Recent advances in research into seagrass restoration

Prepared for
Coastal Protection Branch,
Department for Environment and Heritage

by
Rachel Wear
SARDI Aquatic Sciences

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EXECUTIVE SUMMARY

The process of seagrass restoration is widely recognised as being complex and having produced few successes. Over the years, numerous techniques have been developed for different species and environments including the transplantation of seagrasses and the use of seeds and seedlings in restoration. During the past five years, research has been directed towards improving the success of restoration attempts utilising previously developed methods, and the development of new restoration techniques. The most significant advances in seagrass restoration have arguably been the development of mechanical seagrass transplanters in Western Australia, and the development of non-destructive methods of seagrass restoration that facilitate the natural recruitment of seagrass ramets or seedlings. Further development of such methods is required to identify the locations in which this type of restoration may be used. The development of these techniques illustrates that large-scale restoration may become more affordable and feasible in future years.

1. INTRODUCTION

Seagrass meadows have long been recognised for their ecological and economic importance, and together with coral reefs and mangroves, are thought to represent one of the world's most productive coastal habitats (Short and Wyllie-Echeverria, 1996). Seagrass beds not only play a critical role in primary production (Borum et al., 2006) and nutrient cycling (Hillman et al., 1989; Romero et al., 2006), but they also provide habitat for a diverse array of marine organisms (Bell and Pollard, 1989; Short and Wyllie-Echeverria, 1996; Connolly et al., 1999; Duarte, 2002), and increase the stability of the seafloor through the growth of extensive rhizome mats (Fonseca and Fisher, 1986). Despite overwhelming research that consistently demonstrates the importance of seagrasses, seagrass beds are currently undergoing worldwide declines. While natural loss of seagrass is apparent in some regions (Robblee et al., 1991; Preen et al., 1995; den Hartog, 1996; Seddon et al., 2000), recent estimates suggest that over the past two decades, approximately 18% (or 33,000 km^2) of the world's documented seagrass area has been lost as a result of direct and indirect human impacts (Walker et al., 2006).

While reports of seagrass losses are escalating, the recovery of seagrasses appears to be rare. One of the reasons for the imbalance between loss and recovery of seagrasses is that such occurrences take place over fundamentally different time scales. Seagrass losses, whether mechanically or physiologically induced, often occur rapidly following environmental perturbations. Conversely, recovery of seagrasses from disturbance either via clonal expansion (lateral growth of rhizomes) or recruitment of seeds and seedlings is often very slow and can take decades to centuries (Clarke and Kirkman, 1989; Kirkman and Kuo, 1990; Hastings et al., 1995; Marbà and Walker, 1999; Meehan and West, 2000; Bryars and Neverauskas, 2004).

Increasing documentation of seagrass losses around the globe, and recognition of the importance of seagrasses to coastal protection, biodiversity, and productivity, has prompted researchers and resource managers to investigate ways to protect existing beds and restore disturbed seagrass communities. Such practices may include the improvement of wastewater management, setting aside areas of seagrass habitat for preservation, and the prohibition or regulation of destructive and unsustainable activities. Restoration and rehabilitation[1] of seagrass beds has also been recognised as a means of accelerating the recovery of seagrass beds within reasonable time frames and is an area of research that has received

[1] "Seagrass '*restoration*' refers to returning a seagrass meadow to its pre-existing condition (i.e same species composition, distribution, abundance and ecosystem function). Seagrass '*rehabilitation*' is a more general term and implies returning seagrass to an area where seagrass meadows previously existed (but not necessarily the same species, abundance or equivalent ecosystem function)" (Seddon, 2004). For the purpose of this review, seagrass restoration will be used to describe both restoration and rehabilitation attempts.

increasing attention over the past few decades (Rinkevich, 1995; Field, 1998; Yap, 2000; and references therein).

The first documented attempt at seagrass restoration was carried out in the United States of America in 1947 (Addy, 1947; cited in Fonseca et al., 1998), however, it was not until the mid 1970s that any serious attention was given to the development of seagrass restoration techniques. During the past 30 years there has been considerable development in restoration methodologies, and a significant increase in the number of locations and species involved. Until the early 2000’s, a number of workshops, review articles and book chapters had been conducted and written on seagrass restoration (e.g. Fonseca et al., 1998; Lord et al., 1999; Calumpong and Fonseca 2001; Seddon and Murray-Jones, 2002); however, a review of the most recent literature is not currently available. This report provides an updated review of the most recent seagrass restoration literature around the world. In particular it summarises research that has been published during the past five years. The review is separated into sections based on the main methods used to restore seagrass beds including; the transplanting of seagrasses, the use of seeds and seedlings in restoration, and facilitating natural processes to aid in recovery.

2. SEAGRASS RESTORATION DURING THE PAST FIVE YEARS

2.1. Transplantation Methods

With increasing research directed to seagrass restoration around the globe, we have become aware that seagrass restoration is complex, and success is determined by a number of factors. While many different restoration techniques have been developed and tested over the years, the most common method has involved the transplantation of adult ramets, perhaps because they result in an immediate presence of the plant community. Some of these methods have involved transplantation of seagrass and associated sediments, whilst others transplant only the seagrass itself (Figure 1; Fonseca et al., 1998; Calumpong and Fonseca, 2001). Regardless of the method, the success of previous attempts that have used transplant methods has been variable and unfortunately in many cases, transplant trials have resulted in limited survival and coverage (Thorhaug, 1986; Paling et al., 2003; West et al., 1990). In some cases there has actually been a nett loss of seagrass habitat (e.g. West et al., 1990; Kaldy et al., 2004). Furthermore, there are limits to the area that can be realistically restored and successful restoration programs have generally failed to restore the full area of seagrass lost.

Figure 1. Photographs of some of the methods by which seagrass is transplanted. Divers collecting (a) and planting out (b) *Amphibolis antarctica* cores and (c) weaving sprigs of the same species to hessian matting prior to planting out (c).

Some of the main factors that limit the area that can be restored by transplantation include the poor survival of transplants, and the considerable effort and expense required. In 1998, the average cost of transplanting seagrasses was US$37,000 per hectare (Fonseca et al., 1998) and as much as US$680,000 per hectare (Spurgeon, 1998). Consequently, much of the research directed toward the transplantation of seagrasses during the last five years has investigated ways of increasing transplant survival while reducing the effort and cost.

In Australia, the wave-exposed nature of many areas in which seagrass restoration has been undertaken has reduced transplant survival as a result of high water motion and/or insufficient anchoring (e.g. West et al. 1990; Paling et al., 2002; Seddon et al., 2004). Following the realisation that greater survival of transplants may be achieved by increasing the size of transplanted units (Walker, 1994; cited by Paling et al., 2001b)), researchers developed a mechanical seagrass transplanting machine. The machine, called ECOSUB1, is capable of transplanting 0.25 m^2 units of seagrass (Figure 2; Paling et al., 2001b). Survival of *Posidonia sinuosa* and *P. coriacea* units, two years after transplantation in high wave energy areas, has been reported at 76.8 and 75.8%, respectively (Paling et al., 2001b). Improvements to ECOSUB1 to increase efficiency (Paling et al., 2001a) resulted in the creation of ECOSUB2, which is capable of transplanting 75, 0.55 m^2 seagrass sods per day, albeit at considerable expense. The survival of transplanted seagrass using ECOSUB2 is comparable to ECOSUB1, and transplants are showing signs of expansion, with the restored area showing signs of natural infilling by seagrass seedlings (Paling et al., 2001a; Paling et al., 2002).

Figure 2. Photographs of ECOSUB1 on a trailer (left) and underwater collecting large cores of *Amphibolis antarctica* from a donor meadow (right) (Photographs from van Keulen and Paling, 2002).

The success of transplanting methods in Australia, led researchers in the United States to compare mechanical and manual methods of transplanting *Zostera marina* (Fishman et al., 2004). In this study, 24 weeks after transplantation, seagrass units transplanted with a mechanised planting boat had similar survival rates to those manually transplanted. However, because the planting boat had significant losses of plants during the plant-out stage, a greater number of units had to be planted, resulting in a much greater total labour investment and plant donor stock for each planting unit surviving to 24 weeks. Consequently, the authors of the study concluded that the mechanised planting boat was not a significant improvement over the manual method for transplanting this species of seagrass (Fishman et al., 2004).

In addition to the development of mechanical seagrass transplanters, in areas where sediment movement has reduced the survival of transplanted seagrass, other means of increasing transplant survival have been tested. During the past five years two studies have examined the potential to enhance transplant survival through the stabilisation of surrounding sediments. In the first, 40 x 40 cm squares of plastic garden mesh were used to stabilise the sediments surrounding springs of *Amphibolis griffithii* and cores of *A. griffithii* and *P. sinuosa* (van Keulen et al., 2003). Survival of *A. griffithii* sprigs and *P. sinuosa* cores was poor in all treatments and no significant difference could be attributed to the effects of mesh. However, transplanted cores of *A. griffithii* appeared to survive better when meshed (van Keulen et al., 2003). In the second study, cores of seagrass were transplanted amongst larger squares (1.5 x 1.5 m) of plastic mesh, covered with artificial shoots (Campbell and Paling, 2003). While these artificial seagrass mats appeared to stabilise the sediment composition, they did not stabilise erosion and accretion and did not significantly increase the survival of *P. australis* plugs in comparison to unprotected sites (Campbell and Paling, 2003).

Other means of increasing transplant survival in high wave energy environments may include increasing planting unit size and/or reducing the spacing between units. Both hypotheses have recently been tested in separate studies. The spacing of seagrass units transplanted with ECOSUB1 (0.5, 1.0 and 2.0 m apart) had no significant affect upon transplant survival (Paling et al., 2003), while survival of manually transplanted units increased with transplant size (van Keulen et al., 2003).

Whilst in some areas considerable effort has been put toward developing new methods for enhancing transplant survival, in others, transplantation trials utilising previously developed methods have been undertaken. These trials have met with various outcomes and have demonstrated the difficulties associated with seagrass restoration. In one such case, more than 10,000 *Halodule wrightii* units were transplanted to two sites in Lower Laguna Madre, Texas, however, after just a few months all but one unit had been lost (Kaldy et al., 2004). The authors of the study attributed the failure to substrate loss, elevated sediment ammonia concentrations and insufficient light, illustrating the importance of site selection in seagrass restoration efforts. Two other studies yielded much better outcomes. Following the transplantation of sprigs and cores of *Phyllospadix torreyi*, survival after six months was relatively high with an average of 60% of sprigs and 86% of cores surviving at two sites (Bull et al., 2004). In this study differences in survivorship between sites were apparent, as was the case when Meehan and West (2002) transplanted *P. australis* at five sites in Port Hacking, New South Wales. Sixteen months after transplantation three of the five sites exhibited high survival, while at the other two sites all transplants were lost. The authors of this study attributed the loss of transplants at the two sites to the factors that caused the original loss of *Posidonia* in the study area, which included considerable sand movement and erosion during heavy storms (Meehan and West, 2002).

2.2. Seedling Methods

Despite recent endeavours to improve the capabilities for seagrass transplantation in Australia, including the development of mechanical techniques, the practice is generally not suitable over large scales. As pointed out by Seddon (2004), assuming the maximum predicted rate of 75 sods per day and one metre between sods, ECOSUB2 would take 44 days to plant just one hectare of seagrass. Furthermore, the transplantation of seagrasses relies on the destruction of otherwise healthy meadows, which are reported to have extremely slow recovery rates (Kirkman & Kuo, 1990; Meehan & West, 2000; Cambridge et al., 2002), and is generally labour intensive and expensive (Lewis et al., 1998; Spurgeon, 1998; Calumpong and Fonseca, 2001; Paling et al., 2001a).

An alternative to the transplantation of vegetative stock from one location to another, yet one that has received far less attention (Fonseca et al., 1998), is the planting out of seagrass seeds and seedlings. The use of seeds and seedlings for restoration has recently been endorsed by experts within the field (Seddon, 2004; Orth et al., 2006), as such methods have major advantages over transplantation techniques. Firstly, the utilisation of seeds avoids the destruction of seagrass beds, although at this point in time little research has been done on the role seeds and seedlings play in the maintenance of seagrass bed health. The use of seedlings has also been reported to encourage genetically heterogeneous seagrass beds that grow faster, produce more seeds and have better rates of germination compared with transplantation methods (Williams, 2001). Furthermore, many seagrass species produce copious quantities of propagules that can be easily harvested and stored.

Despite the obvious benefits of using seeds in restoration programs, research on methods for restoring seagrass beds using seeds remains experimental. Far fewer studies have been published on the use of seeds in restoration compared to transplanting techniques, and those that have been undertaken suggest that this type of restoration appears only to be applicable in low energy environments and where seed predators are sparse (Fonseca et al., 1998). Techniques to reduce mortality associated with high energy regimes have previously included embedding seeds in biodegradable mesh, and planting seedlings in biodegradable peat blocks or Growool blocks. However, such attempts have failed (Kirkman, 1998). During the past five years, there have only been two studies published in the scientific literature that have examined the use of seedlings in restoration. Both of these have involved the planting out of laboratory-reared *Phyllospadix torreyi* seedlings on lengths of nylon line, secured to reef habitats (Holbrooke et al., 2002; Bull et al., 2004). In one study, approximately 30% of seedlings survived the three-month experimental period, while in the other, few seedlings survived for six months.

In Australia, research during the past five years has been conducted on the use of *Posidonia* spp. seedlings in restoration efforts. Two separate research groups, the South Australian Research and Development Institute (SARDI), Aquatic Sciences together with the Department for Environment and Heritage (DEH, South Australia), and Kings Park Botanic Gardens (Western Australia), have undertaken such experiments. The process involves the collection of *Posidonia* fruits and their subsequent culture and grow-out as seedlings, prior to planting out (Figure 3; Seddon et al., 2005). While successful seagrass restoration using this method is ultimately determined by the survival of planted out seedlings, to date the majority of research has focused on the earlier phases of the process. Rearing seedlings in culture at SARDI Aquatic Sciences resulted in just 8% of seedlings surviving for 11 months, with variable to slow growth rates. Poor survival in this study was attributed to reduced light from a combined effect of excessive algal growth and the level of shading over the tanks (Seddon et al., 2005). Similar problems have been encountered in Western Australia, although researchers recently overcame excessive epiphyte growth by providing a low enough light climate to reduce epiphyte growth (epiphytes are photophilic), without hindering seedling growth (K. Dixon, pers. comm.).

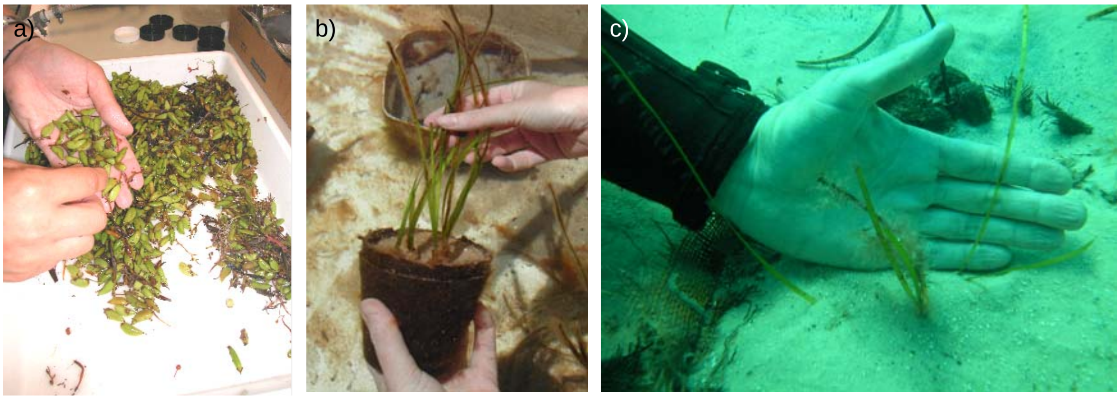

Figure 3. *Posidonia* fruits following collection (a) and eleven months later in controlled environmental conditions at the South Australian Aquatic Science Centre (b). *Posidonia* seedlings planted into sand-filled hessian bags off Adelaide (c).

Following difficulties encountered during the rearing stage, SARDI Aquatic Sciences and DEH are currently testing another method of restoration using *Posidonia* seedlings (Wear et al. in prep). In this trial, *Posidonia* fruits have been collected from metropolitan beaches, held in tanks until dehiscence and the resultant seedlings planted into sand-filled hessian bags (Figure 3c). The idea was developed following observations that *Posidonia* seedlings naturally recruit onto remnant root and rhizome mat at the edges of blow-out scars at Brighton. The hessian bags represent a biodegradable and portable alternative to the underlying root mat, which in many areas along the metropolitan coast has already eroded away (Fotheringham, 2002). This method offers the benefit that the seedlings spend the first year of their life in natural conditions and do not require the same level of maintenance as those grown in tanks. Results to date suggest that while many seedlings do not survive the plant-out phase, those that do survive have very good growth rates and remain over the longer-term (SARDI Aquatic Sciences, unpublished data). In early 2006, seedlings reared in culture by a team led by Dr Kingsley Dixon (Kings Park Botanic Gardens) were also planted amongst hessian bags. Results of this and previous trials undertaken in Western Australia are yet to be published.

2.3. Facilitating Natural Processes

Facilitating the natural recruitment of seagrass ramets or seedlings and encouraging their survival and growth, or facilitating the growth of seagrass into previously damaged areas, may represent additional means of seagrass restoration. These methods of seagrass restoration have only recently been trialled, but offer significant advantages to those previously developed. Consequently more details of the studies in which these types of restoration have been trialled are provided.

2.3.1. Facilitating the natural recruitment of seagrass seedlings and ramets

As pointed out earlier, in high wave energy environments, the survival of transplanted seagrass is negatively affected by high water motion and the instability of sediments surrounding the area (West et al., 1990; Paling et al., 2002). As a consequence, to increase transplant survival in a South Australian experiment, researchers transplanted cores and sprigs of seagrass in amongst a coarse weave hessian fabric, similar to that previously used to stabilise sand dunes from erosion (Seddon et al., 2004). While the survival of transplants did not appear to be significantly improved with the hessian (as many seagrass units did not survive), *Amphibolis* seedlings, which have a grappling hook apparatus for attachment, were observed naturally recruiting onto the hessian matting (Seddon et al., 2004). In a subsequent experiment, hessian strips were laid out in an attempt to recruit seedlings, with the strips trapping up to 18 seedlings per linear meter (Seddon, 2004).

Since this time, a much larger experiment has been conducted which assessed the potential for a range of biodegradable hessian bags, strips and mats in various configurations to recruit seedlings of *A. antarctica* and *A. griffithii* (Wear et al., 2006). The units, which were deployed in September 2004, were extremely effective at recruiting *Amphibolis* seedlings. Approximately five weeks after deployment a total of 16,514 seedlings, or the equivalent of 157.2 seedlings m^{-2}, had recruited onto all experimental units. The retention of seedlings on the experimental units declined over time, but after one-year, 31.4% of seedlings remained. Recruitment and retention of seedlings varied between methods, and while coarse weave hessian strips were particularly effective at recruiting seedlings, survival was poor. The most effective method in terms of seedling density at the end of the experimental period was hessian bags covered with a coarse weave hessian layer, while this method together with large hessian bags were amongst the most cost-effective (Figure 4). The methods developed in this study offer significant advantages to other methods of restoration, particularly as they are non-destructive, cost effective, and may easily be deployed over large spatial scales without the aid of divers. Furthermore, the authors suggest that utilising such methods may cost as little as $10,000 to rehabilitate one hectare of seagrass, which compares favourably with other methods (Fonseca et al., 1998; Spurgeon, 1998), and the estimated economic value of seagrasses ($12,635 to $25,270 $ha^{-1}yr^{-1}$; Lothian, 1999).

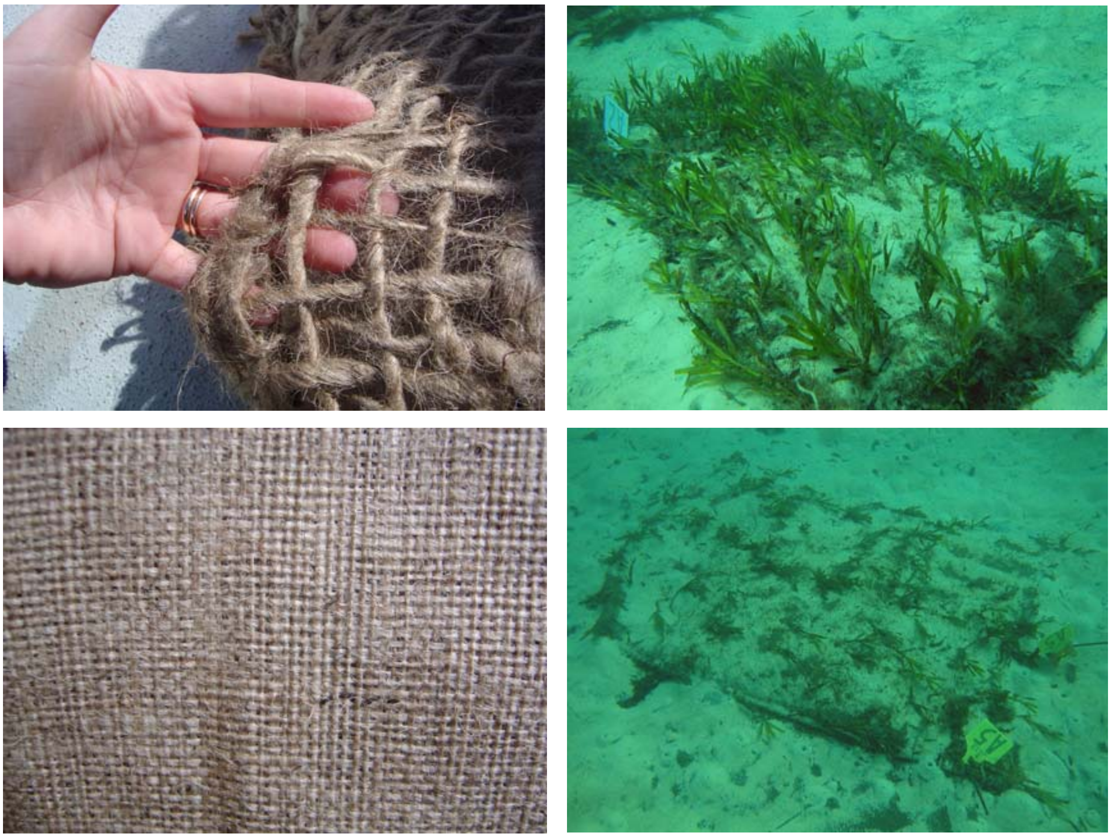

Figure 4. Photographs of the coarse- and fine-weave hessian used for the coarse weave, and large hessian bags, and underwater, both bags approximately five weeks after deployment, with many *Amphibolis* seedlings attached.

Seagrasses not only colonise new areas via the dispersal of seeds and seedlings, but also through the dispersal of vegetative fragments (Orth et al., 2006). As with recruitment of seedlings, habitat requirements need to be met for the successful establishment of seagrasses (Orth et al., 2006). In a recent study undertaken in Sicily, Italy, Di Carlo et al. (2005) identified that rubble, back-filled into a dredge trench, provided a stable environment for the entanglement and anchorage of vegetative fragments of *P. oceanica*. Significantly more seagrass coalescence and sediment deposition was observed in valleys between the rubble mounds than on the top of the mounds. However, the authors of the study suggested that once seagrass patches are established within the valleys, the seagrass patches may expand upwards along the sides of the rubble mounds and ultimately reach the crests.

2.3.2. Facilitating the growth of seagrass into previously damaged areas.

In Florida, where seagrasses inhabit large intertidal flats, vessels that run aground cause propeller scars in *Thalassia testudinum* and *H. wrightii* beds (NOAA, 2006). In addition to using more traditional methods of seagrass restoration, researchers have been investigating the potential for facilitating the growth of seagrasses into these damaged areas through the addition of nutrients. The method adopted includes filling in the propeller scars to the level of adjacent seagrass beds and installing bird stakes (Figure 5). The bird stakes provide a place for birds to roost and waste from the birds (which are rich in phosphorus) provides a higher concentration of nutrients. While the results of these experiments are yet to be published in the scientific literature, information available, suggests that the use of bird stakes is significantly improving the recovery time of the seagrasses (NOAA, 2006). Whether this result would extrapolate to oligotrophic waters is debatable in light of studies that demonstrate a negative impact of nutrients.

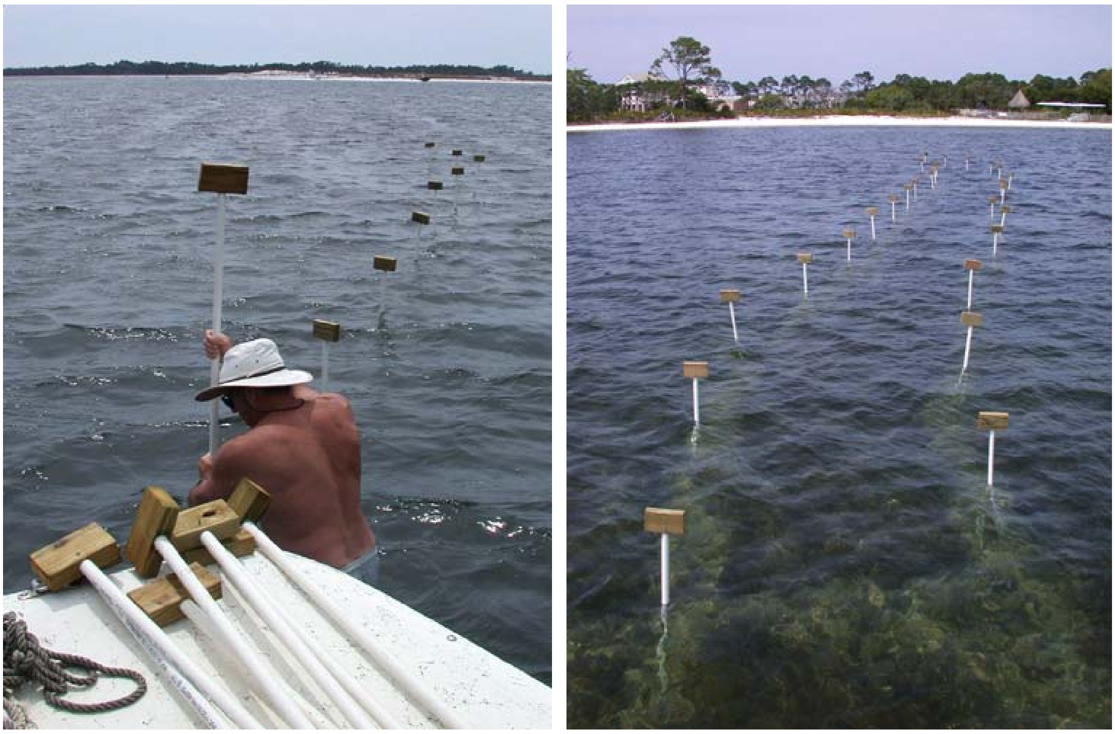

Figure 5. A researcher from NOAA installs bird stakes into propeller scars at St Andrews Bay Aquatic Reserve near Panama City, Florida. Photographs by Florida Department of Environmental Protection/Coastal and Aquatic Managed Areas (http://www.gulfmex.org/crp2004.html).

2.4. Associated Science

In addition to those studies previously outlined that have primarily focused on the development of reliable and/or cost effective means of restoration, other research that has not directly reported restoration attempts, yet supports seagrass restoration, has been undertaken. Such research includes investigations into the effects of nutrients (Peralta et al., 2002) and plant growth regulators (Balestri and Bertini, 2003) on seagrass growth and their potential use in restoration efforts, and a comparison of fauna in natural and transplanted seagrass beds (Sheridan et al., 2003). Other research has been directed towards ways of increasing the success of restoration attempts through careful planning and preparation, and the development of models to aid this process (Campbell, 2002; Short et al., 2002).

3. SUMMARY

The number of research projects directed toward the development of seagrass restoration techniques has increased substantially over the past thirty years. This research has identified that seagrass restoration is complex, and despite considerable effort there is still no single method that ensures success. Furthermore, seagrass restoration is generally a very expensive process that requires considerable effort (often requiring divers to transplant seagrass or plant seedlings), and even with success in most cases the area that is restored falls well short of the area that requires restoration. During the past five years, the majority of seagrass restoration research has been directed towards increasing the success of restoration efforts while reducing effort and increasing cost-efficiency. Increasing the survival of transplants in high-energy areas has been achieved through increasing the size of transplanted sods, and the development of a mechanical transplanting machine capable of transplanting large units of seagrass.

The use of seeds and seedlings in restoration attempts is preferable to transplantation methods at sites where large areas of seagrass do not need to be salvaged. However, the use of seeds and seedlings in restoration attempts remains experimental and more research is needed before rearing and planting out seedlings may become a realistic approach to large-scale restoration, particularly in moderate to high wave energy environments. As outlined in this review some new restoration techniques have recently been developed. These include the facilitation of natural recruitment of seagrass ramets or seedlings, and the aiding of recovery of seagrasses through the provision of natural sources of nutrients. The experiments in which these methods have been examined, in particular those undertaken by SARDI Aquatic Sciences and DEH in South Australia, appear to be relatively cost effective compared to other restoration methods.

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