

## Using seagrasses to understand the condition of the estuary

Macrophytes are aquatic plants that may have fully submerged, emergent or floating growth forms. This article will deal primarily with one species of fully submerged macrophyte, the seagrass *Halophila ovalis* (common name 'paddleweed'), which is found within the shallows of the Swan-Canning estuary, Western Australia. For information on the biology and historical distribution of this species in the Swan-Canning estuary see *River Science* 20.

Estuarine environments are particularly vulnerable to human impacts. Eutrophication has increased nutrient and organic matter deposition within estuaries worldwide. Associated changes in the condition of the sediment and decreased light availability results in additional stresses for benthic organisms.

*H. ovalis* is one of the most widely distributed seagrasses in the world. Our interest in this seagrass is its potential to be used as a biological indicator (bioindicator) of estuarine condition. Bioindicators are organisms which are used to monitor the health of an environment or ecosystem. The primary concept here is that if the organisms within the estuary are healthy, their environment is also in good health.

By measuring appropriate characteristics of the bioindicator, environmental managers can gain information about a particular aspect of the environment, e.g. contaminant exposure, water quality or changes in the ecosystem. An advantage of using bioindicator species to assess environmental quality is that a species living in situ provides a time-integrated measure of the environmental condition.

There are many factors to understand before *H. ovalis* (or any bioindicator species) can be used

effectively as an indicator of ecological health. These include understanding:

- the natural variability of the characteristic/s measured
- the expected response of the organism to changes in environmental condition
- the sensitivity of the species (a successful indicator has the response to environmental changes greater than the natural variability for the measured characteristic).

This article reports on work (undertaken between 2006 to 2008) to understand the distribution and physiological behaviour of *H. ovalis* and examines the potential of using this seagrass as an indicator of estuarine health in the Swan-Canning estuary.

### Seagrasses within the estuary

A good understanding of the extent and abundance of seagrasses is required to show evidence of changes



*Halophila ovalis* in Lucky Bay, Swan-Canning Estuary (Kilminster 2011)

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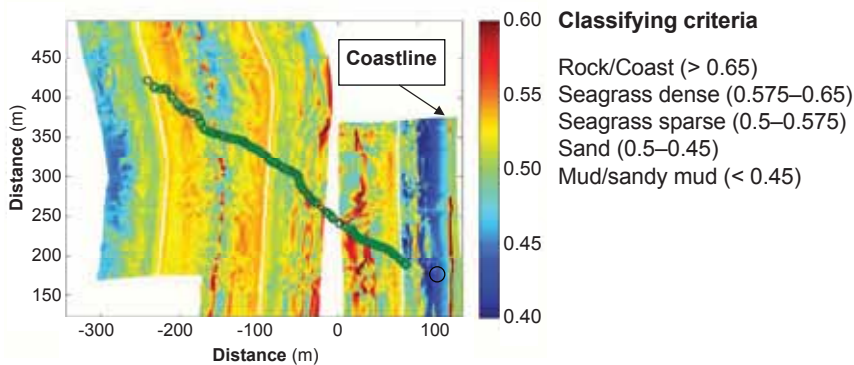
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in seagrass distribution. Light availability is one of the main controlling factors influencing seagrass distribution. Light is strongly absorbed by the water and the growth of seagrass at the deepest edge of a seagrass meadow is limited by light.

Two long-term measures of seagrass status were proposed. The first measure was to record the presence and absence of seagrass and produce maps of seagrass distribution. The second measure was to record the depth range of the seagrass, i.e. the difference between the shallowest and deepest point at which seagrass occurred. These measures – if repeatable over several years – could show loss or gain of seagrass habitat as conditions improved or declined.

## Seagrass distribution

A number of methods have been used to measure seagrass distribution within estuaries. Aerial photography, sidescan sonar and video surveys, as well as diver-intensive techniques have all been used to create seagrass distribution maps in Western Australia and the world. However, there are limitations associated with the reproducibility, bias, cost, frequency, and accuracy of these methods. For example, seagrass mapping by aerial imagery introduces errors associated with sun glitter, turbidity, differences in depth and floating macroalgae. Diver-intensive techniques are labour-intensive (therefore expensive and time-consuming), and difficult to reproduce with accuracy since meadow density classification has a bias associated with the individual diver's interpretation.



**Backscatter maps** from sidescan sonar of Lucky Bay, also showing groundtruthed data by diver transects, where seagrass coverage:  $\circ \leq 5\%$ ,  $\circ = 5-50\%$ ,  $\circ \geq 50\%$

In 2008, Curtin University (Centre for Marine Science and Technology) undertook a survey of the seagrass within the Swan-Canning estuary using acoustic remote sensing with sidescan sonar. Sidescan sonar uses sound waves which are transmitted in pulses. The sound waves travel through the water until they hit the sea floor which bounces part of the wave back to the sidescan sonar instrument. The reflected energy is referred to as

'backscatter'. Surfaces that are hard or rough will produce high backscatter values, whereas smooth surfaces produce low backscatter values. It is this distinguishing property which can be used to create seagrass distribution maps, as seagrasses give a higher backscatter response than the surrounding bare sediment. Whilst this method is quite well established for seagrasses in marine systems, the Swan-Canning system posed a scientific challenge as the shallow water limit for the technique was poorly understood at the time.

Ten foreshore areas within the Swan-Canning estuary were surveyed, equivalent to 4.4 km<sup>2</sup>. Sidescan sonar was able to identify seagrass areas from bare sediment. Backscatter values were categorised into groups describing habitat type: 1) mud/sandy mud, 2) sand, 3) seagrass low-medium density, 4) seagrass medium-high density and 5) rock/coastline. These categories were groundtruthed with diver transects identifying areas of < 5%, 5–50% and > 50% seagrass coverage (see *backscatter maps*).

Producing seagrass distribution maps by sidescan sonar was successful and would be repeatable without operator bias. However, the equipment to carry out these surveys is expensive and requires experts to operate and interpret the acquired data. Effort is also required to groundtruth the data collected by the sidescan sonar. Increasingly, the Department of Water has been looking towards video surveys for a repeatable, low-tech and relatively inexpensive method for producing seagrass distribution maps. Video surveys have been tried successfully in several south-west estuaries to produce seagrass distribution maps. Some advantages of the video surveys are the ability to identify species, estimate plant density and note the presence of epiphytes or macroalgal species.

## Seagrass depth range

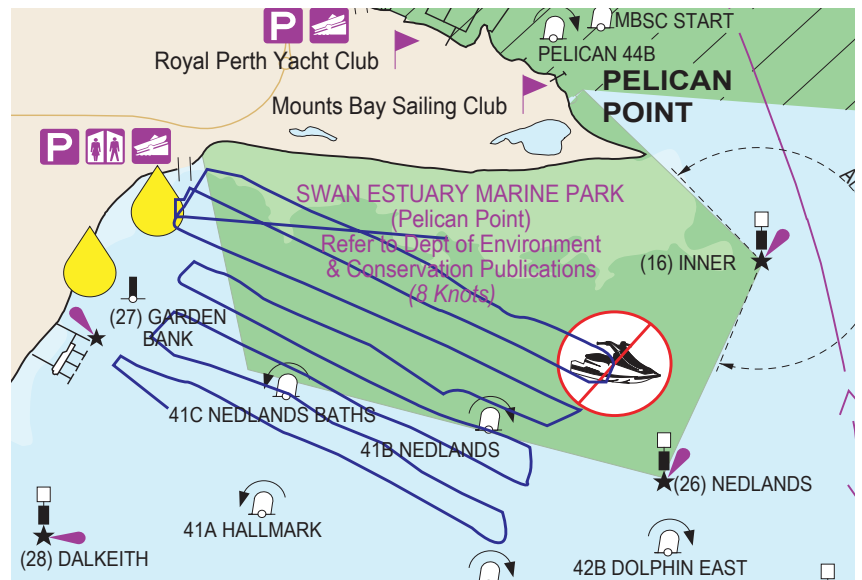
The depth over which seagrasses are able to live may provide a robust measure of habitat quality. The depth range is the distance between the shallowest and deepest points where seagrass is present. A larger depth range would indicate better environmental conditions (improved light penetration). Seagrass depth range may provide an indicator of estuarine health by integrating the amount of light available for photosynthesis over an extended period. This surveying approach (dumpy-level method) has been used previously in south-east Queensland (EHMP 2007).

Researchers from Edith Cowan University investigated the suitability of determining depth range of seagrass at sites in the Swan-Canning estuary using the dumpy-level method. Three sites

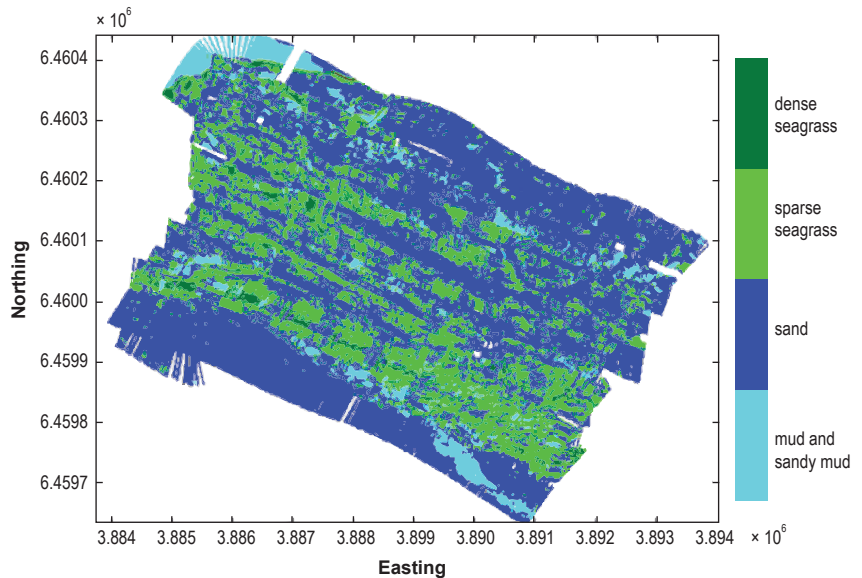
were studied: Como Beach, Matilda Bay and Waylen Bay. Other sites (Chidley Point, Freshwater Bay and Point Resolution) were disregarded during the initial site selection as seagrasses were observed deeper than 5 m, which was impracticable for the method. The method involved three people: one person in the water holding the staff gauge at the edge of the seagrass meadow, a second person marking the position of the transect and a third person reading the theodolite (a precision surveying instrument used for measuring angles). Measurements were taken at the shallowest (inner) and deepest (outer) edge of the seagrass meadow and the depth range was calculated from these.

The shallowest seagrass meadows were located in 0.8–1 m of water and the deepest seagrasses were found around 2.8 m for Como Beach, Matilda Bay and Waylen Bay. The largest depth range (and smallest meadow extent) was seen at Como Beach, reflecting the steepness of the near-shore environment at this site. While the differences in the outer-edge depth limit can be attributed to light penetration and environmental condition, it is less clear what drives differences in the inner-edge depth. Factors may include UV irradiation, disturbance from waves produced by boat traffic or wind and the depth of tidal fluctuations (i.e. minimum overlying water).

The study concluded that it was impractical to use the dumpy-level method of assessment to monitor seagrass depth distribution in the Swan-Canning estuary, mainly due to the depth at which seagrasses were observed. Instead, it was recommended that spatial surveys or monitoring of fixed, permanent depth transects was undertaken in the future.



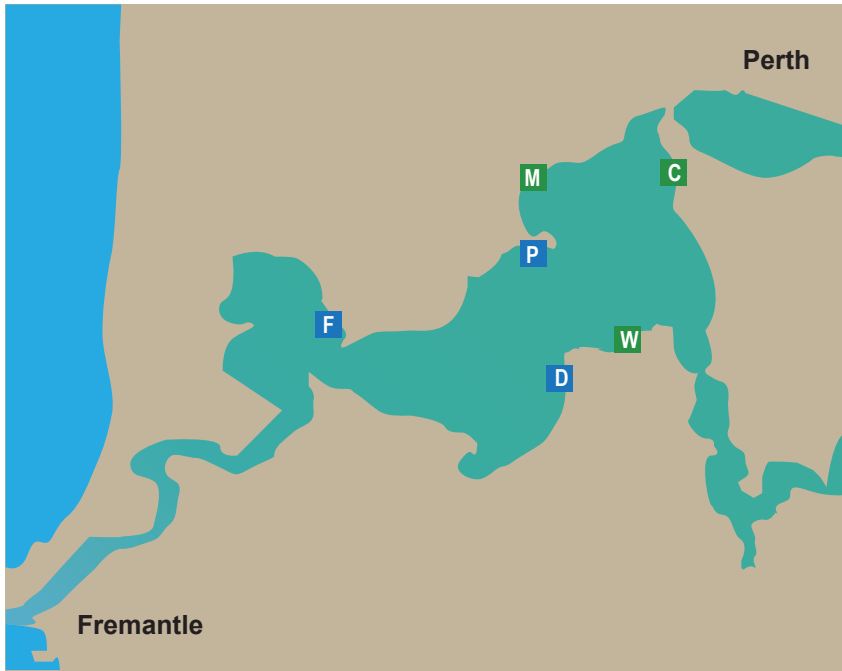
**Survey location** at Pelican Point, where dark blue continuous line shows pathway of sidecan sonar



**Seagrass distribution map** for Pelican Point, where light green and dark green indicate seagrass (sparse and dense).



**Dumpy-level measurement:** Left: holding the staff gauge at the edge of the seagrass meadow, and Right: reading the theodolite.



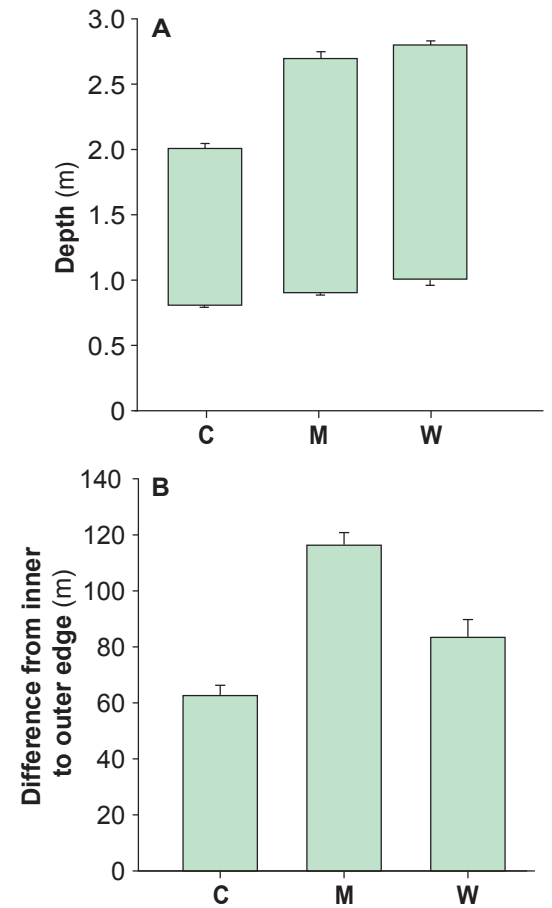
Map of the sites used for dumpy level measurements (Como (C), Matilda Bay (M) and Waylen Bay (W)) and the ecophysiology pilot study (Freshwater Bay (F), Point Dundas (D) and Pelican Point (P)).

## Seagrass growth requirements

In order to grow and survive, *H. ovalis* requires sufficient light, an adequate supply of nutrients and a favourable benthic environment. Seagrass are thought to require a minimum of 10% of the in-water surface irradiance. For some species this minimum can approach 25% of the in-water surface irradiance (Duarte 1991 and Orth et al. 2006). This high light requirement means that seagrasses are acutely responsive to changes in water clarity. The depth to which seagrasses will grow is often thought to be limited by light availability. Seagrass meadows growing where light is limiting are often sparse, with increased distances between leaf pairs (i.e. elongated internode distances), and/or decreased shoot density.

Nutrients are accessible to seagrass from the water column or the sediment (i.e. porewater). Nitrogen (N) and phosphorus (P) are important nutrients for seagrass; however other trace elements are also essential for growth.

Seagrasses invest substantial resources in below-ground parts, producing (on average) as much biomass below-ground as above-ground. As such, seagrasses are affected by the sediment in which they grow. The roots and rhizomes of seagrass have been termed 'an asset and a burden' (Hemminga 1998). The roots allow access to nutrients as nutrient concentrations are generally much higher in the sediment, but toxins such as sulfide may also be present in sediment. Oxygen produced by



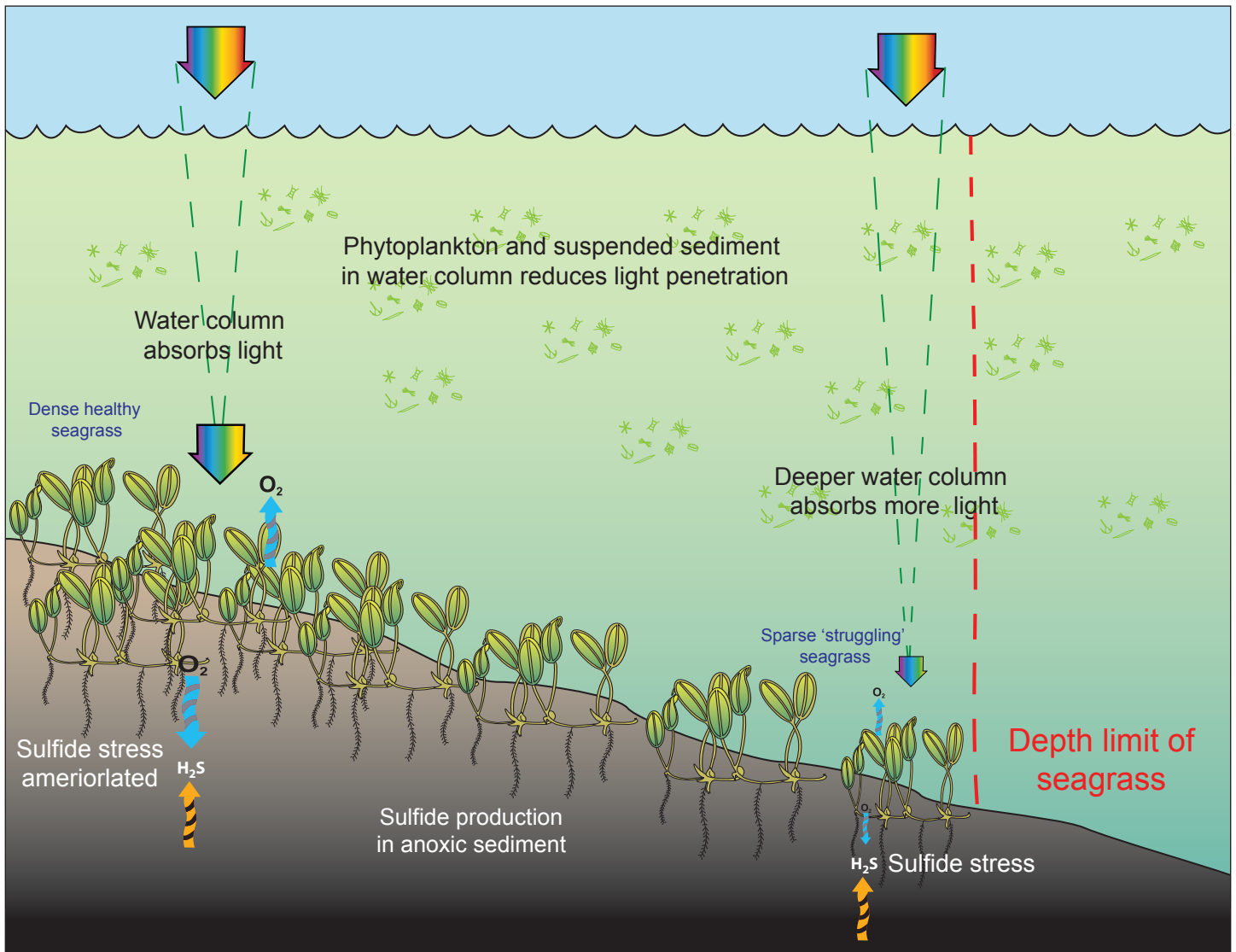
Results of the dumpy level measurements estimating A) depth range and B) seagrass bed extent at three suitable sites in the Swan-Canning estuary – see map of sites.

photosynthesis is used by seagrasses to detoxify sulfide in the root zone (by converting  $H_2S$  to  $SO_4^{2-}$ ).

## Measures of ecophysiology: a pilot study

The Water Science Branch of the Department of Water undertook a pilot study of potential physiological parameters of *H. ovalis* in the Swan-Canning estuary using meadows in three locations (Freshwater Bay, Pelican Point and Point Dundas). This exploratory study of seagrass ecophysiology was undertaken in 2006, and aimed to see if attributes of the seagrass could be used as surrogates for estuarine condition. The environmental quality was assessed by measurements of water column nutrients, porewater nutrients and light. The seagrass 'response' metrics were total nitrogen and total phosphorus concentrations in seagrass tissue (combining above- and below-ground plant material), leaf density and biomass.

There was significant variation observed in both measures of environmental quality and measures of seagrass response. A multivariate analysis



**Conceptual diagram** describing the relationship between light and sediment condition which results in the depth limit of seagrasses

of the data showed that there was a significant (but very small) correlation between variables of environmental quality and nutrient concentrations within the seagrasses. The pilot study concluded that a greater understanding of the physiological responses of *H. ovalis* would be needed before it could be successfully applied as a predictor of estuarine condition.

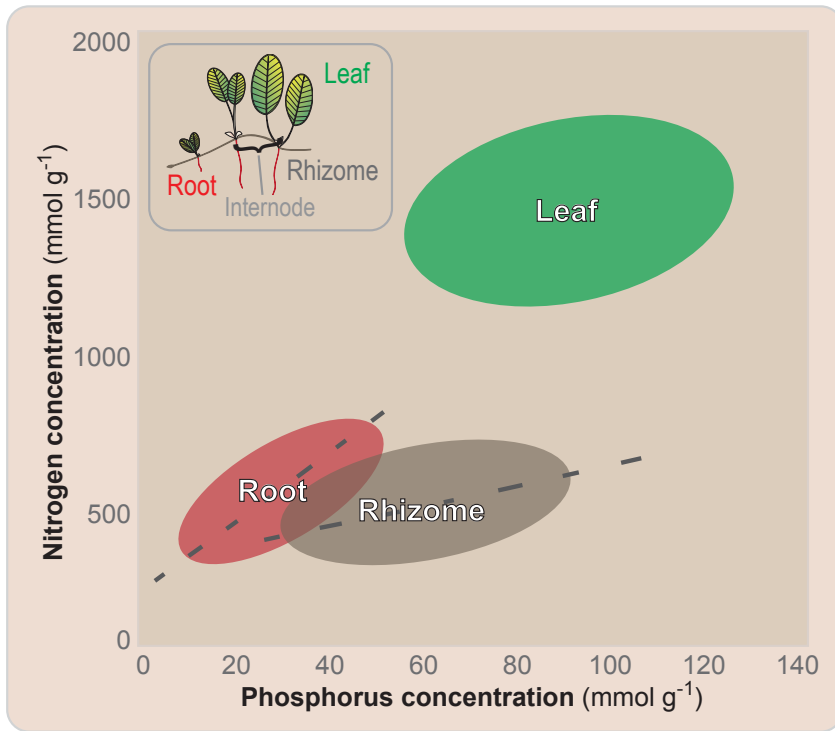
## *Halophila ovalis* physiological responses

Physiological response of *H. ovalis* was also investigated in mesocosm and field studies by researchers at the University of Western Australia (Kilminster et al. 2006; Kilminster et al. 2008). In mesocosm experiments, the *H. ovalis* was exposed to increasing loads of organic matter, in both dissolved and particulate forms. In another experiment the light intensity under which the seagrass was grown

was reduced. Seagrass growth rates, biomass and nutrients within sediment porewater and seagrass tissue were measured as the response variables.

Following organic matter addition, biomass production declined for *H. ovalis* despite an increased availability of nutrients in the porewater. Leaf nutrient concentrations increased with organic matter enrichment, with a disproportionate preference for phosphorus. Analysis of porewater data suggested that phosphate was translocated from below-ground parts to the leaf compartment, but uptake was confined to the first week following organic matter enrichment.

Lower growth rates and lower average leaf weights were observed, with higher leaf nitrogen and phosphorus concentrations for mesocosm treatments with the highest degree of shading. Light reduction was also shown to increase bioavailability of inorganic nutrients within porewater of seagrass sediment.



**Conceptual diagram of nutrient allocation** in leaves, rhizomes and roots of *H. ovalis* grown in culture under varying environmental conditions (Actual data published in Kilminster et al. 2006 and Kilminster 2006)

One important finding of these studies was that each part of the plant (leaf, root and rhizome) had a different relationship of response for the two main nutrients (N and P). Nutrient concentrations in leaves were approximately twice that in the root and rhizomes – see conceptual diagram of nutrient allocation.

In the pilot study undertaken in 2006, above- and below-ground tissues were combined, however, for the most sensitivity in the measured response variables, plant tissues should be analysed individually in the future. The mesocosm study also suggested that chronic organic matter loading of sediments would have only a small nutritional benefit for seagrass and that continued inputs of organic matter would favour microbial or algal nutrient uptake and production, rather than seagrass production.

## Sediment conditions affect seagrass growth

The loss of seagrass worldwide has often been attributed to reduced water quality. However, an argument for the contribution of sediment quality in the decline of seagrasses also exists. It is probable that generation of excess sulfide (following the enrichment of sediment with organic matter) inhibits plant growth. The importance of sediment condition

is of particular relevance to the Swan-Canning estuary, as within the Melville water basin, sediment condition has become increasingly rich in organic matter.

Sulfide concentrations in aquatic sediments are likely to increase with excess organic matter deposition (through eutrophication) and a rise in temperatures (global warming). Hydrogen sulfide is toxic to plants. In seagrass, it enters through the below-ground parts primarily at night (Pedersen et al. 2004) when oxygen loss from roots (a photosynthetically dependant process) is at a minimum (Connell et al. 1999). Seagrass can also re-oxidise sulfide which has entered the plant, leading to an accumulation of elemental sulfur (Holmer et al. 2005). Sulfide re-oxidation is thought to occur within the lacunal gas spaces of the plant tissues.

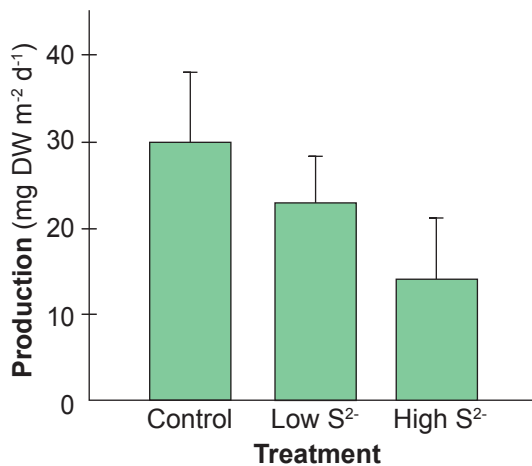
The short-term effects of sulfide on the growth, nutrition and morphology of *H. ovalis* were investigated in situ near Pelican Point in the Swan-Canning estuary. Sediments within a *H. ovalis* meadow were enriched with sodium sulfide ( $\text{Na}_2\text{S}$ ) at 0, 1.1 and 4.2  $\text{g m}^{-2}$ . These treatments were estimated to increase sulfide concentrations by 1–4 mM.

With sulfide addition, a number of biometric responses were noticed: growth rate decreased, internode-distance decreased, and average leaf weight decreased. Growth rate of *H. ovalis* was negatively correlated with both N:P ratio and the concentration of phosphorus in above-ground plant parts. The distance between nodes decreased and the concentration of phosphorus in leaves increased. In fact, measuring just these two response variables alone, could predict 63% of the variability in growth rate. It was estimated that at about 5.5 mM of sulfide enrichment would halt seagrass growth altogether.

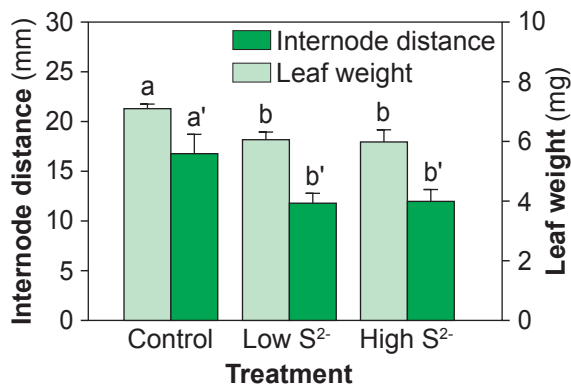
Additionally, this work demonstrated that measurements of biomass alone (above- or below-ground or ratio) were insufficient to reveal the negative response of seagrass to the sulfide stress. Measurements of growth rate, production, or an understanding of changes in plant morphology (reduced leaf weight), were necessary to demonstrate the negative impact of sulfide stress in this study. As biomass is not particularly sensitive to sulfide stress, it should not be used to indicate a ‘healthy’ seagrass population without additional measurements of growth or production.

## Future directions

Determining seagrass distribution on a regular basis is desirable in the Swan-Canning estuary. Not only could this be used to show loss and gain from estuary condition but could also demonstrate influence of



**Mean areal production** of *H. ovalis* exposed to different levels of sodium sulfide via sediment (Kilminster et al. 2008).



**Reduction in internode-distance** and average leaf weight for *H. ovalis* with the addition of sediment sulfide (Kilminster et al. 2008). Different letters signify statistical differences.

climate change. For example, the upstream extent of seagrass is forecast to increase in the Swan-Canning estuary due to a stronger influence of the salt-wedge.

In other south-west estuaries, video surveys have proven to be a low cost and repeatable method for creating maps of seagrass distribution. While the method does not have the same degree of resolution as the sidescan sonar technique and is more prone to bias, it is a lot more cost-effective. Additionally, it is likely that in any survey substantial variation will be introduced simply by the time of sampling since *H. ovalis* is a rapidly growing species over the summer months (it then dies off with winter freshwater flows). It is recommended that the maximum seagrass coverage period be targeted (late summer) in future seagrass surveys.

Ongoing assessment of seagrass ecophysiology should also be included in the assessment of seagrass as an estuary condition indicator. As previously noted, biomass alone is not a very sensitive measure of stress and as such should not be used to indicate a 'healthy' seagrass population. Assessing aspects of seagrass ecophysiology might provide insight into why changes in seagrass distribution have occurred over time. The Water Science Branch (Department of Water) and Swan River Trust are currently exploring this concept with a monitoring program which encompasses a range of seagrass metrics.

## Glossary

**Anoxic:** describing the state where oxygen is absent.

**Benthic:** pertaining to the bottom (or sea floor), under a body of water.

**Biomass:** the total mass of living matter, usually expressed in terms of dry weight per unit area.

**Ecophysiology:** the study of an organisms physiological functioning and the interrelationship with its environment.

**Epiphytes:** in aquatic environments, epiphytes are aquatic algae that grow either on other seaweeds or seagrass.

**Eutrophication:** nutrient enrichment of a water body which promotes excessive plant and algal growth and decay.

**Growth rate:** the rate at which biomass increases.

**In-situ:** in the natural or original position

**Internode-distance:** the distance between two nodes. For *H. ovalis* this is the distance between two leaf pairs, as a leaf pair grows at each node.

**Lacunal:** a cavity or space in an anatomical structure.

**Mesocosm:** an experimental system which simulates real-life conditions while allowing the manipulation of environmental factors.

**Multivariate analysis:** statistical analysis of more than one variable at the same time.

**Porewater:** interstitial water in the spaces between sediment particles.

**Sidescan sonar:** a sonar device that emits fan-shaped sound pulses down towards the seafloor and is used to produce images of the seafloor.

**Uptake:** the act of taking in or absorbing.

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## For more information

More information on estuaries and water quality can be found at <<http://www.water.wa.gov.au/Understanding+water/Rivers+and+estuaries/Monitoring+and+assessing+waterways+health/Assessing+estuary+health/default.aspx>>.

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