Restoration and Creation of Seagrass Meadows with Special Emphasis on Western Australia

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RESTORATION AND CREATION OF SEAGRASS MEADOWS WITH SPECIAL EMPHASIS ON WESTERN AUSTRALIA

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PREFACE

This report was prepared while the author was working for the Environmental Protection Authority. It was written following a review of the relevant literature, and also includes the views and experience of the author with regard to the restoration and creation of seagrass meadows. The techniques reported on have not been attempted in Western Australia.

ACKNOWLEDGEMENTS

Thanks are due to Drs Mark Fonseca, Bob Orth and Robin Lewis for so promptly sending me many unpublished reports and articles unobtainable in Australia. Drs Vivienne Mawson and David Gordon, and Ms Judy Kirkman made comments on the manuscript. Ms Kirkman took the photographs.

i. SUMMARY

This report reviews the literature on seagrass meadow restoration. It addresses the problems of transplanting seedlings and vegetative propagules and explains the precautions necessary for the preparation of a suitable site for restoration projects. The special case of Western Australia is emphasised, including the seagrass species themselves and the particular problems encountered in that State. The report discusses:

(i) the history of seagrass transplants both overseas and in Australia;

(ii) time scales for the natural restoration and the natural causes of seagrass decline;

(iii) the possible ways that planting units can be artificially planted to restore damaged seagrass meadows;

(iv) the chemical, physical and biological conditions which should exist for achieving best results from restoration;

(v) the problems inherent in obtaining planting material, and planting and caring for it.

Finally, conclusions and recommendations are presented for further tactical and strategic research.

1. INTRODUCTION

As ecological problems are addressed by environmental managers, restoration and replacement of seagrass meadows, damaged by man-made impacts, become important issues in repairing estuaries and bays that have been used as dumping grounds for effluent. Seagrass meadows have important effects on the physical, biological and chemical status of their habitat and, when they are destroyed, these components of the ecosystem change. Changes brought about by the destruction of seagrass meadows may be irreversible so that simply attempting to grow back the seagrasses is likely to fail. Before successful restoration can take place, the cause of the decline in the meadow must be identified and, if possible, eliminated.

Seagrass meadows are mainly lost through man-made disturbances, either directly, or through a slower process caused by the interruption of light quality and/or quantity to leaves (Cambridge et al, 1986). Occasionally they are lost through catastrophic storms (Kirkman, 1985). Catastrophic storms which remove stable seagrass beds occur rarely (once in 60-100 years), but man-made disturbances are becoming more and more frequent. Examples of seagrass beds which have declined in area in Australia are: in Western Australia, Cockburn Sound (Cambridge and McComb, 1984) and Princess Royal Harbour and Oyster Harbour (Kirkman, 1987); in South Australia, the Adelaide beaches (Clarke, 1987 and Neverauskas, 1987); in Victoria, Westernport Bay (Bulthius et al, 1986) and Corner Inlet (Poore, 1978); in New South Wales, Botany Bay (Larkum, 1976); and in Queensland, Moreton Bay (Kirkman, 1978).

Because seagrass meadows are important nursery areas for juvenile commercial and recreational fish and crustacea (Young, 1971; Pollard, 1984; Robertson, 1977 and 1982; Howard, 1984; Klumpp and Nichols, 1983; Bell and Westoby, 1986) there is a demand from governments and environmental managers for restoration of damaged or lost seagrass meadows, and for a halt to their continuing destruction.

Once seagrass meadows decline, they are difficult to restore. Seagrass leaves effectively baffle water movement so that any suspended materials in the water fall out, with the result that the water is filtered and valuable organic matter and sediment enter the food chain (Fonseca et al, 1986). Once these water-cleansing properties are lost and turbidity is increased it becomes difficult, if not impossible, to replant the area successfully with seagrasses.

Seagrass rhizomes stabilise the sediments and prevent erosion or accretion and establishment of sand on beaches, (Fonseca and Fisher, 1986). When sediments become mobile, settlement and establishment of seedlings or propagating material may become impossible. Even if the unfavourable environmental conditions can be overcome, there is the problem that many seagrasses have surprisingly slow rates of spreading. Although seagrass meadows are highly productive systems in terms of leaf production, this is not the case for their rhizomes, which do not branch or reproduce rapidly eg in genera such as *Posidonia*, and the tropical species *Enhalus acoroides*. Sexual reproduction may be prolific, but the successful establishment of seedlings appears, in most cases, to be very low. Given this feature, existing dense stands of *Posidonia*, must have taken decades, perhaps centuries to develop.

Recovery from damage is slow. For example, along the west coast of Europe and the east coast of the United States *Zostera* marina did not return for several decades following the "wasting disease" of the 1930's (Rasmussen, 1974).

Evidence for a slow rate of natural recovery of climax seagrass meadows can also be seen in Australia. In Botany Bay, New South Wales, the tracks of amphibious vehicles that drove over *Posidonia australis* beds during World War II, can still be seen. In Spencer Gulf, South Australia, an area mined for *Posidonia* fibre in 1917 can still be identified in the existing seagrass beds. In 1962, seismic blasts to determine the underlying substratum of Jervis Bay, New South Wales, destroyed circular areas of *Posidonia australis;* they have never recovered. Interestingly, the sediment within these circular, 20 m diameter patches has the same horizon as the surrounding seagrass meadow and particle size is similar (Kirkman, unpublished).

Can recovery be promoted? The qualified response to this question is-yes, typically by transplanting. Seagrasses can be transplanted (Thorhaug, 1986; Fonseca et al, 1987) but transplanting cannot cause individual plants to cover the bottom more rapidly than in nature, nor can it make a site suitable for planting. It can shorten the time for colonising a site, possibly by up to ten times (Thorhaug, 1986).

Most of the work and research into transplanting seagrasses has taken place in the United States (reviewed by Fonseca et al, 1987; Thorhaug, 1986), but the seagrass genera are different to those in Australia, the reasons for seagrass loss are sometimes different and most of the habitats are different. The main problem in the United States is the direct loss of habitat. Seagrass beds are being used for seabed cover in marinas and dredged waterways. The problem in Western Australia is that seagrass beds are being lost when the quality and quantity of light deteriorates as excess nutrients in the water enhance the rapid growth of phytoplankton and algal epiphytes (Cambridge et al, 1986). A similar situation has arisen in the United States, Orth and Moore (1983) hint at reduced water quality being one of the main causes of seagrass decline in Chesapeake Bay, Virginia (Orth, 1985).

This report concerns the re-establishment of seagrasses in areas where they originally existed, and their establishment in areas where they apparently have never grown. It also discusses the conditions under which we could expect reasonable success in restorating seagrass meadows.

Before effective restoration or creation of seagrass meadows can be achieved basic ecological and biological data must be incorporated into decision making processes. Physical factors such as tidal range, wind speed and direction, water depth and position of protective headlands or reefs are important factors to consider. Elimination of the cause or the decline of seagrass meadows and modification of the site, if it has changed noticeably, are also necessary for successful restoration. It may often be expedient to transplant a different species from that which has declined. This requires not only a knowledge of the biology of the transplanted species, but an understanding of the biological, physical and chemical characteristics of the area to be planted. These issues are discussed further below.

1.1 TERMINOLOGY

The terminology of seagrass restoration is quite confusing. Transplanting is one of the means by which seagrasses are planted in suitable habitats. To "transplant" means to move a plant from one place to another. Rather than use the word "transplant" for all seagrass planting, Lewis (1987) suggests that the term "restoration" be used when a seagrass bed is being re-established, while "creation" be used when a seagrass bed is established on a site that is documented not to have supported a seagrass bed in the recent past. He suggests that "transplanting" be used for planting plugs removed from another meadow, and that "planting" or "installing" be used for seedlings. These definitions will be used in this report.

"Mitigate" is used by Fonseca et al (1986), and by many others to mean "to make or become less severe: to moderate". Lewis (1987) says seagrass mitigation refers to a wide variety of possible management techniques, only one of which may be seagrass meadow restoration or creation. "Mitigate" will not be used in this report as a word to describe management of seagrass beds.

1.2 HISTORY OF SEAGRASS TRANSPLANTS

The first published report of seagrass transplants was that of Setchell in 1924, who grew *Ruppia maritima* in aquarium tanks for a few months. In the late sixties there was much interest in restoring lost or damaged seagrass beds in the southern United States, when it was realised how important these beds were for retaining water quality and as nursery areas for juvenile fish and crustacea. Fuss and Kelly (1969) were able to grow *Thalassia testudinum* Konig for twelve months in flow-through seawater tanks. They noted the slow vegetative growth of the rhizomes and recommended that only fragments with actively growing rhizome tips should be planted. Several attempts to grow seagrasses in the laboratory were successful (Koch et al, 1974; Kenworthy and Fonseca, 1977; Kirkman, 1978; Fuss and Kelly, 1969.). However, these transplants were mainly used as a source of material for short term experiments, rather than for establishing a meadow.

The first successful transplant of *T. testudinum* in the field is claimed by Kelly et al, (1971) using short shoots (erect lateral branches), a construction rod to secure the shoots and the plant growth hormone Naphthalene Acetic Acid (NAPH). Phillips (1974) successfully transplanted *Zostera marina* across different tidal depths and made reciprocal transplants of this species between Alaska and Puget Sound, Washington. He was optimistic that seagrasses could eventually be transplanted to cover large areas, and suggested that such transplanting could be used to study seagrass biology and phenology.

Fifteen years later we have not progressed much further with transplanting and establishing seagrasses over large areas. Some transplanting has been successful, but as Fonseca et al. (1986) said: "there has not been a seagrass restoration project that has prevented a net loss of habitat". Field plantings on a small scale were made in England (Ranwell et al, 1974), France (Cooper, 1979), the United States (Phillips, 1974) and Australia (Cambridge, 1978; Harris et al, 1979). Planting of *Thalassia testudinum* seeds over fairly large areas in Florida was not a success (Thorhaug and Hixon, 1975). These authors consider it unlikely that *Thalassia* beds can re-establish either by natural invasion of apical meristems or by seed. Thorhaug (1986) believes that *Thalassia* seedlings may be used to restore seagrass meadows.

Orth (1985) was more successful with transplanting plugs containing sediment and slow release fertiliser (Osmocote) in Chesapeake Bay. The slow release fertiliser appeared to significantly increase growth and survival of newly transplanted plugs in the first 216 days.

Vegetative propagules of *Posidonia oceanica* were successfully transplanted in a small area in the Baie de Giens near Toulon, France (Cooper, 1979), weaving rhizomes into a plastic mesh in a frame of concrete. Several thousand of these frames were deployed onto the seafloor. His methods, however, may not be feasible in Australia because *P. oceanica* appears to have a faster growing rhizome shoot than any of the eight species of Australian *Posidonia*.

2. **METHODS OF RESTORATION**

2.1 NATURAL RECOLONISATION

The natural recolonisation of seagrass beds has seldom been documented. Harrison (1987) reported on an expanding seagrass bed of *Zostera marina* and *Z. japonica* on the south-west coast of British Columbia, Canada. Seedlings appeared and then spread in little more than a year, with the leading edge advancing at about 34 m per year. The conditions favourable for creation of this meadow were man-made, in the form of a large earthfill breakwater which provided a protected habitat for seedlings to become established.

Large areas of *Zostera marina* recolonised over a period of forty years on the eastern coast of the United States and the western coast of Europe (Rasmussen, 1973), after the disastrous dieback of the thirties.

Birch and Birch (1984) reported on the recolonisation of a mixed community of seagrasses after a cyclone near Townsville, Queensland and noted that the colonisers re-established rapidly. Even after ten years, however, a complete return to the original species composition was not evident. In contrast, a meadow of *Zostera capricorni* and *Halophila ovalis* in Deception Bay in Moreton Bay, Queensland has returned after 10 years (Hyland, pers. com.). The cause for its decline was not known, although the loss of a nearby meadow was caused by sand movement (Kirkman, 1978).

There is no record of recolonisation of *Posidonia* or *Amphibolis* in Australia. Hillman (1986) reported definite signs of recolonisation of *P. sinuosa* in previously denuded areas in Cockburn Sound. However, the earlier mapping of Cockburn Sound by Cambridge (1979), and that of Hillman (1986) was probably not sufficiently precise to pick up differences, and the area allegedly denuded, or existing as a fibre mat, may have had viable rhizomes under the substrate which have subsequently produced shoots.

At Seven Mile Beach near Dongara in Western Australia, *Heterozostera tasmanica* and *Halophila ovalis* recolonise and grow rapidly after being washed out each year by winter storms (Kirkman et al, in prep). This annual change has been noted over about five years. These colonising seagrass species are small plants and not suitable for most restoration projects as they are easily washed out by vigorous water movement, preventing the establishment of stable communities.

2.2 PLANTING UNITS (PUs)

Whether restoring or creating seagrass beds, one can use four types of planting units. Each has several variations, for planting, and each has several anchoring devices.

2.2.1 PLUGS

Plugs are excavated units of rhizome, leaves and roots with sediment intact. They are planted by inserting them in holes and back filling. If plugs do not contain rhizomes with apical meristematic tissue they will not spread. Because plugs come from living, healthy seagrass beds, care should be taken to make as little impact on the donor bed as possible. Both Lewis (1987) and Orth (1987) recommend plugs as the most successful planting unit. Lewis used *Thalassia testudinum* plugs, 22 cm x 22 cm, while Orth preferred round units of about 9.5 cm internal diameter for work on *Zostera marina*.

2.2.2 SPRIGS

Vegetative shoots or turions with intact roots, rhizomes and leaves attached are called "sprigs". These are free of sediment and easier to handle than plugs. It is easier to check that sprigs have growing tips than it is for plugs. They are usually dug from a healthy bed and washed free of sediment before planting, or they can be collected from the wrack. The sprigs must have apical meristems to ensure that the rhizomes spread (Figures 1 & 2). Fonseca et al (1987) prefer sprigs because they are easy to transplant and have a lower impact on the donor meadow.

2.2.3 SEEDS/SEEDLINGS

Many of the Western Australian seagrasses produce large quantities of seed. *Posidonia* species produce large (1 cm) seeds within a fleshy pericarp (Figure 3), which splits soon after the seeds have germinated. (Figure 5). A month after the fruit has dehisced the seedlings can be planted in pots or in the sediment direct (Figure 4). *Amphibolis* produces large seedlings with grappling hooks capable of attaching to sediment, rock or exposed rhizomes (Figure 6). They make ideal planting units, held down by wire netting.

In the tropics and subtropics there is optimism about using seedlings of *Thalassia testudinum* to restore seagrass meadows (Thorhaug, 1986).

2.2.4 SPROUTING STEMS

Both *Amphibolis* and *Heterozostera tasmanica* are capable of producing adventitious roots from their stems (Cambridge et al, 1984; Kuo et al, 1987). It is not known whether these roots can sustain a planting unit, nor is it known how to stimulate adventitious root growth. Marcotting of stems (ie enclosing nodes on stems with moss or sand to stimulate bud growth) may be the best way to obtain adventitious roots. This is being investigated by the author.

2.2.5 ARTIFICIAL SEAGRASS

Exposed areas to be restored with seagrass could be effectively stabilised by laying sandbags in rows, or using wave dampening devices or mats of artificial, plastic seagrass. Strips of artificial seagrass may also be used to cover areas that were once vegetated with seagrass. These stabilisers may or may not be removed once restoration has taken place. Anchoring artificial

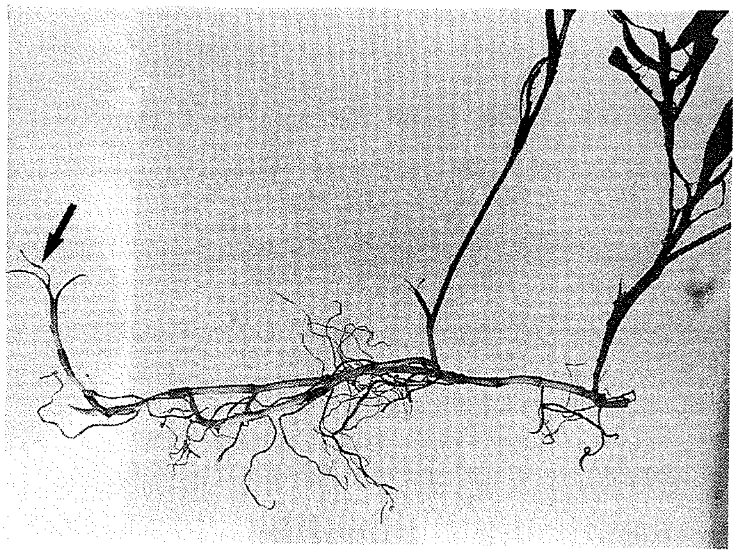

Figure 1 *Amphibolis* sprig, arrow points to growing tip. Scale x 1

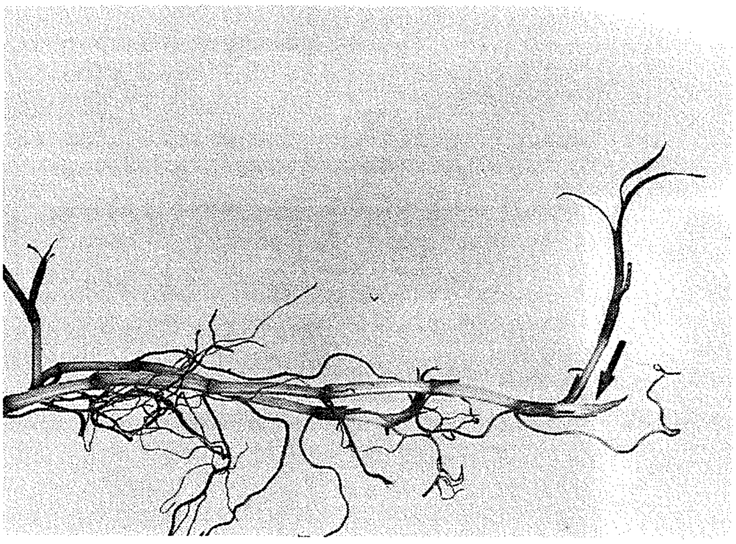

Figure 2 *Heterozostera tasmanica* sprig, arrow points to growing tip. Scale x 1

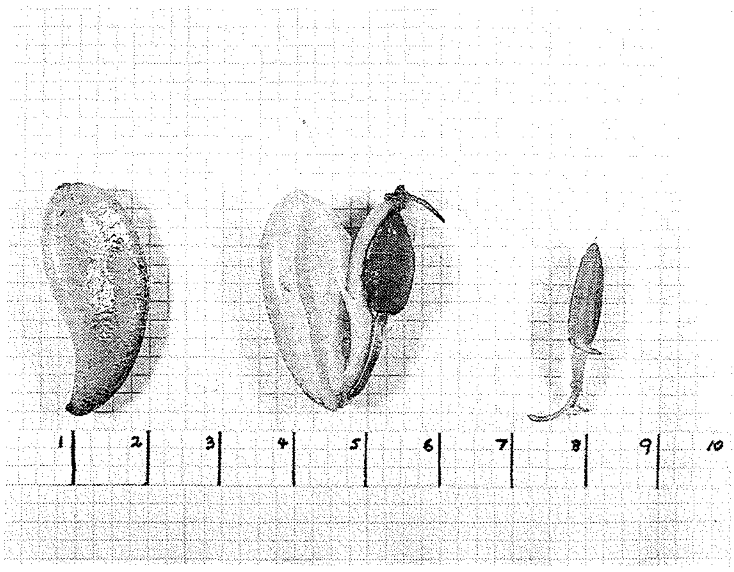

Figure 3 Fruit, pericarp and seed, and seed after pericarp removal of *Posidonia australis.*

seagrass over large areas may be a problem in areas of high water movement, and the costs will be substantial. The plastic, leaf-like structures of artificial seagrass will attract epiphytes and benthic in fauna. How different these are to those found on real seagrass remains to be investigated. It is likely that artificial seagrass will stabilise sediments and act as a host to some juvenile fish and crustacea.

2.3 INSTALLATION OF PLANTING UNITS

Many manual methods for planting seedlings and other planting units have been attempted successfully but none has overcome the problem of extremely high cost (US$25, 000 per acre, or A$61,750 per ha; Fonseca, 1987), and no really large areas have been planted. Because of the nature of the underwater environment, planting units must be secured much more firmly than land transplants and there is no machinery that can be readily adapted to do the job rapidly. Another important consideration is choosing the correct distance separating each planting unit. The closer together PUs are placed the more quickly will they eventually join up, yet the more PUs planted per hectare the more costly it is to restore the area. Orth (1985) planted plugs 61 cm apart; such an interval would require about 27,000 PUs per hectare. At 1 m intervals, as used by Lewis (1987), 10,000 PUs would be required. A compromise must be made between cost and desired time for recovery of the meadow.

In Western Australia restoration is likely to be successful if clumps of *Posidonia* seedlings are planted 10-15 cm apart at 10 m intervals. These clumps are designed to give protection to single seedlings which would be planted out in a one metre grid two years later. Another useful protection to new seedlings may be to plant "windbreaks" of the deep - rooting, clumping *Posidonia kirkmanii* in rows throughout the area and follow this, two years later, with seedlings of the spreading *Posidonia australis* planted in a grid. The quicker the PUs join up the more likely will be the success of restoration. Where planting is undertaken under calm conditions it may be more effective to plant at smaller intervals to promote joining up of the units, and thus strengthen the bed before storms arrive to dislodge the plants.

The only early workers to use growth hormones were very enthusiastic about their ability to encourage the fast production of roots and shoots (Kelly et al, 1971). Since then, nothing has appeared on the subject in the seagrass restoration literature.

There has been no work on genetic engineering to produce fast-growing species. Interspecific breeding of seagrasses is also unknown, probably because very few species within each genera are available, although the genus *Posidonia*, with its 8 species in Western Australia, may be a suitable candidate for hybridisation. The ecological consequences of this are unknown, and such a proposal would need careful investigation.

2.4 SEAGRASS SPECIES IN WESTERN AUSTRALIA AS A SOURCE FOR THE RESTORATION AND CREATION OF MEADOWS

One of the advantages of working with Western Australian seagrasses is their diversity - in southern Western Australia there are 17 species of seagrass represented in 8 genera. Nowhere else, where restoration attempts have been made, are there so many species to work with. In Florida, for example, there are only 4 species.

The following information on each of the species is relevant to their potential for restoration.

Along the southern end south-western coastlines of Western Australia, as far north as Cliff Head (latitude 29° 16', longitude 114° 55') *Posidonia sinuosa* is the dominant species of seagrass. It grows where water clarity is usually high, from a depth of 2 m to 27 m. *P. sinuosa* has the slowest spreading rhizomes of any of the species in the genus. It produces few seeds and, in some years, none at all. The best location to gather seeds of *P. sinuosa* is Cliff Head, where viable seeds have been found each year. The reason for there being viable seeds at Cliff Head may lie in the fact that this lagoon is at the northernmost extent of the range of *P. sinuosa* and has an unusually large range of water temperatures, 12° -28°C. The incidence of an increase in sexual reproduction at the margins of the geographic range of eelgrass *(Zostera marina)* was noted by Phillips et at (1983); this may also be the case with *P. sinuosa* at Cliff Head.

P. angustifolia, which has similar morphology to *P. sinuosa,* is not found in large beds and is not as common. *P. angustifolia* flowers prolifically, for example in Marmion Lagoon (latitude 31° 67', longitude 115° 43') near Perth, in December.

Posidonia australis is a prolific producer of seedlings (Figures 4 & 5) in most years, but its rhizomes, like the other species of *Posidonia,* also spread very slowly. Both *P. australis* and *P. sinuosa* have the occasional faster-growing shoot, approximately one shoot in every six hundred (West, 1987). If rhizomes are to be planted, these faster-growing shoots must be included in the planting unit. *P. australis* seedlings grow rapidly in the first two months after fruit dehiscence (Figure 4), but the duration over which their rapid development continues is not known. The main difficulty at this stage is planting out the seedlings. There is no mechanical seedling planter, and it is not known at what stage of development the seedlings should be planted.

We have planted individual seedlings in peat Jiffy pots and planted these in blowouts at Marmion. Transporting planted seedlings from the aquarium to the sea introduces other problems. We attempted planting seedlings in pots and subsequently transported these pots, in bins, to the planting area. The water in the bins washed out most of the seedlings in transit. The seedlings were then planted into Jiffy pots, underwater, and these buried in the sand. This method is not considered suitable for large scale planting because it is time-consuming.

Posidonia coriacea, P. denhartogii, P. robertsonae, P. ostenfeildii and *P. kirkmanii* are treated together in this report because so little is known of their general biology. The seedlings all have an early primary root that grows rapidly downwards into the sediment, and there is very little horizontal growth of rhizome. The plants later form dense clumps, with roots and rhizomes penetrating down to 30 cm (Figure 7). The beds of some of these species seem able to withstand very strong wave and swell action. *P. kirkmanii* is the largest and strongest species in this group but there are indications that *P. robertsoniae* has the fastest growth rate.

Amphibolis antarctica and *A. griffthii* are discussed together here as they behave in a similar fashion as planting units. The seedlings detach from the parent plant and attach themselves, by grappling anchors, to the

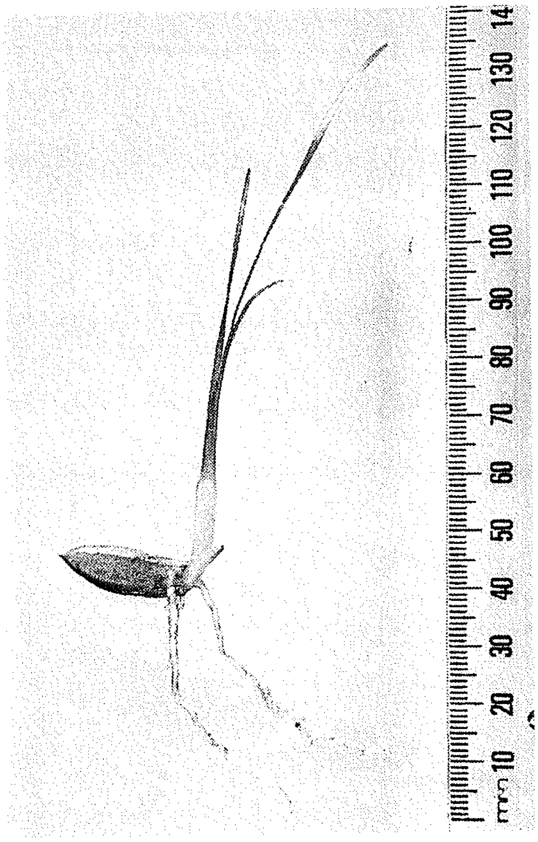

Figure 4 Seedling of *Posidonia australis* two weeks after pericarp removal. Scale x 0.5

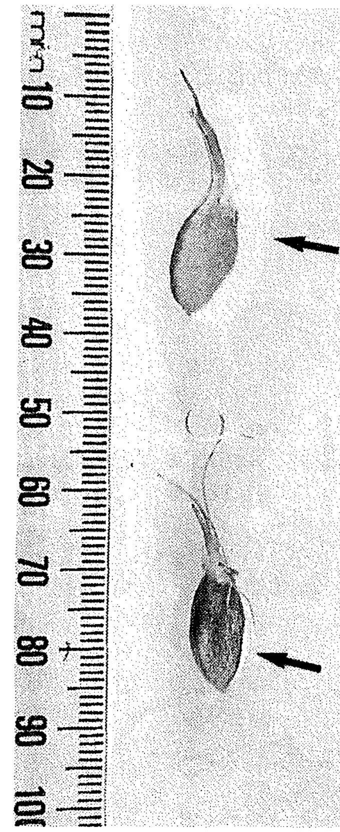

Figure 5 Seedling of *Posidonia coriacea* above and *P australis* below. Arrow points to keel on each seedling. Scale x 0.5

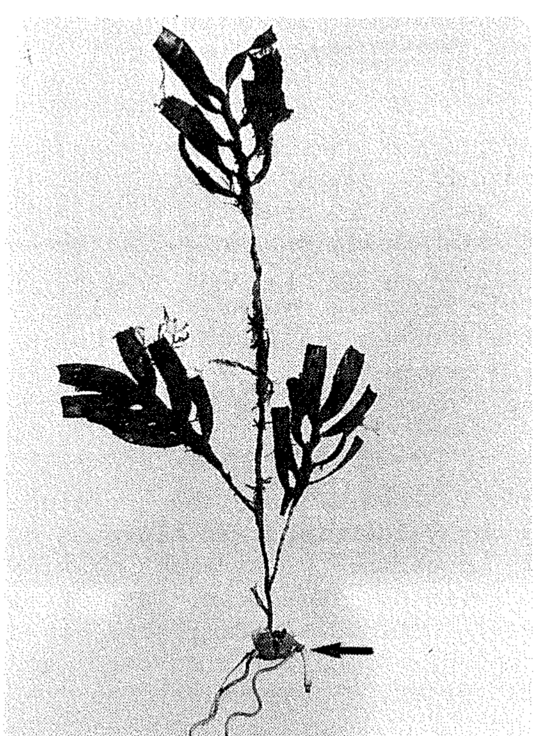

Figure 6 Seedling of *Amphibolis*, arrow points to grappling apparatus. This seedling has been detached from the parent plant for about 1 year. Scale x 1

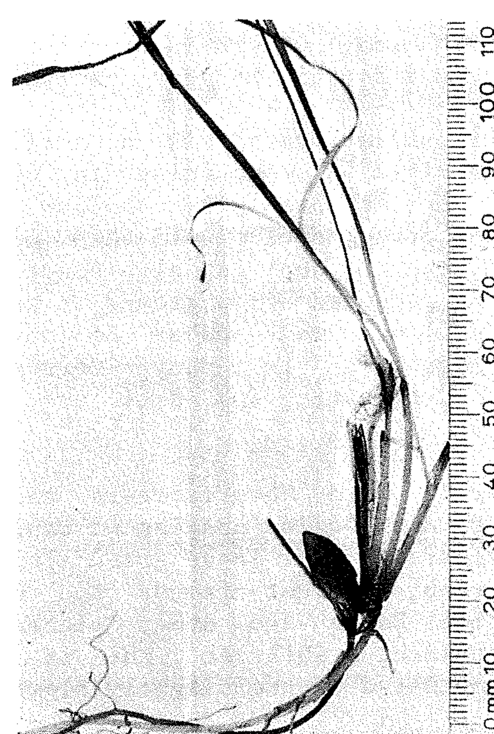

Figure 7 Year old seedling of *Posidonia coriacea*. Note old seed and primary root. Scale x 0.5

exposed rhizomes of *Posidonia* or any other fibrous material (Figure 6). Collection is rapid and easy. The small plants can then be planted directly under chicken wire. Another possibility is to anchor each seedling with a wire peg. Sprigs are easy to collect and can be readily attached to the sediment, but their growth rate is not known (Figures 1 & 2).

Amphibolis plants also produce adventitious roots on their stems, and the stems can be cut and planted under wire, or attached with pegs. Experiments are needed to determine whether these adventitious roots may be induced by marcotting or by planting stem cuttings. If *Amphibolis* is found to be a suitable plant for revegetating large areas in which another species formerly grew, it must be remembered, in taking this step, that the animal communities found in *Amphibolis* meadows are likely to be different to those found in the original meadow, and may not always lead to a desirable change at that location.

Heterozostera tasmanica produces many tiny seeds, but nothing is known of their viability, nor of the ability of the seedlings to grow. Experiments are underway by us to examine this. *H.tasmanica* also produces adventitious roots from its stems (Cambridge et al, 1983), but the stimulus for production of these roots is not known. *H. tasmanica* is vigorous in its production of rhizomes and may invade clear areas within six months. The rhizomes, however, do not penetrate the substrate deeply, and the plant is unable to withstand strong water movement (Kirkman et al, in prep.). Rhizome cuttings, held down by netting or ties, may be an effective way of revegetating damaged areas. Adventitious roots may possibly be induced in *H. tasmanica* stems, which can then be used as planting units. *H. tasminica* will out-compete *H. ovalis* and other early colonisers after about 6 months and has been found growing as continuous monospecific meadows at Seven Mile Beach (latitude 29° 09', longitude 114° 53'). At Marmion Lagoon, a cleared area of 36 m^2 was completely revegetated with *H. tasmanica*, which invaded naturally after two years, having taken over from *H. ovalis* and the green macroalga *Caulerpa*.

Halophila ovalis is a small delicate plant. It is the first seagrass species to recolonise in cleared or disturbed areas (Kirkman, 1985). *H. ovalis* has very shallow rhizomes and root hairs seem to be the main anchoring device of this plant. It is thus easily washed out by water movement, and is also shaded out effectively by larger plants. Many seeds are produced below ground in autumn, but little is known of their viability. Seedlings may appear at any time after the sediment is disturbed. Unlike colonisers in many terrestrial plant communities, *H. ovalis* is opportunistic and does not appear to be a necessary component of plant succession.

Along with *Heterozostera tasmanica*, *Halophila ovalis* and the seedlings of *Amphibolis*, species of *Caulerpa* are also early colonisers in blowouts or cleared areas. These green algae resemble, in appearance, seagrasses, having green, upright fronds and below ground rhizoids. *Caulerpa*, at Seven Mile Beach and other places subjected to continuous disturbance, is a sediment-stabiliser, but is easily torn out by strong water movement and smothered by the slightly slower growing, but larger, *H. tasmanica*.

Syringodium isoetifolium is usually found growing in the tropics or sub-tropics; Warnbro Sound (latitude 33° 13', longitude 115° 32') near Perth, Western Australia is its southernmost limit in Australia. This genus has been successfully used for sediment stabilisation and habitat development in the south-east United States (Fonseca et al, 1987). It does not grow vigorously, however, along the south western coast of Western Australia.

Thalassodendron pachyrhizum grows on limestone reef platforms, often with *Amphibolis*. It has a very patchy distribution but can form quite dense beds down to water depths of at least 34 m. As its name implies, it has large, strong rhizomes, which attach themselves to the porous rock on which they live. These rhizomes grow slowly (Kirkman and Cook, 1987), although the shoots grow rapidly. Flowers and seedlings are not common and the plant does not appear to have great potential as a restoration species.

3. CONDITIONS INFLUENCING SUCCESSFUL RESTORATION

3.1 CAUSES OF DECLINE

Cambridge et al (1986) discuss a number of possible causes for the decline of *Posidonia australis* and *P. sinuosa* meadows in Cockburn Sound. In a later paper, Silberstein et al (1986) implicate the smothering action of epiphytes on seagrass leaves and show how water quality and the reduction of light has an adverse effect on *Posidonia*. Neverauskas (1987) suggests that reduced light availability caused by the excessive accumulation of epiphytes, resulting from the addition of nutrient-rich sewage sludge to the water, may have contributed to the decline of the original seagrass beds near the Adelaide beaches.

3.2 EARLY INDICATORS OF STRESS

Very often in estuaries and bays where seagrass meadows are declining in area, a problem is only recognised when excessive loads of macroalgae appear on fringing recreational beaches, or the seagrasses have already been lost. Apart from the bays and estuaries listed in the introduction there are many others that may be undergoing similar problems but be at an earlier stage of decline. If it were possible to determine, early in the process of decline, that a seagrass meadow was stressed, there may be a much greater chance that the problems can be solved and the process of decline reversed, perhaps eliminating the need for restoration.

In the same way, if it were possible to determine that a meadow, in the process of being restored with transplants, was unhealthy and failing, much time could be saved before the transplants actually died, in attempting to improve the conditions surrounding the new meadow.

High levels of carbohydrates and hemicelluloses in the rhizomes of some Western Australian seagrasses were recorded by Masini (1986). Drew (1976) recorded annual changes of carbohydrates in some seagrasses and discussed their use as storage materials. These stores may possibly act as buffers to stress. A data base of carbohydrate content of rhizomes in important seagrasses in Western Australia could provide a means for evaluating stress. This approach could yield an earlier warning of stress than is currently available from external signs of leaf stress eg leaf-fall.

Stress to the seagrass meadow may take many forms. For example, if the sediment load in the water overlying a seagrass meadow was increased by dredging operations, the resulting effect on the meadow could be determined by measuring associated changes in the carbohydrate content of the rhizomes.

Once this reached a critical level, dredging could be temporarily stopped until the seagrass recovered. At the present time, the only warning indicators of stress are loss of leaves, or death, which may be, or is already, at a stage too late for successful recovery. This aspect of seagrass research requires further investigation.

3.3 ENVIRONMENTAL CONDITIONS FOR RESTORATION OF SEAGRASS MEADOWS

Understanding the reasons for partial or complete destruction of seagrass meadows is necessary if deterioration is to be halted, and the restoration effort begun. The causes of destruction must be eliminated so that they do not destroy the transplanted plants. If the creation of new seagrass meadows is planned for a specific location it is important to know why the plants were not growing naturally at this location. A number of physical, chemical and biological factors need to be considered when determining whether or not an area is ready to be restored.

3.3.1 PHYSICAL

Loss of seagrass meadows may come about through dredging, changing the bottom topography or moving a protective reef or headland. Unless the site where the seagrass grew can again be protected from swell or wind driven waves, a restoration attempt will fail. Before changes to the local topography are made, current meters, or even plaster/latex blocks (Gerard and Mann, 1979), should be deployed to measure water movement. Then, when the changes have been made, water movement should be again measured to ensure that no increase has occurred. If there is an increase in water movement, some protective barrier will have to be developed to return the area to its original state. Dredging is a direct means of removing seagrass meadows. Usually conditions after dredging are so changed that seagrass meadows cannot be restored.

Sediment loads in the overlying water are likely to increase with the loss of seagrass meadows. Particularly in deep locations this load will severely reduce light available to the meadows and make restoration impossible. To overcome this problem it might be feasible to replant along the shallower edges of the meadow where there is more light available. Over time, the sediment load may then be reduced through the shallower vegetation acting as a filter, for the deeper places to be successfully replanted.

If large amounts of sediment are arriving at the seagrass meadow, the sheer bulk of this material may directly smother the plants (Kirkman, 1978). Smaller loads in shallow seagrass beds may gradually accumulate as sediment, and eventually reduce water depth to the extent that the seagrasses receive excessive exposure at low tide. Seagrass species vary in their tolerance to exposure, eg *Heterozostera tasmanica* cannot tolerate exposure as well as *Zostera muelleri*. It may therefore be feasible to replace *H. tasmanica* with *Z. muelleri* in shallow areas where silt is accreting (Bulthius et al, 1986). To replace seagrass killed like this, with the same species, would mean failure.

Compensating levels for light quantity and quality should be known for each species so that these, or better, light conditions are available to the plants before attempts are made to restore meadows.

3.3.2 CHEMICAL

The most likely reasons for the loss of seagrass meadows in Australia are through the effects of excess nutrients, in runoff, causing phytoplankton blooms, excessive epiphyte loads, or enhanced growth of free-living macroalgae, which can compete with the seagrasses for nutrient and light, (Cambridge et al, 1984). Runoff may come from industrial drains, sewage treatment plants or from farms in the catchment of the waterbody in which the seagrass meadows have declined (Mills, 1987). Because algae responsible for blooms, and resulting, shading of seagrasses, can readily take up and store these excess nutrients, the excess is not always detectable in the water (Birch et al 1981). Sources of nutrients, derived from rivers or urban and industrial outlets, need to be identified, and monitored.

Another source of nutrients which may be important in maintaining blooms of algae, once the source of eutrophication has been reduced, is the sediment. This may hold nutrients for years, even after nutrient input from outside sources has ceased. The availability and rate of release of sediment nutrients is not well known in Western Australia. Free-growing macroalgae, or epiphytes may store and use nutrients within live plant material, then when that dies, the nutrients will be recycled and contribute particulate and dissolved organic material to the system.

It would be useful to know the background levels of nutrients for unpolluted water, and the levels expected when the area is ready for restoration. In most cases this is not available. Kirkman (unpublished data) measured nitrate in water over a seagrass meadow thought to be in pristine condition off Marmion over a period of 5 years. He found that winter spikes of nitrate occurred after storms and were as high as 4 μg atoms l^{-1} but that average weekly concentrations rarely exceeded 1 μg atom l^{-1} (Figure 8). Phosphate concentrations for coastal waters off Perth, Western Australia, have also been recently documented (Pearce et al, 1985).

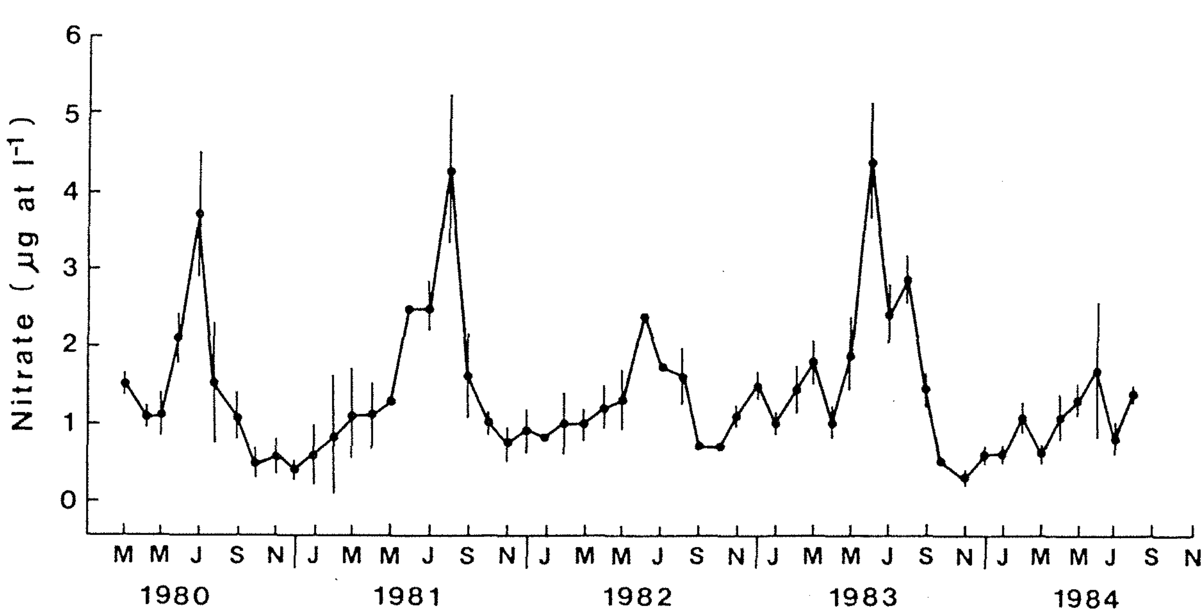

Figure 8 Nitrate concentrations (μg atom l^{-1}) in water over seagrass beds at Marmion Lagoon, Perth, Western Australia

3.3.3 BIOLOGICAL

The most likely cause for seagrass decline in Australia is through excessive epiphyte growth, leading to light shading and smothering.

Another contributing factor to decline may be the action of a burrowing shrimp, *Alpheus euphrosyne* (Coleman, 1985). This animal can have two deleterious effects on seagrass beds: it reduces light by ejecting sediment into the water above its burrow, and it smothers seagrass leaves by covering them with sediment while burrowing. The burrows of *Callianasus*, another shrimp-like burrower, can cause similar problems with restored seagrass planting units (Anon. 1985). Other bioturbative stresses include herbivory and working of sediments by benthic infauna.

4. FACTORS LIMITING RESTORATION

4.1. FINDING PROPAGATING MATERIAL

Seeds, vegetative plant parts or stems with adventitious roots have to be found, collected or induced. *Posidonia australis* and *P. coriacea* can be relied upon to produce viable seeds each year. *Heterozostera tasminica* and *Halophila ovalis* also produce seed prolifically, but their germination rate is not known. *Amphibolis antarctica* and *A. griffithii* both produce well-established seedlings, which can be collected from sites where their grappling apparatus has attached to exposed rhizomes along the edges of seagrass beds.

4.2 MAINTAINING PROPAGATING MATERIAL

Because of the difficulty of newly-planted material holding itself to the substrate, it is usually best to plant during a calm season, preferably well before storms disturb the substrate. In any case, the timing of the arrival of seedlings of most species is adapted to this, although seedlings of *Posidonia australis*, and, particularly, *P. coriacea*, could be planted in November if seed stock were available then, instead of in December and January, respectively. Seeds may be kept in cold storage until required, or they may be stored in darkness to prevent development. Seedlings of *Amphibolis* may be collected throughout the year and stored in aquarium tanks until required. Other propagating material, such as *Heterozostera tasmanica* or *Posidonia*, may need to be kept in holding tanks until they have been treated or are ready for planting. Nothing is known of the light requirements for holding plants, or for inducing them to shoot or flower.

4.3 ATTACHMENT OF PLANTING UNITS

Holding down a planting unit for sufficient time to allow it to become established is an essential part of any restoration or creation project. Left to nature and time, seedlings do not have a very good chance of surviving. Growing colonising species before attempting to restore the climax species is probably not necessary. Kirkman (1985) has suggested that a succession of species is not necessary for a climax community to become established. Plants such as the rather hardy and strong *Amphibolis* seedlings, and growing tips of rhizomes of other species, may be held down by wire netting staked to the substrate with sand placed over the netting. Individual seedlings may be placed in peat pots and planted out once the roots have penetrated the pot walls. Seedlings and sprigs may be staked down and plugs can be dug into the substrate. Once planting units begin to coalesce, the attachment problem is all but over. If PUs are to be planted in Jiffy pots, the plants must be attached to the pots, otherwise the plants will fall out in transport and further time will be needed to replant them underwater.

One way of reducing water movement, which can wash out seedlings before they have firmly established, may be to grow wind breaks of a well-rooted species, such as *P. kirkmanii*, at least two years before the bulk of the restoration is to be carried out.

4.4 LARGE-SCALE PLANTING

The cost of manual planting will probably be the most restrictive item on all but the smallest proposed restoration projects. It may be possible to develop a mechanical planter to plant multiple rows of seedlings at designated intervals. The apparatus could be pulled by a boat, using three divers to sit on it and plant PUs as it is pulled along. This is one of a number of alternatives being investigated for mass planting. Mechanical devices may be the answer, but the PUs prepared for mechanical devices must be sturdy plants, solidly packed on the substrate and attached by some means to the substrate or a pot.

4.5 SLOW SPREAD OF RHIZOMES

Whether the PU is a seedling or a vegetative propagule, most seagrass species have very slow growing rhizomes and roots. It is essential that a unit has at least one growing tip with viable meristematic tissue. There is no record of the rate of growth of rhizomes of any *Posidonia* or *Amphibolis* species. *Heterozostera tasmanica* and *Halophila ovalis* rhizomes grow rapidly (Kirkman et al, in prep.). Perhaps use of growth hormones should be attempted in Western Australia to hasten rhizome growth, as Kelly and others (1971) did overseas in their experiments with seagrasses.

4.6 DAMAGE TO DONOR BEDS

When PUs are collected from a donor meadow, the meadow always suffers damage, particularly if the PU is a plug where sediment is removed. The donor bed is best conserved by removing plugs from widely separate sites so that only small openings are made in the meadow. The larger the clearing made in the meadow, the more likely are the chances it will be enlarged during storms.

4.7 PREPARATION AND/OR MODIFICATION OF THE RECIPIENT SITE

As stated earlier, seagrass meadows cannot be restored if the cause of their decline is not eliminated. Moreover, the recipient seagrass meadow and the factors operating in the meadow need to be well understood.

5. CONCLUSIONS AND RECOMMENDATIONS

Eutrophication of harbours and estuaries is the main danger to seagrass in Western Australia. As soon as the nutrient input and status of these waterways is returned to pristine, or improved, conditions, efforts can be made to begin restoration.

Much work is still required to find a successful and reliable method for long-term restoration of seagrass meadows. Not only must damaged areas be restored, if possible to their original condition, but the seagrass transplants must grow fast enough to cover the areas within a realistic time span ie 3-5 years. Further research, both in the field and in the laboratory, is needed to solve the many problems of seagrass restoration. From overseas experience it is obvious that restoration is an extremely expensive exercise, and this expense must be critically evaluated against the environmental, aesthetic and commercial costs of seagrass decline. The start to successful restoration is selection of a suitable species or combination of species. The plants must be fast growing, with the ability to anchor well. Storage and assessment of likely stock should be undertaken in aquariums. Trials to determine the best ways of storing seed and vegetative propagules need to be carried out so that stocks of planting units can be available for planting at the most convenient time of year. Care must be taken to ensure that field sites are suitable for restoration attempts. In Western Australia either of the two *Amphibolis* species may be the best candidate for transplanting because of their relatively fast rhizome growth.

Mechanical planting methods are seen to have potential for seagrass restoration but need to be examined further because of the prohibitive labour costs of hand planting large areas. Once suitable species, planting intervals and timing of planting have been established, it may be expedient to use volunteer labour to plant seagrasses.

Various types of planting material and the available species in southern Western Australia have been discussed in terms of their ability to act as restoration plants.

Restoration will be a long term project however it is handled. Small plants such as *Heterozostera tasmanica* and *Halophila ovalis* may be used to stabilise sediments and filter water but, as they are susceptible to strong water movement, there are many places in Western Australia where they would not remain long enough to assist in the establishment of the more robust species. The use of artificial seagrass as full cover, or as protection to newly planted units, may be useful in some cases.

Finally, hybridisation, genetic engineering and introductions may be attempted to hasten spreading, combine the useful attributes of various species and facilitate planting. A discussion of these topics is beyond the scope of this report.

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