Department of Water
GOVERNMENT OF WESTERN AUSTRALIA

River Science 20
Science supporting estuary management
Issue 20, March 2010

Macrophytes and macroalgae in the Swan-Canning estuary

Macrophytes are aquatic plants that can be seen with the naked eye, and grow submerged, emergent or floating within marine, estuarine and riverine environments. Seagrasses are one type of fully submerged macrophyte and in the Swan-Canning estuary are noticeable biological components, embedded in soft substrata (e.g. sand) by their root systems. They tend to inhabit shallow sand flats within the estuarine basin, generally in peripheral regions where waters are less than 2 m deep, although they can grow much deeper if sufficient light for photosynthesis is available.

Macrophyte Heterozostera tasmanica *in the Swan Estuary (Source: McMahon 2010)*

Macroalgae (seaweeds) are photosynthetic plant-like organisms that can be seen with the naked eye. Macroalgae may be divided into the groupings: reds (Rhodophytes); greens (Chlorophytes); browns (Phaeophytes); and blue-greens (Cyanophytes). These divisions are primarily based on pigments in their tissues, which are also usually evident in their appearance. Macroalgae may grow attached to hard substrata (e.g. rock), or free-floating.

This article provides a background to the biology of macrophytes and macroalgae, discusses the communities resident in the Swan-Canning estuary, and how these organisms are significant to the ecology of the system.

Macroalgae Chaetomopha linum *collected near Canning Bridge (Source: Huisman 2010)*

CONTENTS

Royal Perth Yacht Club *– shallow areas around the periphery of the Swan-Canning estuarine basin provide an excellent habitat for macrophytes (source: Tracey 2006)*

The role of macrophytes and macroalgae

In aquatic environments with shallow, clear waters, macrophytes and macroalgae are often a significant biotic feature colonising large areas, creating underwater gardens. They are important to the aquatic ecosystem in many ways, related to their various roles, including:

- **Food source**: by harnessing soluble nutrients and sunlight they become a food source for some fish and invertebrates;
- **Habitats**: in creating an underwater garden, they provide a home for many organisms;
- **Sediment stabilisation and water clarity**: rooted macrophytes have a baffling effect and also stabilise sediments, reducing erosion. Slower water speed also causes suspended solids to settle out of the water reducing turbidity;
- **Nutrient sink:** by taking up nutrients from the water (and also from the sediment via roots for macrophytes). This reduces nutrients available for other primary producers such as phytoplankton; and
- **Oxygenation**: oxygen is released into the water (and sediment by macrophytes) as a by-product of photosynthesis.

Factors affecting the growth of macrophytes and macroalgae

The presence of macrophytes and macroalgae in aquatic environments is affected by physical, chemical and hydrodynamic conditions. In particular, light, nutrients, salinity and substrate play an important role.

Light is essential for photosynthesis, but is highly variable within estuarine environments. Reductions in light occur with depth, turbidity and stratification. Seagrasses typically require at least 10% of surface irradiation for growth. The light harnessing capacity of macroalgae is quite varied between species, and is less restricted by depth of water as they may be unattached.

Concentrations of nutrients in an aquatic system influence the types and amounts of these plant and

Info Box #1:
Historical macroalgal problems in the Swan-Canning estuary

Records of 'nuisance algal blooms' in the Swan-Canning estuary date back to 1870, noted in the form of a complaint made to the Inspector of Nuisances via the local newspaper at the time. The disgruntled citizen reported, '…a *large collection of seaweed in the river near Mill Street jetty, from which arose a most abominable stench, to the annoyance of the dwellers in the neighbourhood and even to many residing as far back as Murray Street*.' Reports of algal pollution continued in the early 1900s, also complaining of pollution and malodour. Discharge of sewage to Perth Water from a wastewater treatment plant based at Burswood commenced in 1912, and was redirected offshore in 1936. Within this period however, public complaints increased in number and spirit, noting macroalgal pollution throughout the whole estuary.

In particular, records describing '…*abundant weed or algae growing and floating throughout the salt water reaches of both the Swan and Canning Rivers*' can be found. A biologist, Professor Nicholls, was asked to provide a report on the algae in the estuary at the time (1922). His report detailed the presence of large amounts of the green algal species *Enteromorpha* and *Chaetomorpha*, and in the floating masses of weed with associated 'offensive odour', the presence of *Oscillatoria*. Algal problems associated with waste water treatment and industrial pollution continued to be a problem until the 1980s. From these anecdotal accounts it would appear that the amount of macroalgae in the estuary may have decreased substantially, as the presence of large, decaying accumulations of green macroalgae along the banks of the Swan-Canning estuary is no longer a common feature today.

plant-like organisms in the system – as water column nutrient concentrations change, proliferation of more competitive species may occur.

Salinity also influences the survival of macrophytes and macroalgae in an aquatic system. Salinity within estuaries is variable and typically those species found in estuaries are capable of tolerating a range in salinity. Species tolerant of salinity changes are called euryhaline. Some species however are sensitive to changes in salinity and can grow in only marine (approx 35 ppt) or fresh (< 1 ppt) waters and their occurrence is more localised.

Substratum types in the Swan-Canning estuary include: soft-sediment embayments; shallow, limestone outcrops; loose sands in riverine bends. Macrophytes typically require sandy sediments, whereas some macroalgae require solid substrates for attachment. Other free-floating algae simply move around with the current within the estuary, often accumulating in quiescent waters throughout a water body.

Distribution of macrophytes and macroalgae

Light is the most critical factor in determining primary productivity, therefore depth related light climates determine where species are most productive.

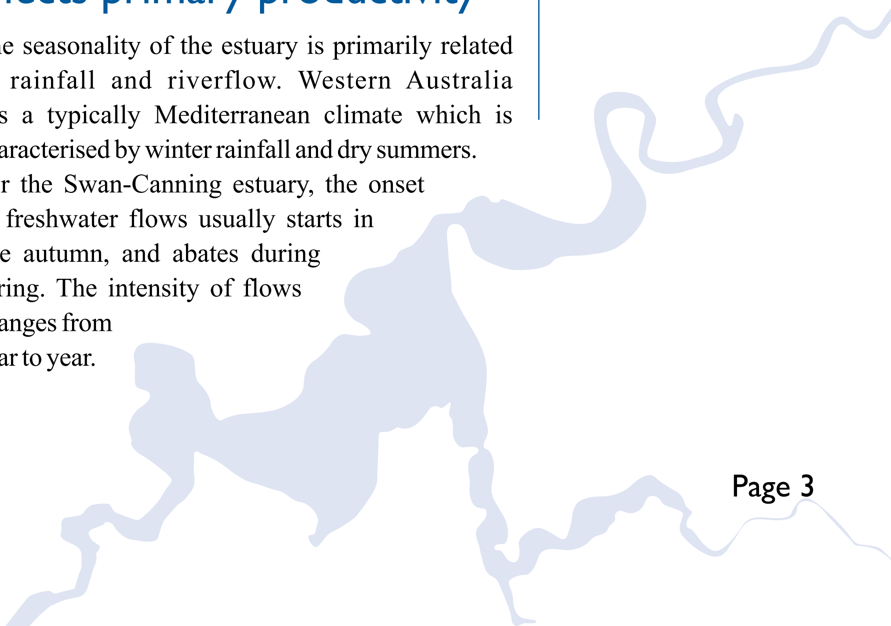
Wide ranges in light climates are present in the Swan-Canning estuary. The estuary is more than 20 m deep in some sections (e.g. Blackwall Reach). There are also extensive shallow sections of the estuary where water depths are less than 2 m. Shallow sand flats are generally found around the periphery of the Swan-Canning estuary, i.e. Melville Waters, Freshwater Bay, Pelican Point and Alfred Cove.

In the shallow sandy areas we see established seagrass meadows, reflective of good light penetration. It is also a good environment for the growth of unattached macroalgal species that simply accumulate over the sediment surface. Areas with rocky substratum and good light penetration encourage the growth of attached macroalgae. Many marine species are often found in the shallows near the estuary mouth.

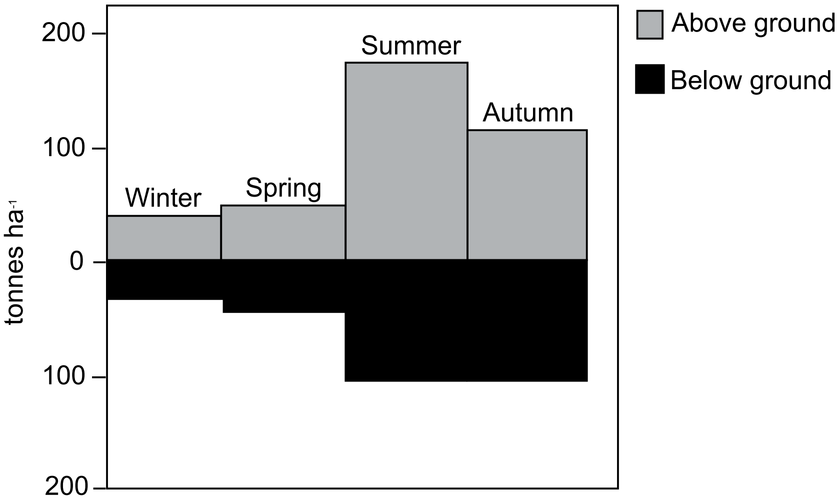
Under optimal conditions, growth of macroalgae can be prolific leading to large accumulations of decaying biomass along the foreshore. Historically this has been problematic in the Swan-Canning estuary (see info box #1).

Seasonality of the estuary affects primary productivity

The seasonality of the estuary is primarily related to rainfall and riverflow. Western Australia has a typically Mediterranean climate which is characterised by winter rainfall and dry summers. For the Swan-Canning estuary, the onset of freshwater flows usually starts in late autumn, and abates during spring. The intensity of flows changes from year to year.



Seagrass Halophila ovalis *near Alfred Cove (Source: Kilminster 2006)*



***Biomass** of* H. ovalis *in the Swan-Canning estuary is highest in summer and lowest in winter (Source: Connell & Walker 2001)*

A more detailed description of seasonality in the Swan-Canning estuary is given in River Science No. 8.

The growth of seagrasses and macroalgae is at a maximum in summer with sufficient light, high temperatures and almost marine salinities.

With the commencement of freshwater flows in winter, a reduction in light occurs as estuarine waters become dark and turbid due to tannins and sediment re-suspension. Also associated with winter flows is a reduction in salinity, although this is dynamic and dependent on salt wedge properties. These conditions can either result in a reduction in the presence or the dormancy of the seagrasses and macroalgae. Reappearance of seagrasses and macroalgae is rapid once favourable conditions return.

The seagrass *Halophila ovalis* is found throughout the Swan-Canning estuary

The most common seagrass species found in the Swan-Canning estuary is *Halophila ovalis* (common name: paddleweed). Studies undertaken by the University of Western Australia have found that this seagrass is ephemeral, growing quickest in the warmer seasons of summer and autumn, and disappearing in winter due to decreases in salinity and light penetration. *H. ovalis* is considered a colonising seagrass species, quickly covering bare sand areas in optimal growing conditions.

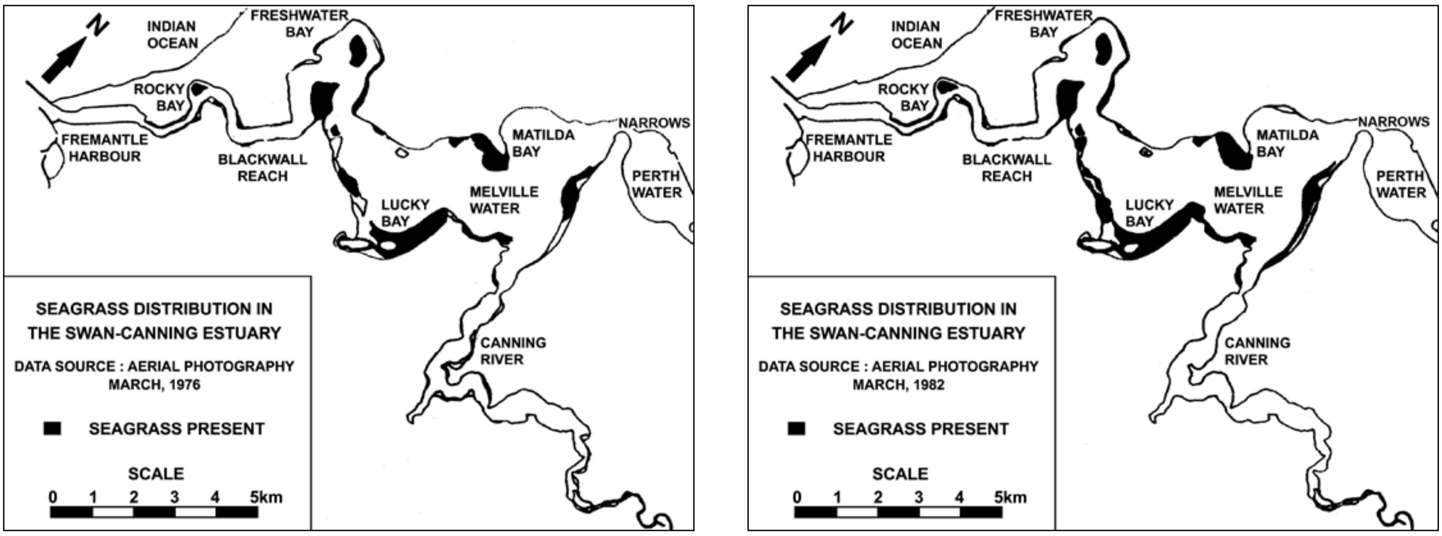
The distribution of this seagrass in the Swan-Canning estuarine basin was investigated, comparing changes in coverage of *H. ovalis* in 1976 to coverage in 1982 (Hillman *et al.* 1995). Most of the seagrass was found in shallow waters, along the periphery of the estuarine basin (75% of coverage < 1 m, and over 99% in water < 2 m). The deepest record of seagrass was near the estuary mouth (4 m deep). The upstream extent of *H. ovalis* was near the Narrows. This was assumed to be related to lower salinities which have been shown to reduce *H. ovalis* growth rates (Hillman *et al.* 1995).

For both years, *H. ovalis* was found to cover approximately 25% of the area investigated. The most notable change between the years was a loss of *H. ovalis* in the Canning River. The loss was offset by an overall increase in distribution throughout the estuarine basin with coverage increasing to 598 ha in 1982 from 568 ha in 1976.

Diversity of macroalgae in the Swan-Canning estuary – two studies

An investigation of macroalgal diversity found 35 species of macroalgae present in the Swan-Canning estuary (Allender 1981). Most species of macroalgae lived in the lower reaches of the Swan-Canning estuary near the mouth at Fremantle. Macroalgae grew in deeper marine waters near Fremantle but were limited to the shallow waters in the upper riverine reaches (likely due to water clarity).

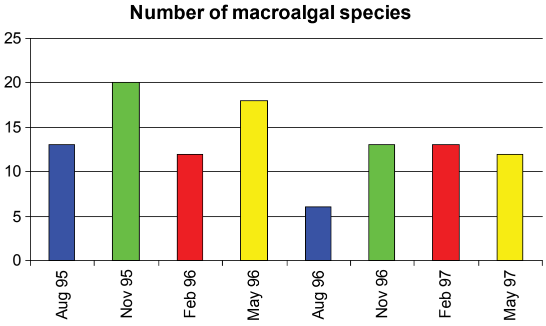
More recent investigations were undertaken seasonally between 1995 and 1997 (Astill & Lavery 2004). Over the two sampling periods, the study found 36 species of macroalgae. Red algal species were most common; however greens and browns were also present. The greatest diversity of species was found near the mouth of the Swan-Canning



***Distribution** (as % cover) of* Halophila ovalis *in the Swan-Canning estuary in (a) March 1976 and (b) March 1982 (Source: Hillman et al. 1995)*

estuary, and the lowest diversity in the upper reaches of the Swan River.

Both studies showed macroalgal abundance to be lowest in winter.



***Number of macroalgal species** found in the Swan-Canning estuary (Source: Astill and Lavery 2004)*

The most prolific macroalga is *Gracilaria comosa*

The most common macroalgal species found in the Swan-Canning estuary is *Gracilaria comosa*, a red alga. It can often accumulate above shallow, soft muddy sediments in sheltered embayments. These accumulations may be exported from the system with increased flows associated with rainfall. Prolific algal growth may lead to shading of underlying algal material. These conditions result in decreased oxygen in the water column and malodour as a result of *in situ* decomposition.

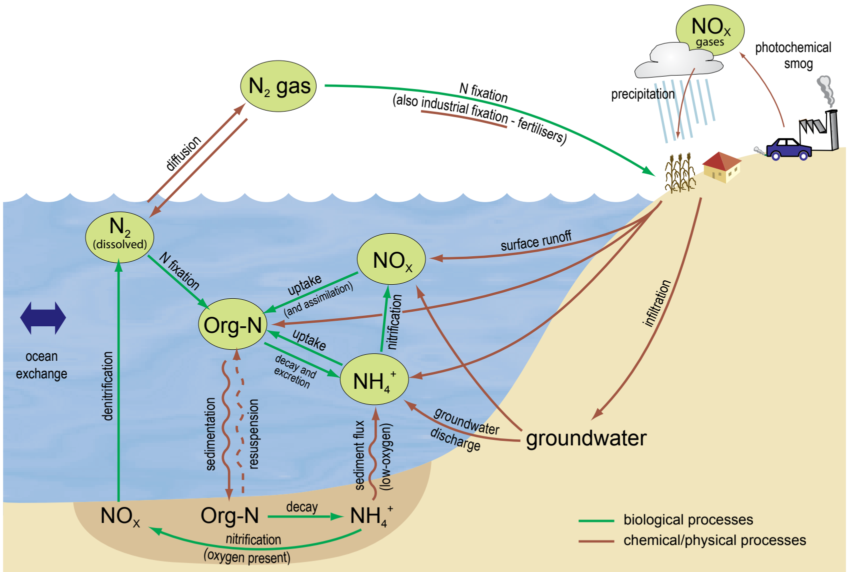
Seagrasses influence nutrient cycling

Macrophytes can cycle nitrogen and phosphorus in an aquatic environment through nutrient uptake and release with their growth and decay

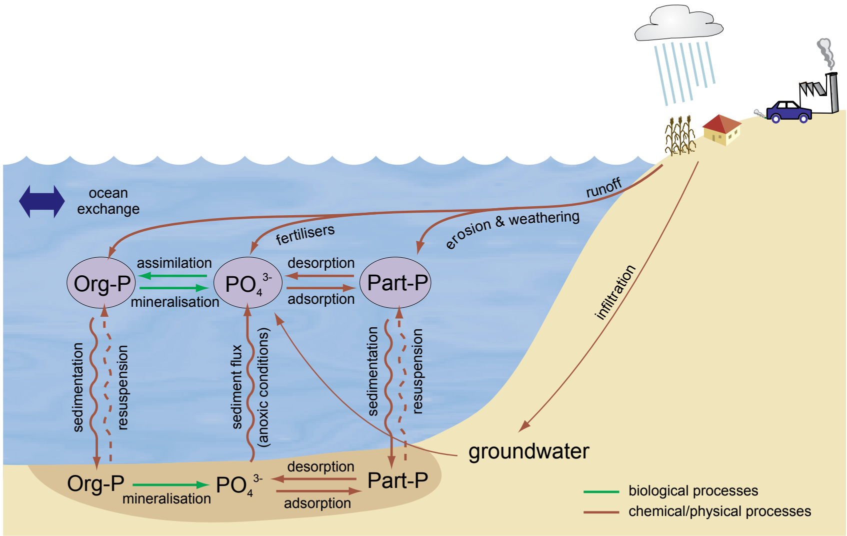
***Macroalgae** Gracilaria comosa growing attached to the the shell of the gastropod (*Batillaria *spp.) (Source: Wernberg 2010)* respectively. Oxygen generation and consumption during photosynthesis and respiration also influence nutrient cycles.

The pathways involved in the nitrogen and phosphorus cycles, and the conditions required for the processes, are summarised in the diagrams below.

Macrophytes influence nutrient cycles through: (1) **uptake and release of nutrient** forms (e.g. nitrate, ammonia, phosphate) due to plant growth and decomposition; and (2) **alteration of the oxygen climate** via photosynthesis (oxygen production) and respiration (oxygen consumption). Localised impacts on benthic nutrient cycling may have large regional impacts when seagrasses are present throughout a waterbody, such as in the Swan-Canning estuary.



***Schematic representation** of the nitrogen cycle in an estuarine environment*



***Schematic representation** of the phosphorus cycle in an estuarine environment*

1. Uptake and release of nutrients by macrophytes and macroalgae

As plants grow, they require nutrients for the construction of tissues. Seagrasses can uptake nutrients through their leaves directly from the surrounding waters, and also through their root structures. Seagrasses take up dissolved, inorganic forms of nitrogen and phosphorus, such as nitrate, ammonia and phosphate.

Macrophytes also contribute nutrients to the estuarine system through decomposition of lost plant biomass or detritus (e.g. dropped leaves). Nutrients locked up within the detrital material may be broken down by fauna or mineralised by microbes and returned to the system. It is through these activities of nutrient uptake during growth, and nutrient release from decomposition, that macrophytes can act as nutrient *sinks* and *sources* within the estuary.

2. Macrophytes and macroalgae influence nutrient cycling indirectly through photosynthesis and respiration

The presence of macrophytes and macroalgae at the sediment surface can influence the oxygen conditions in the sediments. This is due to photosynthetic and respiratory activities performed by macrophytes and macroalgae which produce and consume oxygen, respectively.

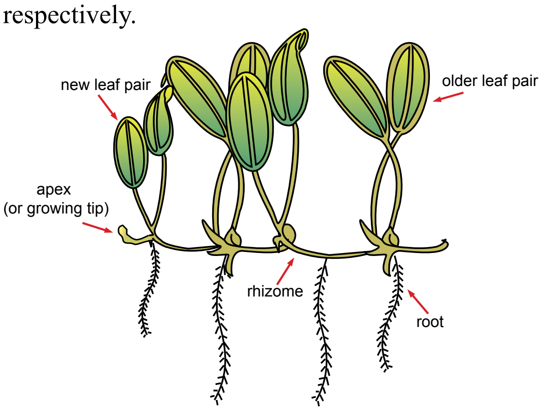
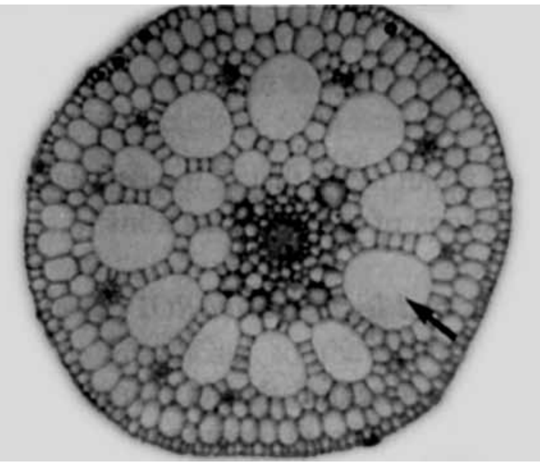


***Diagram** showing plant parts of* Halophila ovalis



***Cross section of* Halophila ovalis *rhizome** with arrow showing lacunal gas spaces (rhizome diameter: 1.25 mm) (Source: Connell et al. 1999)*

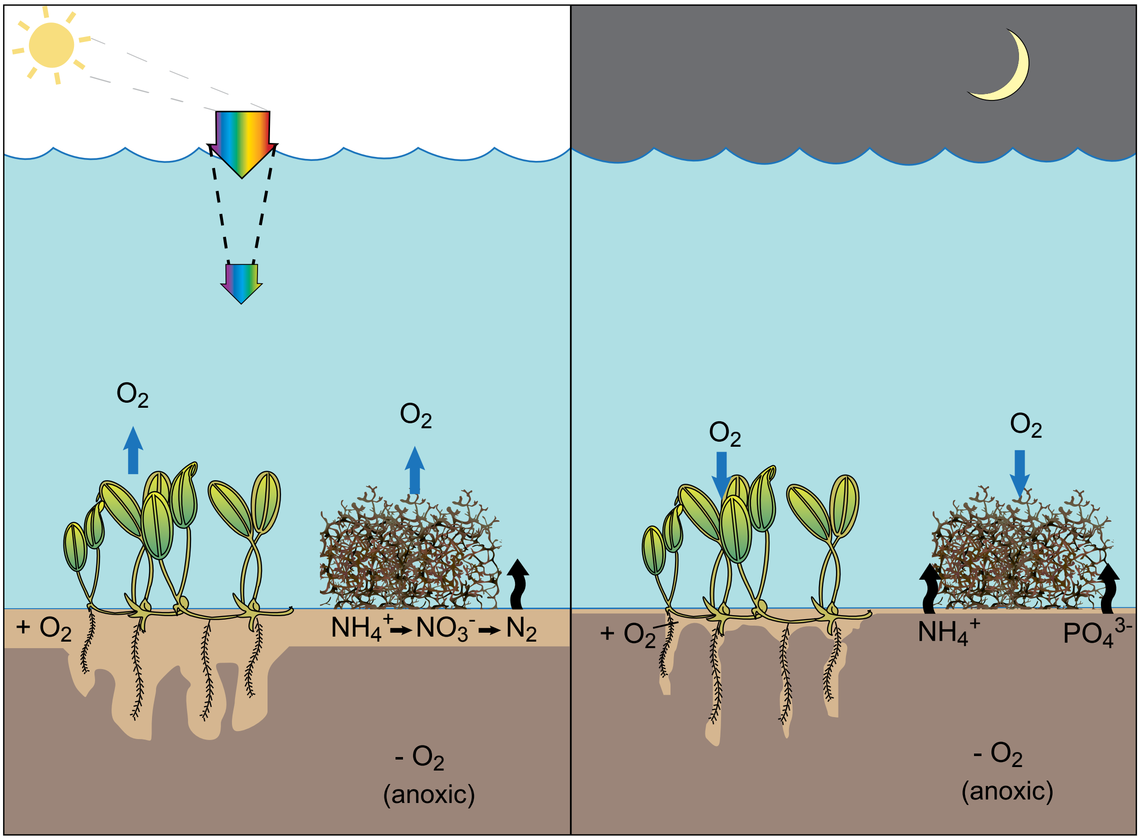


***Diagram** showing the possible influences of seagrasses and macroalgae on local benthic nutrient cycling*

Info Box #2: Luxury uptake of nutrients by macrophytes

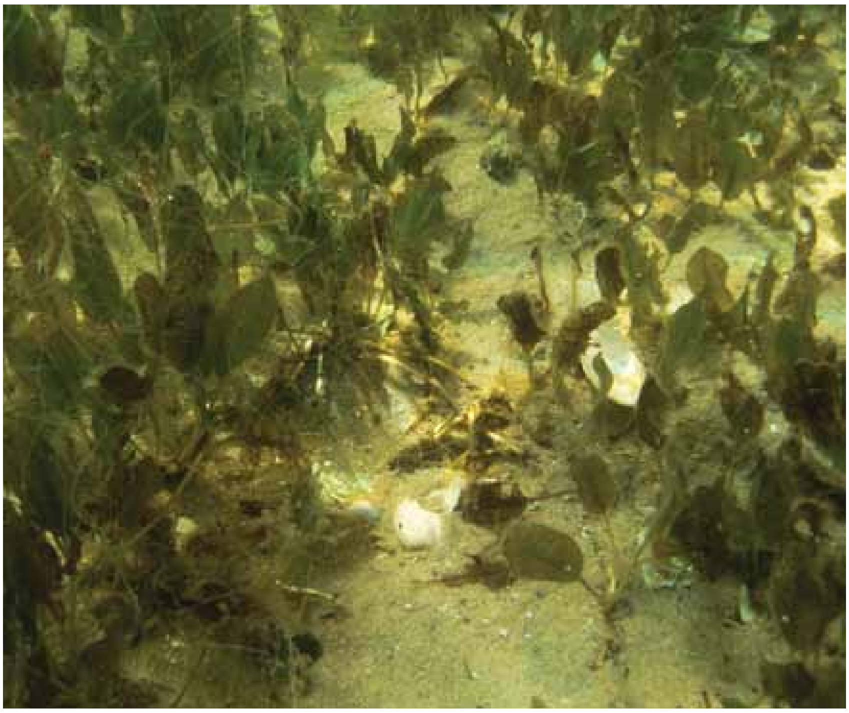
When algae are exposed to nutrients, the nutrients are taken up from the surrounding water and incorporated into their cells. The rate of uptake depends on the concentration of the nutrient in the water, and is described by a relationship known as the Michaelis-Menten equation. The relationship assumes that cell growth occurs at a constant rate regardless of the ambient nutrient concentration or the state of cell nutrition. Sometimes uptake rates deviate from this relationship. For example, when nutrient-starved algae are provided nutrients again, uptake rates exceed the rate required for growth as described by the Michaelis-Menten equation. These high uptake rates are called luxury consumption or luxury uptake. Essentially, nutrient uptake occurs without growth.

Luxury uptake is a common feature in macroalgae, particularly in estuarine environments where seasonal changes in ambient water column nutrients are common. In the Swan-Canning estuary, luxury uptake of nutrients has also been observed in seagrass species *Halophila ovalis*, particularly in late winter/early spring when tissue nutrient concentrations are relatively very high, yet plant growth rates are nil. This feature in *H. ovalis* is an indication that the species takes full advantage of the estuarine environment.

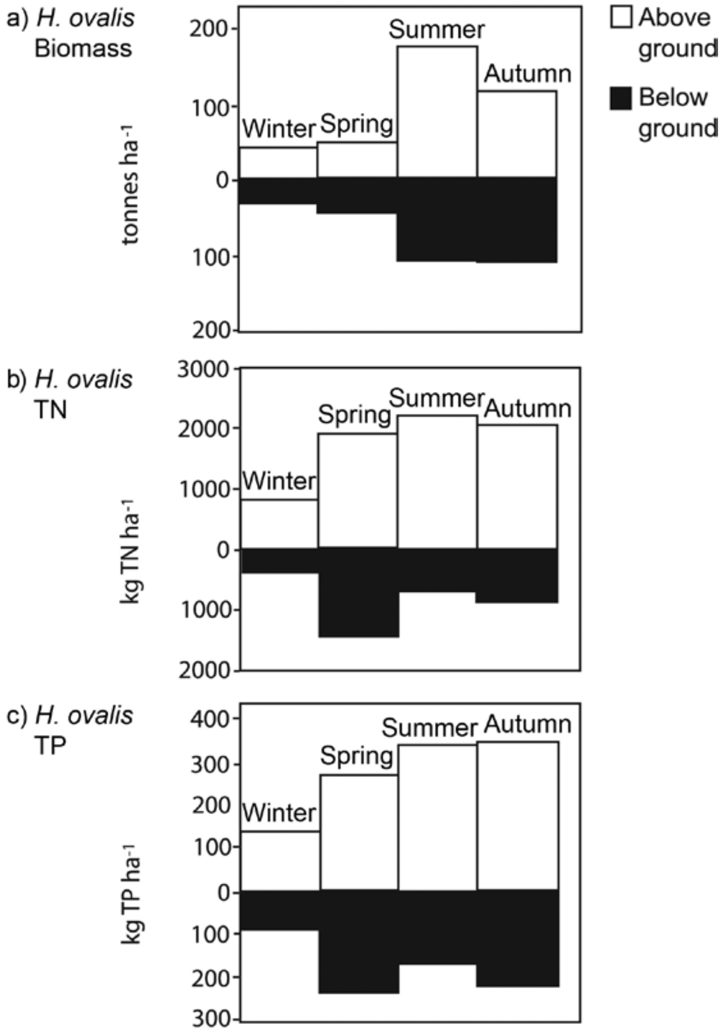
Seagrass roots require an adequate supply of oxygen for root respiration, and in anaerobic sediments, oxygen is provided to the roots by a honeycomb-type structure called lacunae. Lacunae are gas spaces inside the plants that allow the movement of oxygen from the leaves and shoots to the roots.

The nitrogen cycle is influenced by oxygen availability in the sediment since the oxygen climate within sediments determines which micro-organisms can survive. Microbial activity plays a major role in nitrogen cycling. Some of the organisms involved in nitrogen cycling processes require oxygen (e.g. nitrifying bacteria), while others cannot live in the presence of oxygen (e.g. denitrifying bacteria).

The forms of phosphorus present in the sediment are also dependent on the sediment oxygen profile, which affects the phosphorus adsorption in sediments.



Macrophyte Halophila ovalis *(Source: McMahon 2010)*



Seasonal *(a) biomass, plant (b) nitrogen standing stock and (c) phosphorus standing stock of* Halophila ovalis *meadows in the Swan-Canning estuary (Source: Connell and Walker 2001)*

Case studies in the Swan-Canning estuary – nutrient cycling

Seagrasses as seasonal nutrient sinks and sources

Biomass and nutrient dynamics associated with the seagrass *H. ovalis* were extrapolated to illustrate nutrient dynamics at the meadow-scale in a study by Connell & Walker (2001).

The study showed that the highest seagrass biomass occurred in summer. Autumn biomass was still relatively high compared to winter and spring. Nutrient content of the seagrass meadow was fairly consistent over spring, summer and autumn. This suggests that significant luxury uptake of nutrients occurs from winter to spring, in preparation for high growth in summer. While environmental conditions in the estuary were not favourable for high growth, seagrasses are able to exploit high seasonal nutrient concentrations in the environment. Seagrasses therefore act as a temporary sink for nutrients through the conversion of inorganic nutrients in the water column and the sediment porewater to organic plant matter.

Environmental conditions (light, temperature, salinity) favoured high growth between spring and summer. Above-ground biomass increased and tissue nutrient content in the above-ground plant parts was also higher, but only slightly compared to the increases seen from winter to spring. Below-ground nutrient content decreased while below-ground biomass increased from spring to summer.

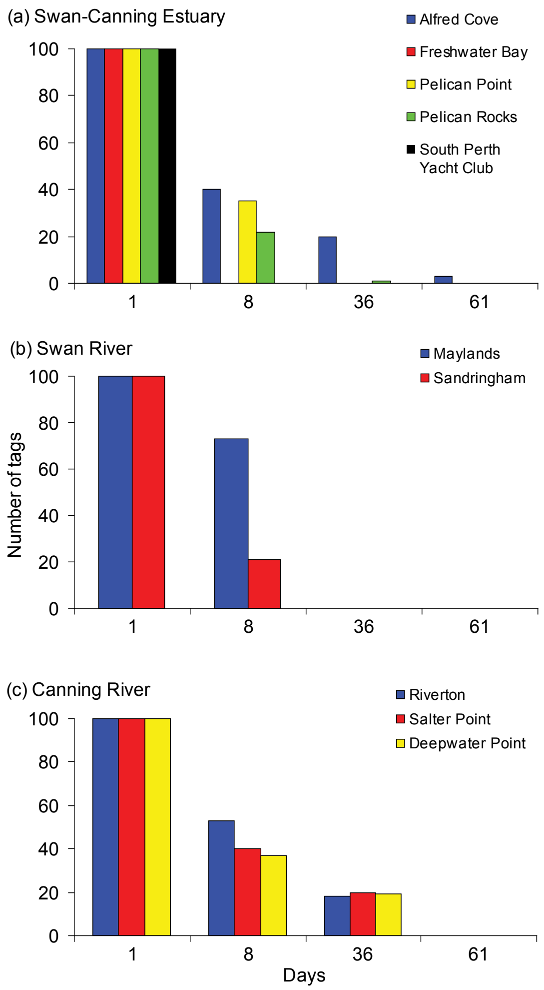
By autumn, a loss of above-ground biomass (with little loss of below-ground biomass) had occurred, and probably represented leaf material shed during storm events. Below-ground nutrient content increased from summer to autumn, suggesting uptake of nutrients within sediment porewater.

With the onset of winter rains, large losses in both above- and below-ground biomass occurred. Tissue nutrient content also decreased markedly by winter, most likely related to the large decrease in biomass at a meadow-scale. This organic matter exported from the meadow may act as a nutrient source to the estuary.

Loss of nutrients through algal export

In a study by Astill and Lavery (2001), macroalgae were tagged and monitored at nine sites. This study showed that macroalgal material is lost from the Swan-Canning estuary primarily through water movement associated with winter freshwater flows.

Loss of macroalgal biomass from some regions of the estuary can be high, with 100% of an accumulation observed in Freshwater Bay lost over the period of a week. Although the actual destination of lost macroalgal material was unknown, it was assumed that lost material is washed downstream and possibly out of the estuary altogether. This export of macroalgal material from the estuary through freshwater flows, results in export of nutrients from macroalgal tissues.



Disappearance of tagged unattached macroalgae from nine sites in three regions of the Swan-Canning estuary over three months (Source: Astill and Lavery 2001)

Case studies in the Swan-Canning estuary – oxygen dynamics

Seagrasses deliver oxygen into the sediments via their roots

Connell et al. (1999) measured the radial oxygen loss of *Halophila ovalis* roots. These investigations showed that the oxygen lost from seagrass roots was at a maximum near the root tip, and decreased further away from the root tip. The release of oxygen was also dependent on photosynthesis, with oxygen transported from leaves through the lacunae to the roots.

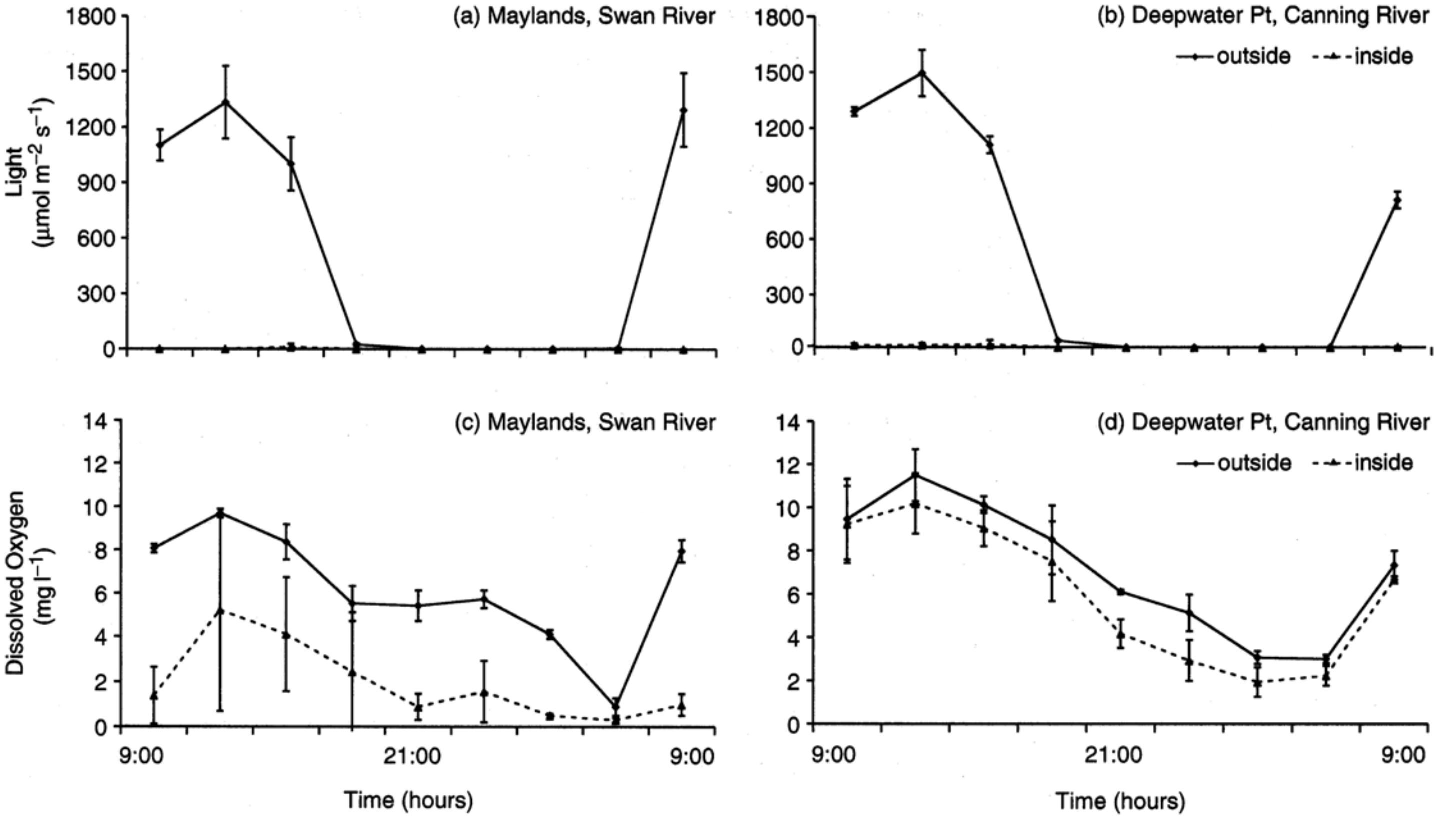
Macroalgae Ulva flexuosa *attached to rocky substrate (Source: Huisman 2010)*

In anaerobic sediments, this lost oxygen from seagrass roots that allows oxygen-dependent microbes to live, restricted to a narrow strip of oxygenated sediment around the seagrass roots This provides a 'micro-environment' for aerobic microbes, enabling oxygen-dependent nutrient cycling.

Oxygen concentrations across macroalgal accumulations change between day and night

Investigations by Astill and Lavery (2001) measured diurnal oxygen and light conditions at various locations within the Swan-Canning estuary.

Macroalgal accumulations can significantly influence the ambient oxygen climate. During the day, macroalgae photosynthesise, producing oxygen, while at night they respire, consuming oxygen. During the day, the net effect is an increase in oxygen concentrations above the macroalgal accumulation. These high oxygen concentrations are above normal (i.e. supersaturated). At night there is an overall decrease in oxygen concentration, particularly below the accumulation. Oxygen is also depleted during the day when dense



Light and oxygen profiles *measured inside and outside macroalgal accumulations over 24 hours at sites in the Swan and Canning Rivers (Source: Astill and Lavery 2001)*

accumulations limit light and photosynthesis. Macroalgae not receiving sufficient light to photosynthesise will die and decompose; this further reduces oxygen concentrations and can result in instances of hypoxia and anoxia at the sediment-water interface.

The oxygen climate relates to photosynthesis of the macroalgae. Oxygen concentrations were highest at midday when light levels were highest and photosynthesis activity maximal. The lowest concentrations we recorded at 6 am just before sunrise after which the macroalgae had been respiring for almost nine hours.

Can we use macrophytes or macroalgae as health indicators for the Swan-Canning estuary?

An understanding of the health of biological components may provide an indication of overall environmental condition for an ecosystem.

The ability to use a biological measure as an indicator for ecological health is very much dependent on having a thorough understanding of:

- natural variability in that biological indicator;
- how the indicator will respond to expected changes in the condition being managed (e.g. water quality); and
- confidence in being able to distinguish a change in the measure of the biological indicator attributable to management activities rather than simply natural variation.

Seagrasses have been used as biological indicators for the health of aquatic systems elsewhere. For example, the distribution of *Halophila ovalis* has been used as a health indicator for Moreton Bay, Queensland, and the density of seagrass shoots in *Posidonia* meadows has been proposed as a health indicator for Cockburn Sound in Western Australia.

Macroalgae however, are much more variable in their distribution and density/biomass making changes in distribution due to deteriorating water quality much more difficult to distinguish from background variability.

Future work and the next River Science will focus on seagrasses as indicators of estuarine health.

Glossary

Aerobic: living or occurring only in the presence of oxygen.

Ambient: surrounding, background.

Assimilation: the incorporation of nutrients into living tissues by the process of absorption

Anaerobic: an organism that can live in the absence of atmospheric oxygen.

Anoxia: absence of oxygen.

Benthic: organisms living on or in sea or lake bottoms.

Detritus: disintegrated or eroded organic matter.

Hypoxia: low (<1 mg/L) oxygen conditions.

Mineralisation: microbial conversion of an organic form of a nutrient to an inorganic form.

Nitrification: the conversion of ammonia to nitrate by specialised bacteria and other microorganisms.

Photosynthesis: the process in green plants and certain other organisms by which carbohydrates are synthesised from carbon dioxide and water using light as an energy source. Most forms of photosynthesis release oxygen as a by-product.

ppt: parts per thousand, a unit of measurement for salinity.

Primary productivity: the conversion of carbon dioxide into organic compounds by photosynthesising organisms

Resuspension: a renewed suspension of insoluble particles

Sedimentation: the deposition of sediment.

Sediment porewater: water found in between sediment particles within the sediment, can also be termed interstitial water.

Stratification: horizontal layers (which form due to differences in temperature and salinity) within a water body that prevent mixing.

References

Allender, BM 1981, *The distribution of benthic macroflora in the Swan River estuary, Western Australia,* Journal of the Royal Society Western Australia 4, 17–22.

Astill, HL & Lavery PS 2001, *The dynamics of unattached benthic macroalgal accumulations in the Swan–Canning estuary*, Hydrological Processes 15: 2387–2399.

Astill, HL & Lavery PS 2004, *Distribution and abundance of benthic macroalgae in the Swan–Canning estuarine system, Western Australia*, Journal of the Royal Society Western Australia.

Connell, L, Colmer, TD & Walker DI 1999, *Radial oxygen loss from intact roots of* Halophila ovalis *as a function of distance behind the root tip and shoot illumination*, Aquatic Botany 63: 219–228.

Connell, EL & Walker DI 2001, *Nutrient cycling associated with the seagrass* Halophila ovalis *in the Swan–Canning estuary based on seasonal variations in biomass and tissue nutrients*, Hydrological Processes 15, 2401–2409.

Fredericks, DJ, Palmer, DW, Smith, CS &. Heggie, DT 2002, *Benthic fluxes and nutrient recycling in the Swan Estuary*, Prepared by Geoscience Australia, Canberra, Australia.

Hemminga, MA & Duarte CM 2000, *Seagrass Ecology,* Cambridge University Press, Cambridge, UK.

Hillman, K, McComb, AJ & Walker DI 1995, *The distribution, biomass and primary production of the seagrass* Halophila ovalis *in the Swan–Canning estuary, Western Australia,* Aquatic Botany 51, 1–54.

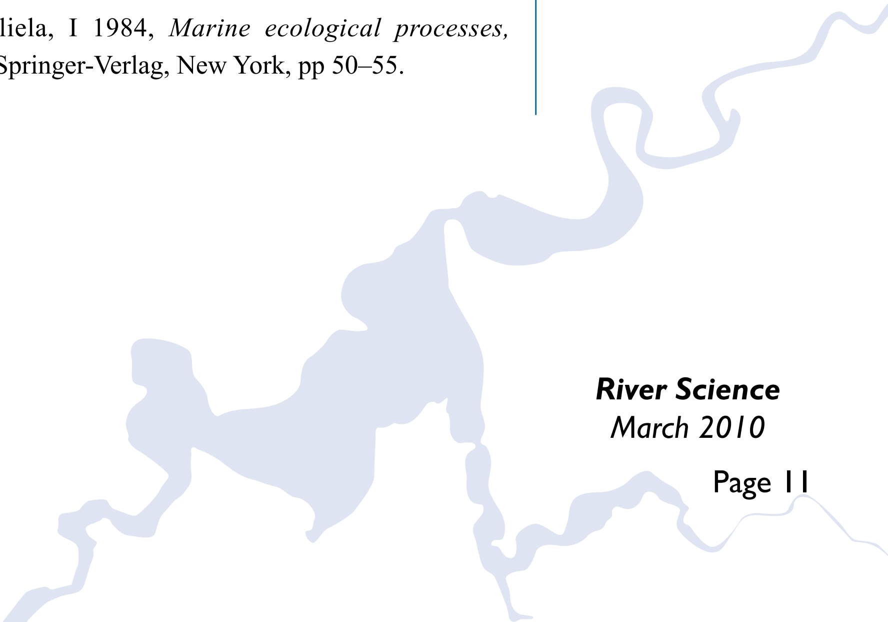
Huisman, JM 2000, *Marine plants of Australia. University of Western Australia Press,* Perth, Western Australia.

Lavery, PS & McComb, AJ 1991. *The nutritional eco-physiology of* Chaetomorpha linum *and* Ulva rigida *in Peel Inlet, Western Australia,* Botanica Marina 34, 251–260.

Nixon, SW\ 1995. *Coastal marine eutrophication: a definition, social causes, and future concerns*, Ophelia 41, 199–219.

SRRC 1955, *Swan River Reference Committee Report,* Prepared by the Sub-Committee on Pollution of Swan River, Perth, Western Australia.

Valiela, I 1984, *Marine ecological processes,* Springer-Verlag, New York, pp 50–55.



Macrophyte Ruppia *in Freshwater Bay (Source: McMahon 2010)*

Macroalgae Colpomenia sinuosa *(Source: Huisman 2010)*

Acknowledgments

This River Science series is an initiative of the Water Science Branch of the Department of Water. This issue was written by Helen Astill, Di Walker, Kieryn Kilminster and Vanessa Forbes. Thanks to John Huisman, UWA Press, Kathryn McMahon, Thomas Wernberg and Kieryn Kilminster for images. Thanks also for input from Malcolm Robb and Dieter Tracy.

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 and Healthy Rivers Action Plan publications are 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. More information on estuaries and water quality can be found at <www.water.wa.gov.au/Waterways+health/default.aspx> and River Science publications are also available from the same Department of Water website under publications

Department of Water

Level 4, 256 Adelaide Terrace
Perth Western Australia 6000

Telephone: (08) 6364 7800
Facsimile: (08) 6364 7888

Website <www.water.wa.gov.au>

ISSN 1443-4539
Printed on environmentally friendly paper
March 2010