

Algal blooms in the Swan-Canning estuary: Patterns, causes and history

A scum of blue-green algae at the Nicholson Road bridge on the Canning River (Photo: Vas Hosja).

History

The history of water quality changes in the Swan-Canning Estuary is a fascinating story. Understanding the biology of nuisance algae and unravelling water quality and ecological changes in the estuary is a complex and on-going challenge. Essentially it is a story about human settlement, land use change, the biology of micro- and macroalgae, nutrient availability, salinity changes and water movement. Algae are central to this story and the ecology of the system.

Algae are a natural part of the Swan-Canning ecosystem

Algae are aquatic plants and are a natural part of the Swan and Canning rivers and estuary, as they are

in waterways throughout the world. They include microscopic plants called phytoplankton and large plants often referred to as macroalgae or seaweeds. Algae are important because they oxygenate the water and contribute to the production of organic matter through photosynthesis. This productivity is the basis of the food web that supports all other aquatic organisms (Figure 1), from the microbes that decompose dead matter to zooplankton, fish and birds.

CONTENTS

- Nuisance and toxic algae are a problem.....*2
- Physical setting of the Swan-Canning rivers ...*3
- Human activity accelerates eutrophication.....*4
- Historical poor water quality.....*4
- The present algae problem.....*4
- Algal bloom cycles.....*5
- Winter and early spring.....*5
- Spring.....*6
- Summer.....*7
- Autumn.....*7
- Which algae will bloom?.....*7
- The Canning River – A separate story.....*9
- Natural controls on algal blooms.....*11
- Managing algal blooms.....*11
- Glossary.....*12
- Acknowledgments.....*12
- For more information .*12



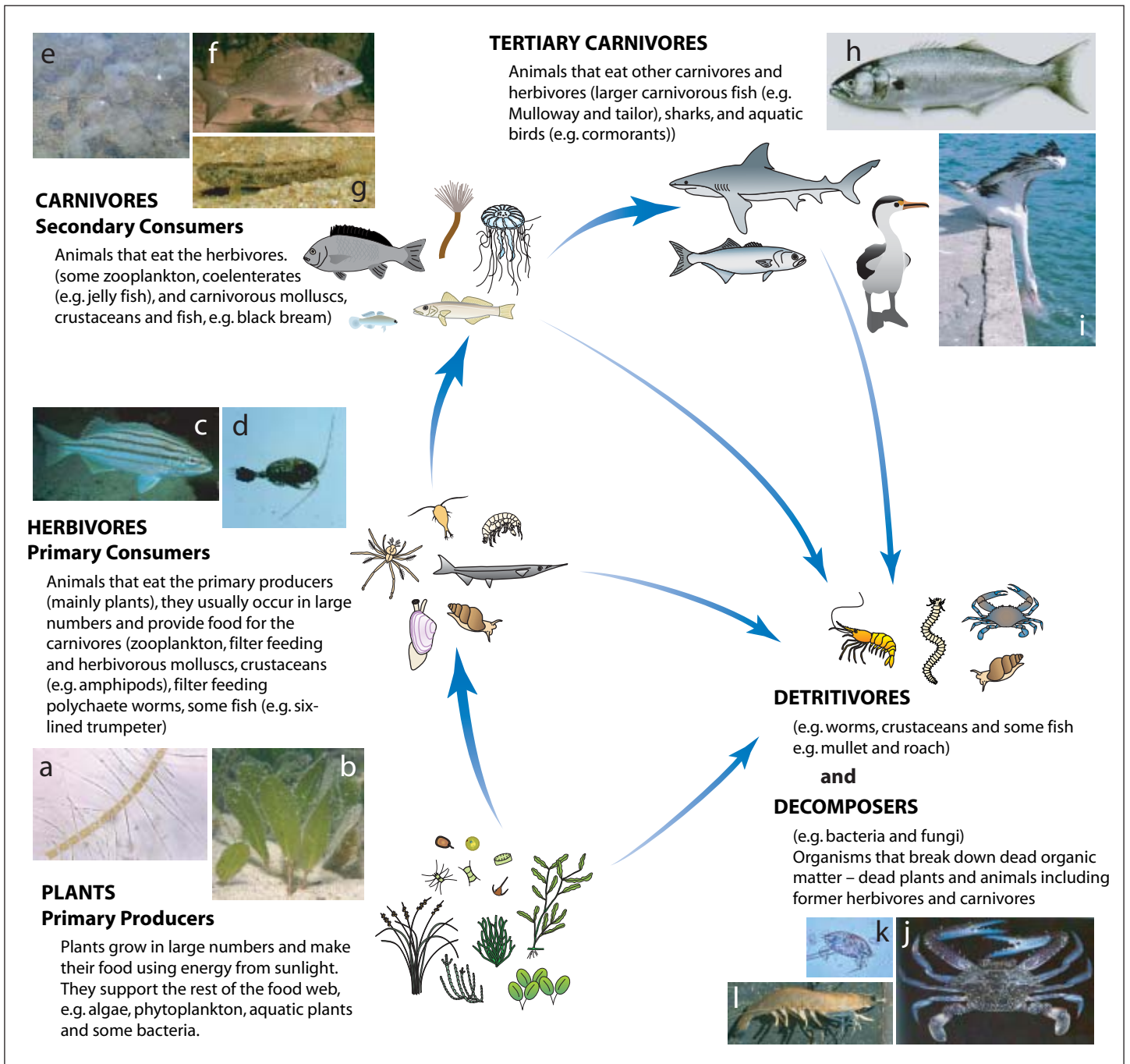


Figure 1: Simple food web with plants and algae as the foundation. A food web shows in simplified form the flow of energy in an ecosystem. Photos: a) Chaetoceros, a diatom; b) Halophila, a seagrass; c) six-lined trumpeter; d) copepod; e) jellyfish; f) black bream; g) Swan River goby; h) tailor; i) pelican; j) blue manna crab; k) juvenile crab; l) western king prawn. (Photos courtesy of Sandy Griffin, Vas Hosja, Margaret Platell, Chris Roelfsema and Dieter Tracy.)

Nuisance and toxic algae are a problem

When human activity alters the balance of the natural system, such as increasing nutrients (food for algae) and changing water flow (usually reducing it) that enters the rivers and estuary, algae often respond by growing rapidly in vast numbers and becoming a nuisance. Most algal blooms are harmless; they may discolour the water but do not pose a problem for the rivers, wildlife or humans. On occasion however, they are toxic (see Box 5) and because of the health risk to people, waterways may be closed to recreational use (swimming, fishing, boating, etc.). This *River Science* provides information on algal



Toxic cyanobacteria bloom in the Canning River.

blooms that occur in the Swan-Canning estuary and what is being done to manage them.

Physical setting of the Swan-Canning rivers

The sandy flat Swan Coastal Plain around Perth has a number of important physical and climatic characteristics that make its rivers and estuaries susceptible to algal blooms. These include leached, sandy soils with poor nutrient holding ability, strongly seasonal water flow and seasonally changing salinity conditions. The coastal plain emerged from the sea over 100 000 years ago and has a surface layer comprised mainly of leached sand with poor nutrient-binding (holding) abilities. Less **pervious** rocks and sediments, such as limestone, sandstone and shale underlay the sand helping to create water-storing aquifers. This underground water storage contributes significantly to the numerous wetlands on the coastal plain. It also contributes to river flow, particularly in summer, and to the deeper aquifers that supply much of Perth's drinking water.

The lower reaches of the Swan-Canning river system form a shallow estuary that was created by drowning of the river channel by rising sea levels some 9000 to 10 000 years ago. Water flows slowly in the system because of the flat coastal plain, broad river and the expansive reaches of the lower estuary.

In this region of WA, rivers flow with fresh water in the winter and dry out in the summer. This is a major consequence of a Mediterranean-type climate, which features wet winters and hot dry summers. Some of the drains servicing Perth also exhibit this cyclical pattern. In others, groundwater seeps into the drains and occasional urban and industrial discharges ensure they flow all year round, with small trickle flows in summer.

Once the Swan-Canning catchment has been saturated by rainfall (usually by mid-winter), run-off flows into the rivers and much of the estuarine system becomes fresh or brackish. Freshwater flows into the estuary become negligible when the catchment dries out during spring, allowing seawater to move upstream from the Indian Ocean. Because of this wet-dry cycle, the tidal portions of the Swan-Canning estuary oscillate from fresh to brackish in the winter, to salty, virtually seawater conditions in the summer. This has important consequences for nutrient cycles and the annual pattern of algal blooms in the system, as well as the aquatic animals like fish, crabs, worms and clams.

Historical changes at the mouth of the estuary in Fremantle in the 1890s increased the intrusion of seawater into the estuary during summer and allowed the weak tidal signals typical of this latitude and region to be felt as far upstream as Barrack Street in Perth. The Swan-Canning is now a permanently open



Photograph of the loops of the Swan-Canning estuary as it meanders to the sea at Fremantle. (Photo courtesy of Scott, Kinder and Stephenson—Corporate Photographers.)

Box I: Aquatic plants and plankton

Macroalgae (seaweed)

Relatively simple plants that live in water—creeks, rivers, estuaries, lakes and oceans. They photosynthesise—use the energy from sunlight to produce sugar and oxygen from carbon dioxide and water. Macroalgae don't flower. They are large enough to be seen with the naked eye (i.e. 'macro') and are attached to the bottom, often on woody and rocky substrates, although some drift in the water.



John Huisman

Macrophytes

Includes macroalgae but often refers to the more complex aquatic ferns and flowering plants such as seagrasses. These plants have typical structures common to land plants e.g. a vascular system, true leaves and flowers.



John Huisman

Phytoplankton

Microscopic plants (usually algae) and bacteria that photosynthesise. They are often single celled and float in the

water. They support other life by releasing oxygen to the water and atmosphere, are essential to the food chain and are only a problem if they bloom excessively, are toxic, create a nuisance or decompose in large amounts, using up oxygen in the water and creating unpleasant smells.



Vas Hosja

Phytoplankton Bloom

When conditions are favourable for growth (i.e. when there is a good supply of nutrients, warm temperatures, calm waters and abundant sunlight), phytoplankton can multiply rapidly producing extremely high numbers of cells. When this happens it is known as a bloom.



Katryn McMahon

Zooplankton

Small free-floating or swimming animals that graze on algae and other plankton. They are essential to the food chain, feed many fisheries and help keep algal blooms under control.



Vas Hosja

Note that all technical terms highlighted in blue are defined in the glossary.

estuary with a **microtidal lunar tide** regime. Regular low and high-pressure systems crossing over the coast from both winter and summer weather patterns and tropical cyclones from the north greatly influence water movements in and out of the estuary.

The Canning River is different from the Swan River because its upper and middle reaches are cutoff from the marine-estuarine influences of the Swan estuary due to the Kent Street Weir. The weir prevents the salty marine water moving upstream with the tides, between late spring and early autumn. In the summer when the weir boards are in place, the upper Canning River is impounded as a freshwater weir pool.

The Swan-Canning estuary is naturally susceptible to algal blooms because it is surrounded by poor sandy soils that allow nutrients, such as those from fertilisers, to leach quickly into the ground water and then to the river system. It has hot summers, seasonal river flow with large oscillations in salinity and poorly flushing tides. The water remains calm and slow-moving for long periods of time. These factors, combined with Perth's abundant sunshine, create ideal algae growing conditions.

Human activity accelerates eutrophication

Eutrophication, of a river or water body, refers to the effects of increases in nutrient inputs caused by human activity in the estuary and its catchment. Estuaries naturally accumulate nutrients and sediments from their catchments, but this takes place over thousands of years, giving time for the plants and animals to adapt. Accelerated changes caused by human-induced eutrophication lead to extreme responses in the **biota**, such as sudden accumulations of macroalgae and large phytoplankton blooms, including toxic blooms that threaten human health, result in poor water clarity and lowered oxygen levels, and often lead to fish deaths and unpredictable water quality.

Historical poor water quality

Prior to European settlement, nutrient levels in the Swan and Canning rivers were thought to be low. There was little nutrient leaching from the natural bush. Settlers cleared the land and applied fertilisers in the river catchment that leached into waterways, and urban and industrial development around Perth poured sewage and industrial waste into the rivers. The level of nitrogen and phosphorus in the system rose dramatically. At the same time the amount of organic matter entering the system increased rapidly, as natural eucalypt leaves and **detritus**, which are slow to decompose, were replaced with rapid decomposing exotic soft leaves, pasture plants and animal manure. This allowed faster cycling of larger amounts of nutrients from the sediments and dead plant material into the water column. Because the natural aquatic fauna responsible for decomposing

Box 2: Fresh water and seawater

Fresh water – considered to be less than 0.5 to 1.5 parts per thousand of salt (ppt) but some freshwater animals and plants can live in brackish water as high as 8 ppt.

Brackish water – 5 to 25 ppt.

Seawater – usually about 35 ppt.

organic material was not adapted to these changes it resulted in frequent build-up of nutrient-rich organic matter in the bottom sediments of the system. The river and estuarine sediments have now become a major storehouse of nutrients that fuel phytoplankton growth during the summer.

These changes led to poor water quality in the Swan-Canning system, especially between the 1920s and 1970s, and produced smelly heaps of decaying macroalgae on the river's beaches and foreshores. Government policy since the 1930s, and particularly between the 1950s and 1970s, encouraged the relocation of industry and sewage treatment away from the metropolitan area. This effectively eliminated large **point sources** of nutrients and industrial waste and significantly improved water quality in the lower and middle estuary. This policy has certainly helped reduce excessive macroalgae growth. The current problem is now mainly centred in the middle and upper Swan and Canning arms of the estuary and is caused by other sources of nutrient enrichment and different types of algae.

The present algae problem

Current water quality problems in the Swan-Canning estuary are largely due to the combined nutrient inputs from diffuse and small point sources spread across the urban and rural catchments. Diffuse and small nutrient sources are more difficult to identify, control and manage. The algae that now cause problems are not seaweeds or macroalgae, as was the case in the past, but microscopic phytoplankton (microalgae).

In particular, river managers are concerned that blooms of nuisance and toxic phytoplankton could become established as a regular feature in the Swan-Canning rivers and estuary. They already occur in the Canning River upstream of the Kent Street Weir, in pools on the Avon River and Ellen Brook, and in ponds, basins, wetlands and lakes in Perth's parks.

There was a major outbreak of *Microcystis*, a toxic cyanobacterium (blue-green algae), in the Swan River estuary in early February 2000 after unseasonally heavy summer rains. The river and estuary were closed for 12 days to recreational use and commercial fishing due to the health risk declared by the Department of Health. This outbreak strongly reinforced the perception that toxic phytoplankton could be established and become a regular feature of water quality if something wasn't done (See *River*

Table 1: Table of common nuisance algae, cyanobacteria and plant species found in the Swan-Canning estuary.

Nuisance phytoplankton, blue-greens and plant species	General criterion for health alert (cells/mL of water)	Comments
1. <i>Heterosigma</i> – a haptophyte phytoplankton	> 15 000–20 000	Slimy, potential killer of fish
2. <i>Scrippsiella</i> , <i>Gyrodinium</i> , <i>Gymnodinium</i> , <i>Karlodinium</i> – dinoflagellate phytoplankton	> 15 000–20 000	Cause red tides, nuisance warnings, may stick to body and bathers, staining skin. Some species cause fish deaths
3. <i>Rhizoclonium</i> – green macroalgae	No health threat	Can create unpleasant smells and be a nuisance on beaches
4. <i>Anabaena</i> , <i>Microcystis</i> – blue green cyanobacterium	> 20 000	Unsafe for recreation, health threat – can cause skin irritation, toxic if consumed.
5. <i>Hydrocotyle</i> – macrophyte plant	No health threat	Noxious aquatic weed, creates navigation hazards, chokes waterways
6. <i>Salvinia</i> – aquatic fern	No health threat	Noxious aquatic weed, chokes waterways, from South America

Box 3: Factors affecting phytoplankton growth

Photosynthesis is when plants including algae and phytoplankton use the energy from sunlight to produce essential sugars and oxygen from carbon dioxide and water for their life processes.

Favourable Conditions for Phytoplankton Growth

Sunlight – long day length and clear skies favour phytoplankton growth

Water temperature – warm water favours rapid phytoplankton growth, though some species can bloom in cold water

Available nutrients – high concentrations of essential plant nutrients such as nitrogen, phosphorous and carbon encourage phytoplankton growth, some species also require trace elements and organic substances to bloom

Changes in salinity – different species of phytoplankton prefer different salinities, some species may require fresh, brackish or saline waters while some species can tolerate a range of salinities

Water movement / turbulence – most phytoplankton do not do well if the water is fast moving or turbulent

Science 2 ‘Summer Surprise’ for details). Scums of cyanobacteria had been recorded in upper reaches of the Swan River in the late 1970s and early 1980s. Each year toxic cyanobacteria detected in the Swan-Canning river system have been traced to eutrophic wetlands in the metropolitan and Avon Catchment. Between April and June 2003 a bloom of the dinoflagellate *Karlodinium micrum* killed thousands of fish in both the Swan and Canning rivers. A smaller fish kill also attributed to *K. micrum* occurred in the Swan River in June 2004. (see box 5).

Algal bloom cycles

A regular cycle of algal blooms occurs in the Swan-Canning estuary every year – usually from spring to autumn. The succession pattern of the blooms is affected by the timing of rainfall runoff, nutrient inputs and sediment nutrient release during the year, seasonal movement of the salt wedge upstream and changes in salinity over the entire tidal portion

of the system. Blooms of different species can co-occur overlapping in time and location. Some phytoplankton species can reproduce very rapidly, doubling their numbers in two hours to a few days under favourable conditions.

Winter and early spring

Diatoms, algae with cell walls consisting mainly of silica, are present in the water during winter when silica is in highest concentrations in rainfall runoff, but flowing water, cold temperatures and short day lengths restrict rapid algal growth. It is not until late winter and early spring when flows slow, temperatures begin to rise and the day length becomes longer that the first large algal blooms occur.

Green single-celled algae, known as chlorophytes, are usually the first to bloom while the water is still fresh (e.g. *Chlamydomonas* species). They are stimulated by nutrients washed into the system

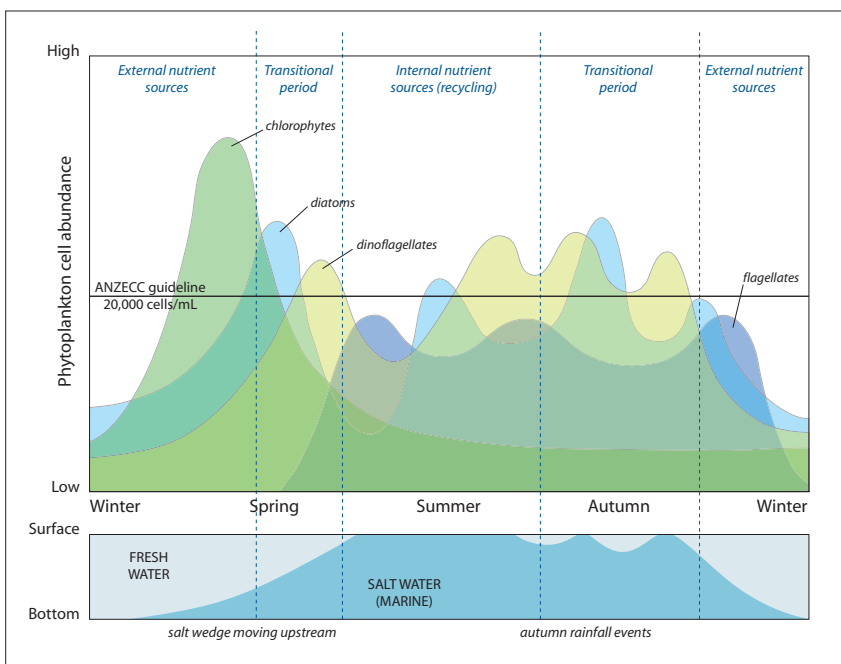
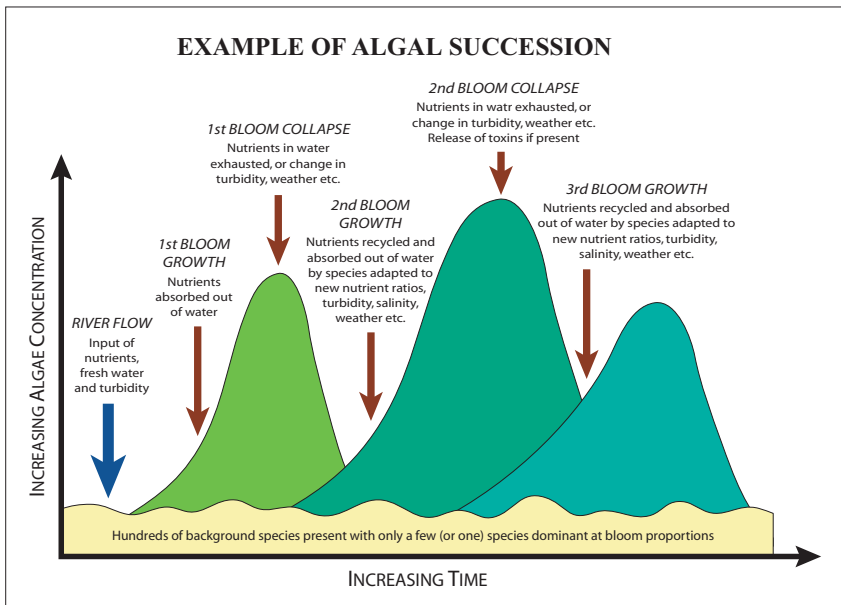


Figure 2: Common successional patterns for phytoplankton (top) and general successional patterns for phytoplankton in the Swan-Canning Estuary (bottom). Note that the vertical scale is arbitrary. Peaks in abundance are actually many times higher than background numbers.

(mainly nitrogen) by the late winter and early spring rains. Chlorophyte blooms are a natural and desirable feature of the upper estuary.

Diatom blooms often occur in the lower reaches at this time when waters are brackish and silica and nutrient concentrations are still high from water flows coming from the upper reaches. The waters often take on a brownish hue.

Spring

Around mid-spring, pioneering estuarine algae, composed largely of diatoms (e.g. *Skeletonema*) begin to bloom. Dinoflagellate blooms are associated with the leading edge of the salt wedge that pushes upstream from the mouth of the river as fresh water flow diminishes. They may germinate from resting cysts in the sediment and are often opportunistic, taking advantage of sediment nutrients released by anoxic conditions created by the salt wedge as it passes upstream of Perth Water. Diatoms and dinoflagellates can reach high numbers in a short period of time, with diatoms being a particularly important component of the food chain (see Figure 1).

Dinoflagellates can form 'red tides' – rusty to dark brown coloured blooms from mid to late spring. During the day they often form streaks at the water surface from late morning to late afternoon. Blooms of dinoflagellates can be followed by blooms of diatoms. These species bloom in response to higher nutrient levels present in the



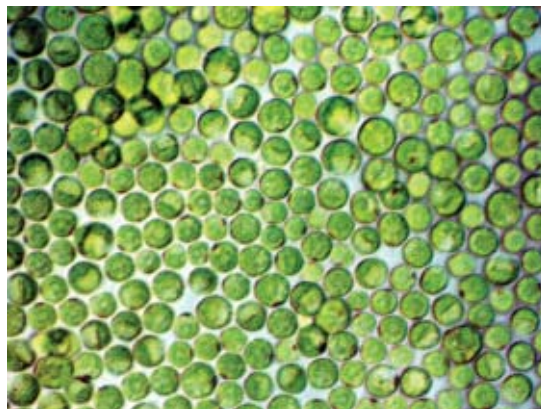
Skeletonema, a common lower estuary pioneer winter-spring diatom.

Box 4: Some common terms

Algal bloom: a proliferation of phytoplankton sufficient to discolour the water. For management purposes blooms are defined by the density of algal cells in the water. If large algal cells exceed 5-10 000 cells per mL, if moderate-sized algal cells exceed 20 000 cells/mL or if some toxic species exceed 10 cells per mL (regardless of size) it is referred to as a bloom. Cyanobacteria densities greater than 20 000 cells/mL lead to signage to alert the public.

Opportunistic algae are normally present in the system in small numbers, however, when conditions favour their growth they can multiply rapidly and become dominant.

Nuisance algal species range from those that pose a human health risk to species that cause fish kills, and some just make the river unsightly and smelly but don't pose a health risk.



Chlamydomonas a common late winter and spring chlorophyte algae (cell size – 6 microns).

brackish-saline bottom waters of the salt wedge that have been released from bottom sediments under stratified conditions. Because dinoflagellates are able to swim using their flagella, they can go down to the nutrient-rich water at night, take up nutrients and then swim back to the surface to utilise the abundant sunlight for photosynthesis during the day. Many dinoflagellate species are considered nuisance species. A few are toxic and may require public health alerts. Dinoflagellates live in an amazing range of environmental conditions. For example, some dinoflagellates are found inside the common brown jellyfish, *Phyllorhiza*, which is very abundant in the lower reaches of the estuary.

Summer

Red and brown coloured blooms of dinoflagellates such as *Prorocentrum*, *Scrippsiella*; diatoms such as *Skeletonema*, *Chaetoceros*; cryptophytes such as *Cryptomonas/Rhodomonas* species, and small raphidophytes such as *Heterosigma* often occur in the middle to upper reaches of the estuary from mid to late summer when the tidal portions of the rivers

and estuary have become saline. The size of these blooms is influenced by the amount of nutrients that have been released into the water column through recycling from previous decomposing blooms, unseasonal runoff events, and bottom sediments. Some of these algae are nuisance species that require careful monitoring.

Autumn

In the upper reaches mixed blooms of opportunistic algae such as diatoms, dinoflagellates and marine algae often occur in autumn. Some flourish before winter rains once again push the salt water out of the rivers and estuary, while others bloom if early autumn rains occur, bringing a flush of nutrient-rich freshwater into the rivers and not reducing salinity significantly. In April-June 2003 a toxic estuarine dinoflagellate bloom, *Karlodinium micrum*, killed hundreds of thousands of fish when densities exceeded 10 000-1 000 000 cells per mL. A similar *Karlodinium* bloom occurred in Autumn 2004, though this bloom resulted in relatively few associated fish deaths.



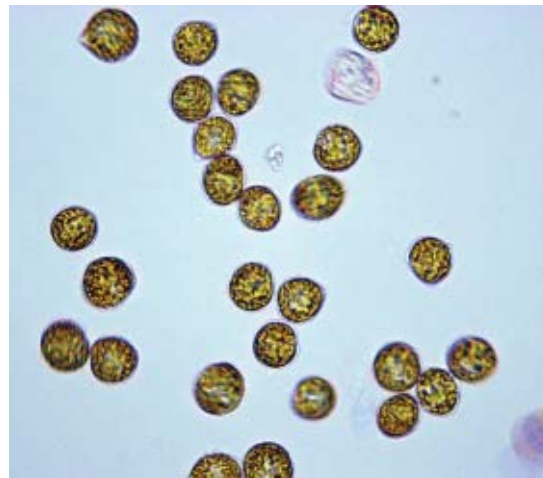
Karlodinium micrum

Which algae will bloom?

Algal species have to compete with each other for a niche within an optimal salinity range for available nutrients – mainly nitrogen as phosphorous appears to be abundant all year round in the Swan-Canning estuary – and sunlight. Different algae prefer different conditions so it depends on a number of factors as to which algae, out of the hundreds of species present in the algal community, will be the most successful and hence bloom at any particular time (see Figure 2). For example the cyanobacterium (blue-green alga) *Microcystis aeruginosa* does especially well in freshwater and low salinity conditions when nutrients are high, water temperature warm, days are long and conditions calm (see *River Science 2* ‘Summer Surprise’). This species can create adverse conditions for other potential competition species.

Another example includes the dinoflagellate species *Scrippsiella* that has a number of characteristics that give it an advantage over its algal competitors, especially during summer-autumn when salinity stratification is common in the upper reaches of the Swan River. Three of the important features of dinoflagellates include:

- A dinoflagellate uses its two flagella (whips) to stay near the surface during the day to photosynthesize and at night to migrate down the water column to absorb nutrients generated by bottom sediments and salt wedge conditions, i.e. stratified conditions.
- It can produce cysts that rest in the bottom sediments that will germinate quickly when the right water salinity re-occurs. These cysts can



Scrippsiella – an opportunistic dinoflagellate in autumn.

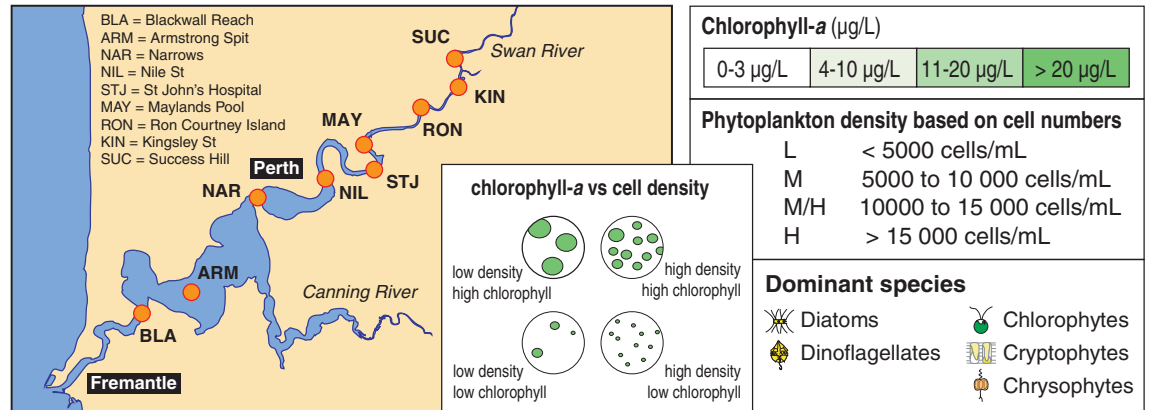
lay dormant for years experiencing very poor environmental conditions such as **anoxia** and fresh water conditions. Dinoflagellates can reproduce quickly and the use of flagella to exploit sunlight or bottom water nutrients lets them acquire the energy and nutrients necessary for reproduction in very short time periods.

- Some dinoflagellates can obtain nutrients by photosynthesis or by ingesting other dinoflagellates and **phytoplankton** as well as **microzooplankton**. This allows it to exploit food resources other than that created by sunlight and dissolved nutrients, i.e. to be **heterotrophic**.

Under these conditions dinoflagellates are able to out-compete other microscopic algae and create a bloom during late spring and early summer.

Phytoplankton variation through the seasons in the Swan River estuary

The table shows both the number of cells present (cell density) and the average concentration of the pigment chlorophyll-a, which is common to all phytoplankton. Chlorophyll-a concentration gives an indication of the relative mass of algae in the water (biomass). The relationship between density and biomass depends on the size of the algal cells present (see inset).



Season	BLA	ARM	NAR	NIL	STJ	MAY	RON	KIN	SUC
Winter 1995	L	L	L	L	L	L	L	L	L
Spring 1995	M	L	L	L	M	L	M	M	L
Summer 96-97	L	L	L	L	L	L	L	M	L
Autumn 1996	L	L	L	L	L	L	L	M	M
Winter 1996	L	L	L	L	M	M	M	M	M
Spring 1996	H	H	L	M	M	L	L	L	L
Summer 96-97	L	L	L	L	L	L	M	M	M
Autumn 1997	L	L	L	L	L	L	L	L	L
Winter 1997	M	M	L	L	L	L	L	L	L
Spring 1997	M/H	M/H	L	M	M	M	M	L	L
Summer 97-98	L	L	L	L	M	M	M/H	M/H	M
Autumn 1998	L	L	L	L	L	L	L	M/H	M/H
Winter 1998	L	L	L	L	M	M	M	M/H	H
Spring 1998	M	M	L	M	L	L	M	M	M
Summer 98-99	L	L	L	M	L	L	L	L	L
Autumn 1999	L	L	L	L	M	M/H	M	M/H	M
Winter 1999	M	M	L	L	L	L	L	L	L
Spring 1999	L	L	L	L	L	L	L	L	L
Summer 99-00	M	M	M	M/H	M/H	M/H	H	H	M/H
Autumn 2000	L	L	L	M	L	L	M	M	M
Winter 2000	M	M	L	L	L	L	L	L	L
Spring 2000	L	L	L	M	L	L	M	M	M
Summer 00-01	L	L	L	H	H	H	H	H	H
Autumn 2001	L	L	L	L	L	H	H	H	H
Winter 2001	L	M	L	M	H	H	H	H	H
Spring 2001	L	M	L	M/H	M	M	M/H	M/H	M/H
Summer 01-02	L	L	L	M	M	M	M/H	M/H	M
Autumn 2002	L	L	L	L	M	M/H	H	H	M/H
Winter 2002	M	M	M	M	L	L	L	L	L
Spring 2002	L	L	L	M	M/H	M/H	M	L	M
Summer 02-03	L	L	L	M	M	M	M/H	M	M
Autumn 2003	L	L	M	H	H	H	H	H	H
Winter 2003	M/H	H	L	H	H	H	M	L	L
Spring 2003	L	M	L	L	L	L	L	L	L

Box 5: The 2003 'Karlo' bloom

Between April and June 2003 a bloom of the dinoflagellate *Karlodinium micrum* referred to here as *Karlodinium* appeared in the Swan and Canning rivers. The bloom killed a wide range of fish in all sizes including black bream, Perth herring, mullet, flathead, flounder, mullet and Swan River gobies.

Karlodinium micrum is highly adapted to estuarine conditions. It can move up and down the water column with its flagella to find food, light and shelter. It uses the energy from the sun like most plants, but when nutrients are in short supply it can also ingest other algae to get the nutrients it requires. Unlike other dinoflagellates, however, *Karlodinium* does not form resting cysts when nutrients are scarce. There is still considerable debate among scientists about how *Karlodinium* kills fish; compounds have been found in Swan-Canning estuary water similar to isolates from *Karlodinium micrum* in Chesapeake

Bay, USA, which have been termed Karlotoxins. *Karlodinium* species appear to produce fatty acids and lipids which break down the epithelial cells in the gills of fish. The affected fish swim very slowly, coming to the surface in an attempt to get oxygen. Over a period of one to two days, the fish become more lethargic, gradually stop swimming and die. The breakdown of organic matter by oxygen consuming bacteria led to very low oxygen levels throughout the Swan above The Narrows and contributed to the fish kill.

Karlodinium were already present in the Swan estuary in moderate numbers before the rainfall in April and some fish were already showing signs of distress from low oxygen levels. The rainfall resulted in runoff from the catchment carrying nutrients and organic matter into the Swan and Canning rivers, followed by prolonged calm, sunny weather between April and June. In particular, it resulted

in high concentrations of soluble oxidised nitrogen entering the Swan River estuary. This form of nitrogen is readily used by plants for growth. The abundance of *Karlodinium* increased to over 100 000 cells/mL at some sites in the estuary as the freshwater pushed both algae and fish downstream. A subsequent storm surge then pushed marine water upstream, which brought the fish and *Karlodinium* together.

Bloom concentrations extended from upstream of Tonkin overpass down to Perth Water. Another *Karlodinium* bloom also developed in the lower Canning River below Riverton bridge and upstream of Canning Bridge and above Kent Street Weir. Towards the end of June, several weeks of heavy rainfall reduced salinity levels in the estuary. This resulted in the collapse of the algal bloom and no further fish kills occurred.

The Canning River – A separate story

The upper Canning River becomes an impounded freshwater weir pool above the Kent Street Weir during spring, summer and autumn. Water quality is affected by high inputs of nutrients in the same way as in the Swan River estuary, but when the weir is in place there is little flow and it is not affected by salinity to the same degree. Succession by different algal species is similar to that described for the Swan River estuary in that there are general succession patterns associated with the seasons. In the Canning River upstream of the weir, freshwater species are usually involved. The main factors influencing the succession are similar – nutrient availability, temperature, light availability and competition between freshwater microscopic algal and cyanobacterial species.

Water stratification or layering occurs above the weir due to the water temperature, with cool heavier layers on the bottom and warmer lighter layers closer to the surface. The cool bottom waters become deoxygenated in the summer from decomposition and decay of organic material. Deoxygenation causes the release of nutrients from the sediments, which are utilised by algae to bloom in much the same way as occurs in the Swan River estuary, only in the Swan's case the deoxygenated water is saline.

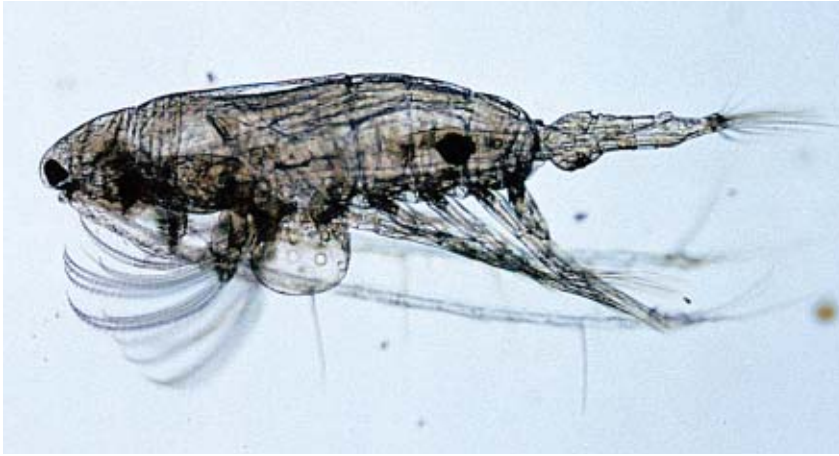
The Canning River also experiences blooms of chlorophytes in spring. In late spring and during summer, when the still impounded water warms up but remains fresh, it can also undergo blooms of potentially toxic blue-green cyanobacteria

(e.g. *Anabaena*, *Anabaenopsis*, *Oscillatoria* and *Microcystis* species). The upper Canning River has a wide range of freshwater algal blooms (diatoms, euglenophytes and chlorophytes) that are different to the species present in the more brackish and marine waters of the Swan River estuary.

In the lower sections of the Canning River, but still above the weir, large aquatic freshwater plants (macrophytes) can become abundant (e.g. *Hydrocotyle*, *Azolla*, pond and duck weed; see *River Science 19* 'Aquatic plants in the Canning'). Freshwater macrophytes are rarely found in the lower Swan River due to large seasonal changes in salinity and short freshwater periods. Although the public often complain about macrophytes in the Canning River, they are usually beneficial (apart from the weed species such as *Hydrocotyle*). They can shade the surface of the water and compete for nutrients with algae, thus reducing prolonged phytoplankton blooms and possibly controlling potentially toxic cyanobacteria blooms. Though they may create an aesthetic nuisance at times, they may also provide an important food for the ducks and swans.



Toxic Anabaena circinalis, a blue-green cyanobacterium found in the Canning River (Vas Hosja).



Sulcanus conflictus (left) is a 'large' zooplankton crustacean that eats both algae and other zooplankton in the Swan-Canning estuary and *Gladioferens imparipes* (right) is a pioneer herbivorous species that becomes very abundant early in spring (25x magnification).

Table 2: Examples of toxic, nuisance and harmless phytoplankton blooms observed in the Swan-Canning estuary in Western Australia.

Date	Dominant species	Location	Total cells/mL (* = surface data)	Potential human health risk
1 Mar 1978	blue-green scum	Middle Swan Bridge	Counts not available	Unknown
2 Nov 1981	<i>Microcystis littoralis</i> (cyanobacteria)	Riverton Bridge	Green scum	Not toxic
23 Dec 1981	<i>Nodularia</i> (cyanobacteria)	West Midland Pool	Scum visible	TOXIC – hepatotoxin
1 Nov 1988	<i>Chlamydomonas</i> (Chlorophyte)	Bassendean – Guildford	515 500–1 083 000*	Harmless
17 May 1993	<i>Prorocentrum dentatum</i> (dinoflagellate)	Hill Street Perth Water	300 000*	Nuisance
Jan–Mar 1994	<i>Anabaena spiroides</i> (cyanobacteria)	u/s Kent Street Weir	20 000–480 000*	Uncertain
Feb–Mar 1994	<i>Gymnodinium cf. simplex</i> (dinoflagellate)	White Rocks – Midland	10 000–1 600 000	Nuisance – red tide
Feb–Apr 1994	<i>Anabaena circinalis</i> (cyanobacteria)	u/s Kent Street Weir	10 000–2 000 000	TOXIC
10 Sept 1996	<i>Cyclotella</i> sp. (diatom)	Armstrong	197 400	Harmless
13 Jan to 17 Feb 1998	<i>Anabaena circinalis</i> (cyanobacteria)	Kent Street Weir – Greenfield Street	14 600–326 000	TOXIC
30 Mar 1998	<i>Gymnodinium simplex</i> (dinoflagellate)	Helena River – Guildford	31 300–83 800	Nuisance
13 Apr 1999	<i>Chaetoceros minimus/Skeletonema</i> (diatoms)	Castledare – Riverton Bridge	71 700–151 200	Harmless
Feb 2000	<i>Microcystis aeruginosa</i> (cyanobacteria)	Swan and lower Canning	2–16 000 cells/mL but dense scums in sheltered bays	TOXIC
24 Jan to 13 Feb 2001	<i>Anabaena circinalis</i> (cyanobacteria)	Kent Street Weir – Hester Park	29 620–191 611	TOXIC
05 Feb 2001	<i>Chaetoceros minima</i> (diatom)	Rivervale – Guildford	54 919–154 968	Harmless
14 May 2001	<i>Fibrocapsa</i> (raphidophyte)	Ascot	158 982 (grab sample)	Nuisance – fish toxic
04 Nov 2001	<i>Katodinium</i> (dinoflagellate), <i>Skeletonema</i> (diatom), <i>Pyramimonas</i> (flagellate), small cryptophytes	Maylands Pool	42 521	Nuisance
05 Nov 2001	<i>Chlamydomonas</i> (chlorophyte)	Maylands – Guildford	29 290–63 933	Harmless
05 Mar to 09 Apr 2002	<i>Anabaena circinalis</i> (cyanobacteria), <i>Aulocoseira</i> (diatom), various other species	Kent Street Weir – Wharf St	123 949	TOXIC
07 Apr to 23 Jun 2003	<i>Karlodinium micrum</i> (dinoflagellate)	East Perth – Bassendean and lower Canning River	> 100 000	TOXIC to fish
26 Feb to 08 Jun 2004	<i>Karlodinium micrum</i> (dinoflagellate)	Maylands – Caversham	20 000–94 000	TOXIC to fish

Box 6: Algal toxins and illnesses

There has been a worldwide increase in problems associated with harmful and toxic phytoplankton over the past two to three decades. These problems have affected public health through consumption of contaminated fish and shellfish, and direct contact with waters contaminated by toxic algal blooms. In WA there has been an increase in the occurrence of intense dinoflagellate 'red tides' and blue-green algal (cyanobacterial) blooms. Phytoplankton species known to have been responsible for serious human health problems and the deaths of fish and other animals overseas have been observed in WA waterways. Fortunately there have been few public health cases reported in WA and no deaths have occurred.

Human health problems can occur after direct recreational contact with or consumption of toxic phytoplankton. Acute poisoning and fatalities can occur after the consumption of shellfish that have been contaminated with algal toxins. These toxins accumulate in the edible tissues of shellfish if their food source includes toxic species of phytoplankton,

especially certain dinoflagellates. Algal toxins include powerful neurotoxins, which affect the brain and nervous system, and hepatotoxins, which damage liver tissues. Worldwide, the main health threats from phytoplankton-caused toxicity are:

- Paralytic Shellfish Poisoning (PSP), Diarrhetic Shellfish Poisoning (DSP), Amnesic Shellfish Poisoning (ASP), Neurotoxic Shellfish Poisoning (NSP);
- Hepatotoxicity/neurotoxicity from cyanobacterial blooms; and
- Ciguatera fish poisoning from coral reef dinoflagellate toxins in tropical areas including northern Australia.

Some potentially harmful and toxic species have been identified in WA including several blue-green algae, dinoflagellates and certain other species. Blue-green algal blooms have been a regular occurrence in many WA waterways for some years. The *Nodularia* blooms in the Peel-Harvey estuary caused toxicity in mussels from Peel Inlet and were shown to be hepatotoxic as early as 1982. Potentially toxic dinoflagellate *Alexandrium*, *Prorocentrum* and *Dinophysis*

species exist in WA estuarine and coastal waters. Dinoflagellate species may be toxic at very low cell densities and can be easily overlooked during routine environmental sampling.

Recent research in Australia suggests that blooms of toxic species may also contain non-toxic strains. This means that toxicity cannot be inferred from simple identification of species alone, and specific tests for toxicity should precede risk assessment for individual blooms.

To date, many algae which are known to produce harmful red tides, neurotoxins or hepatotoxins or have contributed to fish deaths through mucus production, toxins, anoxia or other mechanisms have been identified and characterised in WA. The fact that their numbers, along with their frequency and geographic distribution of toxic blooms, have been increasing, is of major economic, environmental and public health concern. However we have been fortunate in this State and have had extremely few public health problems with toxic and nuisance dinoflagellates and blue-green algae.

Natural controls on algal blooms

Naturally occurring zooplankton (small aquatic animals – see Box 1) and filter feeding mussels and worms, many of which graze on algae (phytoplankton), are important in estuaries and under normal conditions help control microscopic algae populations. However, the numbers of grazing zooplankton always lags behind the faster growing phytoplankton. Their slower reproduction rate, coupled with the eutrophic conditions in rivers and estuary allows algae populations to bloom with such speed that the grazing zooplankton often have little impact. In addition, many of the phytoplankton blooms are composed of large celled algae that are too big for many zooplankton to eat.

The large seasonal changes in salinity may also limit the distribution of some algae-feeding and filtering mussels and worms. Some of the truly marine organisms rarely penetrate into the upper more riverine portions of the estuary where most algal blooms occur. When they do reach the upper estuary, many rarely live long enough to be significant grazers on the phytoplankton or are limited by a lack of suitable habitat such as hard surfaces or coarse sands. Beneficial sessile estuarine organisms inhabit upstream areas but anoxic events sometimes decimate populations.

The collapse of algal blooms in the Swan-Canning estuary is mainly due to:

- sudden changes in salinity – for example freshwater algal blooms collapse when marine water mixes with the freshwater and the salinity increases past their survival level;
- river flow – algae cannot reproduce quickly enough in flowing water before being flushed downstream; and
- nutrient limitation – algae use available nutrients, starving themselves of nutrients that allow them to multiply, and the blooms collapse (see *River Science 10*: 'Nutrient limitation of phytoplankton in the Swan-Canning estuary').

Managing algal blooms

Worldwide experience has shown that when dealing with major environmental problems, such as eutrophication of rivers and estuaries, prevention is the best management action. This is especially so where a system like the Swan-Canning is still in reasonable condition (except for the upper Canning River). An Action Plan addressing nutrients and algal

blooms was released in April 1999 as part of the Swan River Trust's flagship environmental management Swan-Canning Cleanup Program.

The Action Plan emphasises the necessity to reduce nutrient inputs to the drains, tributaries, rivers and estuary from all sources. Within the estuary and Canning River weir pool, intervention techniques such as Phoslock™ and oxygenation are designed to reduce nutrient release from sediments (see *River Science* 17 and 18). Both phosphorus and nitrogen need to be reduced in order to lower the frequency and duration of algal blooms that currently occur in the system. It is also much easier to reduce nutrient inputs at their source rather than trying to remove them or neutralise their effect on algae when they are already in the water or have contaminated bottom sediments. It is very difficult to clean up or control algae once they have bloomed, formed scums or have washed ashore onto beaches. Beach harvesting, sillage pumping and chemical treatments are either limited in effectiveness or expensive.

The Action Plan aims to reduce nutrient inputs from rural and urban runoff and ground water flows (e.g. from fertilisers applied to lawns and gardens), prevent erosion and degradation of foreshores, control and better manage high nutrient generating land-uses (e.g. piggeries, intensive horticulture, sports grounds, runoff from light industrial areas, etc) and better manage leaching of nutrients (and other pollutants) from land fill sites. It adopts a whole-ecosystem approach and highlights the fact that community awareness and involvement are essential to achieving sustainable changes.

Successful implementation of the Action Plan will be achieved through a combination of reform in land-use planning and statutory controls (e.g. state planning policy and local government town planning schemes), improved land management, increased restoration efforts, river intervention (see *River Science* issues 13-15 and 17-18) and Integrated Catchment Management. Long term preventive measures such as catchment and foreshore restoration and Integrated Catchment Management may take up to 20 years to produce marked benefits in river health, so it is crucial that they are fully supported and initiated now.

Glossary

Biota – living organisms in an ecosystem.

Cryptophytes – a group of small single-celled algae with two flagella.

Detritus – decaying plant and animal material.

Diatoms – single celled algae with a silica skeleton; can grow singly, in chains or in simple colonies.

Dinoflagellates – a group of single-celled algae, typically with one or more flagella, that often show plant-like (e.g. photosynthesis) and animal like (e.g. ingesting other organisms for nutrition) behaviour.

Eutrophication – described in the text so in the interests of space don't add to the glossary.

Flagella – whip-like structure used for movement.

Heterotrophic – capable of deriving energy for life processes only from the decomposition of organic compounds.

Lunar tide – tidal movement caused by the gravitational pull of the moon.

Microtidal – having a tidal range of less than two metres.

Point source – a source of pollution that can be attributed to an identifiable, end of pipe, point.

Pervious – having pores or openings allowing water to pass through.

Sessile – fixed in one position; immobile.

Zooplankton – small, floating or weakly swimming animals (**microzooplankton** are less than 0.2 mm in length).

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For more information

More information on water quality in the Swan-Canning Estuary and catchment is available from the Swan River Trust. The complete list of Swan-Canning Cleanup Program publications is available on the Internet at <www.swanrivertrust.wa.gov.au>. *River Science* publications can be obtained from the Swan River Trust or downloaded in PDF format through the same website.

Swan River Trust

Level 1 Hyatt Centre 20 Terrace Road
East Perth Western Australia 6004

Telephone: (08) 9278 0900

Facsimile: (08) 9325 7149

Website www.swanrivertrust.wa.gov.au

Tell us what you think of our publications at
info@swanrivertrust.wa.gov.au

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