RECOVERY AND RESTORATION OF SEAGRASS HABITAT OF SIGNIFICANCE TO COMMERCIAL FISHERIES

**Report to
Fisheries Research and Development Corporation
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Cover photo: Swans grazing on seagrass beds at low tide at Crib Point, Western Port. The photo was taken by Dr. M. J. Littlejohn and shows the scene in 1977, before large scale loss of seagrass in Western Port, a loss that might have resulted from overgrazing by swans.

Recovery and Restoration of Seagrass Habitats

Contents

INTRODUCTION

Graham Edgar

During the past twenty years the importance of seagrass meadows as structural components of coastal ecosystems has become increasingly recognized. This has resulted in a great expansion of research activity being directed towards the biology and ecology of seagrasses (Larkum et al, 1989)[1]. Seagrasses are now known to provide (i) food and shelter for a great variety of plant and animal species, (ii) increased primary production of coastal waters, (iii) increased nutrient trapping and recycling, (iv) stabilizing effects on sediments and shorelines, (v) a nursery area for fishes, including many species of commercial value. It therefore is a matter of considerable concern to fisheries, port and land management authorities that seagrass meadows are being degraded and destroyed around the world. Because this destruction of seagrass habitat is often due largely to anthropogenic factors, the losses of seagrass meadows tend to be greatest in proximity to urban areas. Such seagrass meadows have higher recreational, commercial and aesthetic value than unvegetated habitats or natural seagrass beds located distant from population centres. If successful restoration techniques can be developed, the economic value of these beds in particular areas may exceed the cost of restoration.

Participants at a meeting convened by the Victorian Institute of Marine Sciences in Melbourne in November 1986 recognised that seagrass habitats in southern Australia were increasingly being degraded. At this meeting the general lack of collaboration between investigators in different states was noted, with three themes being identified where workshops should prove to be particularly useful. These themes were: (i) methods for monitoring seagrass habitat, (ii) methods for halting losses of seagrass habitat, and (iii) methods for restoring seagrass habitat in areas where losses had occurred. The present workshop, sponsored by the Victorian Institute of Marine Sciences, CSIRO Division of Fisheries Research and the Fishing Industry Research and Development Council, addresses the third of these areas; it follows the workshop "Methods for Monitoring Seagrass Habitat" held in Melbourne on 20-22 June 1988 (Walker, 1989)[2].

The resumes of the various talks presented at the "Workshop on Recovery and Restoration of Seagrass Habitat" are published here.

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[1]Larkum, A.W.D., McComb, A.J. and Shepherd, S.A. (1989). Biology of seagrasses: a treatise on the biology of seagrasses with special reference to the Australian region. Elsevier, Amsterdam.

[2]Walker, D.I. (1989). Methods for monitoring seagrass habitat. Report of workshop held on 20-22 June, 1988, Melbourne, Australia.VIMS Working Paper No. 18, 1-32.

OVERVIEW OF PRESENTATIONS

RESTORATION AND CREATION OF SEAGRASS MEADOWS

Review of recovery and restoration of seagrass meadows

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Why are we interested in restoring seagrass meadows?

Seagrasses occupy a particularly productive part of the nearshore marine environment. On soft sediments sheltered from direct ocean swell, they fill a similar niche to that of seaweeds on rocky bottoms, viz., they form the basis of food webs and provide habitats and nursery areas for an array of animal species. Usually found in estuaries and sheltered bays, the seagrasses play an important ecological role both as biological substrate and physical baffle to water and sediment movement.

Losses have been extensive, for example:

Cockburn Sound	3 300 ha	97% of total area
Princess Royal Harbour and Oyster Harbour	1 320 ha	58% of total area
Western Port	12 290 ha	71% of total area
Gulf St Vincent	9 000 ha	10% of total area

These losses have been caused by a variety of factors, which may differ in importance in different cases. They include high nutrients from industrial, urban and rural effluent, causing excessive epiphyte growth and changes in the light regime of the seagrass and high sediment loads in the water from land cultivation and clearing and dredging.

The case of Princess Royal Harbour and Oyster Harbour, where urban and rural runoff were the major factors, was discussed in detail.

Natural destruction of climax seagrass meadows is extremely rare; storms such as that which caused extensive damage in 1984 off the north coast of Western Australia have a frequency of 40-100 years. These rare events cause blowouts which are colonised by smaller seagrass plants which, in turn, are often removed by subsequent storms. Natural seedlings of the climax seagrass plants do colonise but are rarely successful.

Man-made destruction of seagrass meadows requires man-made restoration. However, the practice is in its infancy, and does not have a record of success. No net gain in seagrass meadow area due to human activity has occurred in any part of the world.

The problems associated with seagrass restoration were identified (see Fig. 1); among the most critical are those arising from knowledge of seagrass reproductive biology. Examples of the kind of propagules used in a seagrass restoration program were given. *Posidonia* seedlings have been planted but are not spreading and appear to have gone into a dormant stage. If cuttings are used they should have growing tips i.e. meristematic tissue, and these are difficult to find.

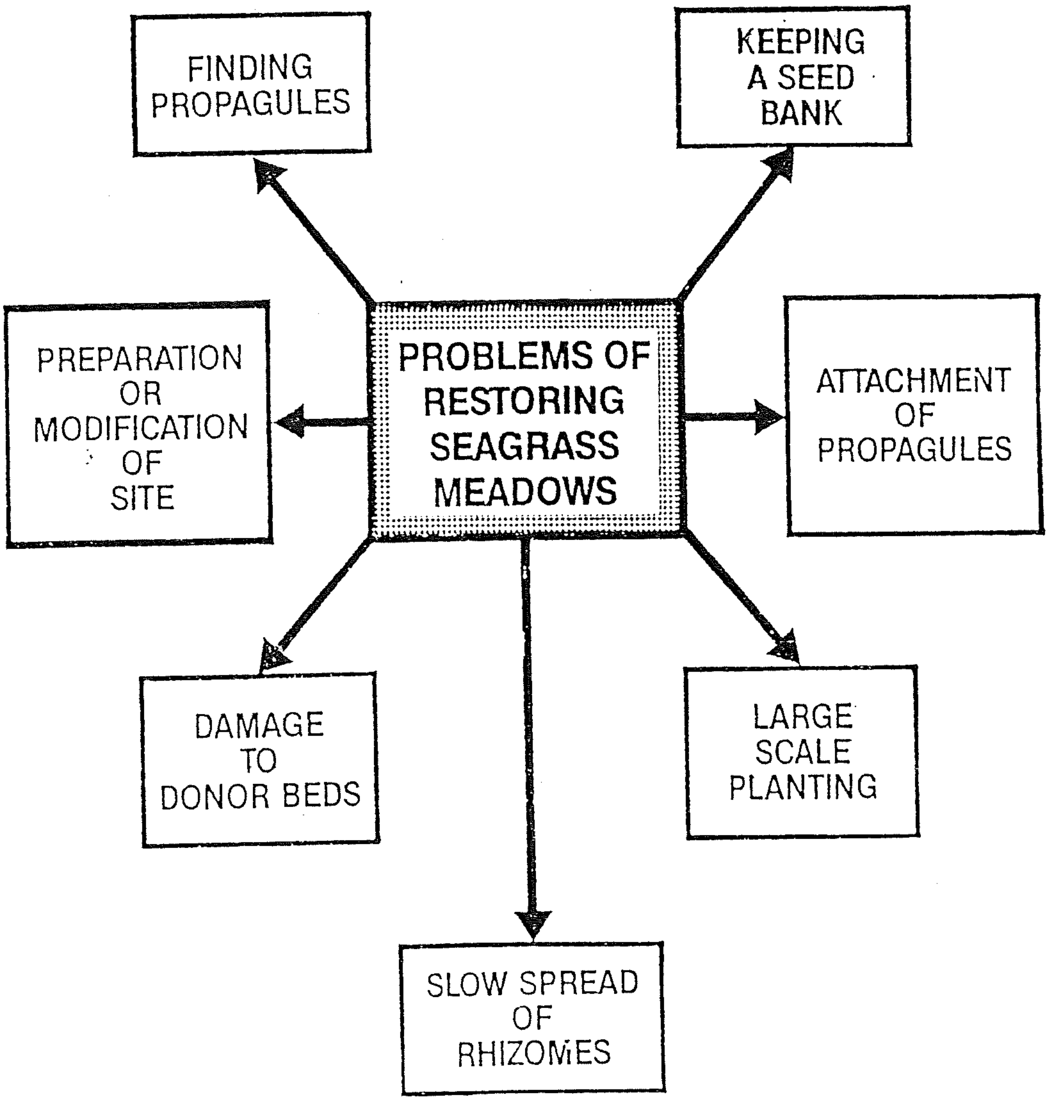
FINDING PROPAGULES
KEEPING A SEED BANK
PREPARATION OR MODIFICATION OF SITE
PROBLEMS OF RESTORING SEAGRASS MEADOWS
ATTACHMENT OF PROPAGULES
DAMAGE TO DONOR BEDS
LARGE SCALE PLANTING
SLOW SPREAD OF RHIZOMES

Figure 1.

In the future the stock can be improved by genetic engineering, hybridisation and introductions, while the plants can be improved in the field by fertiliser, hormones and mechanical planting and handling. Research into the biology of all species must continue to enable workers to decide on what, where and when to plant seagrass propagules.

The Need for Restoration - when should attempts be made to restore seagrass meadows?

The conditions that influenced the decline of the meadow must be reversed. To fully understand the reasons for the partial or complete destruction, three conditions of seagrass growth must be examined.

1. Physical conditions

If dredging or changing bottom topography caused the loss, the area must be restored so that the hydrology is similar to that existing before the disturbance. Current meters or even plaster/latex blocks should be used to measure water movement. Sediment may smother seagrass meadows, or build up and elevate the bottom to such an extent that exposure kills the seagrass. The compensating values for light quality and quantity must be determined.

2. Chemical conditions

High nutrients encourage epiphytes and phytoplankton blooms. The source of high nutrients must be stopped. Sediments store nutrients, so that after input of nutrients to an estuary has ceased there is still the problem of nutrients being released from the sediments. To return nutrient concentrations to levels existing before eutrophication, baseline data must be available.

3. Biological conditions

Excessive epiphyte growth smothers leaves of seagrass, preventing photosynthesis. It is important to know whether the epiphytes found at any one time are normal seasonal loadings or whether they are excessive and caused by eutrophication.

Burrowing shrimps can also cause light reduction by adding sediment to the water column and by smothering leaves with sediment.

Herbivory may be important in localised areas and in the tropics. Urchins eat seagrass leaves and dugongs and the green turtle also consume seagrasses.

Suitable propagules for restoration

1. Planting Units (PU's)

There are several variations in the planting units that can be used. There are also several ways of anchoring them.

* Plugs are excavated units with sediment intact. Larger units are turfs.

* Sprigs are excavated units without intact sediment. They are easy to handle but not suitable where sediment is necessary for continued growth of the plant.

* Seeds may be useful, providing they can be collected in large quantities (e.g. *Halophila*, *Halodule*, *Cymodocea*, *Syrigodium)*.

* Seedlings such as *Posidonia* and *Amphibolis* provide the plant with a start. With both of the above it may be possible to store large numbers for later planting.

* Sprouting stems - adventitious roots may be induced for *Heterozostera* and *Amphibolis* to give large quantities of planting material.

* Artificial stabilisers - may be used as artificial seagrass or as a baffle for other planting units.

2. Problems of installation

The high cost of planting (one estimate is $62,000 per ha) makes most of this prohibitive. Spacings are important as success is deemed to have occurred only if PUs coalesce. The method of attachment also requires some consideration; propagules may be buried or attached to spikes or to fibre mats.

How are seagrass meadows destroyed and when should attempts be made to restore them?

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Man-made changes

A variety of changes resulting from human activity can affect seagrass distribution, and the following list, although not exhaustive, at least demonstrates that examples can be found for most of these impacts.

Reclamation - This is the most destructive and permanent as there is little or no chance of future restoration by either natural or artificial means. As an example, approximately 60ha. of *Zostera capricorni* was reclaimed for a foreshore road between the airport runaway and the port construction, in Botany Bay. Other examples are meadows reclaimed for canal estates e.g. Sylvania Waters in the Georges River.

Dredging - depending on the depth after dredging, there may be natural recolonisation. This is generally not the case, however, when the dredging is for improved navigation or for a commercial operation (e.g. for building sands). For example, there are old (but still active) sand dredging operations being carried out in seagrass beds in many rivers (e.g. *Zostera capricorni* beds in the Clarence River at Oyster Channel). Another example is the shell grit mining carried out in Port Hacking in the early 1960's - the damage to seagrass (*Posidonia australis*) beds can still be seen on aerial photographs, although some areas have recolonised with *Zostera* and *Halophila*.

Modified Wave Climate - See previous discussion of Botany Bay.

Overgrazing - See previous discussion for Botany Bay, where quite significant losses can be directly attributed to a population explosion of a sea urchin (*Heliocidaris erythrogramma*) within the *Posidonia australis* beds.

Siltation/Turbidity - losses of about 60% to the area of *Zostera* between the 1950's and present time have occurred in most of the Northern NSW river systems. I attribute these losses to changes in siltation rates and turbidity levels, after the major deforestation and changes to land usage in these catchments.

Eutrophfication - There are several documented cases, e.g. Cockburn Sound in W.A., generally associated with high epiphyte loads.

Mechanical Damage - Examples are the worm digging in Quibray Bay (NSW), the scars left from amphibious landing craft in Botany Bay and Jervis Bay (NSW) and the scars left from anchor moorings in Port Stephens *Posidonia* beds (some of which have been recolonised with *Zostera*).

Point Source Effluents - The example of the hot water effluents from power generating stations in NSW coastal lakes was given, and discussed further by Dr Robert King during the workshop.

Further possible impacts were discussed, but there are no documented cases of impact yet.

Modified Tidal Regime - This has occurred due to entrance channel changes to Wallis Lake and most other NSW estuaries.

Modified Flooding Regime - Most large NSW rivers were highly modified in the early 1960's due to flood mitigation works. The impact on seagrasses is unknown.

Natural Changes

These were only briefly discussed and included:

* natural cycles, e.g. the south coast lakes in NSW
* effects of cyclones in tropical regions
* effects of floods and subsequent burial
* effects of herbivory e.g. dugongs in Moreton Bay

When should attempts be made to restore lost seagrass?

This question was left largely open for discussion. However, two general aims of restoration were identified:

- to accelerate the natural recovery rates of a modified area, now made suitable for transplanting of seagrasses, and,
- to create entirely new areas (e.g. by dredging the shoreline to make new creek beds or bays) in compensation for losses.

SOME CASE STUDIES

Seagrass in Cairns Harbour

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A detailed study was conducted of the marine environment in Cairns Harbour, north Queensland.

Information was collected on the biology, geology, hydrology and chemistry of the region including, where available, historical data. This database was used to assess the impact of a proposed marina and mixed residential development on the Cairns foreshore. The proposed site includes 25 hectares of seagrass and 55 hectares of bare mud and algae.

A pilot seagrass transplant experiment was designed to assess the potential of seagrass transplantation for reducing the impact on marine life that would occur if the development was approved.

Three experiments, using a variety of seagrass species, evaluated seeds, single shoots, and cores and turfs as planting units. *Zostera capricorni* was selected as the most suitable species with turfs as the planting unit.

As low tide emergence was considered the main factor limiting the upper distribution of seagrass in Cairns Harbour, the selected planting site was modified so that water was retained at low tide. The site was at 0.5m above Port Datum, the mean of the depth distribution of *Zostera capricorni.*

Planting units 25cm square with an average shoot density of 365 shoots/m were planted in October 1988. Fifty to seventy per cent of turfs were lost within the first month. Remaining turfs have established and have increased in shoot density and growth of shoots, but there has not been lateral growth from the turfs.

It is expected that the late winter and spring conditions in Cairns Harbour may be more conducive to rhizome spread and a subsequent increase in area covered.

The experiment is being monitored on a three monthly schedule and updated results will be available in 1990.

Seagrass loss and restoration in N.S.W.

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There are many areas in NSW where large scale changes to seagrass beds can be shown to have occurred over the past 40 years, which is the period for which good quality aerial photos are generally available.

Botany Bay

Most people will be aware of the losses to Botany Bay. About 58% of the 1942 *Posidonia australis* area had been lost up until 1986. Even more of this area has now been lost from Towra Point. This represents about 300ha. In many cases the *Posidonia* has been replaced with *Zostera capricorni*. As Tony Larkum and I have pointed out in the past, this loss was considered to be a consequence of:

* increased and redirected wave energy and sediment erosion after dredging the Bay`s entrance to cater for large ships,

* major storm events in 1974, 1985, and 1986. These storms have had a greater effect than previously due to recent:

  (i) high nutrient levels in the Georges River, and

  (ii) grazing of the disturbed beds by the sea urchin *Heliocidaris erythrogramma* in plague numbers, leading to denudation.

In 1986 replanting trials were carried out to evaluate the possibility of repairing the damaged areas. 1500 transplant units were planted off the beach at Towra Point. Transplant units consisted of either clumps of *Zostera capricorni* (about 10 - 20 shoots) or a shoot and rhizome of *Posidonia*. The main aims of the project were to determine if transplanting was feasible (e.g. do the transplants show rhizome growth? etc.) and what type of anchors or protection should be offered to the transplants. After about 6 months, heavy seas wiped out the experiment, although it had been possible to determine that the best form of anchoring was light wire pegs. In terms of, firstly, convincing engineers that a problem existed and, secondly, of showing the futility of transplanting in the present environment, the project was successful. However, the general comment I often get is that the experiment should be repeated until it works (i.e. the plants grow). Generally speaking the results from the experiment using two species, three depths and a variety of anchors showed a great deal of interaction, although simple wire pegs proved consistently the best anchors.

Other sites

Several other areas have shown losses of seagrass meadows, though very few other transplant experiments have been carried out.

Just about every river system I've looked at in NSW has experienced large losses of the seagrass, e.g.:

* 158 ha. loss in Clarence River
* 33 ha. loss in Tweed River
* 27 ha. loss in Georges River

These losses were of *Zostera* beds, principally in main channels of the rivers. It's very likely that the erosion process is the primary agent causing these declines due to removal of fine sediments, higher turbidity levels and higher nutrient environment.

Worm diggers and seagrass restoration, Moreton Bay, southern Queensland

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The blood or mud worm (*Marphysa sanguinea,* Family Eunicidae, is the most common species) is one of the major baits for line fishing. It inhabits seagrass beds in the estuarine areas of Moreton Bay, at depths of one-third to one-half a metre in the sediment. The dominant seagrass species are *Zostera capricorni* and *Halophila ovalis.* It probably has been dug for bait ever since fishing commenced in the area, but when the depression of the early 1930's forced people to look for other incomes, worms were dug for commercial sale.

The areas dug extended from Deception Bay to Lota Creek. Some of the seagrass beds which existed in the early days no longer exist (e.g. Sandgate to Cribb Island area), or have been badly damaged. This is not all due to indiscriminate worm digging, but this actively has been the major factor in certain areas.

Various other factors could be involved in seagrass decline, indluding some identified during the workshop. It is worth noting that the main seagrass-covered digging banks, around Fisherman Island have, in part, evolved and expanded naturally. Fisherman Island has an interesting background because it was man-made (spoil dump joining up several mangrove islands). The beds to the south and east of the island are now the major digging grounds for commercial worm diggers. The inshore areas near Wynnum and Lota are most commonly dug by amateurs.

In the past (and it still happens, particularly with amateurs) worm digging has been very destructive to seagrass. Holes and trenches were dug with the seagrass sods not being replaced. With subsequent erosion, recovery was slow or never occurred. The trenches used to be up to 40 metres long and two forks width. Conventional length prong forks were used.

In the post-war years, the idea of digging squares protected by a sediment wall became common. The wall was dug at the commencement of low tide, allowing up to one hour extra digging before tidal inundation prevented further excavation. However, it was not until about 20 years ago that a thoughtful young digger, Mr B. Johnson, decided that unless digging methods were modified, there would be no seagrass and, eventually, very few worms left. He introduced the practice of replacing the seagrass in an upright position, using extended and strengthened prongs on forks. The seagrass sod is laid on top of the row just dug. Banks were still used, the size of the square selected being dependent on the number of diggers in the team. Mr Johnson is currently the major commercial digger with up to 16 diggers working together.

In response to pressure from the better commercial diggers, in 1987 the Fisheries Management Branch of the Department of Primary Industries introduced a permit system for commercial worm collecting in designated areas of Moreton Bay. The designated areas excluded Fish Habitat Reserves. Permits are valid for one year and there is a requirement to level the banks and replace the seagrass in an upright position. The worms must be dug by fork or by hand. To obtain new permits to collect worms for sale, it is required that new collectors work under the supervision of an established permit-holder for one year prior to receiving an open collecting permit. This is to ensure that a new operator is adequately trained in digging methods which minimise disturbance to worm banks and seagrass. The number of permits issued annually varies from about 60 to 80.

Observations over the last two and half years indicate that seagrass beds can recover within approximately three years. The wall breaks down gradually but the recovery of seagrass on the walls is much slower, although it eventually occurs. If the management programme is observed by the diggers (and there are a few who need pulling into line) there appears no reason why this system of worm harvesting cannot remain viable in the long term.

Several dug seagrass sites have been pegged and recovery times are being monitored with the aid of photography.

The need for restoration - South Australia case

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A. Extent of the problem

Various figures for the area of seagrass meadow decline in South Australia have been quoted over the last few years. A detailed examination has now been made (May, 1989) and the true extent of the decline in Gulf St Vincent can now be reported. Figures are based on aerial photographs, available from 1935.

Three categories are used:

1. Large-scale total loss (i.e. not a blade survives)

1935 - 1949	Nearshore seagrass lost from Holdfast Bay (Metro. Adelaide)	700 ha.
1949 - Present	Holdfast Bay	1300 ha.
1935 - 1985	Entrance to Port Adelaide River	830 ha.
1961 - 1989	Glenelg sewage sludge outfall	25 ha.
1965-1985	Bolivar sewage effluent outfall	800 ha.
1978 - 1983	Port Adelaide sewage sludge outfall	365 ha.
	Total	4020 ha.

2. Loss within beds (some seagrass cover remains)

1935 - 1985	Holdfast Bay	800 ha.
1975 - 1985	Bolivar sewage effluent outfall	100 ha.
	Progressive Total	4920 ha.

3. Selected loss (selective elimination of species from mixed strands)

1978 - 1985	Port Adelaide sewage sludge outfall	1100 ha.
1961 - 1988	Glenelg sewage sludge outfall	3000 ha.
	Progressive Total	9020 ha.

B. Causes of loss

1. Eutrophication

This is without a doubt the major cause of the losses given above. Holdfast Bay receives sewage effluent and stormwater, though the nutrient load from the former is 12 to 80 times greater than the latter. Most of the other losses have followed the commissioning of sewage effluent or sewage sludge outfalls. Even the losses at the entrance to Port Adelaide River is attributed to eutrophication which results from nutrient release via dredging, stormwater inputs and a sewage effluent outfall.

2. Coastal Developments

The construction of breakwaters at the entrance to Port Adelaide is believed to be responsible for 80ha. of loss. Some of the reported loss in Holdfast Bay may have been due to major dredging and construction activity in 1974-5 when a 4m - diameter tunnel was laid 2m below the sediment to a distance of 500m offshore. Evidence is circumstantial but release of nutrients from sediments is known to follow disturbance and the time-course of events is strongly coincidental.

3. Erosion within beds

This has been documented within Holdfast Bay and it is suggested that accelerated erosion is in fact a secondary effect of sewage effluent and possibly stormwater. This may be caused by the selective loss of *Amphibolis* from the area and the associated slowing of the natural recolonisation process.

4. Summary

Wherever seagrass loss has occurred in SA it has been overwhelmingly due to nutrients. These are added to the water directly, via sewage outfalls (most loss) or indirectly through stormwater runoff and construction activity.

C. When to try restoration?

In the case of point-source discharges, only when the discharge is removed or a major reduction in nutrient loading has occurred. Such a reduction would be the result of nutrient-removal processes or a reduction on flow from the discharge. A greater than 90% reduction in nutrient load would be required.

If seagrass loss followed construction activity it should be possible to start recolonisation within 12 months of completion of activity. Species should be selected with the "changed" environment in mind.

Historic changes in distribution

The loss of seagrass from Gulf St Vincent has been documented above. Other records show that natural recolonisation is slow, if it occurs at all. Areas mined in 1917 for seagrass fibre have not recolonised. Seismic survey marks blown out in 1968 have remained. This seems inconsistent with the findings of some workers who report colonisation from the edges of natural blowouts to be occurring at rates as high as 0.9m per annum.

Cairns Harbour

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Seagrass beds, mudflats and mangroves in Cairns Harbour were mapped from aerial photographs taken between 1952 and 1987. Due to the highly turbid waters the seaward extent of seagrass could not be accurately mapped, hence mapping was limited to intertidal seagrass beds exposed or visible at the time of the aerial photograph. Nevertheless some noteworthy changes were observed which relate primarily to losses in seagrass or a decrease in seagrass abundance from the upper intertidal areas. The aerial photographs clearly show that mangroves between Little Barron River and Saltwater Creek (on the western side of the bay) and between Hills Creek and Bessie Point (on the eastern side of the bay) have replaced seagrass communities. Sediment deposition has caused an elevation of the seabed, facilitating the progradation of mangroves but at the same time resulting in the complete loss of seagrass and a reduction in seagrass abundance along the shoreward edge of the seagrass beds. Unfortunately it was not possible to determine from the aerial photographs whether the seagrass had extended further seaward.

In early 1989 substantial areas of intertidal seagrass beds were lost following a heavy and extended wet season. A combination of lowered salinities, increased turbidity and increased sediment deposition probably contributed towards this loss. A year later there had been no recovery of *Zostera, Thalassia* or *Cymodocea* between Hills Creek and Bassie Point but some recovery on the western side of the channel.

The implication of rising sea-levels (as a possibloe consequence of the Greenhouse Effect) on seagrass distribution in Cairns Harbour was briefly examined. It was recognised that the response of the seagrass beds to rising sea-levels will depend on the relationship between the rate of sedimentation and the rate of submergence. In the total absence of sediment deposition over the next 50 years, the seagrass could be expected to move landward over the mudflats to the current level of the 1.9m contour (i.e. 0.9m above present upper limit, assuming the most commonly quoted prediction for sea-level rise over next 50 years) - i.e. distances of 300 - 1000 m into the mangrove zone. However the success of seagrass colonising such large areas of intertidal mudflats will depend on the ability of the seagrass to propagate. Currently only *Zostera capricorni* occurs in the upper intertidal areas - *Zostera* does not appear to produce seeds in Cairns Harbour, hence colonisation would have to be from vegetative growth of the horizontal rhizome system. In order to colonise 300 - 1000 m of mudflats in 50 years, rhizome growth would have to be 6 - 10 m per year.

The lower seaward limit of the seagrass bed would be expected to recede with increasing water depth, as the seagrass would gradually die due to insufficient light. Thus, if the landward colonisation of seagrass cannot keep pace with the seaward loss there will be an overall reduction in seagrass in Cairns Harbour and it may be necessary to establish seagrass by transplantation.

Changes in the distribution of seagrass in Great Sandy Strait, southern Queensland

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LANDSAT TM satellite imagery was processed to highlight and map seagrasses in Great Sandy Strait, southern Queensland (Fig. 1; Lennon & Luck, 1989,1990). Using a September 1988 image and four study sites, image enhancement identified two classes of exposed seagrass and five classes of submerged seagrass. Field observations indicated that six of these classes corresponded to variations in density. A seventh (submerged) class could not be precisely located for field asessment. Compared with an earlier study (Dredge et al., 1977) there were no changes in seagrass species composition. However, there was a major increase in area of seagrass.

The areas of seagrass for each of the study sites are shown in Table 1. Using the same seagrass classification technique, a seagrass map (1:50 000 scale) was produced for the entire 95 km length of the Strait.

The image-produced map was compared with the results of a survey undertaken in the early 1970s (Dredge et al., 1977). The total area of seagrass mapped using satellite imagery was approximately 12,300 ha. (Table 1). In the 1970s survey an area of just greater than 4,800 ha was recorded. A comparison of seagrass distribution between the two surveys is difficult because of the difference in mapping techniques. Nevertheless, there appears to be a most significant expansion of seagrasses in Great Sandy Strait. It is impossible to compare the mapping accuracy of the two surveys. Using satellite imagery a mapping accuracy of greater than 83% was achieved (Lennon & Luck, 1990).

Distinct patches of seagrass were found in this survey which did not appear in the 1970s maps. In the earlier survey some of the seagrass may have been missed because of the distance between the transects. However, this does not explain why no seagrass was found north of the Mary River mouth while considerable quantities were present in this area in 1988 (Study Area 1). This area is subject to periodic heavy siltation (fluvial sediments from the Mary River following flooding). As a result seagrass in this area can be literally buried. There have been numerous reports in the literature of seagrass being adversely affected by lower salinity and high turbidity. Kirkman (1978) reported that sand movement was an important factor in seagrass decline. The possible benefits to seagrass of siltation have not been examined. Such benefits could relate to nutrients bound to silt particles. In Study Area 1, old oyster banks have been buried, perhaps leading to an increase in area suitable for seagrass colonization.

After severe flooding in April 1989, it was estimated that a deposition of at least five centimetres of silt and sand covered much of the seagrass on the intertidal and subtidal banks north of the Mary River mouth. This seagrass was observed in late May 1989 to be producing new shoots. The general appearance was similar to a heavily topdressed lawn. The recovery of seagrass on these banks is being monitored.

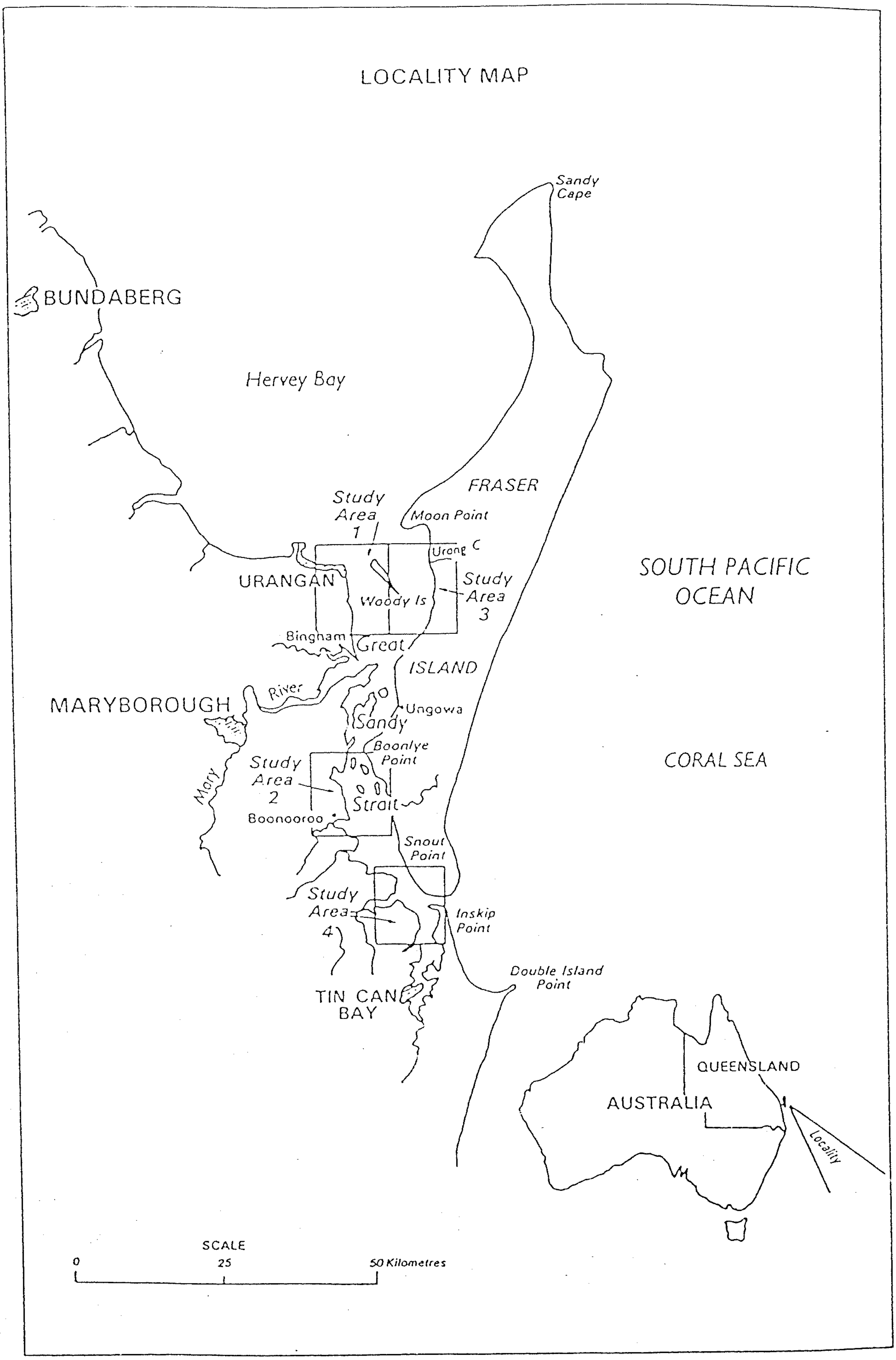

Figure 1. Locality Map

Field checks indicated that there have been no great changes in the composition of the seagrass species found in Sandy Strait. All of the species reported by Dredge et al. (1977) are still present. The most widespread species are *Zostera capricorni* and *Halophila ovalis* while the species with the greatest biomass (*Cymodocea serrulata*) is still evident in extensive subtidal beds in Study Area 4. The other species common to both surveys are *Halodule uninervis, Syringodium isoetifolium* and *Halophila spinulosa.*

There are obvious changes in seagrass distribution. The main species now found in Study Areas 1 and 3 are *Zostera capricorni* and *Halophila ovalis.* To enable comparison with the 1988 satellite image map a suitable 1990 image will be obtained and processed in the same manner to produce an updated assessment of seagrasses in the Strait. The practicalities of using this technique for the monitoring changes in seagrass over time will be examined. There is a need to closely examine the degree to which variables associated with reflectances of water and water turbidity may limit the accurate delineation and density categorisation of submerged classes of seagrass.

The use of remote sensing, particularly satellite LANDSAT TM, has considerable potential for mapping large distribution of seagrass and monitoring long term changes. This is especially so where seagrass is mainly present in shallow water, to a depth of approximately 2 m.

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Table 1. Area measurements of seagrass, Great Sandy Strait

	Class No.	Area 1	Area 2	Area 3	Area 4	Total for Strait
Exposed	1	165	337	99	137	1228
	2	72	1065	37	547	2160
Submerged	3	1012	591	48	88	2910
	4	254	102	28	15	669
	5	1168	511	257	80	3599
	6	14	121	1	105	352
	7	8	325	8	603	1403
Total		2693	3052	478	1575	12 321

PHYSIOLOGY AND ECOLOGY

Early warning signs of stress in seagrass

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Changes in the status of seagrass meadows are rarely recognised until dramatic declines in distribution are observed. Attempts to document losses rely on changes large enough to quantify from inadequate baseline distribution records.

Some ways of assessing seagrass decline are required, before a system reaches the "too late" stage. Changes in shoot density, biomass and/or productivity may be useful, but these often have a seasonal component, and it is hard to provide adequate reference controls. However, good models of light response may be used in a predictive capacity.

Under eutrophic conditions, artificial seagrass may provide a useful tool to quantify epiphyte load, and hence reduction in light available for seagrass photosynthesis (see Silberstein *et al.*, 1986, and Neverauskas,1987, for details). This may also help to separate the effects of increased turbidity from nutrient enrichment.

It may be possible to use the physiology of the seagrasses themselves as indicators of plant stress. The plants are the best integrators of their environment, but finding a measure of "health" is difficult. Investigating energy storage compounds in seagrass rhizomes may provide a measure of seagrass "health".

A CSIRO/UWA Collaborative grant to Chris Crossland and Di Walker is being used to investigate the variation in sugars, starch and cellulose in rhizomes of the seagrass genera *Posidonia* and *Amphibolis*. Experimental work has been carried out in conjunction with Hugh Kirkman, involving stressing of artificially isolated areas of meadow, by leaf removal to see whether this results in a decrease in storage carbohydrates. Preliminary results suggest that there are different strategies of storage associated with different species, and that leaf removal in *Amphibolis* does result in decreases in rhizome carbohydrate. The larger reserves of *Posidonia* have been less affected. There are obviously seasonal differences, which need to be documented, but there is potential to use the ratios of different carbohydrates (e.g. starch to cellulose) as a physiological index of seagrass health.

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Light as a component in restoration and destruction of seagrass meadows

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The light climate represents a major environmental factor affecting seagrass production and maintenance of meadows, especially at depth limits for different species. The light climate is particularly modified by many anthropogenic impacts, e.g., eutrophication processes, dredging, sand mining.

The significance of the light climate and attenuation effects was discussed in relation to the seagrass meadows in Princess Royal Harbour, Albany, where eutrophication processes are impacting on the benthic communities. Of particular issue is determination of light attenuation data, construction of a light "envelope", and the effect of meteorological conditions (e.g. cloud cover, rain squalls) on the "light envelope" at the depth limits for *Posidonia australis* and *Posidonia sinuosa*. *In situ* gas exchange measurements and calculation of productivity indicate that rhizome storage carbohydrates must be metabolically important for the continued existence of the seagrasses at their depth limits. These data, and calculations based on *in situ* experiments (rather than "pieces of leaves in laboratories"), provide a realistic model for depth limitation of existing *Posidonia* beds and are relevant to any revegetation attempts for the perturbed harbour.

Light environment and physiological response of seagrasses in Cairns Harbour

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Seagrasses in Cairns Harbour have a narrow depth distribution. Five species are found growing interidally, *Zostera capricorni, Cymodocea serrulata, Thalassia hemprechii, Hadodule uninervis* and *Halophila ovalis. Zostera* is the most abundant seagrass and has the widest distribution, occurring furthest landwards, 1.05 m above Port Datum (0.0 m), down to -0.25 m. *Cymodocea* and *Thalassia* form dense stands in shallow depressions which become tidal pools when exposed at low tide. A sixth species, *Halodule pinifolia,* was found subtidally forming dense stands between 0.0 m and -0.5 m below datum.

Light appears to be the limiting factor controlling the lower depth distribution of these seagrasses. A study was therefore undertaken to investigate the light saturation point (I_k) of *Zostera, Thalassia* and *Cymodocea.* The site selected was at 0.7m above datum and therefore exposed at low tide. Irradiance (PAR $\mu E/m^2/s$) was measured with an integrating Licor light meter. At high tide (2.5 m) irradiance immediately above the seagrass ranged from 25 $\mu E/m^2/s$ under sunny conditions (1% surface irradiance) to 1.9 $\mu E/m^2/s$ for complete cloud cover. Although irradiance increased with the falling tide, due to the highly turbid waters, PAR values were low. Values between 100 and 150 $\mu E/m^2/s$ occurred between 40 cm and 10 cm however with only 5 cm of water covering the seagrass PAR increased to about 225 $\mu E/m^2/s$. PAR values of 2000 $\mu E/m^2/s$ were recorded in 2 cm of clear water remaining in the tidal pools exposed at low tide.

From the P-I curves, the photosynthetic saturation point (I_k) for all three species was around 100 $\mu E/m^2/s$, with maximum photosynthesis around 200 $\mu E/m^2/s$. By cross reference to the light regime during the tidal cycle, the duration that the seagrasses are above their light saturation point can be determined. The length of this daily light saturation period (H_{sat}) is more important in regulating depth distribution than total daily irradiance. For example, at the experimental site in Cairns total daily irradiance above the seagrass was 5.6 E/m^2/day but 60% of this occurred during the 30 minutes of exposure when the shoots would be light saturated anyway. The H_{sat} period was between 2-4 hours.

This H_{sat} period was about half the H_{sat} period recorded for *Zostera marina* at its lower depth limit in Woods Hole (Dennison and Alberte, 1985, 1986), suggesting that the seagrasses in Cairns Harbour can tolerate very low light regimes.

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Physiological considerations for seagrass restoration

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Introduction

Any attempt to restore seagrasses and their habitat requires a sound understanding of their special requirements and the importance of each of these requirements.

Traditionally, plant physiology has been physiochemically oriented, focussing on photosynthesis, mineral nutrition, enzyme kinetics, water relationships, *etc.* While many of these areas are physiologically interesting, they do not provide the sort of information required by those involved in the restoration of seagrasses.

There are two ways in which physiological considerations may be applied to aid in restoration. A site may be selected and then a seagrass with appropriate physiology may be chosen to complement that site, or a seagrass may be firstly selected and a site chosen that provides the necessary environmental features.

In selecting a site, it must be decided whether to restore an "old" site or find a new site. In selecting a seagrass, it must be decided whether to introduce a new species from another region or to use one endemic to the area. Introducing a new species from another region may be of particular interest in areas where physical changes in the environment, such as thermal pollution, may not be easily reversed.

In order to construct models which accurately predict the response of seagrasses to environmental pressures, an understanding is needed of the physical and chemical environments in which these plants grow. The most important parameters of these environments may be split into above-ground and below-ground factors, as outlined below.

Above-Ground Factors

1. Exposure to Air

This factor has received little consideration in the literature, but is probably the single most important consideration before any restoration work is undertaken. If a site is subject to tidal fluctuations, the ability of a chosen seagrass to survive exposure to the atmosphere becomes critical. Some seagrasses, for example *Zostera* spp., exhibit a high tolerance to exposure. Other species such as *Halophila* spp. will tolerate short periods of exposure before permanent damage occurs, while some species, such as *Syringodium* spp. and *Posidonia* spp., have no tolerance to atmospheric exposure.

On mudflats and sand banks exposed at low tide. the composition of the seagrasses is determined by their resistance to a variety of damaging factors, such as the degree and time of exposure to air and the proportion of enzyme inactivation (due to desiccation, photoinhibition, or UV damage). Furthermore, the role of the water layer on the seagrass in providing a suitable source of photosynthetic carbon (e.g., CO_2(g) or HCO_3) is unclear. Few studies have directly examined this problem although a variety of hypotheses has been proposed.

2. Current Velocity

Water movement affects seagrass photosynthesis and production and therefore must play a major role in the distribution of seagrasses, meadow configuration and in determining the benthic plant community of a region. In general, plants with roots (ie seagrasses) are excluded from areas that are exposed to currents of around 2 knots (1 $m.s^{-1}$) by the lack of suitable, stable sediment. It is only in areas where the current velocities are less than 2 knots

(1 $m.s^{-1}$), that a wide range of seagrasses occur. Within these areas, there is an optimum current velocity at which the uptake of nutrients and inorganic carbon is greatly enhanced by a reduction in the boundary layer surrounding the leaves. However, as the canopy structure of a seagrass meadow becomes more compressed (or better developed), the current velocity becomes more stratified. This may result in the development of two flow zones: one within the canopy, the other above the canopy. Thus the optimum current velocity based on measurement of individual shoots may, in effect, be somewhat lower than what is experienced by the community.

It should be possible to grow seagrasses successfully in areas that experience currents of less than 1 knot (0.5 $m.s^{-1}$), but in terms of the restoration of seagrass beds, there is virtually no information concerning the maximum currency velocity a particular seagrass will tolerate.

3. Light

(a) Quantity of Light.

Seagrasses are able to tolerate a wide range of variation in light intensity. In general, they have photocompensation points somewhere around 30-60 $\mu E.m^{-2}.s^{-1}$ and the maximum rate of photosynthesis occurs around 1200 $\mu E.m^{-2}.s^{-1}$. However, in some species the maximum rate of photosynthesis can be very high (3600 $\mu E.m^{-2}.s^{-1}$ for *Zostera noltii*), while in others, such high light intensity can cause photoinhibition (for example, *Halophila ovalis* and *Zostera marina*).

(b) Light Duration.

Although this parameter is not often considered in physiological studies, its relative importance increases in situations where extremes of light are experienced. When the duration of light (greater than the photocompensation point) is short, the photosynthetic production of organic compounds will be small. In this situation, should net respiration exceed net photosynthetic production, attempts to grow seagrass will fail. In contrast, if photoinhibition takes place in high light regimes, a similar although rarer situation may occur.

4. Temperature

The gross photosynthetic rate of seagrasses increases with temperature in a manner similar to that of higher plants. Enzymic activity also increases with temperature until enzyme degradation occurs, usually within the range of 28-35°C. Certainly, there are adaptation responses, within species, to localized extremes in temperature. For example, *Zostera marina* in Alaska can withstand being frozen in ice at -6°C, whereas plants from Washington and California cannot tolerate this stress. However, there is little information on the average temperature ranges and tolerances of tropical seagrasses.

5. Salinity

Seagrasses, as a group, tolerate a wide range of salinities (from 10 ppt to 50 ppt). Each species has an optimum salinity range and prolonged exposure to either side of this optimum has a detrimental effect on photosynthetic rates.

6. Eutrophication

Eutrophication is one of the major causes of seagrass decline. In some areas, subsequent loading of epiphytes as a result of eutrophication is substantial. In these areas, the ability of a seagrass to survive will depend on its rate of growth or its ability to produce new leaves. Therefore, a substantial proportion of photosynthesis must be devoted to the production of expandable biomass and not storage (reserve) products. Thus, fast-growing seagrass, such as *Halophila ovalis*, are capable of producing leaves at a rate greater than the rate of epiphyte colonization and, although under considerable stress, are able to survive. However the survival of slower growing seagrasses, such as *Posidonia* spp. depends on a variety of factors such as the duration of eutrophication, rate of consumption of storage reserves, etc. Little is known in this area.

Below-Ground Factors

1. Sediment Stability

One of the prime factors to be considered in examining the below-ground physical requirements, is the stability of the sediment. Obviously, plants which are anchored by roots and rhizomes need to be in sediments that are not easily resuspended and transported by wind, wave and tidal action. Where this occurs "blowout" areas are created.

2. Organic Matter

Seagrass roots exude organic carbon, nitrogen, and phosphorous and modify the concentrations of these compounds in the surrounding sediment. These in turn will affect properties of the ground such as the redox potential and pH. In addition the presence of seagrasses leaves also encourages sediment deposition by dispersing currents and thereby increasing sediment stability. Other edaphic factors, such as sediment type and chemistry, are equally important - these are discussed by Peter Pollard.

Conclusions

There is little information available on the physical and chemical environments of seagrasses to aid in the selection of a particular seagrass for a particular location. However, matching each of the above criteria with an appropriate seagrass would be an initial step.

In order to use physiological features to aid in seagrass restoration, the following are required:

(a) an inventory of the physiological responses of seagrass to environmental pressures;
(b) a method of assessment of suitable sites and seagrasses;
(c) procedures to help decide when to use: 1) endemic *versus* introduced species, and 2) old sites *versus* new sites for restoration; and
(d) an understanding of the differences between genetic and environmental adaptation of seagrasses.

Seagrass sediments: the geochemistry and the structure of the microbial community

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The minerals and nutrients required for the survival of seagrasses come from a complex array of oxidation-reduction reactions, which are mediated by the sediment microbial community. Benthic bacteria as reducers and mineralisers are an essential part of the sediment geochemistry, providing the phosphate and ammonia necessary for seagrass (and algal) growth. The carbon, phosphorus, nitrogen and sulphur cycles are all inextricably dependent on each other (see review by Valiela, 1984). The energy necessary to drive these cycles is derived from the organic carbon synthesized during photosynthesis. Seagrasses provide carbon either through the release of dissolved organic matter or detritus.

Although the amount of phosphate in seagrass sediments is relatively high, the amount available for seagrass growth (the reactive phosphate) is low because the phosphate remains tightly bound to calcium carbonate, clay and amorphous oxyhydroxides, or is in the form of insoluble metal phosphate (Froelich, 1988). Despite the strong binding of phosphate, reactive phosphate in vegetated sediments can be forty times higher than in areas where there is no vegetation. This is because phosphate is released by two major abiotic processes. In the anoxic sediment of seagrass beds the sulphate-reducing bacteria (SRB) reduce sulphate to sulphide. The sulphide reacts with iron, releasing bound phosphate to form insoluble pyrite (FeS_2; the black colour often seen in reduced sediments). The SRB also reduce ferric iron (Fe^{3+}) to ferrous iron (Fe^{2+}), thus solubilising the iron hydroxides that bind phosphate.

Nitrogen also can be a limiting nutrient in seagrass beds. Therefore, any sediment microbial process that produces ammonia (in for of N prefered by seagrasses) is essential to the growth of seagrasses. In anaerobic environments there are fermentative bacteria that release ammonia and others that reduce nitrate to ammonia. Bacterial fixation of nitrogen also results in the production of ammonia.

Nitrogen fixation has a high energy demand and the action of the nitrogenase enzyme requires an environment totally free of oxygen and the presence of a co-factor (molybdate). These conditions exist in seagrass sediments and the nitrogen-fixing bacteria are stimulated during light periods, suggesting that seagrasses can release enough dissolved organic carbon for nitrogen fixation by bacteria. The reduced (anaerobic) sediment essential for the microbial release of phosphorous and nitrogen for seagrass growth is maintained by the SRB.

This suggests that given the appropriate microbial community structure in the sediment, seagrasses have the ability to control the supply of inorganic nutrients (phosphate and ammonia) by stimulating the bacterial activity through the release of dissolved organic carbon.

It is little wonder that most seagrass transplant experiments are unsuccessful when we know so little about the interactions between the microbial processes and sediment geochemistry necessary to re-establish the original conditions which are critical for the long-term survival of seagrasses.

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PROPOGATION STUDIES

Attempts to grow *Amphibolis* from seedlings

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The southern Australian temperate endemic seagrass genus *Amphibolis* has two species, *A. antarctica* and *A. griffithii.* Both of these species, but particularly *A. antarctica*, show wide tolerances, and have distributions covering a wide range of depths, salinity, water movement and sediment type. They also produce large numbers of viviparous seedlings (up to 150 m^{-2}) which have a 'comb anchor' or 'grappling apparatus' which entangles readily with old rhizome mat, macroalgae or any other suitably textured substratum - settlement densities of 25 m^{-2} occur after seedling release. They may provide an ideal species for use in revegetation attempts, because of the availability of propagules.

However, rates of survival are low, both under field conditions and in aquarium culture experiments. Seedlings which have settled in the field tend to be removed by water movement. Seedlings kept in aquaria are subject to fungal and bacterial infections. Field experiments on seedling survival were carried out, anchoring the seedlings by placing them in loosely twisted baling twine, attached to metal quadrats secured by pegs. This proved effective at anchoring the seedlings but their mortality rates were still high, often due to fungal and bacterial infections or epiphyte smothering. Survival rates were less than 5% and the process was very labour intensive. However it may be possible to keep seedlings in circulating seawater systems, and put them out in the field when they are more mature. Although these trials were disappointing *Amphibibolis* still may provide a useful species for use in recolonisation experiments.

Possible application of plant tissue culture

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Introduction

Two of the major problems facing a large scale seagrass restoration project are the provision of sufficient planting units and appropriate planting units, i.e. the creation of a suitable propagule bank.

For example, with a planting density of 1 propagule per metre at a site like Cockburn Sound in S.W. Australia, thirty million planting units would by needed to cover the 3,000 hectares requiring restoration. In order to collect this many seeds, seedlings or plant parts from nature would be prohibitively labour-intensive and time-consuming and may have a destructive impact on the donor beds. The production of plants via Plant Tissue Culture (P.T.C.) has the potential to provide a large scale propagation facility.

Processes in P.T.C.

There are four sequential stages involved in a typical P.T.C. operation:

1. Establishment - the function of this stage is to establish a sterile explant in culture. Important factors include the selection of an appropriate explant and culture conditions.

2. Multiplication - in this stage repeated culturing gives rise to an exponential increase in propagules.

3. Pretransplant - the function of the pretransplant stage is to prepare the plantlet for transplanting and establishment outside the artificial, controlled environment of the culture vessel. This usually involves the production of roots by application of auxins. Shoot profileration is encouraged in the multiplication stage by application of cytokinins.

4. Transplant - the transplant stage is an acclimation process involving the transfer of the plantlet from aseptic culture to the free living conditions of the greenhouse and ultimately the field.

There are five fundamental types of vegetative regeneration in tissue culture systems:

1. Meristem Tip Elongation - regeneration occurs by elongation of the excised apical meristem and only a single plant per culture is produced. This procedure is used primarily to produce a virus-free plant rather than for mass propagation.

2. Axillary Shoot Proliferation - in axillary shoot formation, lateral growing points on the explant at the nodes below the apical meristem are stimulated to grow and the apical meristem is inhibited. Growth from these axillary shoots provides a rapid multiplication system in which the number of plants is increased exponentially by repeated culturing.

3. Adventitious Shoot Initiation - in this process, high rates of adventitious shoot formation can be achieved by hormonal manipulation of the excised plant parts. This can be either **direct** - on the explant itself, or **indirect** - in unorganised masses of callus tissue. Callus tissue is that tissue which develops naturally as a response to wounding and is composed of undifferentiated cells which lend themselves to hormonal manipulation.

4. Organogenesis - this refers to the process by which adventitious shoots and roots are induced from within masses of callus cells. These highly vacuolated and largely parenchymatous callus cell masses can develop meristemoids which initiate organs under particular culture conditions. The process is similar to the initiation of adventitious shoots on explants except that an intervening period of independent callus growth has occurred.

5. Embryogenesis - in the normal seedling cycle, embryogenesis proceeds from the single celled zygote to the initiation and development of an embryo. An important discovery was that carrot cells grown in a suspension culture with unautoclaved coconut milk and auxin and subsequently placed in hormone-free culture medium, could produce millions of individual embryos. These structures have been called embryoids or somatic embryos to distinguish them from either sexual or apomitic embryos produced naturally.

Potential Applications for Marine Angiosperms

For all P.T.C. methods except meristem tip elongation, multiplication is exponential, providing the mechanism for large-scale propagation. This is the major potential benefit of this process as it may allow the generation of sizeable and appropriate propagule banks which would be non-destructive to the environment and easily controlled.

Other potential applications include:

1. General control of plant production with guaranteed supply of sufficient quantities of propagules with year round scheduling of propagule production to suit optimal seasonally determined planting times.

2. Selection and multiplication of faster growing meristems not normally found in profusion i.e. as in *Posidonia australis* where 1 in 600 tips found in the natural environment is fast-growing.

3. Seedlings of *Posidonia* spp. are known to take up to two years to form a rhizome. With manipulation of hormone regimes this could be initiated much earlier with a resultant faster rate of coverage of the seabed.

4. P.T.C. media techniques of nutrient and hormone manipulation could be adapted to the planting-out stage in order to enhance survival and expedite growth in the field.

5. Embryogenesis has potential for the production of prodigous quantities of somatic embryos as a source of planting units. Considerable progress has been made in the techniques of somatic embryogenesis as a potential propagation procedure.

6. Organogenesis likewise has potential for propagation of meristemoids on a large scale with subsequent formation of organs.

7. The production of genetically and physiologically standard plants from P.T.C. would allow accurate assessment of *in vitro* growth-enhancing experiments.

8. Transport of plants interstate, should it be deemed acceptable, would be much simplified by the fact that only very small quantities of material are required providing the receiver has a P.T.C. facility. In addition, material provided from P.T.C. would be in axenic culture, thus avoiding the introduction of undesirable foreign flora or fauna.

9. It is also possible that, with the large increases in production rates, improved cultivars may be isolated from the increased occurrence of mutants.

Problems

The fundamental problem which exists is that micropropagation of marine angiosperms has never been tried, apart from some very cursory attempts by myself and, independently, workers at the C.S.I.R.O. Division of Plant Industry. Sterilisation proved to be the first stumbling block, as species used in preliminary trials were susceptible to the established techniques and were all killed, apart from one axillary bud of *Amphibolis* spp. which survived and is growing, although very slowly. It is clear therefore that techniques established for terrestrial plants will need considerable modification for marine plants. Dr Jenny McComb from Murdoch University in W.A. has experience in the successful micropropagation of salt-tolerant *Eucalyptus* spp. and marine macroalgae which may provide pertinent information for the development of techniques for seagrasses.

Facilities already exist at the CSIRO Division of Plant Industry and Division of Fisheries (Marmion) for P.T.C., including laminar-flow hoods, transfer rooms and autoclaves.

Many plant forms, from single cells to large woody trees are available now from P.T.C. as a result of recent and rapid developments in the field. The inherent adaptability of plant cells and tissue indicates that much is possible with P.T.C., limited only perhaps by imagination. The technique of P.T.C. suggests some advantages for any seagrass restoration project which may be critical for its success and therefore warrants serious consideration.

Scientific short cuts

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When confronted with questions of an applied nature "biologists" can always argue for more funding, but there is also an argument for taking the already available literature more seriously. With seagrasses we are dealing with a number of different plants, and at the level of detail required we might expect (and indeed do find) differences. At the same time there are some general ecological principles (see for example Harper's (1977) 'Population Biology of Plants', Academic Press: London) concerning establishment, which are broadly relevant.

Some differences between seagrasses and their relevance to seagrass transplantation and restoration can be seen in the following examples:

1. Studies of seed germination and dormancy. What is the relevance of the type of dormancy, whether innate, induced, or enforced; and can we use our knowledge of this to direct our experiments? Is seed masting a strategy of some seagrasses?

2. What can we learn from natural variation? The role of genetic variation has been largely ignored.

3. Roots and root types. Basic biological facts (e.g. the fact that seagrasses such as *Zostera* have root hairs and *Amphibolis* does not) should influence the sorts of approaches used. In this specific case one could question the relevance of transplanting sediment with *Amphibolis*.

Vegetative propagules and seedling anatomy in seagrasses

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The extension of existing or transplanted seagrass beds is dependent on rhizome branching, the formation of vegetative propagules and seed production. Frequency of branching and number of branches may determine the future size of the meadow. Vegetative propagules have been observed in *Heterozostera* and *Zostera* in the Zosteraceae and *Thalassodendron* and *Amphibolis* in the Cymodoceacae. Both vegetative propagules and seedlings can initiate a meadow, but the actual successful establishment of a new meadow by these means is probably very low.

The information on the reproductive phenology of Australian seagrasses is still in the embryonic stage, with available data suggesting that phenology varies with species and location. It has been suggested that both water temperature (summer and winter) and day-length may play important roles in floral initiation in most seagrass species. Tidal cycles may also be important, since flowering in *Enhalus* appears to be associated with tidal fluctuation. It has been found that not all species flower annually and flowers of some species (e.g. *Cymodocea angustata*) have yet to be recorded.

The embryo and hypocotyl develop after anthesis, through cell division, cell elongation, cell expansion and finally deposition of nutrient storage products, predominantly starch grains, protein and lipids in the hypocotyl. It normally takes three to four months for fruit to mature after anthesis. The number of fruits and seeds produced may vary between species; in general, the number is smaller in the Cymodoceaceae than in other seagrass families.

The seeds of *Posidonia, Enhalus* and *Thalassia* show little or no dormancy phase. On the other hand, seed dormancy occurs in *Halodule, Syringodium, Cymodocea, Zostera, Heterozostera* and *Phyllospadix,* due to the pericarp remaining in place, acting as a 'seed coat'. It has been shown that dark treatment prevents seed germination in *Halophila,* whereas lower salinity stimulates germination in *Cymodocea*.

During seed germination, seagrasses have similar patterns in this utilization of storage nutrients (starch, protein and lipid). In general, storage nutrients are utilized from the periphery of the seed and from those tissues near the vascular bundle of the hypocotyl. Although storage products are used primarily for the production of young roots and leaves in *Posidonia* and *Halophila*, they are used for the production of young leaves only in *Phyllospadix.*

The plants of *Amphibolis* and *Thalassodendron* have viviparous seedlings; the seeds germinate and develop on the maternal plant and mature seedlings finally detach from it. In contrast to other seagrasses, these species do not store starch, lipids and protein in their seeds. Instead, the development of the numerous transfer cells at the interface of the developing seedling and the maternal plant suggests that essential nutrients can be transferred from the parent plants to the germinating seedlings.

Seed distribution, dormancy, germination and storage

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For the past 2 years CSIRO has been studying the growth and reproduction of tropical seagrasses at Groote Eylandt in the Gulf of Carpentaria. The work was designed to complement the monitoring of seagrass beds and their response to cyclones in the western Gulf of Carpentaria.

There are nine seagrass species growing at Groote Eylandt, ranging in size from the very massive and robust *Enhalus acoroides* to the very fine and fragile *Halophila* spp. and the thin morph of *Halodule uninervis*.

Both *Enhalus* and *Thalassia hemprichii* have large fleshy seeds that are unlikely to last for a long time. In the monitoring program that has been going on since 1984, very few seeds have been found for either of these species, despite frequent flowering of *Enhalus*.

In contrast the seeds of *Halodule, Syringodium isoetifolium* and *Cymodocea* spp. are small and have a hard teste. We suspected that there may be a perenating reserve of these in the sediment. These were also the species, along with *Halophila ovalis*, that were the first to recolonize following cyclone 'Sandy', and this recolonization was by seed.

The seed and flower sampling program began in October 1988 and is still continuing. It is designed to look at small and large scale variation in seed and flower densities, both in the sediment and on the plant. Random sediment cores and shoot samples are taken at a couple of depth zones for each species, inshore and offshore of each species, and at distant locations which are similar but where that particular species doesn't occur.

So far we have only found seeds in, or close to, the seagrass beds in which the particular species is found (i.e. there is very little dispersion). To date, seed densities for the thin, intertidal morph of *Halodule* have been very high (up to 2,000 seeds m^{-2}) on each sampling trip. Flowering for this species has been almost continuous with occasional peaks.

Flowering of *Syringodium* is not as prolific as of *Halodule* and occurs only once a year. Similarly, seed densities for *Syringodium* have been lower than for *Halodule*; however, despite the seasonal flowering, seeds are present in the sediment throughout the year. *Cymodocea serrulata* flowers once a year, and flower and seed densities are low. No *Cymodocea rotundata* flowers and fruit have been found.

At the moment we are trying to germinate seeds of *Halodule, Halophila, Syringodium* and *Cymodocea serrulata.* However, as reported in the literature, there seems to be a long dormancy period. We are still waiting.

Implications for restoration:

1. Seeds of *Halodule, Syringodium* and *Cymodocea* would be easy to store.

2. However, before they could be readily used for restoration a way of overcoming their dormancy would have to be established.

3. There are a lot of *Halodule* seeds in the sediment, and they can be extracted with minimal damage to the seagrass bed. As seed densities are much lower for other species, extraction would cause a lot of damage.

4. The value of establishing a *Halodule* bed is uncertain - in the Gulf of Carpentaria very few juvenile commercial prawns are found in it. It is possible that it may condition the sediment and increase the chance of survival of other species.

CONCLUSIONS AND RECOMMENDATIONS

Seagrass meadows can be successfully restored only if a number of conditions are met. First, the causative factors responsible for the seagrass loss must be removed. Second, the area selected must be made suitable for seagrass growth again. Third, appropriate seagrass species and planting units (i.e. seed, seedling, vegetative fragments etc.), and translocation and anchoring methods, must be selected. Fourth, costs cannot be prohibitively expensive.

Translocation experiments have now been carried out in Australia, as well as elsewhere in the world, with transplanted seagrass patches surviving for long periods. However, little outgrowth from these transplanted patches has occurred. This lack of outgrowth has numerous parallels in natural seagrass beds, which generally show slow recovery rates after man-induced perturbations. In addition to problems with a lack of outgrowth, the translocation experiments have been labour intensive, and thus extremely expensive if carried out on a large scale. Considerable progress in several areas of research clearly still needs to be made before the routine restoration of seagrass meadows can be economically undertaken.

The participants at the workshop agreed that research of the following five areas is critical if we are to restore seagrass meadows on an economically viable basis:

1. Planting Units (PUs)

    - annotated inventory of possible PUs for each seagrass species
    - grow-out techniques for PUs
    - anchoring methods for PUs
    - performance evaluation of PUs
    - establishment requirements (biological aspects) of PUs

2. Site Selection

    - optimum sediment geochemistry
    - appropriate light environment
    - appropriate nutrient concentrations in water column
    - appropriate hydrodynamics
    - inventory of naturally occurring species

3. Seagrass Life-History Parameters

    - growth
    - reproduction
    - natural variation
    - herbivory
    - appropriate time and space scales
    - mortality
    - population dynamics

4. Seagrass Community Ecology

    - epiphytes
    - animal/plant interactions
    - interspecific interactions between seagrass species
    - sediment chemistry and biology

5. Seagrass Horticulture

- hormones
- fertilizers
- hybridization
- genetic engineering and tissue culture
- mechanical harvesting/planting techniques
- introduced species

The research needs outlined above were not ranked in order of priority because economical seagrass restoration was thought unlikely to eventuate from research in a single field but from integrated advances.

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