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Seagrass Restoration in Australia

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Abstract
This paper will briefly examine the current status of seagrass restoration in Australia and, after some definitions have been dispensed with, describe where most of the efforts have been located and their relative ‘success’. Attention is placed more upon the lessons regarding transplant failure we have learned from past studies, as opposed to an in-depth study of each project. In addition, factors contributing to variable success rates with different techniques (seedlings, sprigs and cores) will be highlighted using examples from Western Australia – where many transplant efforts have been located. Examples will then be given of the most recent rehabilitation studies in Western Australia, focusing on mechanical transplanter development, refinement and operation. Concluding comments are then made regarding suggestions to maximise success in future transplantation programmes along with a basic list of requirements.

1. Introduction
This document briefly examines the current status of seagrass restoration in Australia. Rather than dwell upon each project in detail however, which has been covered elsewhere (Lord et al., 1999; van Keulen and Paling, this volume), it focuses upon the primary causes of transplant failure. It finishes with a restatement of recommendations to maximise success in future seagrass restoration projects in Australia.

It is necessary at the outset to standardise the way in which projects involving seagrass transplantation are referred to because there may be clear distinctions made between ‘rehabilitation’ and ‘restoration’ in terms of the goals and expected outcomes of particular projects. The following definitions may be useful in this discussion: ‘seagrass rehabilitation’ is a general term with the sense of improving, augmenting or enhancing a degraded or affected area, with the expectation that there will be an improvement through return of seagrass and seagrass ecosystem function. It is nominally equal to the terms ‘reclamation’ and ‘habitat creation’ (USNRC 1992). ‘Restoration’, on the other hand, conveys the meaning of a return to pre-existing conditions. Since this is acknowledged as being an unlikely outcome in practice, ‘restoration’ is widely interpreted as returning the ecosystem to a close approximation of its condition prior to disturbance. By that definition, structure and function of the ecosystem are approximately created, but still
with the expectation of producing a natural, functioning and self-regulating system integrated with the ecological landscape.

Seagrass ‘rehabilitation’ rather than ‘restoration’ is usually what is carried out in practice because projects or studies are most often concerned with replacing seagrass in areas where it once grew. It is important to note that while meadows may decline through both natural (e.g. storms, sedimentation) and anthropogenic changes (e.g. eutrophication, dredging) it is usually loss through the latter that warrants our attention. It is also logical to assume that, while the conditions causing initial seagrass decline (such as elevated nutrients) remain, there will be little chance of success in returning seagrass (Paling, 1995). In other environments, sedimentation causing loss may have modified the habitat topography sufficiently to preclude seagrass replacement – at least with the same species. While on the subject of seagrass decline it is worthwhile to note that more information is becoming available to demonstrate that seagrass meadows may be quite dynamic systems, changing in areal coverage on the scale of decades (Hastings et al., 1995a, 1995b; Kendrick et al, 1999; Kendrick et al., 2000), rather than fragile systems prone to disturbance and irreplaceable loss.

A final cautionary note in the consideration of seagrass rehabilitation is that of defining performance criteria and success for particular projects. Transplant success can be defined in a number of ways including: survival (per unit, per shoot), area achieved, spreading rate, shoot or meadow growth, and functional return. It is vital to ensure that the appropriate criteria are defined at the beginning of a project (and possibly during it), as this will determine the way in which the project is both carried out and assessed. It is also important to apply a time frame of consideration for the various performance criteria. As is noted below, many projects run for an insufficient time to determine their true success rate.

2. Rehabilitation efforts in Australia
Over 60% of rehabilitation efforts in Australia (reviewed in detail by Lord et al., 1999) have been located in Western Australia (Table 1) with the most common genera being *Posidonia*, *Amphibolis* and *Zostera*.

Table 1. The location of rehabilitation efforts in Australia.

<table>
<thead>
<tr>
<th>Location</th>
<th>Number of studies</th>
<th>Time frame</th>
<th>‘Success’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western Australia</td>
<td>18</td>
<td>1977 - 2001</td>
<td>0 – 85%</td>
</tr>
<tr>
<td>New South Wales</td>
<td>5</td>
<td>1988 - 1997</td>
<td>0 – 50%</td>
</tr>
<tr>
<td>Queensland</td>
<td>4</td>
<td>1990 - 1998</td>
<td>0 – 100%</td>
</tr>
<tr>
<td>Victoria</td>
<td>1</td>
<td>2000</td>
<td>?</td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The success of these projects (Table 1) is difficult to portray because the distinction between ‘unit survival vs spreading’ and ‘area intended to be rehabilitated/transplanted’ may cause confusion depending on the time scale considered. For example units of transplanted *Zostera* that survive and spread to form a small meadow can be considered a 100% success in the short term. But, as has happened both in Australia and overseas, should the meadow subsequently be consumed by amphipods or washed away by unseasonal storm events, then it may be considered a failure and ranked at 0% accordingly.

It is possibly more valuable to review the reasons for failure in the various projects. By examining the most commonly occurring ones, we can gain a further idea of ways to maximise success. This is particularly appropriate for this review because many of the rehabilitation studies in Australia have either been carried out over too short a time frame and/or have provided no mechanism for feedback and subsequent modification.

### 2.1 Factors contributing to failure

It is clear that a number of common factors have contributed to the loss of seagrass transplants in Australia. These are listed and discussed in order of priority below:

- **Water motion/inappropriate unit size selection (insufficient anchorage)**

  In Western Australia, of the 7500 transplant units placed within the Perth Metropolitan area (Paling, 1995; Paling et al., 2000a), most simply washed away, due to either inappropriate unit size selection (i.e. the transplant unit was too small to withstand normal water motion or storm activity), or storms removed them. This has also happened in other areas of Australia (e.g. Botany Bay; West et al., 1990). It is clear that transplant units of an appropriate size, or with sufficient anchorage matched to a particular environment, are vital to ensure success.

  Various units have been used in seagrass transplant work, ranging from newly dehisced seeds (Kirkman, 1998), *in situ* seedlings (Hancock, 1992), rhizome sprigs (van Keulen et al., in press), intact cores (Paling et al., 2000a; van Keulen et al., in press), to large mechanical sods (Paling et al., 2001a). Mesh protection has also been used as a means of combating erosion. The success of transplant type measured per unit survival and time has usually been in the order: sods > cores > seedlings > rhizomes. This may be partially explained by considering the disturbance to the rhizosphere. In all but cores or sods there is a considerable disruption to the rhizomes and roots of the plant. Obviously there is no disturbance to the rhizosphere of *Amphibolis* seedlings as they have a comb anchor at the early stages (in this species lack of survival has been caused either by the seedlings washing away or by their necrosis). A seagrass core or sod extracts the sediment with minimal disturbance to the rhizosphere and its resident chemical cycles and infauna. The larger the core (van Keulen et al., in press) or sod (Paling et al., 2001b) the better the survival.
All of the studies carried out to the present indicate that rhizomes do not meet with success as a transplant technique. However this appears not to be due to their death so much as to their being washed away rather rapidly. Further study is required to discover a suitable anchoring method for rhizomes before this transplant technique can be fully evaluated.

It is difficult to generalise about transplanted seedlings due to the varying results that have been obtained. In some cases seedlings were washed away, in others they became necrotic or were affected by other factors that are discussed further below. Of the three transplant techniques employed seedlings have produced the least growth and unit expansion. In Posidonia seedlings the use of the endosperm for up to five years (Hocking et al., 1980, 1981) would reduce the need for rhizome growth as a mechanism for promoting survival and would limit spreading rate.

Current research indicates that the transplant technique can be matched to the environmental conditions of the prospective site. Cores of seagrass can grow in the high-energy environment of Success Bank but are often removed by the water motion. In areas such as Cockburn Sound, where energies are reduced, cores and sprigs may be a viable technique (Tunbridge, 2000).

- **Sediment movement (loss/smothering)**

The high-energy wave environment in Australia’s coastal waters also contributes to sediment movement on a massive scale. Changes in sediment height of 30 to 40 cm over months, and indeed tens of centimetres over hours, has been recorded in Western Australia (van Keulen et al., in press). Protection of seagrass transplants, by meshing for example, may afford some protection from erosion but can also enhance sediment settling and consequent smothering of some genera such as Posidonia (Paling et al., submitted). Amphibolis appears to be more tolerant to smothering events. Another factor related to sediment is its nutrient content. There have been some indications that moving transplants to bare sand may compromise their nutrition and subsequent survival. The limited research that has taken place however suggests that the addition of fertilisers does not enhance survival (Paling et al., 2000a).

- **Grazing**

Both urchins (Western Australia and New South Wales) and amphipods (New South Wales) have been known to consume seagrass transplants, as they do meadow edges (Cambridge et al., 1986; Hancock, 1992). The problem with grazing and transplants may be considered two-fold. Firstly, as transplants are removed from a meadow they may become a ‘beacon’ because they are now the sole food source in an otherwise bare area and therefore risk being consumed (Virstein and Curran, 1986). Secondly the lack of mobile epiphytic grazing fauna, usually occurring within a meadow, but not accompanying the transplanted unit may cause epiphytes to proliferate. This then causes
decline by increased shading or increasing leaf weight, which promotes erosion or settling of the leaves and subsequent burial.

- **Disease**

Fungal attack was positively identified as causing failures in *Amphibolis* seedling transplants (D. Walker, Pers. Comm.). Seedlings contracted the disease and rotted away or lost anchorage. Kirkman (1995) also noted a general decline in transplant appearance in his work. There is no present correlation between water quality and occurrence of disease as Walker was conducting experiments at Rottnest Island (a clean water environment) and Kirkman (1998) conducted experiments at the same location and at Cockburn Sound.

- **Poor water quality**

Poor water quality contributes to lowered transplant survival in the same way it does for meadows, by light reduction at the seagrass leaf. In terms of nutrient enrichment, enhanced epiphytic growth has been implicated in the loss of seagrasses in a number of areas throughout Australia and the world (e.g. Cambridge et al., 1986; Fonseca et al., 1998). Phytoplankton densities may also contribute to seagrass decline by reducing light penetration through the water column (Chiffings, 1987). Other sources of turbidity, such as suspended solids, are now becoming more accepted as contributing to seagrass decline (DAL & PPK, 2001). The improvement of water quality in Cockburn Sound (Paling et al., 2000b) has been matched by an enhanced survival of seagrass transplant survival (Tunbridge, 2000), lending support to the view that, until water conditions that caused decline are restored, transplantation will not be successful.

- **Procedural**

In many cases specific seagrass transplant projects have not taken place over a sufficiently long period to allow for the identification of failures and the implementation of possible solutions. Many have been “one-off” studies or *ad hoc* in nature, and not specifically focussed on progressing transplant research. Rather, they have often been exercises carried out to satisfy regulatory requirements, and often not funded sufficiently to allow goals to be achieved. In addition there have often been unrealistic expectations placed upon seagrass rehabilitation, a relatively recent exercise in Australia, from overseas experiences with different species (e.g. *Zostera*; Paling et al., 2001b) and from experiences noted in terrestrial rehabilitation, which has taken place for some decades.

3. **Recommendations to advance rehabilitation research in Australia**

At present there is only limited research and development being undertaken in Australia that can assist seagrass restoration. For example there is little research on seagrass
spreading across different species. As noted above, few large mitigation projects have been carried out, with most ventures on an ad hoc basis rather than having the ultimate goal of developing a feasible restoration technique. In most cases, experimental rehabilitation programmes have not been conducted for a sufficient period to allow for optimising techniques and for success to be properly monitored.

A purposeful seagrass restoration programme in Australia should be based on the acceptance that success can only be achieved by a sufficiently substantial programme that should last at least five years as a first stage. This amount of time is needed to allow for sufficient development of techniques and to sensibly monitor the success of any operation (Lord et al., 1999). The implications from this are that sufficient funding and long-term vision must be present for this exercise to succeed.

It was suggested by Lord and colleagues (1999) that three major seagrass environments be chosen for restoration research. These were Northeast, Eastern and Western Australian areas with varying climates and wave energies and substrates (Table 2). The latter two environments would overlap on the south coast such that information from studies on *Amphibolis* and *Heterozostera* could be applied to South Australia.

**Table 2. Three major seagrass environments recommended for restoration research** (modified from Lord et al., 1999).

<table>
<thead>
<tr>
<th></th>
<th>North east Australian</th>
<th>Eastern Australian</th>
<th>Western Australian</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>sub-tropical</td>
<td>temperate</td>
<td>temperate</td>
</tr>
<tr>
<td>Tidal regime</td>
<td>intertidal</td>
<td>subtidal</td>
<td>subtidal</td>
</tr>
<tr>
<td>Environment</td>
<td>Estuarine</td>
<td>Estuarine</td>
<td>Open Ocean</td>
</tr>
<tr>
<td>Energy</td>
<td>High energy</td>
<td>Low energy</td>
<td>High energy</td>
</tr>
<tr>
<td>Sediment</td>
<td>Mud</td>
<td>Sand</td>
<td>Sand</td>
</tr>
<tr>
<td>Suggested species</td>
<td><em>Halodule uninervis</em></td>
<td><em>Posidonia australis</em></td>
<td><em>Posidonia australis</em></td>
</tr>
<tr>
<td></td>
<td><em>Cymodocea sp.</em></td>
<td><em>Heterozostera tasmanica</em></td>
<td><em>Posidonia sinuosa</em></td>
</tr>
<tr>
<td></td>
<td><em>Zostera capricorni</em></td>
<td></td>
<td><em>Posidonia corticea</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><em>Amphibolis</em></td>
</tr>
</tbody>
</table>

Several recommendations for an Australia-wide coordinated effort into rehabilitation research were suggested by Lord et al. (1999), and they are worth repeating here in brief.

1. It is anticipated that for higher energy environments, such as those in southern and south-western Australia, greater emphasis might be placed on developing mechanically-based techniques to harvest and plant out some of the perennial seagrass species that occur in deeper, more physically-exposed waters and under more energetic and sandier environments than occurs in estuarine or shallow, intertidal
areas. Similarly, the shallower, intertidal areas and estuaries of the east coast may warrant development of both manual and mechanical techniques.

2. Identification of local sites within each representative habitat type where features and environmental conditions dictate that experimental seagrass restoration may be successful. The main local issues that need to be addressed include: identifying reasons for loss, or absence, of seagrasses at the site; historical information on changes in seagrass cover around the site; degree of sediment stability; hydrodynamic features affecting stability and biological processes; and existing and future water quality.

3. Development of a protocol and procedures for assessing the most appropriate techniques for transplanting or planting seagrasses under the different conditions experienced within each regional habitat. This will include an assessment of both mechanical and manual techniques, making use of some of, or all of, the following planting units: seeds; sprigs/rhizomes; cores and sods/turfs.

4. Implementation of pilot trials to provide information on the most appropriate seagrass species and techniques for use in restoring or rehabilitating seagrass habitat within each representative habitat type. The development and application of the ‘Dugong’ in planting out Zostera in Botany Bay, NSW and the development of the ‘ECOSUB’ to transplant Posidonia in Western Australia are examples of pilot stage development of technology using different species. Pilot studies, should, preferably, run for a minimum of three years to allow for modification of the techniques and for collection of sufficient data to reasonably assess success or failure.

5. Implementation of programmes to monitor and evaluate the performance and success of pilot and experimental seagrass restoration efforts within each representative habitat. Monitoring and assessment should include; development and use of standard protocols and indicators for evaluating and measuring success; observations on natural dynamics of the adjacent seagrass beds and seafloor, to integrate with any research being done on seagrass physical dynamics; and evaluation of the effects of seagrass removal on donor beds.

6. Implementation of aspects of research on seagrass biology that are specifically related to the development of seagrass restoration techniques; e.g. development and testing of site augmentation procedures (landscaping, filling, reprofiling) and their role in improving survival, growth and spreading rates of seagrasses at restoration sites; development of seagrass propagation techniques to promote faster spreading rates (also in situ exercises); development of culture techniques to provide appropriate planting stock for overcoming the present reliance on natural seagrass beds as a source of seagrass planting units; and development of genetic techniques to develop faster growing propagules.

7. Finally, it was recommended that a national, coordinated programme to develop seagrass restoration technology in Australia be undertaken through close cooperation among industry, government and the developers of the technology, in both economic
and technical aspects of the programme. This will also require due consideration of the intellectual property rights involved in the development of such technology.

4. Conclusion
In summary then, it seems clear the direction that seagrass restoration research should take in Australia to be successful. Firstly, a major requirement is long-term funding of some magnitude contributed by industry, government and technology stakeholders. Secondly, these projects need to be planned from 5 to 10 years, and finally, it is necessary to proceed with the intention of success. To achieve this, it is important to utilise valid pilot trials, feedback to enhance success and realistic performance criteria that are developed in tandem with the project.

5. References


