can often crowd into an area and create significant damage to soil structure. Species such as such cows pug and compact wetland soils, and pigs wallow in mud in warm weather.

Consuming

Like invertebrates, arguably the key role of vertebrates in wetland ecosystems is as consumers in the food chain, controlling populations of the organisms they eat. This role extends to the landscape surrounding wetlands too. Colonies of breeding waterbirds at wetlands may range some distance from wetlands to feed. They are sometimes considered by farmers important in pest control in crops and pasture because they eat caterpillars, crickets and grasshoppers.[17] Wetland vertebrates also provide food sources to predators that predominantly inhabit dryland.

Animals: invertebrates

Invertebrates are animals without backbones. While small, they are not inconsequential, as observed by E. O. Wilson in 1987: “If human beings were to disappear tomorrow, the world would go on with little change........ but if invertebrates were to disappear, I doubt that the human species could last more than a few months.”

Invertebrates are categorised based on their size. Some groups, such as protozoans, rotifers, copepods, ostracods and cladocerans are usually smaller than 0.25 millimetres and often known as **microinvertebrates**, whilst most aquatic invertebrate groups are usually larger than 0.25 millimetres and known as **macroinvertebrates**. Microinvertebrates are unable to actively disperse.

Wetland invertebrates include worms, molluscs, leeches, water mites and spiders, shrimps, crayfish and many other crustaceans, bugs, beetles, dragonflies, damselflies, mayflies, caddisflies, sponges, midges and mosquitoes. Over 3000 species have been recorded in Western Australia. They are found in virtually all habitats in wetlands including in and on wetland sediments, in the water, on plants and on submerged rocks and logs. Some invertebrates are aquatic in their larval and adult phases, whilst others are only aquatic in their larval phase.[179]

To date, invertebrates that inhabit waterlogged wetlands have not attracted as much attention as those invertebrates that inhabit the water column either permanently or for some portion of their life cycle. This is now being addressed, with a range of specialised spiders, bees and other insects of waterlogged wetlands now being identified and studied.

The total number of wetland invertebrate species in Western Australia is extremely high. For example, more than 1000 species have been identified in the Pilbara and 1200 in the Wheatbelt (A. Pinder pers. comm.). Aquatic invertebrate sampling is used to get a snapshot of the aquatic invertebrate community at a point in time. Aquatic invertebrates are also a popular target for wetland monitoring programs because they are found in almost all wetlands, are found in the water column for at least part of their life cycle and many are relatively easy to survey (but often difficult to identify). Invertebrate monitoring can provide insight into a wetland's food web, for example, benthic sampling can indicate the benthic invertebrates that form part of the diet of many waterbirds, particularly waders.

Monitoring of aquatic invertebrates is sometimes also used as a surrogate to infer water quality, wetland condition or habitat. The diversity of invertebrate taxa usually provides a good indication of the conditions in a wetland, provided there is some reference level of diversity for the wetland in question, as some wetlands have naturally low diversity. Some invertebrate taxa have quite specific ecological requirements, for example, persisting only within a narrow range of environmental conditions (particularly salinity and pH), and for this reason these particular taxa are sometimes used as a surrogate measure to infer water quality, wetland condition or habitat. In general though, the direct measurement of water quality is always a more reliable and straightforward approach.

➤ The following resources provide guides to invertebrates:

- *A guide to wetland invertebrates of southwestern Australia*[179]
- *The waterbug book: a guide to the freshwater macroinvertebrates of temperate Australia*[180]
- *What bug is that? The guide to Australian insects website*[181]
- *The Bugwise website*[182]
- The Bug guide website: *Identification and ecology of Australian freshwater invertebrates*[183]
- *Critter catalogue: a guide to the aquatic invertebrates of South Australian inland waters*[184]

For technical taxonomic guides, including keys, see the Murray Darling Freshwater Research Centre's list of publications, available from www.mdfrc.org.au/bugguide/resources/taxonomy_guides.html

Freshwater sponges

Sponges are simple, primitive animals which as adults are sessile, or fixed to the spot (they disperse as gemmulae or through fragmentation and re-attachment as adults). Sponges exist in all different shapes, sizes and colours, and members of the same species can vary greatly depending upon where they live.[185] They consist of numerous cell types with special functions, but they lack tissues and organs like more complex animals. They are best known from marine environments, but one of the three classes of sponges, the Demosponges, also occur in freshwater wetlands. The skeleton of Demosponges is composed of spongin, a flexible material made of collagen, some with spicules of silica dioxide. Over time, **spicules** can build up in wetland sediments, forming a common component of sediment on the Swan Coastal Plain (Jurien Bay–Dunsborough), particularly of peats and diatomites, where they may constitute up to 10 per cent of the sediment.[186] Twenty-four species of freshwater sponges, all from the family Spongillidae, have been recorded in Australia.[180] They are referred to as 'freshwater' species to distinguish them from marine species; they do occur in brackish to saline wetlands.

The presence of Spongillidae in Western Australia has been recorded at wetlands from the south coast to the Pilbara (Figure 36). During a study of wetlands on the Swan Coastal Plain, researchers noted that encrusting sponges were commonly encountered on vegetation of permanently and seasonally inundated wetlands, noting that they were not abundant at any site[186]; this is thought to be the general pattern of occurrence in the Pilbara too.

Spicule: minute, needle-like body made of silica or calcium salts found in some invertebrates

Freshwater sponges are typically thin crusts or mats, found on the undersides and edges of solid surfaces such as submerged wood and can be confused with fungi. They are an irregular shape but sometimes with regular patterning and dull grey, brown, yellow or alternatively green if covered by algae, and may be spongy to touch. Sponges are fixed to the spot so they cannot escape from predators and instead produce strong chemicals and bristly textures to deter predators. Sponges belong to the Phylum Porifera, which means 'pore bearer'. They feed by pumping water into and out of their bodies through these pores, filtering out bacteria and other tiny organisms and dead plant and animal particles. This passage of water also brings in oxygen and takes out carbon dioxide and wastes. The (limited) literature suggests that sponges inhabit wetlands of reasonable water quality and that some pollutants may cause growth and developmental abnormalities in sponges.[184]

Figure 36. A Pilbara sponge. Photo – A Pinder/DEC.

Sponges are the main food sources for the larvae of sponge flies (Sisyridae), an aquatic family of lacewings.[180] Sponge flies lay their eggs on vegetation, and when the eggs hatch, larvae fall into the water and swim to a sponge by flexing their body.[181] They have specialised mouthparts that allow them to pierce and extract the contents of the sponge tissue.

Birds and floods transport the gemmules (resting bodies) of sponges to other wetlands; these gemmules are resistant to adverse conditions.[183]

Worms and leeches

Aquatic worms include segmented (Phylum Annelida) and unsegmented worms (various phyla). They are mostly sediment-dwelling but some crawl on the sediment surface, swim directly above it, or live amongst macrophytes or periphyton. They are either detritivores, grazers or predators. A few are predatory on other oligochaetes.[179]

Unsegmented worms include flatworms and roundworms, amongst others. Wetland flatworms (Platyhelminthes) vary in colour from transparent to bright green. They probably survive seasonal drying of wetlands as thick-shelled resting eggs that are resistant to desiccation. Their food comprises live or decomposing animal matter. They prefer wetlands with low to moderate nutrient levels, being sensitive to organic pollution.[184]

Roundworms (Nematoda) are long, thing and cylindrical with a cuticular body wall. They are present in almost all wetlands other than the most saline ones. Roundworms feed on a variety of organisms, dead and alive. They are usually found in or near sediment at the wetland bed. Many species tolerate low concentrations of oxygen and can even remain inactive for weeks at a time if oxygen levels are very low, or go into a state of hibernation if dehydration is a threat.[184]

There are two main groups of segmented worms (Annelida) in WA wetlands. These are Clitellata (which includes all earthworms and leeches) and Polychaeta (bristle worms – mostly marine). Aquatic earthworms (oligochaetes) are numerous in Australia, with more than 119 recorded species (with nearly as many known but undescribed). Most aquatic earthworms are much smaller (generally 1 to 20 millimetres) than their terrestrial counterparts. A few cosmopolitan species are known to be very tolerant of poor water quality, though their presence does not necessarily indicate pollution. However, most endemic species have been collected in wetlands and rivers with good water quality and their tolerance to pollution is unknown. They are highly sensitive to salinity, with a few exceptions. Bacteria and algae in the sediments are their main source of food, though some live above the sediments and some of those are grazers or are predators, such as the genus *Chaetogaster*).

Genetic research has shown that leeches are simply highly modified oligochaetes so they are no longer classed separately (instead being grouped along with oligochaetes with the combined group now known as the Class Clitellata). Leeches occur in a wide range of freshwater habitats but are intolerant of salinity.[187] Most have suckers at each end of the body, and are predators or parasites, feeding on blood of worms, molluscs, midge larvae, frogs, turtles, waterbirds, cattle[180], or predators, eating invertebrates.[184] They can have several pairs of eyes. Leeches are not well studied in Australia.[179] They are able to survive in wetlands that dry by burrowing into the sediment and constructing a mucus-lined cell where they lie dormant.[184]

Most bristle worms (Polychaeta) are found in marine or estuarine environments, but one *Manayunkia* species is found in WA salt lakes, where it inhabits gelatinous tubes in the sediment.[187] Several species of *Aeolosomatidae* are also known from Australian freshwater wetlands and species of other marine families may be found in near coastal saline wetlands such as Lake MacLeod near Carnarvon.

Molluscs

Wetland molluscs include snails, limpets, mussels and clams.

Snails and limpets form the class Gastropoda (derived from Greek, meaning 'stomach-footed'). Snails typically have a coiled shell while limpets have simple shells that lack coiling and are cap-shaped. There are twelve native and one alien families of non-marine gastropods in Australia, which are comprised of forty-six valid genera and around 220 valid species[188], many of which are represented in the wetlands of Western Australia.[189]

Most notable is the critically endangered Cape Leeuwin freshwater snail *Austroassiminea letha* which occurs in stream systems and swamps fed by springs at Ellensbrook and Cape Leeuwin.[190] Introduced species include the infamous liver fluke snail, *Physa acuta*, which is an intermediate host for the sheep liver fluke (*Fasciola hepatica*), which can seriously damage the internal organs of their host (such as kangaroos, wallabies and sheep).

Snails and limpets have a pair of tentacles with eyes at the tips or bases. Some lay their eggs in characteristic cylindrical masses of jelly, while others bear live young. Most snails and limpets are grazers, feeding on plant material, particularly the algal film coating submerged plants; but some gastropods are omnivores. Snails and limpets tend to be rare in waterbodies of high nutrient concentration or low pH.[179] Gastropods tend to fossilise well[191], hence they are used in palaeontological studies.

The attractive *Coxiella* snails inhabit salt lakes and are easily recognised by their colourful banded spires which are often broken off at the tip (Figure 37). The superficially similar hydrobiid snail *Ascorhis occidua* occurs in salt lakes along the south coast. Many arid zone species can survive for periods without water by sealing off the opening of their shell, either closing their 'door' (opercula) if they have one, or secreting calcified mucus plugs.[184]

Mussels, clams and basket shells are also molluscs and belong to the class Bivalvia. The name bivalvia refers to their shells, made of two valves. There are three recognised families in Western Australia: freshwater mussels (Hyriidae), basket shells (Corbiculidae) and pea clams (Sphaeriidae), each with their own anatomy and method of reproduction and dispersal.

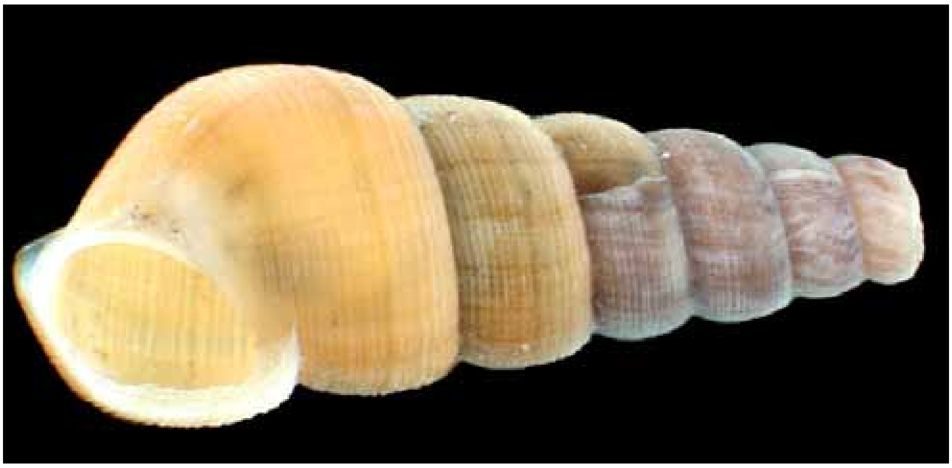

Figure 37. A close up photo of *Coxiella* snails, recognisable by their colourful banded spires which are often broken off at the tip. Photo – A Pinder/DEC.

Figure 38. *Coxiella* snails are often numerous in salt lakes. Photo – J Lawn/DEC.

Freshwater bivalves are generally filter feeders, taking in water through an inhalant siphon and moving food into their mouth and stomach for digestion using mucus and by moving microscopic hairlike cilia. The undigestible material is pushed out from between the shells and the filtered water continues out the exhalant siphon. This filtering function reduces fine **particulate** matter in the water column, improving water clarity and quality. Filtration capacity and diets of freshwater bivalves in WA are largely unknown and in need of further research. Oxygen exchange takes place in the gills. All organs in freshwater bivalves are internal, although they can extend a muscular foot to move themselves through the sediment and their inhalant and exhalant siphons can extend out beyond their shells. During drought, mussels can seal their shells tight until water returns.[180]

Particulate: in the form of particles (small objects)

Five of the eighteen Australian freshwater mussels are known to occur in Western Australia.[192] As well as being the only mussel in the south-west of WA, Carter's freshwater mussel *Westralunio carteri* is endemic to the south-west, occurring between Moore River and the Frankland River (Figure 39). They occur in waterways and wetlands, most commonly in areas with muddy, silty and sandy bottoms and permanent water.[193] Unlike their marine and estuarine cousins, they do not attach to structures. This allows them to move with receding water levels and position themselves to the best feeding spots, so tracks can sometimes be an indication they are present. They have a complex life cycle involving a parasitic stage in which larva known as 'glochidia' use hooks on the edges of their shells to attach to passing fish. The glochidia live on the fish host for weeks to months, metamorphosing into juveniles, before dropping off the fish. The fish enable the mussels to disperse to new areas. Therefore the fate of Carter's mussel is closely tied to fish. Fishes responsible for supporting the life cycle of Carter's mussel include native species such as the freshwater cobbler, Swan River goby, southwestern goby, western pygmy perch, western minnow, western hardyhead and nightfish. Although the introduced eastern gambusia has been found to be a suitable host, goldfish and pearl cichlids were not.[194,195] There is also a new theory that freshwater shrimp, *Palaemonetes australis*, may be involved in the release of the glochidia from mussels.[196] This reliance on other animals leaves them susceptible to changes in environments that affect the other species; added to this is their intolerance to salinity greater than 3 parts per thousand.[197] These factors have lead to a decline in Carter's mussel, and it is now listed as a priority four species (taxa in need of monitoring).[4] Recent research is assisting conservation efforts.

➤ New resources are increasing awareness of the importance of Carter's freshwater mussel, including:

- Mussel Watch Western Australia website: www.musselwatchwa.com.[193] A comprehensive list of research papers is provided on the 'Resources and links' page.
- *A field guide to freshwater fishes, crayfishes and mussels of south-western Australia*[96]
- An excellent film, *Native freshwater fishes of south-western Australia film no. 3: Carter's freshwater mussel*[107], is available for viewing from the Envfusion website: www.envfusion.com.au/Portfolio.htm

The conservation status of WA's wetland molluscs is as follows:

Threatened: Cape Leeuwin freshwater snail *Austroassiminea letha*[3]

Priority two: *Glacidorbis occidentalis*

Priority four: Carter's freshwater mussel *Westralunio carteri*[4]

➤ Technical identification guides for molluscs include:

- *Identification keys to the families and genera of bivalve and gastropod molluscs found in Australian inland waters*.[198]
- *A guide to provisional identification of the freshwater mussels (Unionoida) of Australasia*.[199]

Insects

All adult insects have three pairs of legs, one pair of antennae and typically one or two pairs of wings. Wetland insects include, but are not limited to: bees, dragonflies, damselflies, mayflies, caddisflies, beetles, bugs, midges and mosquitoes. Insects are generally the dominant invertebrate group in terms of species number, **biomass** and productivity in freshwater wetlands, while crustaceans are usually dominant in biomass and productivity in salt lakes.[179]

Invertebrates that disperse from wetlands during adult phases, such as dragonflies, damselflies, and a wide range of true flies such as midges, all provide food for wetland and dryland animals such as bats, birds, reptiles and spiders.

Biomass: the total mass of biological material (living or dead), usually expressed as live or dry weight per unit area or volume

Nymph: a juvenile insect that resembles the adult, but has poorly developed wings

Dragonflies and damselflies

Dragonflies and damselflies (in the order Odonata) are well-known wetland insects because the adults are often colourful and visible flying around wetlands. Their grace and beauty has inspired the fields of art and literature in many cultures, but their physical attributes also enable them to be one of the most efficient aerial predators of the insect world. They have almost 360 degree vision, and are even able to fly backwards at speeds of 25–35 kilometres per hour.[184] Research suggests that there are relatively few pollution-tolerant dragonflies and damselflies.[179] Adult damselflies are usually smaller and more delicate than dragonflies and tend to hold their wings together over their backs when resting (Figure 41), rather than flat on either side of their body like dragonflies. Dragonflies and damselflies are all predators, feeding on other aquatic insects.[179] Vegetation plays an important role in harbouring eggs and nymphs. Some groups lay their eggs on submerged plant stems, others in the water column. The **nymphs** are commonly found amongst submerged plants or within the wetland sediment where they feed on aquatic earthworms and other food sources, and in many species they crawl up vegetation out of the water prior to emerging from their larval cases. Nymphal cases may be found attached to the vegetation for some time afterwards.[179] With more 300 hundred species of Odonata in Australia, they are a diverse group in terms of physiology, habitat and ecology.

➤ *The complete field guide to dragonflies of Australia*[201] covers both damselflies and dragonflies.

- Resources for the southwest include *Dragonflies and damselflies of southwest Australia: a photographic guide* and the website http://museum.wa.gov.au/waiss/dragonflies/

Figure 41. Damselfly at Ewans Lake, east of Esperance. Photo – S. Kern/DEC

Bees

Approximately 800 native bees occur in WA, and many of these are endemic. In 2010, a new and as yet unnamed species of bee (*Leioproctus* sp.), was discovered by a WA Museum volunteer and a WA Museum curator in seasonally waterlogged/inundated wetlands in Jandakot, south of Perth (Figure 40). The megamouth, named after the remarkably large jaws of the males, has been found to pollinate paperbarks (*Melaleuca* sp.) and spearwood (*Kunzea glabrescens*). Surprisingly, they nest in the ground, in an area subject to inundation during winter, and the entrances to their burrows are extremely inconspicuous. It is not known if the Jandakot Regional Park is their only or last remaining habitat. It is thought that, with the exception of very shallow nests, ground-dwelling bee larvae/pupae can survive fire.

The short-tongued bee, *Leioproctus douglasiellus* is a threatened bee.[3] It is thought to be dependent on the flowers of the thread-leaved goodenia, *Goodenia filiformis* (a priority three species), and *Anthotium junciforme*, both found in wetlands of the south west.[139]

Another threatened native bee, *Neopasiphae simplicior*, has been found only from two Perth locations—Cannington and Forrestdale Lake—and is also associated with wetlands, as it has been collected on flowers of wetland species including the thread-leaved goodenia, *Goodenia filiformis*, slender lobelia *Lobelia tenuior* and *Agianthus preissianus*.[139,151,3]

➤ For more information on native bees, see the WA Museum website and its native bees information factsheet.[200]

Figure 40. The charismatic megamouth bee, discovered in a Perth wetland in 2010. Photo - T Houston/WA Museum. Image copyright of WA Museum.

True bugs

The true bugs (of the order Hemiptera) usually have two wings and all have piercing and sucking mouthparts to suck body fluids from their prey. The majority are terrestrial but the aquatic and semi-aquatic true bugs include a range of charismatic species whose entertaining antics captivate children and adults alike. These include the water striders and pond skaters (Gerromorpha), which are able to skim or skate across the surface film of the water. Water boatmen (Corixidae) are up to 10 millimetres in size and are so-called because they use their oar-like middle legs to propel them through the water in a motion similar to a rowboat. They are excellent fliers, enabling them to move to other wetlands. They feed on plants and insects such as mosquito **larvae**. Backswimmers (Notonectidae) swim on their backs. They also have long oar-like middle legs with hairs on them that help them swim 'backstroke' quickly. Water scorpions (Nepidae) are also Hemipterans. They have a breathing tube that can be as long as their body. This allows them to hold the breathing tube to the water surface like a snorkel rather than having to surface for air.

Larvae: juvenile insects (the singular being 'larva')

Beetles

Beetles (of the order Coleoptera) inhabit a range of habitats available in WA's wetlands. Some require a water column in order to survive, while others favour wetlands that are only wet seasonally or intermittently, for example, those beetles found on the lake beds of dry salt lakes in the Wheatbelt.[202]

Western Australian wetlands support a range of aquatic beetles, including weevils, whirligig beetles, crawling water beetles and diving beetles. After living on dry land for millions of years[180], aquatic beetles have adapted to life underwater, most living in water both as larvae and adults but with terrestrial pupae.

Diving beetles (Dytiscidae) are the most diverse beetle group and are most common in freshwater wetlands and less common in fast flowing streams, saline lakes and waterbodies where fish are present.[179] Their diving behaviour is driven by the need to surface for air; they store air bubbles on the body before diving. Eggs are usually laid beneath the water surface, attached to aquatic plants. Both larvae and adults are carnivorous, and prey commonly include water fleas, larval mosquitoes and midges[179] and sometimes small fish and tadpoles.[180] It is thought that, because they breathe air from the atmosphere, they can tolerate poorer water quality, especially low oxygen levels.[38]

Beetles have hardened wing cases to protect the wings when they are folded. Most have retained their ability to fly, meaning that they can disperse to new habitats.

True flies

The true flies (Diptera) are a large and diverse group that encompasses mosquitoes, midges, hover flies, horse flies, sand flies, crane flies, march flies, marsh flies, black flies, moth flies and soldier flies. They have a single pair of flying wings, with the second pair modified into halteres used as stabilizers or wind speed detectors. The family Chironomidae (non-biting midges) is one of the most diverse aquatic invertebrate families.

All true flies live their adult lives in dryland ecosystems, but some have aquatic larval forms. Some adults can skate on the water surface to scavenge for food. They have a very short adult lifespan (rarely longer than a month) and can lay hundreds of eggs at a time. Some midge species have drought-resistant adaptations and survive as larvae in a partly hydrated state.[203]

➤ Nuisance midge and mosquitoes pose a particular challenge for wetland managers. The topic 'Managing nuisance midge and mosquitoes' in Chapter 3 provides guidance on possible approaches to their management.

- A photographic guide and keys to the larvae of Chironomidae (Diptera) of south-west WA is available from DEC's website.[204]

Mayflies

Australian species of mayfly (Ephemeroptera) nymphs are not tolerant of saline waters, but are found in most freshwater habitats, except for those with poor water quality, as most are not very tolerant of pollution.[184] They have three long thin 'tails'. Most are herbivorous, grazing on diatoms and other algae, or are detritivores. The adult flies are very short-lived, most only living a day but some up to several days.[179] Mayflies are the most primitive living winged insects: their fossils date to as far back as 300 million years ago.[184] Some species have desiccation resistant eggs, which allow them to colonise temporary water bodies.[184]

Caddisflies

Caddisflies (Trichoptera) are well-known because the larvae of some species build protective cases in which to live. They often appear to be a moving stick. Many use plant material, sticks, gravel and/or sand to construct their cases, which means that some species can't be identified by the look of their cases alone. Others spin cases from silk and some families do not construct cases at all. They live just about anywhere in wetlands and are detritivores. One species, *Symphitoneuria wheeleri*, inhabits saline waters along the south coast of Australia and some species require running water.

Moths and butterflies

Adults of all moths and butterflies (Lepidoptera) are terrestrial, but the moth family Pyralidae have aquatic larvae. They have a similar appearance to dryland caterpillars but most have gills and are often found on plants or rocks, feeding on plants and algae. They inhabit fresh to moderately saline wetlands across WA.

Springtails

Springtails (Class Collembola) are tiny animals with six legs and one pair of antennae. However, they are regarded as being distinct from insects. They rarely grow larger than 3 millimetres, and most of the 6000 species (including 1630 from Australia) are not aquatic[184] but do have an affinity for moist areas so they may be found at many wetlands. They burrow and remain underground during hot, dry weather. Those that do live in inundated wetlands live on the surface of the water using water-repellent hairs, often amongst vegetation. Despite their small size, they can jump over 30 centimetres. They feed on algae, fungi and plankton and can live in polluted wetlands. In turn, they are eaten by bugs, beetles and fish.

Spiders and water mites

Water mites, like spiders, have eight legs, but they are usually easy to distinguish from spiders; they have very simple, rounded bodies and only reach a maximum of 5 millimetres (most are less than 2 millimetres). Water mites are often highly visible, despite their small size, because of their spectacular red, orange, blue, green or yellow colouration and sometimes distinctive patterning. Water mites occur in a wide variety of freshwater habitats, including the interstitial waters of waterlogged wetlands, but are thought to be most abundant in shallow, heavily vegetated wetlands[179] including seasonally inundated wetlands. The Muir-Byenup system is known to support eleven water mites, including many of considerable zoogeographic interest.[190] The adults swim and/or crawl. Water mite larvae overcome their inability to move between wetlands when they dry up by simply taking a ride on another animal, such as dragonflies. Being parasites, their prey offers them food, board and transport! They typically parasitise insects and microcrustaceans, feeding on their body fluids, while some are known to feed mainly on midge eggs.[179] Most water mites have low salt tolerance, although *Acercella falcipes* and *Koenikea verrucosa* are found in slightly saline wetlands of the Wheatbelt.[88]

Aquatic spiders, like water mites, are thought to occur in shallow wetlands with dense overhanging vegetation. There is one family of truly aquatic spiders, the Pisauridae, which live underwater. In addition, many spiders are recorded from WA wetlands that are only seasonally or intermittently inundated. Lake Minigal, east of Kalgoorlie in the Goldfields, for example, is reported to be covered in spider webs at times. This intermittently inundated wetland is reported to be habitat for millions of spiders, which in turn are thought to be prey for dunnarts (*Sminthopsis* sp.), salt lake lizards and birds.[205,206]

Spider assemblages at salt lakes in the Wheatbelt are often distinct from those in surrounding dryland[202], due to the occurrence of salt flat specialists.[207] Some of the burrowing spiders are able to build burrows that can withstand flooding, using mud plugs, palisades or other physical barriers to water.[202] Some wolf spiders, such as those in the genus *Tetralycosa* (Lycosidae) are known to inhabit salt lakes[208] and claypans, while others are specially adapted to, and as a result particularly abundant in, many environments prone to inundation (including sandy beaches) because in the event of rising water levels, the mother spider can carry spiderlings to safety.[208] *Lycosa salifodina* is a known salt lake specialist occurring across arid salt lake systems in a number of Australian states.[202] The threatened Minnivale trapdoor spider (*Teyl* sp.) is a fascinating Wheatbelt spider that inhabits perched wetlands on high terrain.[139] Several undescribed species occur further to the east of the Minnivale trapdoor spider in salt lakes of the eastern Wheatbelt.[139] The christmas or jewel spider *Austracantha minax* is a colourful and highly visible species in many wetlands.

The conservation status of wetland spiders and water mites is:

- Threatened: Minnivale trapdoor spider *Teyl* sp.[3]
- Priority two: Poorginup Swamp watermite *Acercella poorginup*
  Doeg's watermite *Pseudohydraphantes doegi*[4]

Crustaceans

Crustaceans include large, well-known species such as freshwater crayfish and crabs, generally the largest of the wetland invertebrates. There are also many much smaller species called microcrustaceans, which are no less fascinating. All crustaceans have an external carapace; sometimes this is a hard casing (as in crayfish and crabs) but for some microcrustacea it is softer. Some clam shrimp (Conchostraca) have their carapace formed into a bivalve-like shell.

Crayfish

There are many non-marine crayfish in WA. While some species (such as koonacs) tolerate brackish conditions, none are tolerant of high salinities. Interestingly, freshwater crayfish do not naturally occur in either the Kimberley, Pilbara[103] or arid interior, with the Queensland redclaw *Cherax quadricarinatus* introduced to Lake Kununurra.[209] There are thirteen species of freshwater crayfish native to south-western Western Australia, belonging to two genera. The seven *Engaewa* species are rarely seen, being small, burrowing crayfish that are confined to small areas along the south west and south coast, a number of which are considered endangered or critically endangered by the IUCN (Figure 42).[131] *Cherax* species are found throughout the south-west.

Figure 42. (a) the endangered Dunsborough burrowing crayfish, *Engaewa reducta* (b) a 'chimney' of soil pellets at the entrance of a crayfish burrow. Photos – (a) K Rogerson/DEC (b) M Podesta/DEC.

(a)

(b)

Gilgies (*Cherax quinquecarinatus*) are widespread between Hill River and Denmark. They reach a maximum size of 140 millimetres, and are found in wetlands with sandy or peaty sediments. They inhabit both permanently and seasonally inundated wetlands. They survive drying of seasonally inundated wetlands by burrowing into the soil. A much less common species, the restricted gilgie *Cherax crassimanus* is found between Margaret River and Denmark.

In the southwest the glossy koonac *Cherax glaber* are found on the coast between Dunsborough and Windy Harbour, while the better known koonac (*Cherax preisii*) are found inland in wetlands with clay and organic sediments from Moore River to Albany. Both species can burrow well, which allows them to inhabit seasonally inundated wetlands and burrow into the soil when they dry.

Zooplankton: tiny invertebrates and protozoans floating or suspended in the water that drift with water movements, generally having little or minimal ability to control their location

The smooth marron *Cherax cainii* is native to south-western WA, but its range has been extended both north and south, occupying only permanent waterbodies. In contrast, the hairy marron *Cherax tenuimanus* is restricted to the upper reaches of the Margaret River. The smooth marron is the third-largest freshwater marron in the world (with the two largest being eastern Australian species).[210]

The yabby *Cherax destructor* has been introduced from south-eastern Australia and now occupies south-western wetlands between Kalbarri and Esperance. It is able to inhabit seasonally inundated wetlands, burrowing into the soils as the wetlands dry. They carry diseases which affect other freshwater crayfish and, if caught, following positive identification, should be destroyed. Sightings should be reported to the Department of Fisheries' FISHWATCH service on 1800 815 507.

The conservation status of WA's wetland crayfish is:

Threatened: Margaret River burrowing crayfish *Engaewa pseudoreducta*
Dunsborough burrowing crayfish *Engaewa reducta*
Walpole burrowing crayfish *Engaewa walpolea* [3]

A recovery plan is in place for these three crayfish. For more information, see the 'Recovery planning and implementation' webpage of the DEC website.[117]

➤ *A field guide to freshwater fishes, crayfishes and mussels of south-western Australia*[96] provides an excellent summary of the crayfish of the south-west.

- The pamphlet *Identifying freshwater crayfish in the south west of WA*[211] is an easy to use guide.

Other crustaceans

The south-west of Western Australia is one of the global hotspots for inland aquatic crustacean diversity[212]. Smaller crustaceans include water fleas (Cladocera), seed shrimps (Ostracoda), copepods (Copepoda), water slaters (Isopoda), side swimmers (Amphipoda), brine shrimp and fairy shrimp (Anostraca), shield shrimp (Notostraca) and clam shrimp (Laevicaudata and Spinicaudata).

These smaller crustaceans are highly abundant and diverse, inhabiting a range of fresh and saline Western Australian wetlands. Most are well adapted to drying that is a feature of most of WA's wetlands. Many produce desiccation-resistant eggs that lie dormant in the sediment, remaining viable during prolonged dry periods. Others survive drought as encysted embryos. They are usually the dominant invertebrate group in intermittently inundated salt lakes in terms of biomass and productivity, although species richness is often low.[179]

Very small crustaceans, namely the water fleas and copepods have limited powers of locomotion to overcome currents and wave action, and along with other organisms such as rotifers and protozoans, are known as **zooplankton**.

The transparency of the south-west glass shrimps, *Palaemonetes australis*, makes them an easily identifiable crustacean. They are benthic inhabitants of fresh and estuarine waters[179] across south-western Australia,[213] scavenging on decaying plant and animal material. Research suggests they may be a potential bioindicator of crustacean health in relation to hydrocarbons.[214] It has also been suggested that they may be involved in the lifecycle of Carter's freshwater mussel, *Westraluno carteri*, a threatened endemic mussel of south-west Western Australia.[196] At a total body length of up to 35 millimetres, they are dwarfed by the cherabin *Macrobrachium rosenbergii*, a freshwater prawn native to the Kimberley that grows up to 300 millimetres.

Shield shrimp are a particularly fascinating crustacean of ancient origin. They have not changed physically in almost 300 million years[184] (Figure 43). They are typically found in wetlands that dry out and which do not support fish, surviving in the form of desiccation-resistant resting eggs, which are so small they can be carried by wind to other wetlands.[184] They are mostly found in wetlands with naturally high turbidity, protecting them from predation by waterbirds.[187] They feed on algae, bacteria, protozoa, rotifers, aquatic worms, fairy shrimp, frog eggs, tadpoles, rotting leaves and other detritus.[184]

Figure 43. The fascinating shield shrimp (*Notostraca*). Photo - W Chow/DEC.

Brine shrimp inhabit naturally saline wetlands while fairy shrimp tend to inhabit freshwater wetlands. Fairy shrimp eat bacteria, protozoa, rotifers, algae and detritus.[184] The brine shrimp *Parartemia* are an important component of many of Western Australia's primary saline wetlands, particularly in terms of their role in the food web supporting waterbirds, but they are rarely found in secondarily saline wetlands.[187] *Parartemia contracta* is uniquely restricted to acidic wetlands with a pH of between 2 and 6.[187] Despite being quintessential components of saline wetlands, little is known of the distribution, abundance and habitat requirements of brine shrimp.[215] Some appear to be quite rare. The introduced genus of brine shrimp, *Artemia*, were introduced as fish food and to control algae in salt production ponds but are now found in natural wetlands[187] and their distribution appears to be spreading. They are also sold as pets, commonly called 'sea monkeys'. Both the native and introduced species can inhabit wetlands that dry out, occurring as cysts during dry periods. It is thought that *Artemia* are less likely to occur in wetlands that dry regularly.

Clam shrimps (Laevicaudata and Spinicaudata), water fleas (Cladocera) and seed shrimps (Ostracoda) live within a two-halved shell, and move around using legs and/or antennae that can be protruded from the shell. The shells of Laevicaudata and Ostracoda can be closed shut whereas those of Spinicaudata and Cladocerans are permanently open.

Clam shrimp look a lot like molluscs such as mussels and clams because they are entirely enclosed in a shell. They usually inhabit seasonally to intermittently inundated wetlands, with their desiccation-resistant eggs remaining viable during prolonged dry periods.

The common name of 'water flea' given to Cladocera is due to their jerky swimming style, resembling a jumping flea. Visually they can be very interesting; for example, in some water fleas a green digestive tract, due to their algal diet, is visible, while in others, multitudes of eggs are visible in or on the female. Many aspects of their life are also fascinating, including the fact that while conditions are favourable, populations usually consist of female clones. When a wetland begins to dry, males are produced and sexual reproduction occurs, producing drought-resistant eggs.[187] Their ability to withstand drying, freezing and digestive juices as eggs allows them to disperse widely and survive in harsh conditions. Invertebrate specialists Gooderham and Tsyrlin[180] note that water flea eggs have been hatched from sediments that have been dry for 200 years! Water fleas of the genus *Daphnia* are familiar to many Western Australians, being common and abundant in many wetlands. They graze significant numbers of bacteria and phytoplankton as well as detritus and are food for many animals themselves. One species is largely restricted to granite outcrop pools (*Daphnia jollyi*) and some others occur only in salt lakes.

More than 150 species of surface water seed shrimps (ostracods) are known from Western Australia, although fewer than half are described.[216] Most inhabit wetland substrates (that is, benthic habitat). They can be important in wetlands, both when alive and dead, for example, their skeletons have been found to contribute to wetland sediments.[217] They fossilise well[218], so they are often used in palaeontological studies.

Copepods (Copepoda), water slaters (Isopoda) and side swimmers (Amphipoda) do not have shells. Copepods are very small crustaceans (most less than 2 millimetres) and inhabit all types of wetlands and are often extremely abundant. They vary in their habitat requirements. Water slaters are common in inland wetlands and waterways, with *Paramphisopus palustris* being the most common in south-western Australian wetlands and *Haloniscus* species the only ones to occur in saline wetlands. Water slaters and side swimmers don't produce drought-resistant eggs so are more common in permanently inundated wetlands, although they also take refuge in waterlogged soils.[187] The most common inland water amphipod of south-western Australia, *Austrochiltonia subtenuis*, is moderately salt tolerant. In inland Australia, amphipods and isopods are largely restricted to groundwater or groundwater fed wetlands.

➤ A key to and checklist of amphipods is available from the Australian Museum.[219]

Rotifers

Rotifers are microscopic to near-microscopic animals, with most being less than 1 millimetre in size. Close to 700 species are known from Australian inland waters[220], with over 300 known from WA. They can be extremely diverse and very abundant in almost all types of wetlands. Rotifers form part of wetland zooplankton communities, although some are sessile and are more common in submerged plant communities. Despite their size, their often high abundance means they can significantly contribute to nutrient cycling by eating small particles including particulate organic detritus, bacteria, algae, protozoans and other rotifers, mostly by filter feeding although some are active predators. Some live on the surface of other animals (epizoic) while others parasitise algae and zooplankton. Rotifers affect the species composition of algae in ecosystems through their choice in grazing.[221] In turn, they are eaten by some crustaceans and insect larvae. Many aspects of rotifers are fascinating, not least that most are female[19] and that some rotifers, such as bdelloids, can change from an inert state to normal activities within hours of a dry wetland flooding.[187]

The south-west is a biodiversity hotspot for rotifers, with more than one hundred species recorded in the Avon region alone.[187] They are readily dispersed as resting eggs by wind, birds and people, which helps to explain the widespread distribution of many species, though there is some regional endemism. Due to their small size, rotifers are sometimes omitted from sampling even though they can have extremely important ecological roles in wetlands.[221]

➤ For more information on rotifers, see the chapter 'Australian rotifera' in *Limnology in Australia*.[220]

➤ *A guide to the identification of rotifers, cladocerans and copepods from Australian inland waters*[222] contains a range of information including keys and general ecological and life history information.

The role of wetland invertebrates

- Invertebrates play a pivotal role in wetland food chains and nutrient cycling. They are a particularly important food source for wetland vertebrates such as fish, frogs, turtles, lizards, mammals, birds and bats. Moreover, many insects leave wetlands as adults, providing a very important source of food for a wide range of terrestrial animals. In seasonally inundated wetlands, remains of dead invertebrates on the dry bed provide a food source for terrestrial communities.
- Invertebrates that feed on algae, such as small crustaceans, molluscs and rotifers, improve water clarity by removing particulate matter from the water column. Water clarity is an important determinant of aquatic biota.
- Burrowing invertebrates (such as freshwater crayfish and oligochaetes) turn over and oxygenate wetland sediments. Oxygen in the sediment has a critical influence on the organisms that will inhabit it, as well as affecting other aspects of sediment and water chemistry.
- Molluscs and crustaceans such as seed shrimp create calcium carbonate in the form of calcite for their shells and this accumulates as a component of wetland sediments once these organisms die (Figure 44).
- Insects that leave wetlands as adults export nutrients, material and energy.

Figure 44. Mollusc shells are part of the sediment of the Mandora Marsh
Photo – M Coote/DEC.

PART 2: WETLAND ECOLOGY

Water, whether it is present permanently, seasonally or intermittently, is common to all wetlands. But what makes a wetland suitable for a particular plant or animal is a much more complex tangle of factors, as can be seen in Figure 45. Part 2 outlines major drivers of habitat. These include climate, and requirements for water, salinity, oxygen, light and food.

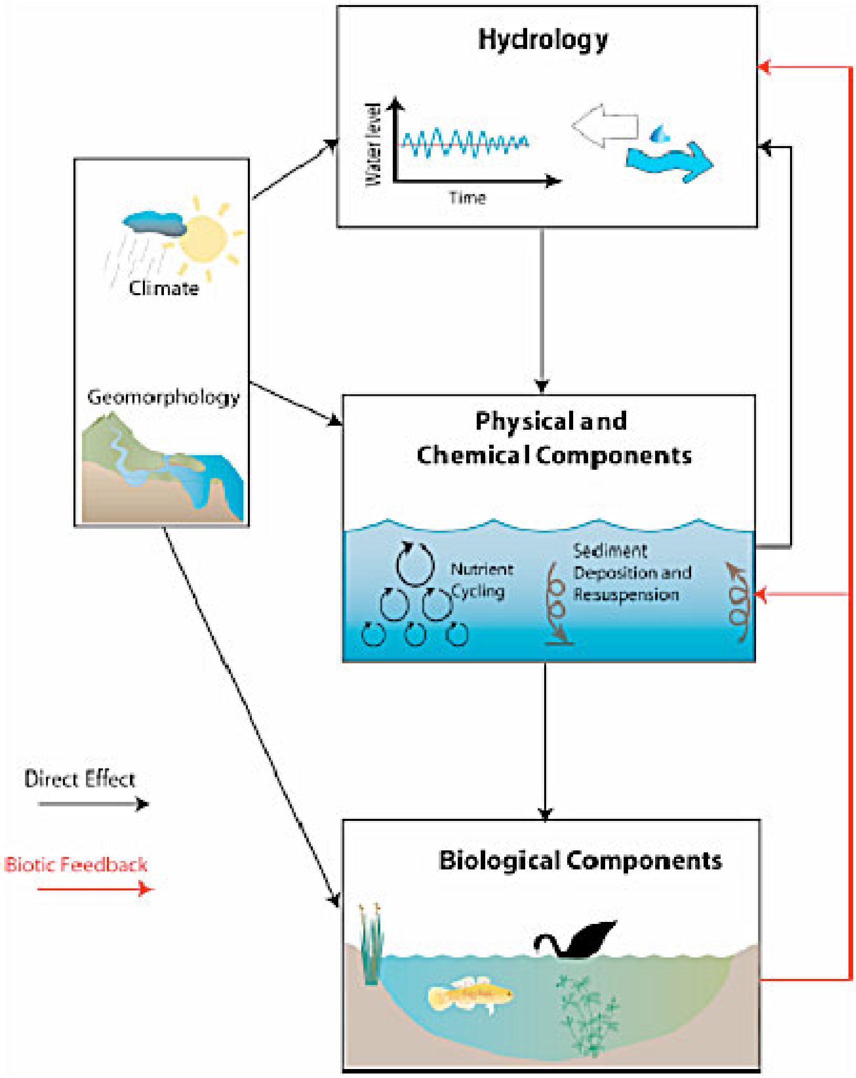

Figure 45. Connectivity between living and non-living parts of wetlands: linkages between physical, chemical and biological aspects. Adapted from Mitsch and Gosselink (2007).[223]

Regional climate and ability to disperse

Like dryland organisms, there are wetland species that occur widely across WA and beyond (**cosmopolitan** species). Other wetland species only occur in a particular region or subregion of Western Australia. The reason for this is the extreme regional differences in current and historical climates across WA, from tropical, to arid, to Mediterranean; and the environmental heterogeneity (diversity) produced by the evolution of landscapes, soils, aquifers and fire regimes over thousands of years in response to climatic variability.

Over geological time, species have had to adapt to changing conditions driven by rising and falling sea levels, aridity and ice ages; most of those that did not change significantly have become extinct or remain only in **refugia** including mound springs, permanently inundated wetlands in arid areas and damplands in wetter regions retaining Gwondanic elements.[224] For example, the ancient sedge species, *Reedia spathacea* (Figure 46), occurs in the Walpole region and the Blackwood Plateau. *Reedia* is considered to be a Gondwanan relict species, that is, a relict from the time when Australia, India and Antarctica were one landmass. It is found in wetlands with constantly high groundwater levels. Its current distribution is suspected to be the remains of a wider distribution during wetter conditions during the early and middle Tertiary period.[225] It is declared rare under the state *Wildlife Conservation Act 1950* and listed as critically endangered under the national *Environment Protection and Biodiversity Conservation Act 1999.*

Refugia: restricted environments that have been isolated for extended periods of time, or are the last remnants of such areas

Generalist: a species that can live in many different habitats and can feed on a variety of different organisms

Figure 46. The ancient sedge species, *Reedia spathacea*, occurs in the Walpole region and the Blackwood Plateau. Reedia is considered to be a Gondwanan relict species. Photos – main: J Liddelow/DEC; inset: S Kern/DEC.

The distribution of a species is also determined by its ability to disperse, either because it is mobile or it can make use of an alternative mode of 'transport'. This can be a lift on another animal (in a variety of forms including as an adult, larvae, egg, seed, cyst or spore) or via wind or water. Dispersal ability is very important in landscapes with variability in wetting and drying regimes. For example, studies of the Mandora Marshes in the northwest show that the macroinvertebrate fauna is dominated by highly vagile predators (species with a strong ability to move about).[216] Once a species disperses, it will only survive if it can either cope with different conditions (**generalists**) or adapt to them. Geographic barriers to dispersal can have a very strong influence on the occurrence and persistence of a species.

Western Australia's wetland plants are distinctive to three zones: the Kimberley, the deserts and the south west (Figure 47). These three zones are identified as distinct regions by both climatologists and biogeographers (who study the relationships between plants, animals, soils, water, climate and humans). The wetland flora and vegetation characteristics of each zone is described in detail in the topic 'Wetland vegetation and flora' in Chapter 2.

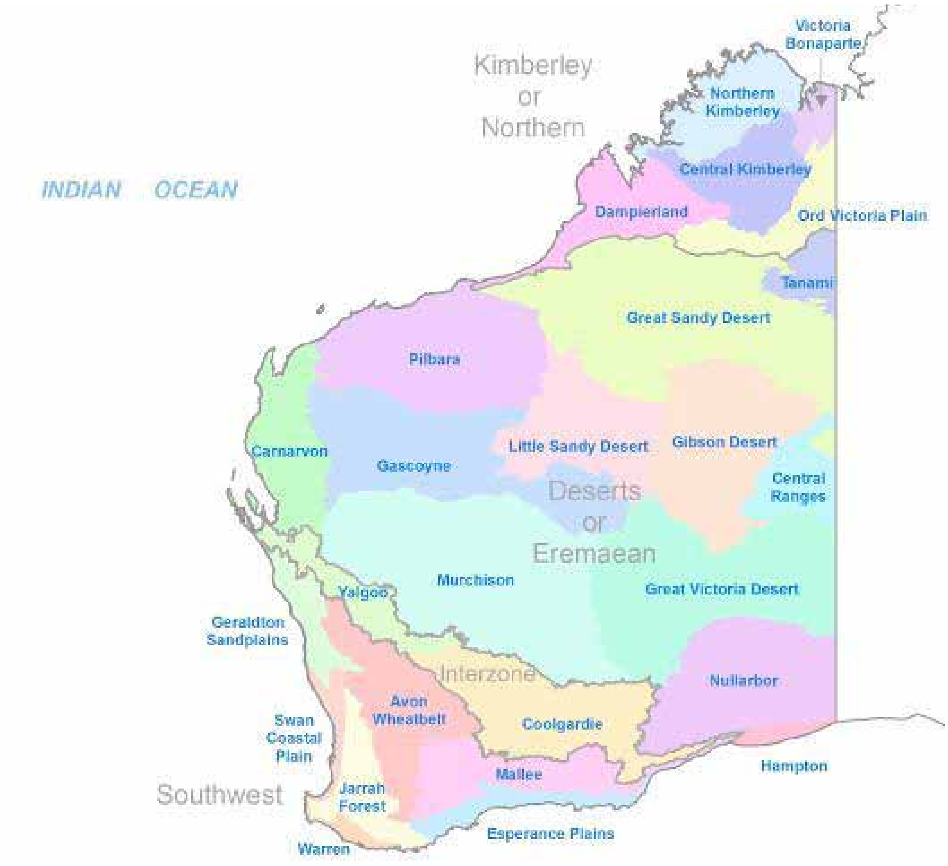

Figure 47. The three zones of wetland vegetation: the Kimberley, the deserts and the south west. Image - C Aurich/Auricht Projects

Niche: the role of an organism in a community, in terms of its presence, activity, habitat and the resources it uses

Many vertebrate animal species also show similar distribution patterns, including many wetland species. For example, researchers identify three unique fish provinces in Western Australia: the Kimberley, the Pilbara and the south west.[103] These provinces support different species, with very little overlap between the Kimberley and Pilbara, and no overlap with the south west region. Frog researchers also identify three Western Australian regions that define frog fauna (the Kimberley, arid zone and south west).[109] Distributions of turtle species are also extremely well defined, with little overlap in species composition between these broad areas.

Distribution patterns are also evident amongst invertebrates; for example, there are no crayfish species native to the deserts, while the Kimberley supports only one freshwater prawn (also of the Decapoda order), the cherabin *Macrobrachium rosenbergii*. However, due to the sheer number of species within many invertebrate groups such an analysis is complex.

Species water requirements

Water is the defining feature of all wetlands and influences the composition, richness and abundance of organisms in a wetland.

Water is naturally variable across the Earth, but especially so in Australia, a land 'of droughts and flooding rains'.[226] Its variability in terms of presence and absence, timing, duration, frequency, extent and depth is what makes each wetland unique. The flux of water drives many physical and chemical fluctuations in wetlands, such as the amount of oxygen, light, salts and nutrients. This creates a myriad of habitats and resources, and wetland organisms are adapted to these **niches**. Therefore, in managing wetlands, it is important to maintain the natural water variability of wetlands, in order to conserve the biological, physical and chemical diversity they support.

Most of Western Australia's wetlands are not permanently wet. In response to this transience of water, wetland organisms have many adaptations for surviving or avoiding drought, and this is part of the reason for the uniqueness of our wetland flora and fauna.

At a basic level, WA's wetland organisms can be grouped into one of four extremely broad groups:

1. those that inhabit, or need permanent access to a water column
2. those that inhabit, or need access to a water column for a period sufficient to fulfil part of their annual cycle or life cycle
3. those that inhabit, or need permanent access to saturated soils (without an overlying water column)
4. those that inhabit, or need access to saturated soils for a period sufficient to fulfil part of their annual cycle or life cycle

Many organisms may not fit neatly into one of these groups; they are useful as broad generalisations only. In reality, each wetland species has specific **water requirements** that determine where and how it lives and reproduces. If the **water regime** of its habitat changes beyond its tolerance, an organism must move to a new habitat on either a temporary, seasonal or permanent basis, or it will die; many smaller animals and annual plants do, typically reproducing first.

'Boom and bust' cycles are a natural part of the population dynamics of many wetland species in Western Australia. When a dry wetland wets, water seeps through the soil and soaks the resting eggs, seeds, spores and cysts, which begin to develop.[227] The influx of water releases a pulse of nutrients from the soil that, together with light and water, provide the resources for germination and growth of algae and plants. Algae and bacteria proliferate, providing food for consumers. A succession of small animals hatch, grow, reproduce and die. Emergent plants flourish, and in inundated wetlands, aquatic plants grow in submerged or floating habits, and both types of plant provide habitats for other organisms. As water recedes, new plants germinate on the exposed soil, flourishing on the nutrients released by anaerobic bacteria on drying. If water recedes through evaporation, concentration of the salts may result in increases in salinity. The smaller water volume may also lead to increases in temperature. These types of cues trigger plants, algae, bacteria and animals to prepare for another dry period.[227] Those that cannot tolerate dryness leave, burrow down, or die, first replenishing seed or egg banks.

Water requirements helps to explain why, for example, fish are not as prevalent in Western Australia's wetlands as some of the eastern states: with the exception of two species, all fish need to inhabit inundated wetlands or waterways for all parts of their life cycle, and a relatively small proportion of the state's wetlands are permanently inundated. It also helps to explain why annually renewed plant species that renew from seed, underground or above-ground storage organs on an annual basis, tend to be much more prevalent in wetlands than drylands. In the southern Swan Coastal Plain, for example, annually renewed species are twice as prevalent in wetlands than drylands.

As well as explaining the presence of species, water requirements provide an insight into the patterning of species over space and time. For example, why the same species of plants can be found at similar water levels in different wetlands, and why events such as a particularly wet season can result in a mass germination of tree seedlings in a given area of a wetland, or a larger than usual frog population. Wetland managers can use

Water requirements: the water required by a species, in terms of when, where and how much water it needs, including timing, duration, frequency, extent, depth and variability of water presence.

Water regime: (of a wetland) the specific pattern of when, where and to what extent water is present in a wetland, including the timing, duration, frequency, extent, depth and variability of water presence this knowledge for a variety of purposes, from planning revegetation to predicting how a long term change in a wetland's water regime to a wetter or drier state will affect the organisms that inhabit it.

Hydroecology: the study of the water regimes required to maintain and enhance conservation values of ecosystems

The study of water requirements of native species and ecosystems (known as **hydroecology**, and sometimes ecohydrology) has been driven by the widespread alteration of water in wetlands, waterways and terrestrial environments. In Western Australia, research into the water requirements of wetland organisms has focused on the Gnangara and Jandakot groundwater mounds in the greater Perth region[228,229,230], the Blackwood and Scott Coastal Plain groundwater areas[231], and Ramsar wetlands. Riparian studies that include wetland species in the Pilbara and Kimberley have also been the subject of a number of studies (for example, Loomes[232,233,234]).

Water requirements of plants

Given its optimum water regime, a wetland plant has the ability to grow, maintain new growth, periodically flower and set seed, and maintain resilience to disease and other factors.[234]

The study of the water requirements of wetland plants is instructive, because they are not mobile and can provide an insight into the water regime of a wetland, potentially over a long period. Trees in particular must become established at the right location in the landscape to meet their water requirements in order to survive. They will only germinate if the right conditions, including water regime, occur. These conditions must also prevail while the seedlings become established. Recruitment of some species, such as the moonah *Melaleuca preissiana*, has been found to be predominantly episodic rather than common, with particular events resulting in mass recruitment.[235] This is why it is common to see stands of these trees of the same age (height) and structured age sequences up and down elevational gradients in basin wetlands.

Once the trees are mature they are more likely to be able to cope with conditions outside of their optimum water requirements (this is sometimes referred to as 'plasticity'). In particular, if a seasonally inundated wetland is mainly groundwater fed and the groundwater level steadily falls further below the level of the wetland in the dry season over the course of an extended drought, some wetland trees will attempt to 'follow' the water down with their roots.[235] This is only possible, however, if the rate of decline is slow. The energy required for the tree to do this can be substantial, particularly for a tree experiencing water stress (often evident as yellowing, browning, wilting or dead foliage in vegetation). Rapid and prolonged alteration of water regime to wetter or drier conditions can result in the death of individuals, and potentially the whole population at a wetland. This is because in a time of rapid change, the conditions suitable for recruitment may not occur. For this reason mature wetland trees tend to be a good indication of the water trends in a wetland over their lifespan.

Wetland sedges, on the other hand, are typically capable of responding more rapidly to water fluctuations, because they can alter their distribution in the landscape using new recruits from seed, or using vegetative reproduction to produce clones. Clonal growth is more common and rapid than reproduction by seed. A below-ground rhizome grows parallel to the ground, producing a clone of its parent a short distance away.[236] This means that if the current position of a stand of sedges becomes unsuitably wetter or drier, the stand may use rhizomes to extend into an area more suited to their water requirements. But, as with wetland trees, if a change is too rapid or too extreme for the population to respond to, it will decline and lead to death. For this reason, sedges can be a good indication of short-term water conditions. A useful guide to the optimum water depths for a number of south-west sedges is the handbook *A guide to emergent plants of south-western Australia*[237].

Thresholds: points at which a marked effect or change occurs

Submerged plants and charophytes usually persist for up to four to five months at seasonally inundated wetlands in southwest WA.[238] Within the time that surface water is present, they must germinate, grow and reproduce. The persistence of a population at a wetland is therefore very dependent upon particular aspects of water regime including depth and drying time, as well as salinity and nutrient levels. The interplay of these factors can determine whether individuals and populations germinate, survive and reproduce.[239]

In 2000, a study was carried out on the water levels and duration of inundation or waterlogging being experienced by sixty wetland species at wetlands on the Swan Coastal Plain.[228] The results of this study have been used to inform the management of a number of wetlands in the greater Perth area. For example, the common wetland tree *Melaleuca rhaphiophylla* was found, on average, to exist at a maximum water depth of 0.006 metres above the ground and minimum water depths of 2.14 metres below the ground. However, the maximum water depth at which the tree was found during the study was 1.03 metres, while the minimum water level at which it was found was 4.49 metres below the ground. It was found to live in wetlands that are inundated on average 2.15 months of every year, but the longest period was 9.4 months of every year. This information is useful in that it provides wetland managers with a coarse indication of the maximum and minimum **thresholds** for the species' survival. Of equal importance, it shows that there is a great deal of variation amongst a species. However, identifying the water regime that supports a species is not as simple as defining the extreme measures (maximum and minimum). Simply maintaining the water level between a maximum and minimum height is a simplistic approach, because variability in water level is important for plant reproduction and other aspects that determine the ecological character of the site. Since this study, further studies have been undertaken across the broader south-west, resulting in updates to this water range data.

When managing a wetland of conservation value that is at threat of altered water regime, the physiological tolerances of the plants should be determined using information and measurements taken at the site (that is, empirical data). Knowledge of their physiological responses, morphological plasticity and reproductive flexibility is invaluable. Sophisticated on-site measurement techniques, such as sapflow sensors and water potential, are now available to quantify a plant's use of water. However, there are still limitations with extrapolating this data to stands, populations and communities.

Water requirements of animals

The water requirements of wetland animals is often considered in broad-brush terms, particularly those that require permanent surface water, such as almost all fish, rakali, waterbirds, and many aquatic worms, insects and crustaceans. Their requirements can be relatively simple in comparison to other wetland animals which have complex water requirements because they vary with life stages. Animals that require surface water for some of their life cycle include burrowing fish, tortoises, frogs, crocodiles, and many worms, insects and crustaceans (Table 2). The requirements of species that use seasonally waterlogged wetlands are even less well understood.

Table 2. Adaptations to wetland drying.

Strategy	Which organisms	Examples
Disperse to other wetlands/ waterways	Many waterbirds; freshwater crocodiles, some turtles, many invertebrates, such as true bugs and water mites	Movements of all waterbirds are closely tied to the availability of water and associated habitat conditions
Aestivation, hibernation, dormancy or burrowing	Some turtles, some crayfish, some fish, many frogs, mussels, snails, roundworms, leeches, rotifers	In response to dehydration, some roundworms enter a state of hibernation called 'cryptobiosis' that they can maintain for months or years.[184] Midge larvae in wetlands on granite outcrops are also known to do this[17]
Skin adaptations	Frogs	Specialised skin secretes mucus to help stop frog skin from drying out
Water holding capacity	Frogs	The water holding frog *Cyclorana platycephala* absorbs large quantities of water through their skin and store it in their tissues and particularly in the bladder where it can be reabsorbed later[114]
Drought-resistant larvae	Some midge species	Some midge species have drought-resistant adaptations and survive as larvae in a partly hydrated state[203]
Desiccation-resistant eggs	Many crustaceans, many insects such as some may flies, true flies and beetles	Water fleas (Cladocerans) have been recorded hatching from eggs that have been dry for 200 years[174]
Drought tolerant spores, cysts	Algae and bacteria, protozoans	Some advanced colonies of cyanobacteria are able to produce akinetes, thick-walled dormant cells that allow them to resist drought
Drought tolerant seeds	Plants	Nardoo sporocarps are resistant to desiccation and can survive for up to 20 years when wetlands dry out[10]

Mobile animals can move in response to changing water availability. If habitat is subject to changes in water regime, and changes to vegetation occur in response to this, it may no longer be suitable habitat for a particular animal, and might prompt it to move to other areas of a wetland, or to new wetlands. For example, if a waterbird's usual nesting sites are no longer inundated, they may seek a new nesting site. Human land uses can create barriers and fatal hazards to migration, particularly for land-based animals such as frogs, tortoises, quendas, rakali, snakes and lizards. These barriers and fatal hazards can coincide with a bust cycle of a population with catastrophic consequences for that population.

Water requirements of wetlands

Water managers and wetland managers often infer the water requirements of a particular wetland on the basis of data about the water requirements of a number of key species.

In WA, when water is being allocated to users in the community and to the environment by the Department of Water, two key concepts are used: EWRs and EWPs. An **ecological water requirement** (EWR) is defined as the water regime needed to maintain the ecological values of a water dependent ecosystem at a low level of risk. The EWR is typically expressed as measurable hydrological variables and their limits of acceptable change for key components and processes of the water dependent ecosystem (for example, Table 3). Managers can then determine the social and cultural (traditional owners) water requirements. Once these are known, the **environmental water provisions** (EWP) can be decided upon. This is defined as the water regimes that are provided as a result of the water allocation decision-making process taking into account ecological, social, cultural and economic impacts. They may meet in part or in full the ecological water requirements.

Aerenchyma: interconnected air-filled spaces within plant tissue that transport air from plant parts above the water or saturated soils to the roots

Table 3. Environmental water requirements expressed as measurable hydrological variables and their limits of acceptable change. Adapted from material drafted by the Department of Water.

Environmental objective	Baseline condition/ range of natural variation	Water regime attributes	Ecological water requirement	Interim limits of acceptable change (based on water regime)	
				Short-term (1–2 years)	Long-term (5–20 years)
Fringing sedge community	Area: 2 ha	Water level	Range: x m AHD	Observed range +/- x %	Observed range +/- x %
	Condition: excellent		Timing: Max levels in x ; min levels in x	Observed range +/- x %	Observed range +/- x %
	Trend: successful recruitment		Rate of change: x	+/- x %	+/- x %
		Hydrologic events	Magnitude: receives overflow in events exceeding x ARI	X events exceeding x ARI	X events exceeding x ARI

➤ The Department of Water is preparing guidelines on ecological water requirements for urban water management.

➤ *Statewide policy no. 5: Environmental water provisions policy for Western Australia*[240] provides a policy position on protecting wetland ecological water requirements.

Species oxygen and carbon dioxide requirements

Oxygen is needed by most living things. Oxygen exists in much lower proportions in water (about 1 per cent) than in air (about 21 per cent).[241] This affects which organisms can inhabit waterlogged sediments and wetland water columns. Wetland waters that are saline, warm, coloured, turbid, stratified, nutrient-rich or plagued by algal blooms tend to have even lower oxygen levels than other wetlands.

The sediments of wetlands that dry are subject to large variations in oxygen levels. This exposure of sediments to air between inundation or waterlogging events typically causes a shift in the suite of organisms present.

Many wetland plants, and particularly shrubs and trees, need the soil around their roots to dry out periodically, to let in air. This is because plants evolved on land, where oxygen is abundant and can be accessed from the soil by plant roots. The plants that we now know as wetland plants have, over time, developed a variety of adaptations in order to colonise wetland habitats where the waterlogged or inundated conditions mean that oxygen levels are low or completely absent due to waterlogging of the soils. The adaptations include:

- Fine, shallow root systems that avoid the need to transport gases a long way, for example, *Melaleuca* species.[242]
- Air spaces known as **aerenchyma** in their roots and stems, that act like straws,

moving air from aerial parts of the plant to the root tissues where it is needed. In sedges, this is often visible as spongy or hollow tissue in the leaves and stems.[43] Genera which display this adaptation include *Viminaria, Melaleuca, Juncus, Typha, Sesbania, Eucalyptus* and *Marsilea*[243] including local species such as *Melaleuca cuticularis*[244], *Melaleuca cajuputi*[245] and *Typha domingensis*.[246] This can have implications for plants such as *Typha*, which can decline in health when cut or grazed to below the water line, as this seriously impedes oxygen access.

- Pressurised gas flow from the surface to the roots. A study of a number of southwestern WA sedges demonstrated that those species that produced more pressure are able to survive deeper water than those that produce low pressure. Amongst others, this study found this link occurred in *Typha domingensis, Typha orientalis, Eleocharis sphacelata, Schoenoplectus validus, Baumea articulata* and *Cyperus involucratus*.[223]
- Specialised roots known as **adventitious** roots that grow from the plant trunk, just above the water line in order to access the air. *Melaleuca* trees (Figure 48) and river gums (*Eucalyptus camaldulensis*) are known to employ adventitious roots.[244]
- Loss of pores in leaves used for gas exchange (**stomata**) in submerged plants.[43] This waxy layer on the outside of the leaf that functions to reduce water loss in land plants is not required. Instead, the cell walls are very thin, to allow absorption of gases from the water column.[242,38] Unfortunately this also means submerged plants can absorb herbicides quickly, directly from the water.[43]
- Similarly, algae and cyanobacteria have very thin cell walls, making it easier to absorb dissolved gases and nutrients from the water column.
  - Floating leaves, both on plants rooted to the sediments and those that are floating, unattached to sediment. Floating leaves with stomata on the upper surface can take up gases from the atmosphere. These often have a large surface area, for example, *Nardoo* and waterlilies such as *Nymphaea* species. Duckweed *Lemna* is an unattached, floating plant.

Adventitious roots: roots that arise from mature plant tissue such as stems or trunks and which take up oxygen and nutrients in inundated conditions

Stomata (plural of stomate): pores in leaves and stems used for gas exchange

Figure 48. The adventitious roots of a *Melaleuca* tree at Manning Lake, in the suburb of Hamilton Hill. Photo – J Lawn/DEC.

The diffusion of oxygen from plants into wetland soil is often evident in the areas around plant roots or rhizomes. The presence of narrow, orange or brown-coloured areas along roots, known as ‘oxidised root channels’ indicates oxidised conditions due to radial oxygen loss.[247,242] The oxidised area, known as the rhizosphere, also supports types of bacteria and other organisms that are not found in surrounding areas with low oxygen levels.

Low-oxygen conditions pose a problem for large animals; for example, fish cannot survive in water with less than 30 per cent oxygen saturation.[67] They employ gills to maximise oxygen intake, as do larval insects (for example, dragonfly larvae), crustaceans, and tadpoles. The phenomenon of ‘fish kills’, when large numbers of fish perish, is often caused by low oxygen levels. Animals that don’t have gills instead have other interesting ways of accessing oxygen. Diving beetles and some of the true bugs (Hemipterans) capture bubbles of air from the surface, and carry them underwater to breathe. Crocodiles and turtles also surface to breathe. Frogs have specialised skin that absorbs oxygen and releases carbon dioxide.

Some snails have gills, while others such as pond snails (Lymnaeidae) have lungs, allowing them to better survive in oxygen-poor conditions. These snails can be seen just under the surface of the water, refilling their lungs. Mussels and clams continually pump water through their bodies, supplying their gills with a constant supply of oxygen. Some larvae of moths and butterflies (Lepidoptera) use a cylindrical case constructed of plant material, which they use like a scuba tank to stay underwater for prolonged periods.[180] The larvae of aquatic weevils (Curculionidae) live inside air-filled stems of aquatic plants.[180] Some animals move to another area of the wetland if conditions become anoxic. In deeper wetlands, invertebrates inhabiting the deepest area of the water column move into shallower waters when oxygen levels decline.

Many species of midges, worms and mosquitoes are well adapted to low-oxygen conditions. The distinctive red colour of the larvae of some midge (*Chironomus*) is due to their blood pigment (haemoglobin), which makes them efficient at breathing dissolved oxygen. Segmented worms (oligochaetes) can be common in low oxygen conditions.[18] In fact, some segmented worms can live in waters with an oxygen concentration close to zero.[180] Mosquito larvae and water scorpions breathe air from above the water surface through structures on their abdomens. Mosquitoes will either return to the surface, or they will often float with their snorkel-like siphons puncturing the water surface, which provides them with a constant supply of oxygen. Similarly, the unpleasantly named rat-tailed maggot (Syrphidae) survives in putrid, anoxic water by using their extendable snorkel (the so-called rat-tail) to take in air from the surface.

A range of bacteria do not require oxygen to survive, making them an important part of wetlands which support anoxic conditions. Some use oxygen when it is available but switch to other chemicals when it is not.

The oxygen level in water also affects the decomposition of organic matter. The process of decomposing organic matter in low oxygen conditions is less efficient and for example, freshwater wetlands with consistently low oxygen levels (and low pH) tend to build up peat.

➤ For more information on the conditions that influence oxygen levels in wetlands, see the topic 'Conditions in wetland waters' in Chapter 2.

Species light requirements

Light availability in wetlands with a water column is quite different to that of drylands, because once sunlight reaches wetland waters it is rapidly altered and reduced, so that both the quality and quantity of light available is quite different to what first reached the surface of the water. This affects which organisms can inhabit wetland water columns. Wetland waters that are deep, heavily shaded, turbid or coloured (for example, tannin stained) tend to have reduced light levels compared to other wetlands.

➤ For more information on the conditions that influence light levels in wetlands, see the topic 'Conditions in wetland waters' in Chapter 2.

Plants and algae are particularly affected by light availability. All plants and algae need light for photosynthesis and in wetlands with a water column they need to remain within the euphotic zone (also known as the photic zone). Put simply, this is the area of the water column penetrated by light of sufficient intensity and of suitable wavelength to enable photosynthesis by aquatic plants.

Aquatic plants with their roots in the sediment are almost always restricted to relatively shallow water. Their need for light means that they can be greatly affected by sudden declines in water clarity or changes in water level. A reduction in light availability tends to favour phytoplankton over plants (Figure 49). Therefore, plants use a number of strategies to maximise their access to light and to disadvantage phytoplankton. These 'self-stabilising mechanisms' include providing refuges for phytoplankton grazers, removing nutrients from the water column and using their surface area to reduce sediment re-suspension.

Figure 49. Plants and algae compete for light in wetlands, particularly those with a water column. Photos – (a) G Keighery/DEC (b) J Lawn/DEC (c) M Lyons/DEC.

(a) aquatic plants prevail in clear water with good light

(b) phytoplankton can completely block out light

(c) abiotic turbidity can affect both plant and phytoplankton growth

To maximise both light and nutrient absorption submerged plants maximise the surface area of the leaves; often forming very dissected or fine leaves especially in deeper waters. Examples include water milfoils (*Myriophyllum species*) and fennel pondweed (*Potamogeton pectinatus*). Other species form whorls or spirals of leaves down the stem to increase their access to light, such as curly pondweed (*Potamogeton crispus*).[43]

Water milfoils, *Myriophyllum*, are typically adaptable species, able to grow as a submerged plant or an emergent plant. Water milfoil is very common in coloured (tannin-stained) wetlands where having aerial shoots enables it to cope with the severe light limitation in these wetlands.[43]

Some plants get the best of the light, oxygen and nutrients by having their roots in the sediment where nutrients are concentrated, long stems that span the water column, and leaves floating on the surface where light is available. Because their stems must span the water column, sudden increases in water depth is a potential problem for these plants. Waterlilies have this growth form. The tropical climates and nutrient-rich sediments in which they grow allow them to have a high growth rate, and the stems elongate rapidly with rising water levels.[43,242]

In comparison to submerged and emergent plants, phytoplankton and floating aquatic plants are not restricted to shallow water. To cope with low light conditions in deep and/or turbid water, some algae and cyanobacteria can adjust their buoyancy to stay in the euphotic zone. Floating aquatic macrophytes can also live in wetland zones where water is deep, because at the surface they have easy access to light and oxygen. Some floating plants make use of the water's surface tension, laying their leaves flat on the water surface (for example, duckweeds, *Lemna*). Other larger floating plants have air-filled tissue that assists them to float (for example, the introduced aquatic pest plant, water hyacinth, *Eichhornia crassipes*). However, they trade off the ability to access nutrient-rich sediments.

Species salinity requirements

All wetland species are adapted to particular ranges and types of salts in their environment. Species range from very intolerant of salinity, through to **halophiles**, named after the Greek term for 'salt-loving'. Many of the ions dissolved in wetland water columns and pore waters are essential to life and play important roles in the functioning of particular species and the ecosystem.

Halophile: a species that shows a preference for saline habitat such as salt lakes

Samphire: the common name for a group of succulent sub-shrubs and shrubs including *Tecticornia, Halosarcia, Sarcocornia, Sclerostegia, Tegicornia* and *Pachycornia*, belonging to the family Chenopodiaceae

Saline wetlands are inhabited by very different species than freshwater wetlands. This applies both to organisms in wetland water columns, and also to those in the sediments that are bathed in saline pore waters and/or ingesting salt associated with waters and sediments. To a much lesser degree, species salinity requirements are also evident in wetlands that are seasonally fresh but which become increasingly saline following seasonal evaporation.

Importantly, juvenile plants and animals are often much more susceptible to increased salinity levels than adults of the same species[248], therefore in order for a species to persist, salinities must be low enough during their development, as well as during reproductive phases, for recruitment to occur.

Organisms adapted to either naturally saline or freshwater conditions usually cannot tolerate large changes in the timing, duration, seasonality or range of salinities.[249,248] Although plants require some salts for development and growth, when grown in saline conditions, most plants (both wetland and dryland) suffer from stress. Osmotic stress occurs when saline conditions inhibit plants from taking up water, so that they become water-stressed. Ionic stress occurs because the dominant ions of salty water (often sodium and chloride ions) can disrupt proper functioning of cells, and can also inhibit the uptake of nutrients important for plant growth.

In the overstorey, some species of sheoaks (*Casuarina*) and even some paperbarks (*Melaleuca*) can be relatively salt-tolerant, such as *Casuarina obesa* and *Melaleuca cuticularis* respectively. Sedges such as *Gahnia trifida* are also salt-tolerant. However, more extremely salty environments are the domain of true saltmarsh plants, the **samphires**. Samphires include plants such as *Halosarcia* and *Sarcocornia* which are succulent in order to dilute the salt. For example, *Sarcocornia quinqueflora* accumulates salt in swollen leaf bases which fall off, thus removing excess salt.[43,76]

Some plants have roots with surfaces that exclude salt. Other plants have salt glands in which salt taken up is gathered and then excreted from plant leaves. Salt crystals, formed from very salty water excreted by salt glands, can often be seen on leaf surfaces in these species, such as in the grass Marine couch (*Sporobolus virginicus*) which grows at inland as well as coastal wetlands.[43]

Compartmentalising salt in a **vacuole** (package) within the cell is another method some plants use to keep salt from damaging the cell. However, compartmentalisation must be accompanied by osmotic adjustment, in which the cell must produce organic solutes to be kept outside the vacuole, to ensure that water from the cell does not flow into the vacuole through osmosis.[43]

➤ For more information on salinity thresholds for submerged plants and charophytes of south-west WA, see Sim (2006).[239]

The adults of many vertebrate species found in Western Australian wetlands are highly mobile, and can tolerate salinity if they can access alternative sources of fresh drinking water.[250,251,129] An example is the Australian shelduck (*Tadorna tadornoides*), which feeds at saline wetlands and is able to rid itself of excess salt it ingests through specially-adapted nasal glands.[250] However, when breeding, Australian shelducks are dependent of fresh waters until their young develop an ability to rid their bodies of salt.[250] Another example of a moderately salt-adapted freshwater vertebrate is the oblong turtle (*Chelodina colliei*), which is known to be able to tolerate estuarine level salinities if it has access to fresh water for breeding and long term health (J Giles 2009, pers. comm.).[129] It does not possess a salt excretory gland (J Giles 2009, pers. comm.).

Some species, such as the brine shrimp *Parartemia*, are able to regulate the concentration of their internal fluids in relation to the environment (osmoregulators), while others have no ability to do this, and their internal concentrations reflect that of the solution they are immersed in (osmoconformers).[252]

Species food/energy requirements

Much is made of the productivity of wetlands worldwide, but wetlands are not wet islands; most are very connected to the surrounding dryland, and often to waterways. Wetlands import and export energy and nutrients in two main ways: through the movement of water, which carries with it energy and nutrients in the form of particulate and dissolved matter; and the movement of animals. WA's wetlands vary widely in the amount of food and energy they contain, and this is a major influence on the amount and types of life they sustain.

Food chains and food webs are concepts to help describe how food and energy moves. **Food chains** describe who eats whom, in a simple linear order. They represent the flow of energy or nutrients in ecosystems. Vertebrate animals are usually at the 'top' of the chain. **Food webs** are comprised of two or more interconnected food chains, because many species can eat (or be eaten by) a range of organisms; these can be extremely complex. Understanding these **trophic** relationships can be very important to understanding a wetland's ecology.

In particular, food webs assist in explaining how nutrients, energy and biomass cycle through a wetland as well as what comes in and goes out. When one organism consumes another, nutrients and energy are transferred. Food webs shed light on a variety of natural processes, from why wetlands that wet and dry experience pulses of energy and life, to why some wetlands build up peat. It can also explain why alterations to the catchment of a wetland can affect wetland species. Alterations to the amount of nutrients and energy in a wetland are one of the most common challenges for Western Australia's wetland managers, resulting in booms in some populations of algae, nuisance midge and mosquitoes, weeds and other opportunists, at the expense of other species, as well as leading to problems such as botulism in waterbirds. On the other hand, high levels of nutrients and energy are the reason why some ecosystems support high numbers of birds (such as the Vasse-Wonnerup estuary in the south west).

Vacuole: A storage compartment found within a cell

Food chain: a diagram of who eats whom in a simple linear order, representing the flow of energy or nutrients in ecosystems. Two basic food chains are the grazing and detrital food chains.

Food web: a diagram that represents the feeding relationships of organisms within an ecosystem. It consists of a series of interconnecting food chains

Trophic: relating to nutrition, food or feeding

Along with other factors, food webs can assist in explaining why a species is present or absent at a wetland, and also a species' population dynamics. For example, foxes, which eat turtles, may act as a population control on turtles. If foxes decline, turtle numbers may return to natural levels, or alternatively, the cat population may instead flourish. Either scenario can have flow-on effects on an ecosystem. Wetland managers can use this information to understand how to maintain or restore natural populations and minimise unintended effects of management actions.

The concept of food webs is useful, but managers rarely construct anything but the most conceptual of food webs as management tools. Knowing what a species eats can vary according to the resources available in a region, site and season, and according to the phase of an individual in its life cycle. Scientists use inference, observation, confirmation of gut contents and isotopic analysis techniques to establish eating patterns.

At the beginning of every food chain on Earth are the **primary producers**: plants, macro and microscopic algae and cyanobacteria. Primary producers may be eaten alive or dead. They are called primary producers because they are able to produce their own energy for growth and survival. Via the process of photosynthesis, they harness the sun's energy and store it as carbohydrates built from carbon dioxide. As well as carbon dioxide, they need nutrients, such as nitrogen and phosphorus for growth and survival. Western Australian soils (and by extension waters) are some of the most nutrient-poor in the world, and in undisturbed wetlands, the plants and algae are in balance with levels of nutrients available. Nutrient cycling in wetland soils is very active and there is competition between plants and microbes occupying the soil for available nutrients.[253]

Organisms that consume other organisms, either dead or alive, are called **consumers**. These include herbivores (plant-eaters), carnivores (meat-eaters) and omnivores (plant and meat eaters); and they may be either specialists, with very specific diets or generalists, such as water boatmen, which eat a range of prey. Animals are sometimes described according to feeding **guilds**, particularly waterbirds. Usually the consumers at the top of the food chain in Western Australia's wetlands are large predators, including fish, tortoises, snakes, lizards, crocodiles, water rats and waterbirds. Predators such as birds of prey have large hunting territories including wetlands, and may consume the top wetland predators and, along with mammals such as kangaroos and wallabies, export nutrients and other material from wetlands.

Those consumers that predominantly eat decaying organisms are known as detritivores. Large **detritivores** such as crayfish fragment detritus, feeding on the larger pieces and creating smaller pieces that smaller detritivores eat with the help of bacteria and fungi that 'condition' the material. Very fine particulates are eaten by near-microscopic detritivores such as rotifers. Where oxygen levels are high, such as when wetland soils are dry, detritivores including earthworms, millipedes, isopods, mites, springtails, beetles and true flies may occur.[13] In saturated soils, where oxygen levels are low, insects such as midge (chironomid) larvae, craneflies, mayflies and caddisflies, worms (Oligochaetes and Platyhelminthes) and crustaceans such as seed shrimps (Ostracoda), water slaters (Isopoda) and side swimmers (Amphipoda), and sometimes sponges, prevail.[18,13] Many inhabit the sediment of wetlands where much of the detrital material settles. Although this can be a challenging environment because of the low oxygen conditions that can occur (particularly in deep, permanently inundated wetlands), many species employ a strategies to overcome the low oxygen in order to take advantage of the relatively abundant nutrient and food supply that settles at the bottom of a wetland. This trade-off seems to work, as the biomass of detritivores can be high.

Decomposers complete the cycle of life, with their ability to make use of carbon and nutrients that primary producers, consumers and detritivores are not able to take up. These fungi and bacteria perform most of the chemical breakdown of dead organisms, unlocking carbon and nutrients from complex molecules from this organic matter, with

Primary producer: a photosynthesising organism. Primary producers, through photosynthesis, harness the sun's energy, store it in carbohydrates built from carbon dioxide

Consumer: an organism that feeds on other organisms, either dead or alive

Guild: a group of species that exploit similar resources in a similar fashion

Detritivore: an animal that feeds on detritus

Decomposer: organisms, mainly bacteria and fungi, which break down complex organic molecules from detritus, liberating nutrients and assimilating carbon their armoury of chemicals known as enzymes. These enzymes enable them to assimilate dissolved and particulate organic matter that originates from dead microbes, animal faeces and algal secretions. This chemical decomposition of organic matter releases nitrogen in inorganic forms, which are then available for uptake by plants and algae. It also allows bacteria to assimilate carbon in the form of dissolved organic carbon, which is the most abundant form in wetlands.[22] This makes them a nutritious food source, forming a vital food source for organisms further up the food chain.[17] Much of the nutritious value of detritus (such as dead leaves) is not in the detritus itself, but rather in its coating of microbes that are decomposing it, that provides an energy-rich food source. They are efficient at assimilating the carbon they consume, converting 20–50 per cent of the carbon they consume into new bacterial biomass. This makes bacteria essential in wetlands because carbon is needed for growth and survival of all life in wetlands. Decomposers are fundamental to the nutrient, carbon and energy cycling of wetland ecosystems[17,18]

Wetland ecosystems

An ecosystem is a community of interdependent organisms together with their non-living environment. How wetlands function at the ecosystem level is a reflection of their physical, chemical and biological characteristics.

Wetland scientists use a number of tools to describe wetland ecosystems, including conceptual models, the alternate stable states model, and ecological character descriptions. These are outlined briefly below.

Conceptual models

A popular way to understand and communicate important influences and relationships in wetlands is to use simple diagram often called 'conceptual wetland models'. They typically depict how a wetland functions or how a change to a wetland may drive a series of further changes within the wetland. They may be basic, somewhat generic or stylised

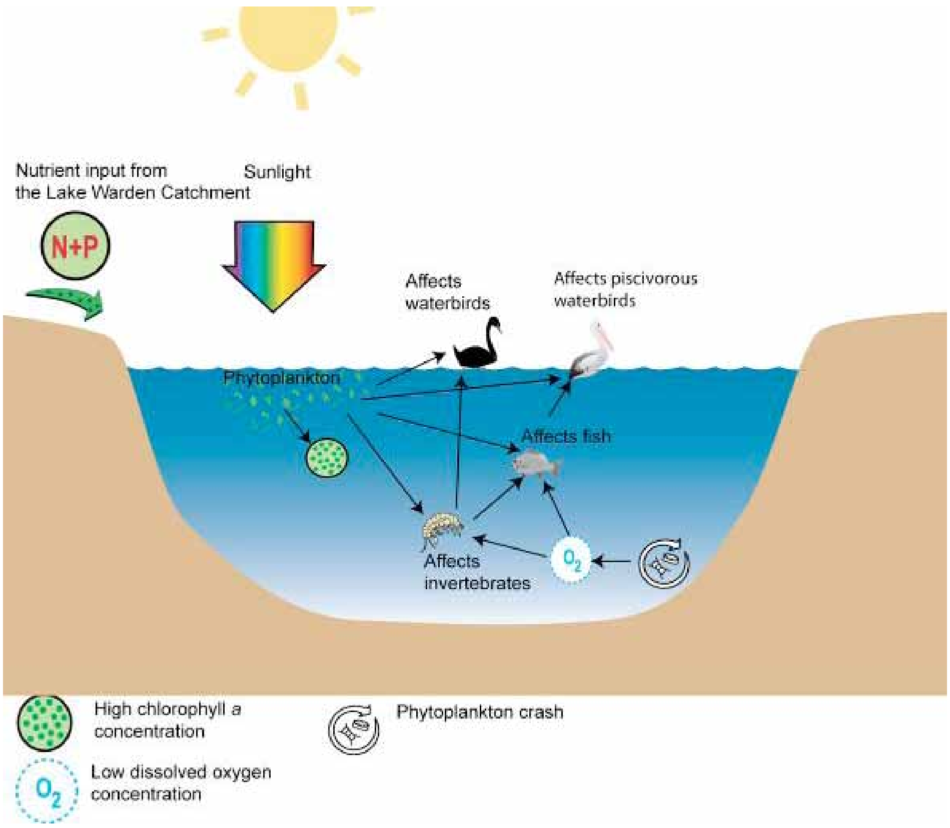

Figure 50. A stylised conceptual model of the potential effect of nutrient enrichment from the catchment at the Lake Warden System Ramsar Site, Esperance. Image - G Watkins.

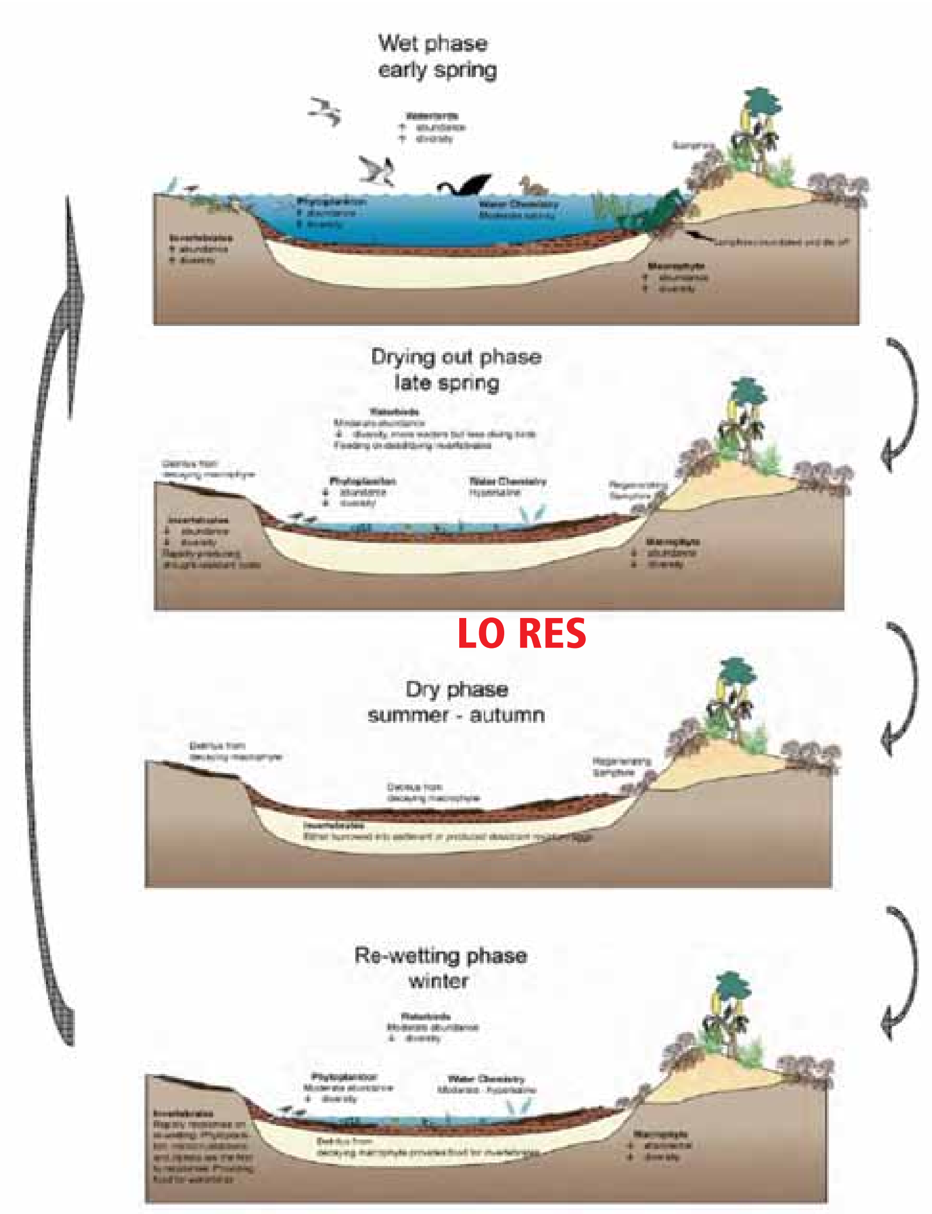

Figure 51. A conceptual model of a naturally saline playa, showing changes in wetland organisms over the course of a year. Image – Jones et al.[32]

models, such as Figure 50, or more detailed models, such as Figure 51. Conceptual models can also help wetland managers to identify important elements of a wetland that should be monitored.

➤ The Queensland State government is developing conceptual models for most of their wetland types. They provide a lot of resources online to assist individuals create conceptual models, available from the Queensland Department of Environment and Resource Management website.[254]

Alternate stable states

The alternate (or multiple) stable states model accounts for the combined effect of light, nutrients, salinity and water regime in wetlands with a permanent, seasonal or intermittent water column. It is based on the concept that within an ecosystem there may be two or more stable states that can exist at any one time depending on the influence of a determining factor or factors. A stable state is one where the ecosystem tends to remain the same (that is, comprises the same species in the same relative abundances) over a certain period of time (for example, a season or a year). Often a positive feedback system is present with a particular state creating conditions that will favour its persistence. Between the stable states is an unstable equilibrium. The change in the ecosystem between the alternate states often occurs very rapidly and with little warning. Hysteresis is also likely to occur, that is, the condition that caused a shift from one state to another does not necessarily result in a shift back to the first state when the condition is simply reversed. For shallow European lakes undergoing nutrient enrichment, the concept of two states has been described: clear water dominated by aquatic macrophytes (aquatic plants) and turbid (cloudy) water dominated by phytoplankton. For Australian lakes, this model has been extended to describe five 'states' or ecological regimes recognised by Davis et al. [255], Strehlow et al.[238], and Sim et al.[256] for southern Australian wetlands:

I Clear, submerged macrophyte-dominated;

II Clear, benthic microbial community-dominated;

III Turbid, sediment-dominated;

IV Turbid, phytoplankton-dominated; and

V Free-floating plant dominated.

Regime I is defined as clear water with aquatic plants (submerged, floating and emergent species). Regimes I, II, and III all represent regimes found in undisturbed wetlands and may often be the baseline state. The first regime represents undisturbed wetlands of fresh or low salinities and low to moderate enrichment. The second regime represents naturally hypersaline or acidic lakes. The third occurs naturally in shallow wetlands with clay substrates, for example, claypans, or under the low water levels associated with naturally occurring drying or wetting phases in seasonal wetlands. It is usually produced by wind driven re-suspension of bed sediments. The fourth and fifth regimes occur at high phosphorus levels, often more than 150 micrograms per litre, and usually represent a shift from Regime I driven by eutrophication. The submerged macrophyte-dominated regime demonstrates some resilience to increased nutrient loading before reaching a threshold. Secondary salinisation or acidification can drive a shift from Regime I to II. Drawdown of water levels as a result of surface water or groundwater abstraction can result in a shift from Regime I to III.

Text sourced from Department of Environment[70] and Maher and Davis.[257]

Ecological character descriptions

Wetlands that are recognised as internationally significant under the Ramsar Convention are now described by scientists using a report type known as an 'ecological character description'. This report describes the key aspects of the wetland that result in its **ecological character**, that is, the sum of a wetland's biotic and abiotic components, functions, drivers and processes, as well as the threatening processes occurring in the wetland, catchment and region.

These characteristics form a benchmark against which any future change in condition is measured. In particular, the primary determinants of ecological character must be monitored. These are the features of the wetland that make it special or unique. In the case of a Ramsar listed site, these include the **wetland components, wetland processes** and **ecosystem services** that support the relevant nomination criteria. For example, if a site is internationally significant because it supports large numbers of waterbirds, it is important to protect these birds and the habitat that they utilise. This may include maintaining the water level and the water quality to ensure that the birds' food source persists, as well as maintaining vegetation that is used for nesting. At a minimum, monitoring must determine if the site continues to meet the Ramsar criteria under which it was nominated. Ideally, a monitoring program will include elements of the ecosystem that will provide early warning of any pending deterioration in ecological character.

Ecological character: the sum of a wetland's biotic and abiotic components, functions, drivers and processes, as well as the threatening processes occurring in the wetland, catchment and region

Wetland components: the physical, chemical and biological parts of a wetland (from large scale to very small scale, e.g. habitat, species and genes)

Wetland processes: the dynamic physical, chemical and biological forces within a wetland, including interactions that occur between wetland organisms, within the physical/ chemical environment, and the interactions of these

Ecosystem services: benefits that people receive or obtain from an ecosystem, including provisioning services (such as food, fuel and fresh water), regulating services (such as ecosystem processes such as climate regulation, water regulation and natural hazard regulation), cultural services (such as spiritual enrichment, recreation, education and aesthetics) and supporting services (such as the services necessary for the production of all other ecosystem services such as water cycling, nutrient cycling and habitat for biota)

➤ To view the ecological character descriptions for each of WA's Ramsar sites, see the wetlands webpage of the DEC website www.dec.wa.gov.au/wetlands.[258]

- For information on the Ramsar ecological character description template, see the report and checklist available online from the Department of Sustainability, Environment, Water, Population and Communities.[259]

GLOSSARY

Adventitious roots: roots that arise from mature plant tissue such as stems or trunks and which take up oxygen and nutrients in inundated conditions

Aerenchyma: interconnected air-filled spaces within plant tissue that transport air from plant parts above the water or saturated soils to the roots.

Aerobic: an oxygenated environment (organisms living or occurring only in the presence of oxygen are aerobes)

Aestivation: a state of dormancy that occurs in some animals to survive a period when conditions are hot and dry

Algae: a general term referring to the mostly photosynthetic, unicellular or simply constructed, non-vascular, plant-like organisms that are usually aquatic and reproduce without antheridia and oogonia that are jacketed by sterile cells derived from the reproductive cell primordium; includes a number of divisions, many of which are only remotely related to one another[30]

Algal bloom: the rapid, excessive growth of algae, generally caused by high nutrient levels and favourable conditions

Amphibian: the class of animal to which frogs, toads and salamanders belong. They live on land but develop by a larval phase (tadpoles) in water.

Anaerobic: without air (organisms that live in these conditions are anaerobes)

Anaerobic respiration: respiration without oxygen (O_2). Respiration is the process by which organisms convert the energy stored in molecules into a useable form. In most organisms, respiration requires oxygen, which is why breathing by animals is referred to as respiration. However, some bacteria are capable of anaerobic respiration, in which other inorganic molecules (such as sulfur, metal ions, methane or hydrogen) are used instead of oxygen

Anoxic: deficiency or absence of oxygen

Annual: a plant that completes its life cycle within a single growing season (from germination to flowering, seed production and death of vegetative parts)

Benthic: the substrate of a wetland; the organisms inhabiting it are known as benthos

Benthic microbial communities: bottom-dwelling communities of microbes (living on the wetland sediments)

Benthos: organisms living in or on the wetland substrate

Bioavailable: in a chemical form that can be used by organisms

Biofilm: bacteria, microalgae, fungi and unicellular microorganisms enmeshed in a hydrated mucopolysaccharide secretion that sequesters ions and isolates microorganisms from the water column[14]. May be present on living and non-living surfaces and substrates.

Biomass: the total mass of biological material (living or dead), usually expressed as live or dry weight per unit area or volume

Bioremediation: the use of microorganisms to break down environmental pollutants

Blue-green algae: an older term for cyanobacteria

Botulism: a paralytic disease caused by ingestion or exposure to a toxin produced by the bacteria *Clostridium botulinum*

Charophytes: green algae of the Characeae family; complex algae that superficially look like submerged flowering plants

Colony (algal): a closely associated cluster of cells, joined together or enclosed within a common sheath or mucilage.[26] A colony may incorporate thousands of cells.[17]

Consumer: an organism that feeds on other organisms, either dead or alive

Cosmopolitan: can be found almost anywhere in the world

Cyanobacteria: a large and varied group of bacteria which are able to photosynthesise

Cyanobacterial bloom: the rapid, excessive growth of cyanobacteria, generally caused by high nutrient levels and favourable conditions

Deciduous: a plant that sheds its leaves annually

Decomposer: organisms, mainly bacteria and fungi, which break down complex organic molecules from detritus, liberating nutrients and assimilating carbon

Decomposition: the *chemical* breakdown of organic material mediated by bacteria and fungi, while 'degradation' refers to its *physical* breakdown.[22,17] Also known as mineralisation.

Desmid: a member of the Desmidialies (Zygnemophyceae) within the Division Chlorophyta (green algae)

Detritivore: an animal that feeds on detritus

Detritus: organic material originating from living, or once living sources including plants, animals, fungi, algae and bacteria. This includes dead organisms, dead parts of organisms (e.g. leaves), exuded and excreted substances and products of feeding.

Diatom: a microscopic, single-celled alga with cell walls made of hard silica, freely moving in the open water and forming fossil deposits

Diatomite, diatomaceous earth: siliceous deposits made up of the sedimentary build up of diatom shells (frustules)[30]

Ecological character: the sum of a wetland's biotic and abiotic components, functions, drivers and processes, as well as the threatening processes occurring in the wetland, catchment and region

Ecosystem: a community of interdependent organisms together with their non-living environment

Endemic: naturally occurring only in a restricted geographic area

Environmental water provisions (EWPs): the water regimes that are provided as a result of the water allocation decision-making process taking into account ecological, social and economic impacts. They may meet in part or in full the ecological water requirements.

Ecological water requirements (EWRs): the water regime needed to maintain the ecological values of a water dependent ecosystem at a low level of risk

Ecosystem services: benefits that people receive or obtain from an ecosystem, including provisioning services (such as food, fuel and fresh water), regulating services (such as ecosystem processes such as climate regulation, water regulation and natural hazard regulation), cultural services (such as spiritual enrichment, recreation, education and aesthetics) and supporting services (such as the services necessary for the production of all other ecosystem services such as water cycling, nutrient cycling and habitat for biota)

Epiphyte: organisms such as bacteria, algae and plants that grow attached to plants

Eutrophication: the nutrient enrichment of a water body, which can trigger prolific growth of plants, algae and cyanobacteria. May occur naturally over geologic time or may be human-induced.

Facultative plants: plants that can occur in both wetlands and dryland under natural conditions in a given setting

Filament: cells in a linear series, usually abutting one another, creating threads or strands

Flyway: a geographic region that supports a group of populations of migratory waterbirds throughout their annual cycle. Up to nine flyways are recognised worldwide.

Food chain: a diagram of who eats whom in a simple linear order, representing the flow of energy or nutrients in ecosystems. Two basic food chains are the grazing and detrital food chains.

Food web: a diagram that represents the feeding relationships of organisms within an ecosystem. It consists of a series of interconnecting food chains

Generalist: a species that can live in many different habitats and can feed on a variety of different organisms

Guild: a group of species that exploit similar resources in a similar fashion

Halophile: a species that shows a preference for saline habitat such as salt lakes

Hydroecology: the study of the water regimes required to maintain and enhance conservation values of ecosystems

Inorganic: compounds that are not organic (broadly, compounds that do not contain carbon)

Invertebrate: animal without a backbone

Larvae: juvenile insects (the singular being 'larva')

Lichen: a composite organism consisting of a fungus and a cyanobacterium living in symbiotic association

Lignin: a material (a complex organic polymer) deposited in the cell walls of many plants, making them rigid and woody

Luxury uptake: the process by which some organisms take up more nutrients than they need for current growth, instead storing them for future growth

Macroalgae: algae large enough to be seen with the unaided eye

Macroinvertebrate: an invertebrate that, when fully grown, is large enough to see with the naked eye (larger than 0.25 millimetres)

Marl: fine-grained calcareous material (usually from dead charophyte algae that are able to biogenically precipitate calcium carbonate)[17]

Microalgae: microscopic algae

Microbe: an organism that can be seen only with the help of a microscope for example, bacteria, some algae (also referred to as microorganisms)

Microinvertebrate: an invertebrate that is too small to see with the naked eye (smaller than 0.25 millimetres)

Migratory species: those animals that migrate to Australia and its external territories, or pass through or over Australian waters during their annual migrations

Motile: capable of motion

Mycorrhiza: a symbiotic association between a fungus and the roots of a plant, from which both fungus and plant usually benefit

Niche: the role of an organism in a community, in terms of its presence, activity, habitat and the resources it uses

Nymph: a juvenile insect that resembles the adult, but has poorly developed wings[180]

Obligate wetland plants: plants that are generally restricted to wetlands under natural conditions in a given setting

Organic: compounds containing carbon and chiefly or ultimately of biological origin

Organism: any living thing

Particulate: in the form of particles (small objects)

Peat: partially decayed organic matter, mainly of plant origin

Perched: not connected to groundwater

Perennial: a plant that normally completes its life cycle in two or more growing seasons (from germination to flowering, seed production and death of vegetative parts)

Periphyton: organisms such as bacteria, fungi, algae and invertebrates that are attached to underwater surfaces including sediment, rocks, logs and plants

Photosynthesis: the process in which plants and some other organisms such as certain bacteria and algae capture energy from the sun and turn it into chemical energy in the form of carbohydrates. The process uses up carbon dioxide and water and produces oxygen.

Phytoplankton: aquatic organisms that photosynthesise and which float or are suspended in water, drifting with water movements and generally having minimal ability to control their location, such as algae

Plankton: aquatic organisms floating or suspended in the water that drift with water movements, generally having minimal ability to control their location, such as phytoplankton (photosynthetic plankton including algae and cyanobacteria) and zooplankton (animals)

Precipitate: cause a substance to be deposited in solid form from a solution

Primary producer: a photosynthesising organism. Primary producers, through photosynthesis, harness the sun's energy and store it in carbohydrates built from carbon dioxide

Propagule: a unit or a piece of an organism that facilitates the organisms' reproduction. Plant propagules primarily include seeds, spores and plant parts capable of growing into new plants. Invertebrate propagules are usually eggs or, in the case of sponges, gemmules. Protist propagules are usually cysts. Bacteria and algae propagules are usually spores.

Refugia: restricted environments that have been isolated for extended periods of time, or are the last remnants of such areas

Respiration: the process in which oxygen is taken up by a plant, animal or microbe, and carbon dioxide is released

Rhizome: a horizontal, underground stem which bears roots and leaves and can usually persist, even if above-ground parts die back

Rhizosphere: the area of soil immediately surrounding plant roots, which is altered by their growth, respiration, exchange of nutrients etc

Samphire: the common name for a group of succulent sub-shrubs and shrubs including *Tecticornia, Halosarcia, Sarcocornia, Sclerostegia, Tegicornia* and *Pachycornia*, belonging to the family Chenopodiaceae

Saprotroph: an organism that absorbs soluble organic nutrients from inanimate objects (e.g. from dead plant or animal matter, from dung etc)

Sedge: tufted or spreading plant from the families Cyperaceae, Centrolepidaceae, Hydatellaceae, Juncaginaceae Restionaceae, Juncaceae, Typhaceae and Xyridaceae. In these plants the leaf sheath generally not split, there is usually no ligule, the leaf is not always flat and there is an extended internode below inflorescence. Some sedges are also known as rushes.

Sediment pore water: water present in the spaces between wetland sediment grains at or just below the sediment surface. Also called interstitial waters.

Spawn: eggs surrounded by jelly; generally applied to a group of eggs

Species richness: the total number of species (in a defined area)

Spicule: minute, needle-like body made of silica or calcium salts found in some invertebrates

Spore: a reproductive structure that is adapted for dispersal and surviving for extended periods of time in unfavourable conditions

Stomata (plural of stomate): pores in leaves and stems used for gas exchange

Stonewort: a term applied to *Chara* species that precipitate and deposit calcium carbonate on their surfaces

Stromatolite: a type of microbial structure formed by microbial communities precipitating calcium carbonate (see also 'thrombolite')

Symbiosis: a relationship in which dissimilar organisms live in close association, and which is mutually beneficial to both organisms

Tannins: complex organic compounds (polyphenols) occurring in various plants

Thrombolite: a type of microbial structure formed by microbial communities precipitating calcium carbonate (see also 'stromatolite')

Transpiration: the process in which water is absorbed by the root systems of plants, moves up through the plant, passes through pores (stomata) in the leaves and other plant parts, and then evaporates into the atmosphere as water vapour

Trophic: relating to nutrition, food or feeding

Turbid: the cloudy appearance of water due to suspended material

Turbidity: the extent to which light is scattered and reflected by particles suspended or dissolved in the water column

Vacuole: a storage compartment found within a cell

Vascular plants: plants with defined tubular transport systems. Non-vascular 'plants' include algae, liverworts and mosses.

Vertebrate: animal with a backbone

Water column: the vertical section of water between the surface and the wetland bed

Wetland components: the physical, chemical and biological parts of a wetland (from large scale to very small scale, e.g. habitat, species and genes)

Wetland processes: the dynamic physical, chemical and biological forces within a wetland, including interactions that occur between wetland organisms, within the physical/chemical environment, and the interactions of these

Zooplankton: tiny invertebrates and protozoans floating or suspended in the water that drift with water movements, generally having little or minimal ability to control their location

APPENDIX 1

Table 4. WA's wetland threatened ecological communities

Source: the Department of Environment and Conservation's Threatened Ecological Community Database endorsed by the Minister for the Environment (DEC, sourced April 2012)

Community identifier	Community name	General location (IBRA regions)
2. Toolibin	Perched wetlands of the Wheatbelt region with extensive stands of living Swamp Sheoak (*Casuarina obesa)* and Paperbark (*Melaleuca strobophylla*) across the lake floor.	Avon Wheatbelt
3. SCP10b	Shrublands on southern Swan Coastal Plain Ironstones (Busselton area)	Swan Coastal Plain
4. SCP19	Sedgelands in Holocene dune swales of the southern Swan Coastal Plain	Swan Coastal Plain
5. Clifton-microbialite	Stromatolite like freshwater microbialite community of coastal brackish lakes	Swan Coastal Plain
6. Richmond-microbial	Stromatolite like microbialite community of coastal freshwater lakes	Swan Coastal Plain
7. Mound Springs SCP	Communities of Tumulus Springs (Organic Mound Springs, Swan Coastal Plain)	Swan Coastal Plain
10. Nthiron	Perth to Gingin Ironstone Association	Swan Coastal Plain
11. Muchea Limestone	Shrublands and woodlands on Muchea Limestone	Swan Coastal Plain
14. SCP18	Shrublands on calcareous silts of the Swan Coastal Plain	Swan Coastal Plain
15. SCP02	Southern wet shrublands, Swan Coastal Plain	Swan Coastal Plain
16. SCP3a	*Eucalyptus calophylla - Kingia australis* woodlands on heavy soils, Swan Coastal Plain	Swan Coastal Plain
17. SCP3c	*Eucalyptus calophylla - Xanthorrhoea preissii* woodlands and shrublands, Swan Coastal Plain	Swan Coastal Plain
18. Thetis-microbialite	Stromatolite community of stratified hypersaline coastal lakes	Geraldton Sandplain
19. Scott Ironstone	Scott River Ironstone Association	Warren
21. SCP15	Forests and woodlands of deep seasonal wetlands of the Swan Coastal Plain	Swan Coastal Plain
32. SCP07	Herb rich saline shrublands in clay pans	Swan Coastal Plain
33. SCP08	Herb rich shrublands in clay pans	Swan Coastal Plain
34. SCP09	Dense shrublands on clay flats	Swan Coastal Plain
35. SCP10a	Shrublands on dry clay flats	Swan Coastal Plain
38. Morilla swamp	Perched fresh-water wetlands of the northern Wheatbelt dominated by extensive stands of living *Eucalyptus camaldulensis* (River Red Gum) across the lake floor.	Avon Wheatbelt
40. Bryde	Unwooded freshwater wetlands of the southern Wheatbelt of Western Australia, dominated by *Muehlenbeckia horrida* subsp. *abdita* and *Tecticornia verrucosa* across the lake floor	Avon Wheatbelt
42. Greenough River Flats	*Acacia rostellifera* low forest with scattered *Eucalyptus camaldulensis* on Greenough Alluvial Flats.	Geraldton Sandplain
46. Themeda Grasslands	Themeda grasslands on cracking clays (Hamersley Station, Pilbara). Grassland plains dominated by the perennial Themeda (kangaroo grass) and many annual herbs and grasses.	Pilbara

49. Bentonite Lakes	Herbaceous plant assemblages on Bentonite Lakes	Avon Wheatbelt
63. Irwin River Clay Flats	Clay flats assemblages of the Irwin River: Sedgelands and grasslands with patches of *Eucalyptus loxophleba* and scattered *E. camaldulensis* over *Acacia acuminata* and *A. rostellifera* shrubland on brown sand/loam over clay flats of the Irwin River.	Avon Wheatbelt
72. Ferricrete	Ferricrete floristic community (Rocky Springs type)	Geraldton Sandplain
74. Herblands and Bunch Grasslands	Herblands and Bunch Grasslands on gypsum lunette dunes alongside saline playa lakes	Esperance Sandplain
80. Theda Soak	Assemblages of Theda Soak rainforest swamp	North Kimberley
81. Walcott Inlet	Assemblages of Walcott Inlet rainforest swamps	North Kimberley
82. Roe River	Assemblages of Roe River rainforest swamp	North Kimberley
84. Dragon Tree Soak	Assemblages of Dragon Tree Soak organic mound spring	Kimberley Region, Great Sandy Desert Bioregion
85. Bunda Bunda	Assemblages of Bunda Bunda organic mound spring	West Kimberley, Dampierland Bioregion
86. Big Springs	Assemblages of Big Springs organic mound springs	West Kimberley, Dampierland Bioregion
89. North Kimberley mounds	Organic mound spring sedgeland community of the North Kimberley Bioregion	North Kimberley
92. Black Spring	Black Spring organic mound spring community	North Kimberley
95. Mandora Mounds	Assemblages of the organic springs and mound springs of the Mandora Marsh area	West Kimberley, Dampierland and Greats Sandy Desert Bioregions
97. Mound Springs (Three Springs area)	Assemblages of the organic mound springs of the Three Springs area	Avon Wheatbelt

Personal communications

Name	Date	Position	Organisation
Dr Jacqueline Giles	3/05/2009	Wetland Ecologist	Department for Environment and Heritage, South Australia
Adrian Pinder	05/10/2012	Research Scientist	Department of Environment and Conservation

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