COASTAL WETLANDS

AN INTEGRATED ECOSYSTEM APPROACH

EDITED BY

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CHAPTER 24

Seagrass Restoration

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Contents

1. Introduction

It is useful to begin this chapter with definitions of the terms "rehabilitation" and "restoration." "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 improvement through return of seagrasses and seagrass ecosystem function. The term "restoration" conveys the meaning of a return to pre-existing conditions. Since this is acknowledged as being an unlikely outcome in practice, "restoration" is usually interpreted as returning the ecosystem to a close approximation of its condition prior to disturbance (USNRC, 1992). 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.

The first recorded seagrass transplantation took place in Europe in 1939 (Reigersman et al., 1939). However, since the 1960s, serious restoration experiments and mitigation projects using different seagrass species have been attempted world-wide with varying degrees of success (Fonseca, 1992). The focus, however, has mainly been on the United States (Treat and Lewis III, 2006), Europe (this chapter) and Australia (Seddon, 2004). In this regard, it is worth noting that terrestrial restoration, even of emergent wetlands, has taken place over a much longer time frame – in the case of the former, for centuries. It is unsurprising therefore that seagrass restoration is still an evolving science that, globally, remains quite difficult and challenging (Gordon, 1996). In 1996, while there had been many failed projects, there had also been successes in putting back small areas of lost or damaged seagrasses, particularly with faster growing species such as *Zostera marina* (eelgrass), *Halodule wrightii* (shoal grass) and *Syringodium filiforme* (manatee grass).

Gordon (1996), in his review of the status of international seagrass restoration, summarized the key issues related to planning, policy and management affecting seagrass restoration, planting methods, critical issues confronting successful restoration and research gaps identified to further develop the technology. He considered that the return of functional seagrass (or any other wild community) could not be guaranteed although success in attempting to restore, rehabilitate or create seagrass habitat, regardless of location, was more likely where the following factors were considered: selecting suitable sites, developing methodology appropriate to site conditions, improving seagrass spreading and coverage rates, accounting for self-facilitative properties, minimizing donor bed damage, overcoming high labor and time costs and preventing bioturbation.

In the decade since Gordon's (1996) review, several of these factors remain pressing issues (Lord et al., 1999; Greening, 2006). Considerable progress has been made, however, in addressing many of them. Site selection, for example, has improved markedly now that factors affecting seagrass growth are better understood. The application of exposure indices (Fonseca et al., 1998; Kelly et al., 2001; Fonseca et al., 2002) and technology such as sediment erosion sensors (Chisholm, in preparation) has also helped to rapidly characterize potentially successful sites. This and other research has been incorporated into models allowing assessment of site suitability for seagrass transplantation (Short et al., 2002; Biber et al., 2008) and has generated better logistical frameworks to guide restoration programs (Fonseca, 2006).

Methodologies have improved in recent years. Although Gordon (1996) considered that overcoming high labor and time costs might be met by the development of mechanical techniques, site-specific manual methods have proven to be relatively efficient in planting appreciable areas (i.e., hectares) fairly efficiently (Davis et al., 2006; Montin and Dennis 2006; Orth et al., 2006b; Paling et al., in preparation). Various mechanical devices have also been developed for seagrass transplantation ranging from plug and sprig planters for shallow areas (Lewis et al., 2006; Orth et al., 2006b), boat-based hydraulic extraction of large (i.e., $>1\ m^2$) sods both in the United States (Lewis et al., 2006) and Japan (Nakase and Shimaya, 2001; Suzuki, 2002), and submerged machinery capable of operating to 15 m depth to move large sods in Australia (Paling et al., 2003). However, these mechanical devices typically have limited ranges of application with unknown cost effectiveness (Uhrin et al., in press).

Other advancements have been the increasing evidence that restored seagrass beds may become self-sustaining in appropriate time frames (Fonseca et al., 1996; Paling et al., in preparation; Bos and van Katwijk, 2007; van der Heide et al., in press) and that many functional attributes return within a few years (Cambridge et al., 2002; Fonseca, 2006). Recovery of donor meadows has also been better demonstrated in a range of environments, providing affirmation as a viable source of transplant material (Fonseca et al., 1987, 1994; Paling et al., in preparation). However, salvage still remains widely used as a technique for mitigation (Lewis et al., 2006; Montin and Dennis, 2006).

Despite these advances, problems remain. Bioturbation remains one of the most vexing problems in many areas (Philippart, 1994; Molenaar and Meinesz, 1995; Davis et al., 1998; Townsend and Fonseca, 1998; Siebert and Branch, 2007) although some transplant techniques (Fonseca et al., 1994, 1998; Short et al., 2006) do provide excellent protection from biotic disturbance. Improving spreading rates is also challenging. Nutrient additions to transplants provide mixed results in different locations and sediment types (Powell et al., 1989; Kenworthy and Fonseca, 1992) and research investigating hormone enhancement has been negligible. Ten years ago, techniques had been tested sufficiently to allow small areas of seagrass to be restored with reasonable assurance (Gordon, 1996). In the last decade, we have been able to transplant several hectares, and while returns of hundreds of hectares of seagrass through restoration efforts are still to be realized, tens of hectares have been attempted (Milano and Deis, 2006).

This chapter updates the progress that has been made over the last decade and reviews the current status of seagrass restoration and transplant research in those areas of the world where much activity has taken place: Europe, Australasia and the United States. Within each region, a brief background is provided on seagrass geographic distribution, community species composition, causal nature of seagrass decline and an overview of attempts to facilitate recovery via transplanting. The chapter concludes with an evaluation of the ecological and economic appropriateness of restoration as a tool for conserving seagrass.

2. Regional Activities

2.1. Europe

In Europe, four seagrass species are widespread: *Posidonia oceanica*, *Cymodocea nodosa*, *Z. marina* and *Zostera noltii*. The Mediterranean Sea hosts all four species, with *P. oceanica* and *C. nodosa* most abundant. Since the 19th century, additionally, *Halophila stipulacea* has been spreading into the Mediterranean Sea from the Red Sea through the Suez Canal. The Atlantic, North, Baltic and Black Sea coasts are vegetated by *Z. marina* and *Z. noltii* (Boström et al., 2003; Hily et al., 2003; Lipkin et al., 2003; Milchakova and Phillips 2003; Procaccini et al., 2003; Ruggiero and Procaccini, 2004) and the Caspian Sea is vegetated by *Z. noltii* (Milchakova, 2003).

Particularly in Europe, with its ancient history, the economic value of seagrasses has left scattered imprints in written heritage. For instance, the use of seagrass for dike enforcements in the Netherlands was referenced in documents of 1328 (Oudemans et al., 1870). The dynamics of seagrass beds were also noticed in the 18th century: "at one place it proliferates, at another it declines, and in still other places it disappears altogether; or, at places where it was never found before, it appears and increases year by year" (Martinet, 1782). People tried to predict abundant yields of seagrass: a rainy and warm spring was thought to enhance growth, hence the proverb (which can be considered as a primitive predictive model) "good hay grass, good seagrass" (Martinet, 1782).

These quotes refer to *Z. marina* in the Wadden Sea, where hundreds of families depended on its harvest. When this species started to disappear at an unprecedented scale from the Wadden Sea at the beginning of the 1930s, related to wasting disease, a local fisherman transplanted seagrass from a remote remaining bed to his former site of harvest. This attempt was recorded by Reigersman et al. (1939) and is to our knowledge the oldest record of seagrass transplantation. It failed. Transplantations with a scientific goal were performed in the same area and era by Harmsen (1936), who found that subtidal and intertidal morphotypes did not survive when transplanted reciprocally but that control transplantations survived.

During the 1930s, in northwestern Europe and the Black Sea, wasting disease decimated eelgrass (*Z. marina*) beds; they recovered only partially, and since the 1970s or 1980s new declines related to anthropogenic activities have occurred (Zaitsev et al., 2002; Boström et al., 2003; Hily et al., 2003; Milchakova and Phillips, 2003; Duarte et al., 2006). In these areas, seagrass beds are now estimated to cover only 20–35% of their pristine extent (Boström et al., 2003; Hily et al., 2003). In the Wadden Sea, subtidal beds did not recover at all (Giesen et al., 1990). In the western Mediterranean, losses are estimated to be between 30 and 40% (Procaccini et al., 2003). There is not much known about the eastern Mediterranean, but losses are probably less severe (Lipkin et al., 2003; Procaccini et al., 2003).

Losses of deep seagrass beds are generally attributed to increased turbidity resulting from eutrophication and/or construction activities. Other seagrass beds are lost due to mechanical destruction (construction of harbors, beaches, land reclamation, sediment-disturbing fisheries activities, anchoring, etc.) or due to pollution (eutrophication, organic loads, thermal plumes, etc.; reviews in Duarte et al., 2006; Ralph et al., 2006).

When circumstances improve, spontaneous seagrass recovery may be rapid, particularly when the losses were local and the species are capable of growing and dispersing rapidly. For example, in Portugal, recovery of *Z. noltii* was recorded after decreased nutrient loads and decreased fisheries activities. Rapid recolonization following cyclic geomorphological changes was also recorded in Portugal (Cunha et al., 2005). *C. nodosa* rapidly colonized areas that were buried by moving sand dunes (Marbá and Duarte, 1995). *Z. marina* beds are highly dynamic (den Hartog, 1971) and local disappearances and recoveries sometimes occur rapidly, as was shown for the Baltic Sea (Frederiksen et al., 2004a,b), the Wadden Sea – both subtidal and intertidal (Martinet, 1782; Reigersman et al., 1939; van Katwijk et al., 2006; Reise and Kohlus, 2008) – the Atlantic (Glémarec et al., 1997) and in the Mediterranean (Plus et al., 2003; Olsen et al., 2004).

P. oceanica, however, is a slow-growing species, its recoveries are slow and the recovered areas remain vulnerable (Marbá et al., 1996; Gonzalez-Correa et al., 2005; Gobert et al., 2006). Increased coherence of patchy *Posidonia* beds or other small-scale recovery may be observed after improved wastewater treatment (Jaubert et al., 1999; Pergent-Martini et al., 2002) or after deployment of artificial reefs protecting the beds against trawling (Gonzalez-Correa et al., 2005).

Recoveries at the system scale are limited. For example, after large-scale seagrass decline in the 1930s along the northern Atlantic coasts, there was no recovery in the Wadden Sea (Giesen et al., 1990). Partial recovery was recorded in the Baltic Sea and along Atlantic coasts, but often with a time lag of decades (Ostenfeld, 1908; Duarte and Sand-Jensen, 1990; Glémarec et al., 1997; Boström et al., 2003; Frederiksen et al., 2004a; Bernard et al., 2005; Gonzalez-Correa et al., 2005; Duarte et al., 2006), as is also found in other parts of the world (Rollon et al., 1998; Moore et al., 2000; Neckles et al., 2005; Walker et al., 2006). These findings suggest nonlinear feedback processes. The existence of multiple stable states in seagrass beds has been postulated (Duarte, 1995; 2002; Duarte et al., 2006; Valentine and Duffy, 2006) and even convincingly indicated by long-term data of Munkes (2005) of an estuary in the Baltic Sea, Greifswalder Bodden. She found that continuing high turbidity prevented recovery of *Z. marina*, *Ruppia* and a number of freshwater macrophytes despite marked reductions in nutrient inputs over the last 15 years. In contrast, *Z. marina* recovered in a similar area in Puck Lagoon, Poland (J. M. Weslawski, personal communication), where a sewage treatment plant, constructed in 1988 (Schiewer et al., 1999), reversed the decimation of the *Z. marina* meadows that had disappeared between 1957 and 1988 due to nutrient enrichment (Kruk-Dowgiallo, 1991). Similarly in Orbetello Bay, Italy, seagrasses (*Ruppia cirrhosa*, *Z. noltii* and single plants of *C. nodosa*) recovered from almost absence in 1990 to more than 1,250 ha cover (>50% of the bay area), concurrent with macroalgal harvesting, pumping of clean sea water into the lagoon and reduction of nutrient inputs (Lenzi et al., 2003).

Many transplantation programs have been set up in Europe as a result of retarded seagrass recovery and also for mitigation purposes. In Limfjord, Denmark, a large-scale *Z. marina* transplantation program was carried out to restore natural values after nutrient loadings were reduced. Of the several techniques tested, only patches greater than 0.20×0.20 m were able to survive a winter season with heavy storms in shallow waters. In general, growth and survival rates were highest in these blocks, though 20% of the plugs also survived at the most favorable site. Surviving patches increased to 25 times their original size during the first 2 years. Spring transplants performed best in comparison to summer and autumn transplants. Seed dispersal efforts largely failed due to poor germination in the field. Poor seed germination was not typical; a batch collected 1 month previously showed high germination rates in the laboratory (Christensen and McGlathery, 1995; Balestri et al., 1998).

Presently, only intertidal *Z. marina* and *Z. noltii* beds grow in the Wadden Sea, though during the 1970s these beds also disappeared in the western part. Intertidal seagrass reintroduction programs started in 1987 mainly to reintroduce intertidal *Z. marina* (Giesen et al., 1990; van Katwijk and Hermus, 2000; Bos and van Katwijk, 2007). Research on habitat requirements revealed that sheltered areas around mean sea level, with some freshwater influence, are preferred in the

Wadden Sea (van Katwijk et al., 1999, 2000; van Katwijk and Hermus, 2000; van Katwijk and Wijgergangs, 2004). Suitability tests of donor populations indicated that nearby populations were preferred over remote ones (van Katwijk et al., 1998). Several anchoring techniques were tested and seed-bearing shoots were transplanted. The latter was successful for several years, but plants had largely disappeared by 2006. In short, *Z. marina* can maintain itself at very sheltered sites but is vulnerable to suffocation by macroalgae (Chapter 13). At slightly less sheltered sites, development is better, but seed germination or young seedling survival fails for unknown reasons (Bos and van Katwijk, 2005). Bare root transplantations of *Z. noltii* were more successful. Transplanted in 1993, patches are still spreading slowly (Figure 1a, van Katwijk et al., 2006). As in Limfjord (Denmark) in the Wadden Sea, spring transplantations generally survive better (Noten, 1983; van Katwijk and Hermus, 2000).

In the 1970s, *Z. noltii* transplantation had also been performed in the United Kingdom to increase wildlife potential, particularly for Brent geese, anticipating mitigation related to the building of an airport. Turf or sod trials were reasonably successful, but larger scale transplantation failed (Ranwell et al., 1974; Boorman and Ranwell, 1977). In Mondego Bay, Portugal, experimental bare root transplantations of *Z. noltii* were carried out to test the most suitable season for transplanting. In contrast to more northern locations in Europe, late autumn or winter was preferred over spring or summer (Martins et al., 2005).

In the Mediterranean, *Z. noltii* transplantation was carried out using sods during the 1970s and 1980s in Beaulieu, Martigues, and Toulon, France (Meinesz et al., 1990; Boudouresque et al., 2006), and in Venice Lagoon (Curiel et al., 1994; Rismondo et al., 1995). Most efforts used bare root cuttings attached to grids or looped pickets (Figure 1b), or turfs ("matte") placed in dug holes. Results varied by type of cutting (Molenaar et al., 1993; Molenaar and Meinesz, 1995), season (Meinesz et al., 1992; Boudouresque et al., 2006) and depth (Genot et al., 1994). Higher planting densities yielded higher survival rates (Molenaar and Meinesz, 1995), which was also found for *Z. marina* in the Wadden Sea (Bos and van Katwijk, 2007). At the same locations except Martigues, *C. nodosa* was transplanted,

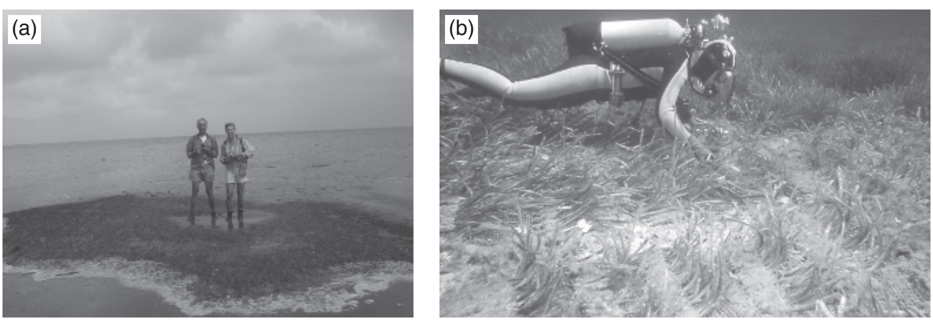

Figure 1 **(a) Three-year-old transplants of *Zostera noltii* in the Wadden Sea, fringing the North Sea. These have continued to expand annually. (b) Transplantation of *Posidonia oceanica* in France.**

but their fate is unknown after 2 years (Meinesz et al., 1990 and references therein; Curiel et al., 2005). Additionally, in Venice lagoon, transplantations of *Z. marina* and *C. nodosa* have been carried out, comparing bare root and sod methods (Curiel et al., 2005). After two growing seasons, cover using the bare root method was nearly equal to that of sods and was more cost effective. Both *C. nodosa* and *Z. marina* transplantations were successful and expanded at Venice Lagoon.

In France, three patents have been obtained for seagrass transplantation techniques (Meinesz et al., 1993). As seagrasses are protected there, it is assumed that no losses occur (however, see Boudouresque et al., 2006). Therefore, no more restoration programs have been carried out in France since the beginning of the 1990s (Meinesz personal communication). Presently, large-scale – but unmonitored – mitigations of *P. oceanica* take place in Spain, with quite poor results (Sánchez-Lizaso et al., 2006). Innovative approaches that account for environmental unpredictability and the dynamic population of donor material have been carried out in the Wadden Sea (van Katwijk et al., 2002).

Recovery of seagrass in Europe has been possible mostly at a local scale, particularly for slow-growing species like *P. oceanica*. Large-scale declines may be irreversible at human timescales for two reasons. Firstly, seagrasses modify their environment and once they have disappeared, conditions may have become unsuitable such that only large-scale efforts can overcome problems with erosion and turbidity (Bouma et al., 2005; van der Heide et al., 2006). Secondly, eutrophication and organic loading may have altered both sediment and water column properties, a topic discussed in detail in Chapter 13.

2.2. Australia

A number of authors have reviewed seagrass rehabilitation efforts in Australia over the past two decades (Kirkman, 1989, 1992, 1997; Gordon, 1996; Lord et al., 1999; Seddon, 2004). Additional reviews on seagrass communities as a habitat for fisheries have also been carried out (Cappo et al., 1998; Hopkins et al., 1998). These works have led to the development of guidelines for the protection and restoration of fisheries habitats in some places (Hopkins et al., 1998; Western Australian Environmental Protection Authority, 2004). Despite the acknowledged importance and significant losses of seagrass habitat in much of coastal Australia due to both natural- and human-induced causes, seagrass rehabilitation techniques were not seriously considered in Australia until the late 1980s. Major rehabilitation efforts have since been undertaken in Queensland, New South Wales, Victoria and Western Australia (Paling and van Keulen, 2002) and more recently in South Australia.

Initial reviews suggested that rehabilitation of seagrasses in southern Australia was almost impossible due to the slow growth rates of the large temperate meadow-forming species, reflecting the lack of attention given to pioneering species. Numerous experiments and development of new techniques have now changed that view to one of optimism, with the most recent published review proposing that it is now possible to rehabilitate small-scale seagrass loss (up to several hectares) (Seddon et al., 2004). Seagrass rehabilitation experiments to date have included transplantation trials using mature plants as well as seeds and seedlings, improvement or alteration of degraded habitat to encourage natural return of seagrasses and addition of plant growth enhancers including fertilizers and growth hormones.

Transplantation experiments initially employed the range of techniques commonly used in the United States and Europe, but with little success. This was thought to be largely because most northern hemisphere seagrasses grow in relatively sheltered conditions in estuaries or coastal lagoons, whereas many southern Australian seagrasses grow in the open ocean, exposed to oceanic swell. Work in Western Australia, using plug planting units (PUs), showed that increasing PU size improved their survival, ostensibly as a result of increased stability against wave action (van Keulen et al., 2003). This realization led to the development of the ECOSUB mechanical technique capable of transplanting very large PUs, up to $0.5\,m^2$ by 0.4 m deep (Figure 2a, Paling et al., 2001a,b).

Within more sheltered waters, traditional manual transplantation techniques are still viable. Paling et al. (2007) concluded that seagrass rehabilitation was possible at several locations around Cockburn Sound, Western Australia, following manual transplantation trials using plugs and sprigs. Subsequently, a large-scale manual

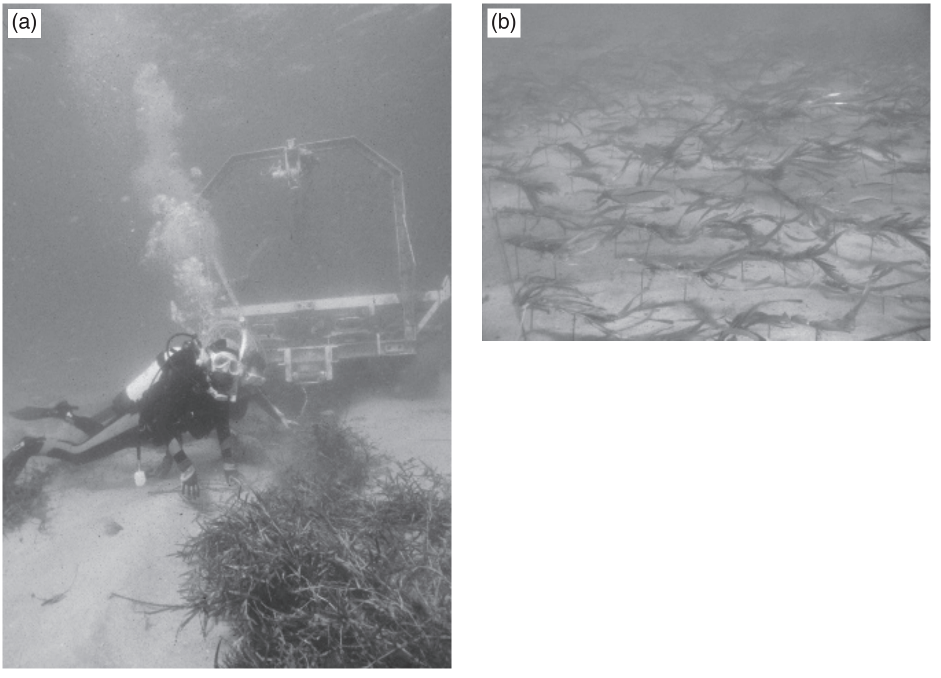

Figure 2 (a) The ECOSUB system is used in Western Australia to mechanically transplant large sods of seagrass. Diver operated to 15 m, the cutting machine is capable of removing 0.5-m deep sods that are 0.7×0.7 m in area. A line of *Posidonia coriacea* sods are shown here recently planted by ECOSUB2 which is able to plant in any configuration. (b) A viable hand-planting method used in sheltered areas of Western Australia. The sprigs of *Posidonia australis* are attached to wire staples by biodegradable cable ties, spaced (as shown here) and then inserted into the sediment.

transplanting operation has begun in southern Cockburn Sound using community volunteers to transplant sprigs of *Posidonia australis* (Paling et al., in preparation). This program is being conducted in conjunction with a study on the role of sediment stability in transplant survival (Figure 2b; van Keulen et al., 2005). Concurrent transplantation exercises underway in Albany, Western Australia, have met with very high levels of success (Bastyan, 2002). In a project targeted for the metropolitan area near Adelaide, sprigs woven into hessian sheets showed better growth characteristics and appeared healthier than plugs of *Amphibolis antarctica* and *Heterozostera tasmanica*, but plug survival percentage was greater (Seddon et al., 2004).

Slow recovery times of many large meadow-forming species have led to the realization that seagrass harvesting and transplantation as a mitigation technique is not practicable. In response, observations on the role of naturally recruited seedlings in infilling seagrass meadows led to the use of seeds, seedlings and laboratory-cultured material as alternatives for rehabilitation. Using various anchoring approaches for seeds and seedlings of *Posidonia* spp. and *Amphibolis* spp., Kirkman (1998) had consistently poor results. Overall, *Posidonia* spp. did not survive well and *Amphibolis* PUs did not spread after 17 months, apparently due to too much wave action and inappropriate anchoring. Development of seed stock has recently been studied. Seddon et al. (2005) cultured naturally collected seagrass seeds within holding tanks. They concluded that using a large-scale nursery approach to provide seedlings for rehabilitation was not yet practicable because of excess nutrients. Likewise, Wilson (2004) worked to develop in vitro propagation of seagrass seedlings, but ongoing contamination severely limited its application for large-scale rehabilitation work.

Observations of seedlings becoming established around natural and transplanted seagrass patches suggest that propagation by seed is a viable means of patch consolidation (Paling et al., 1998). However, subsequent studies by Langridge (2002) confirmed the poor survival of naturally established seedlings in exposed locations. High wave energy in southern Australian makes survival of artificially established seedlings doubtful, with little improvement when sediment-protection meshes are used. Hessian mats were successful by contrast as a means of trapping and protecting seedlings in South Australia. A focus is therefore required on methods of protecting seedlings from erosion and disturbance until they can become firmly established.

2.3. Oceania

Australia and the Indo/west Pacific have a diverse tropical seagrass flora characterized in many places by mixed-species meadows that include species of *Cymodocea*, *Thalassia*, *Enhalus*, *Syringodium* and *Halodule* (Larkum and den Hartog, 1989). Australia, China and Japan by virtue of their broad latitudinal ranges additionally have subtropical/temperate seagrass floras, dominated by monospecific meadows of *Posidonia* and *Amphibolis* spp. in Australia and *Zostera* spp. in China and Japan (Green and Short, 2003). The important roles seagrasses perform in coastal habitats are slowly being recognized and acknowledged in Oceania. The role of seagrasses as nursery areas for juvenile fish has been assumed for some decades; the physical influence of seagrasses on their substrate has been realized only recently and is now receiving careful scrutiny following significant coastal erosion problems resulting from seagrass loss.

In the Oceania region, there is a growing concern about coastal habitat loss including seagrass habitats. Many causes are cited as responsible for these losses, both natural and human, but until the reasons for seagrass decline are understood and dealt with, restoration remains difficult. While seagrass rehabilitation efforts are well progressed in Australia and to some extent in Japan, most of the countries in the region are not in a position to seriously tackle issues of large-scale habitat restoration; indeed, the concept of marine conservation is not well advanced in many developing countries in the region. There is a clear push from intergovernment agencies to advance marine conservation with a view to encouraging local ownership of these environments and provide training in grass roots environmental management.

Numerous reports have identified the problem of habitat loss and degradation in southeast Asian and Pacific countries, particularly in areas of high population density and human impact, including deforestation, mining and agriculture. While there is considerable concern about these losses, particularly at a local level, efforts to protect and rehabilitate seagrass habitats are hampered by a number of factors. The first of these is a poor knowledge of the distribution and condition of seagrass habitats; this is largely due to a lack of accurate mapping and monitoring, exacerbated by high turbidity in many tropical coastal areas, hampering the effectiveness of aerial photography. The detailed aerial mapping exercises carried out in parts of Australia are not possible in many parts of southeast Asia because of lack of water clarity and economics. The second major factor is the poverty experienced by much of the coastal populations of southeast Asia and the Pacific Islands. Their reliance on subsistence fishing and the urgency of obtaining food leaves little energy or resources for environmental stewardship.

2.4. Southeast Asia

Throughout southeast Asia, there has been a growing awareness of the importance of seagrass ecosystems to local fisheries. The Philippines government in particular has been active in promoting the values of seagrass ecosystems. In the early 1980s, the government requested assistance from the Food and Agriculture Organization of the United Nations to investigate the feasibility of seagrass rehabilitation in the Philippines (Thorhaug, 1987). An international consultant was appointed to provide a technology transfer program to introduce seagrass rehabilitation techniques and to undertake an experimental transplantation program. In addition, the program examined transplantation by plugs and sprigs of five common species, as well as of *Enhalus* seeds. Transplantation was carried out in areas subject to a range of human impacts, including dredging and pollution by sewage, mine tailings and thermal effluent. All species showed moderate success in the trials, with best performance by *Enhalus*, although the colonizing species *Halodule*, *Cymodocea* and *Syringodium* showed the most lateral spreading. Of the techniques used, sprigs were most successful; dredged and filled areas showed the best results overall for transplant survival (Thorhaug, 1987).

While the trials of transplanting conducted by Thorhaug appear to have been largely successful, Fortes (1990) acknowledged that perhaps the poverty of these communities precludes the luxury of being able to implement western-inspired conservation measures. To help combat these problems, a recent UNEP/GEF program has established a number of habitat demonstration sites across the region, aimed at demonstrating sustainable environmental management practices and reversing habitat degradation (UNEP, 2004). The habitat sites selected included four for seagrasses located at Bolinao, Philippines; Hepu, China; East Bintan, Indonesia; and Kampot, Cambodia; these have been progressively implemented since 2005 (UNEP, 2006). Project targets include control over seagrass-destructive practices and recovery of damaged areas within demonstration sites, as well as community education and training to encourage community ownership and custodianship of the sites across the southeast and eastern Asian region (Fortes et al., 2006).

Artificial seagrass units were deployed in Singapore to provide an artificial habitat in degraded areas (Talbot and Wilkinson, 2001). This was found to be effective in providing a sheltered habitat for benthic organisms, thus enhancing recovery of degraded systems. Similar deployment of artificial seagrasses has been undertaken in the Philippines with a view to improving fisheries production (Fortes, 1988). Talbot and Wilkinson (2001) suggested that seagrass recovery best responds to removing the cause of disturbance but noted that this is difficult where limited resources preclude such broad level changes to environmental management. In the interim, transplanting and artificial seagrass projects were seen to provide a short-term solution.

Most seagrass on the Korean coast, primarily *Z. marina*, has been lost due to anthropogenic disturbances since the 1970s; however, there has been no large-scale rehabilitation program in place to date. Recent research has been conducted using staples, Transplanting Eelgrass Remotely with Frame Systems (TERFS) and oyster shells at different times of year and sediment types (Park and Lee, 2007); the authors noted that staple transplants were most successful but particularly costly when compared to the other two methods that did not require diving (Short et al., 2002). High temperatures were observed to have a strong deleterious effect on transplants established in summer.

2.5. China and Japan

During the recent development of the new Hong Kong International Airport, attempts were made to transplant *Zostera japonica* that was at risk from sedimentation during the land reclamation process at San Tau Beach. While transplanting the *Z. japonica* at San Tau was successful, attempts to transplant seagrass to other locations were not. It was suggested that there was a lack of appropriate locations for transplanting seagrass to, as most suitable habitat was subject to land reclamation or other coastal development (Fong, 1999). As part of the UNEP/GEF sustainable marine habitat management demonstration program, a site was established at Hepu in southern China. The intention again is to improve community and local government awareness of the importance of seagrass ecosystems with a view toward involving the community in seagrass management.

Numerous concerns have been aired about the loss of seagrass meadows from the Japanese coast, particularly in response to large-scale coastal developments. While little has been published, there are a number of workshop proceedings; detailed methods and results are not readily available, however. Attempts have been made to enhance germination and growth of seagrass seedlings using a "sowing sheet." This consists of a cloth sediment protection that prevents loss of seeds and seedlings during the initial growth stages. Results appeared promising after 2 years, although it was concluded that coarser cloth might be better for root penetration (Yoshida et al., 2001). More recently, a seed harvesting mat was developed to trap naturally released *Zostera* seeds and provide a stable substrate for germination and establishment before transplantation to the restoration site (Taisei Corporation, 2006). Results from controlled mesocosm studies that replicated tidal flows and wave exposure indicated that seagrass restoration would be feasible in Tokyo Bay (Nakamura, 2005).

Experimental seagrass transplantation was conducted in Japan as part of mitigation studies for coastal landfill activities in the Awase Tidal Flat, Okinawa. This project transplanted large ($\sim$1.5 m^2) blocks of seagrass and sediment using a modified backhoe. The process is modified from terrestrial turf transplantation techniques. Transplanted blocks did not survive the high wave energy; in fact sand from the disintegrating blocks smothered some of the surrounding patchy seagrass. Subsequently, manual transplantation experiments were deemed appropriate and the landfill project was allowed to proceed (Suzuki, 2002).

Penta-Ocean Corporation developed a seagrass transplantation machine built on an excavator platform for intertidal applications. The technique appears similar to the Western Australian ECOSUB system and consists of a bucket harvester that scoops up an intact sod of seagrass; the interior of the bucket can be removed from the machine and transported separately to the transplant site (Penta-Ocean web site, http://www.penta-ocean.co.jp/english/r_d/envi/eelgrass.html). Encouraging results were obtained during trials in Hiroshima Province (Nakase and Shimaya, 2001); however, these authors also cautioned about the need for appropriate wave energy conditions to ensure long-term survival and growth.

2.6. New Zealand and the Pacific Islands

While there has been recent concern about damage to seagrass ecosystems in New Zealand's developed coastal areas, few rehabilitation studies have been conducted. Transplantation trials using sprigs, plugs and 1 m^2 sods of *Zostera novazelandica* in Manukau Harbour in 1993 showed good survival until the onset of winter storms after 6 months. The cause of decline was believed to be increased sedimentation and erosion of the PUs (Turner, 1995). Extensive loss of seagrass from Whangarei Harbour since the 1960s was believed to be due to increased sediment load and turbidity resulting largely from dredging and sediment discharge (Reed et al., 2004). Subsequent evaluation of environmental conditions within the harbor determined that conditions were suitable for a proposed transplantation program (Reed et al., 2005; A.M. Schwarz, personal communication). A comprehensive management document for New Zealand seagrasses was released that outlines key concerns and priorities for conservation (Turner and Schwarz, 2006).

Coles (1996) visited several Pacific island nations as well as Malaysia and reported an overall support for environmental restoration work, including the rehabilitation and transplantation of seagrasses. It was felt, however, that these were not more than cosmetic attempts and not likely to be particularly effective.

2.7. United States

There are approximately 12 species of seagrass in North America and they form substantial habitats in all coastal states except Georgia and South Carolina. Eelgrass (*Z. marina*) occurs in the temperate zone, along with *Ruppia maritima*, which appears to be ubiquitous. On the west coast, *Phyllospadix* spp. (surfgrasses) are found in the rocky intertidal zone, as well as an invasive *Z. japonica*. In the southeast and Gulf of Mexico, *Thalassia testudinum* forms extensive, slow-recovering beds. In addition, *S. filiforme*, *H. wrightii* and four *Halophila* species are present.

Seagrasses were used by Native Americans, and early 20th century Europeans used *Z. marina* for insulation. More recently, they have only been valued for their role in supporting waterfowl and fisheries, especially the bay scallop (*Aequipecten irradians concentricus*). Although recognized for their functional role in coastal ecology as early as the 1920s on the east coast, quantitative studies did not begin in earnest until the 1970s. Since then, published work on seagrasses has grown exponentially.

The correlation between human activities near the shoreline and seagrass decline was clear a decade ago (Short and Burdick, 1996). Large-scale losses had been documented in Chesapeake Bay (Orth and Moore, 1981) and in the Gulf of Mexico (Livingston, 1987). Seagrass beds in Tampa Bay were reduced by over 50% (Haddad, 1989) and 35% of the seagrass acreage in Sarasota Bay was lost, as well as 29% of that in Charlotte Harbour, Florida and 76% of that in Mississippi Sound (Eleuterius, 1987). Pulich and White (1991) reported a loss of 90% in Galveston Bay, Texas. Thom and Hallum (1991) reported similar ranges of losses from Puget Sound and large declines have occurred in the San Francisco and San Diego Bays (Kitting and Wyllie-Echeverria, 1992).

The loss of seagrasses due to dredge-and-fill activities has been significant although direct impacts from mooring scars and propeller scars (Sargent et al., 1995) also emerged as a major source of habitat loss, along with scallop harvesting and the practices of raking and prop-dredging for other shellfish and crabs. In contrast to physical damage, most of the documented seagrass loss in the United States, as elsewhere in the world, has been due to human-induced reductions in transparency associated with degradation of water quality (Kenworthy and Haunert 1991). Thermal effluents from electric power plants have also caused extensive declines (Zieman and Wood, 1975; Fonseca et al., 1998). Losses due to decreased light availability tend to be irreversible except in rare cases where nutrient discharges are reduced to improve water quality (Johansson and Lewis, 1992).

Tremendous losses of this habitat have therefore occurred as a result of development within the coastal zone. While disturbances usually kill seagrasses rapidly, their recovery is often comparatively slow (Fonseca et al., 1987). In recognition of this, seagrass ecosystems are now protected in the United States under the federal "no-net-loss" policy for wetlands in recognition of their role in performing important ecological functions.

Prior to the decision to transplant, site selection should be carefully evaluated. In many cases where the injury was mechanically derived, restoration can often be achieved, but may also require engineering interventions to "fix" the site, such as filling excavation holes caused by vessel groundings (Figure 3a) or altering water flow. However, when the injured site has been irrevocably altered and offsite selections are made for restoration, more significant problems arise, usually from improper identification of potential sites. The most common mistake in site selection is the assumption that open areas or gaps among existing seagrass are prime sites for restoration when, in reality, the sites either cannot support seagrass or currently support very low densities. This problem has been addressed in detail in several publications (Fonseca et al., 1987, 1998; Fonseca, 1992, 1994). Suffice it to say, Fredette et al.'s (1985) condition "If seagrass does not grow there now, what makes you think it can be established?" best sums the problem and defines the question that must be answered in order to begin a logical process of site selection. Criteria for offsite selection include (1) locations that have similar depths as nearby natural seagrass beds and are similarly

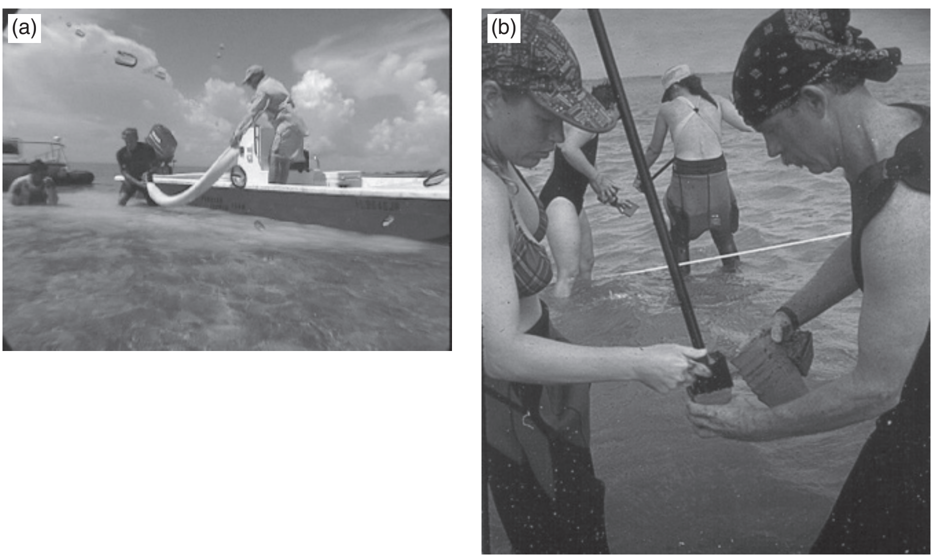

Figure 3 (a) Sediment-filled tubes constructed of biodegradable fabric are placed into propeller scars in Florida to prevent additional erosion and to enhance seagrass recovery. Filling the scar with tubes brings the sediment to the surrounding level, which enables adjacent seagrass rhizomes to grow over the scar. (b) Transplanting *Halodule wrightii* near Beaufort, North Carolina, using the peat pot method. This photograph shows the use of the plugger dropping a small plug into a peat pot in which pelletized fertilizer has been added.

anthropogenically disturbed; (2) areas not subject to chronic storm disruption; (3) sites not undergoing rapid and extensive natural recolonization by seagrasses; (4) similarity to sites where seagrass restoration had been successful; (5) areas of sufficient acreage to conduct the project; and (6) an area that could be restored to a similar quality of that lost (Fonseca et al., 1998; Calumpong and Fonseca, 2001). By giving attention to these criteria, the probability of successful restoration can be greatly enhanced. Recently, however, significant advances have been made using modeling approaches in site selection (Short et al., 2002; Biber et al., 2008).

Since the publication of Fonseca et al. (1998), there have been few observable advances in technological innovation in regard to seagrass transplantation (Figure 3b), with two notable exceptions. Mechanical planting, once only represented by large benthic machines in Western Australia, has now been developed for shallow-water planting in the United States. Versions of the machine that transplant large sods have had successful field trials (Uhrin et al., in press) in contrast to designs for individual planting, which are ineffective relative to manual methods (M. Hall, personal communication, Florida Fish and Wildlife Commission).

Another innovation has been the improvement of seeding techniques (at least for *Z. marina*) through improved holding processes (R. Orth, personal communication, Virginia Institute of Marine Science) and deployment techniques such as reusable seed buoys (Pickerell et al., 2005). The use of appropriate seeding techniques is undoubtedly the most promising method for large areas. Nonetheless, even moderate attention to logistics and manual techniques can have large payoffs. Recent restoration work in Tampa Bay, Florida, was most successful by simply using shovelfuls of seagrass hand-dug, transported with care and installed.

3. Policy Issues Relevant to Mitigation

The US federal "no-net-loss" policy, based initially on wetlands, places emphasis on replacing the area and functions of areas that are converted to other uses. "Compensatory mitigation" is a term used for destruction of existing habitat when the agent of loss and the responsible party are known. Compensation assumes that ecosystems can be successfully replaced. While planting seagrass is not technically complex, there is no simple way to meet the goal of maintaining or increasing acreage. Rather, the entire process of planning, site selection, planting and monitoring requires attention to detail if successful outcomes are to be expected. [In contrast, "restoration" is the term that is often used when there is no responsible party. In these cases, community-based approaches place emphasis on planting, with little attention to monitoring the outcome. Because the causative agent is ambiguous in such cases, and may be related to water quality, it is unlikely that planting efforts will be successful (see site selection above).] To prevent continued loss of habitat under compensatory mitigation, decisive action must be taken by placing emphasis on improving site selection, compliance, generating desired acreage and maintaining a true baseline. Many recent projects that involve logical site selection and new planting methods show great promise for reversing the trend of project failure.

A logical and ecologically defensible goal of mitigation is to replace the lost seagrass species with a surface area that compensates for interim lost resource services and shoot density. Effective examples of plantings quickly provide many of the functional attributes of natural beds. However, when destruction of an impacted site requires planting in another location (i.e., offsite), it is often difficult to find a location with suitable biological and physical conditions.

Given these goals and assumptions, the status of seagrass restoration can be viewed from within the US legal framework. Seagrass beds in coastal waters are generally viewed as public trust resources. Injuries to these resources are considered losses suffered by the public, and violations have been successfully prosecuted in US Federal Court. To evaluate this loss in a fair and reasonable manner, however, considerations include not only the actual loss in acreage in an injury – but also the loss of resource services provided by the seagrass bed between the time it is injured and the time it recovers to 100% of preinjury conditions (Fonseca et al., 2000). It is noteworthy that most effective restorations are in response to mechanical disturbance rather than degraded water quality that may only be resolved through more stringent watershed management.

Beginning with the assumption that seagrass ecosystems produce irreplaceable goods and services enjoyed by society, how can the value of these attributes be quantified? This issue emerges in two contexts: (1) how much does it cost to restore (and subsequently monitor) seagrass ecosystems and (2) what is the value of services provided by seagrass ecosystems on an annualized basis so that losses can be compared with gains? The former question can be answered using existing reports. The latter is addressed by describing the habitat equivalency analysis (HEA).

3.1. Costs of restoration

Seagrass restoration is expensive. Much early experimental research was driven either by entire ecosystem degradation or by loss from nonpoint source factors (e.g., eutrophication) and the desire to return the seagrass, along with the services they provided, to "damaged" ecosystems (i.e., true "rehabilitation") or the requirement for offsite mitigation for "small-scale" development. These two activities (i.e., large vs. small-scale) are quite different and need separate consideration. In terms of the small-scale setting, what metric should be used to determine the economic viability of seagrass restoration?

Sufficient seagrass restoration projects, along with transplant research, have now been attempted to allow their appropriate costing (Fonseca, 2006) and comparison with terrestrial activities. In Europe, recent mitigation activities in the southwest Netherlands have cost approximately $50K/ha (2007 US dollars), although restoration research in the Wadden Sea over the last two decades has amounted to $4,000K. In Australia, mechanical seagrass transplantation (including design and development, construction, testing and associated site selection) can be costed at $1,000K/ha. Recent exercises using volunteer manual planting are far cheaper at $16–$34K/ha, depending on plant unit spacing. The same planting using professionals range from $84 to $168K/ha. In the United States, the most expensive programs have cost between $1,900 (McNeese et al., 2006) and $3,387K/ha (Lewis et al., 2006) depending upon the site and project involved. The lower end of the range is between

\$33 and \$99K/ha (Bergstrom, 2006). Even these rough comparisons may or may not include monitoring costs. Underwater restoration is on average far more expensive than that on land and will likely continue to be so in the future (Short et al., 2006). In the United States, an agreed upon "all-inclusive" price, including monitoring, was presented in Treat and Lewis (2006) as between \$570 and \$972K/ha (Fonseca, 2006). By comparison, terrestrial restoration, while more advanced in practice, is commonly conducted at much larger scales. Costs range between \$18 and \$353K/ha for land rehabilitation of mining effects and for special purpose restoration (i.e., difficult or "iconic" sites; R. Hobbs personal communication) to much cheaper, large-scale bushland restoration (\$2–\$8K/ha).

So is restoration a viable tool for conserving seagrass in both ecological and economic terms? It would appear that there is sufficient information to indicate that it is ecologically defensible in regard to donor meadow recovery, return of function and self-facilitative properties. From an economic viewpoint, however, it is clearly far more cost effective (e.g., \$1.4K/ ha; Stowers et al., 2006) to preserve a seagrass habitat from damage than to restore an area after its degradation. This is especially true at large scales because it will simply be too expensive to put back areas greater than, for example, 20 ha. Thus, there is little hope in using transplant restoration to offset receding seagrass beds worldwide where declining water quality is a major cause. At small scales, however, we possess the ability to successfully generate small seagrass meadows (at high cost), and these are often directed toward offsetting small-scale damage.

3.2. Valuation of ecosystem services

The valuation of ecosystem services is now a global exercise (Millennium Assessment, 2005). Within the context of a particular ecosystem or restoration program for replacing ecosystem services, the specifics of a particular habitat need to be acknowledged (Costanza et al., 1997). For seagrasses in the United States, the HEA has been employed as a way to compensate for habitat lost, but also for the loss of services over time. In its most basic application, HEA determines the appropriate scale of a compensatory restoration project by adjusting the project scale such that the present value of the compensatory project is equal to the present value of interim losses due to the injury. Because these services are occurring at different points in time, they must be translated into comparable present value terms through the use of a discount rate, a standard economic procedure that adjusts for the public's preferences for having resources available in the present period relative to a specified time in the future. For argument's sake, if 1 ha of seagrass were destroyed today and replanted tomorrow and reached standards of equivalency (e.g., shoot density, biomass and coverage) in 2 years, the interim loss of ecological services over this 2-year period would be relatively low. However, if restoration of this site were not undertaken immediately and it required 7 years to reach its preimpact state, the level of compensation due the public for the interim losses from this same injury would be substantially greater. This highlights the weakness of fixed compensation ratios, for example, replacing 2 ha of restored seagrass for every 1 ha irreversibly altered by a particular project (dredging, filling, etc.). HEA is one of the more frequently used methodologies available to natural resource trustees (Fonseca et al., 2000). The basic approach underlying HEA is to determine the amount of compensatory habitat to be restored, enhanced and/or created such that the total services provided by the compensatory project over its functional lifespan are equal to the total services lost due to the resource injury. While HEA is conceptually and computationally straightforward, its proper application requires a detailed understanding of the biological and ecological processes that affect the recovery and productivity of injured and restored habitats.

Recently, NOAA developed and applied HEA using basic biological data to quantify interim lost resource services (National Oceanic and Atmospheric Administration, Damage Assessment and Restoration Program, 1997). While sharing many of the same principles as other methods by incorporating interim losses into replacement ratio calculations for wetlands (King et al., 1993; Unsworth and Bishop, 1994), HEA focuses on the selection of a specific resource-based metric(s) as a proxy for the affected services (e.g., seagrass short-shoot density) rather than basing its calculations on a broad aggregation of injured resources. Its use does not reduce the need for appropriate performance standards to ensure that a project provides the anticipated level of services. Well-defined and measurable standards are essential for the success of the project regardless of whether the restoration will be implemented by the parties responsible for the original resource injury or by the trustees using monetary damages that are recovered.

4. Conclusions

Having examined and updated seagrass restoration in a worldwide framework, it is useful to reflect on generalities that have arisen independent of geographic location and which allow us to evaluate the ecological and economic appropriateness of this activity as a tool for conserving seagrass. The last decade has seen the development of a suite of innovative techniques (Treat and Lewis, 2006) with broad applicability to a range of environments. It remains inevitable that population pressures and economic necessity will generate coastal development and destructive activities in areas currently occupied by seagrass. While minor damage, such as boat groundings, may be reduced through relatively inexpensive means such as exclusion enforcement, legislation and education, it is likely that restoration will still be required as offsite mitigation for port and harbor development. We now possess the ability to successfully generate small seagrass meadows, at high cost, to support this mitigation. However returns of areas greater than 20 ha via restoration efforts are unlikely to be realized in the near future.

Acknowledgments

We thank E. Balestri, A. Bos, P. Christensen, K. Hermus (Figure 1a), I. Martins, A. Meinesz (Figure 1b), A. Rismondo, J.L. Sanchez-Lisazo and J.M. Weslawski for providing data or photographs. Thanks are also due to Professor Richard Hobbs for his editorial advice and land rehabilitation costings and to Mark M. Brinson and an anonymous reviewer for their suggestions.

REFERENCES

Bastyan, G.R., 2002. Successful seagrass transplants in Oyster Harbour and Princess Royal Harbour. Albany, Oceanica Pty Ltd, Western Australia.

Balestri, E., Piazzi, L., Cinelli, F., 1998. Survival and growth of transplanted and natural seedlings of *Posidonia oceanica* (L.) Delile in a damaged coastal area. J. Exp. Mar. Biol. Ecol. 228, 209–225.

Bergstrom, P., 2006. Species selection, success, and costs of multi-year, multi-species submerged aquatic vegetation (SAV) planting in Shallow Creek, Patapsco River, Maryland. In: Treat, S.F., Lewis III., R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services. Valrico, Florida, pp. 49–58.

Bernard, G., Bonhomme, P., Boudouresque, C.F., 2005. Recovery of the seagrass *Zostera marina* in a disturbed Mediterranean lagoon (Etang de Berre, Bouches-du-Rhone, Southern France). Hydrobiologia 539, 157–161.

Biber, D.C., Gallegos, C.L., Kenworthy, W.J., 2008. Calibration of a bio-optical model in the North River, North Carolina (Albemarle-Pamlico Sound): a tool to evaluate water quality impacts on seagrasses. Est. Coasts 31, 177–191.

Boorman, L.A., Ranwell, D.S., 1977. Ecology of Maplin Sands and the coastal zones of Suffolk, Essex and North Kent. Institute of Terrestrial Ecology, Natural Environment Research Council, Colney, Norwich.

Bos, A.R., van Katwijk, M.M., 2005. Herintroductie van Groot zeegras (*Zostera marina*) in de westelijke Waddenzee (2002–2005). Dept. of Environmental Science, Radboud University, Nijmegen.

Bos, A.R., van Katwijk, M.M., 2007. Planting density, hydrodynamic exposure and mussel beds affecting survival of transplanted intertidal eelgrass. Mar. Ecol. Prog. Ser. 336, 121–129.

Boström, C., Baden, S.P., Krause-Jensen, D., 2003. The seagrasses of Scandinavia and the Baltic Sea. In: Green, E.P., Short, F.T. (Eds.), World Atlas of Seagrasses, UNEP. University of California Press, Berkeley, pp. 27–37.

Boudouresque, C.F., Bernard, G., Bonhomme, P., Charbonnel, E., Diviacco, G., Meinesz, A., Pergent, G., Pergent-Martini, C., Ruitton, S., Tunesi, L., 2006. Préservation et conservation des herbiers à *Posidonia oceanica*, Ramoge pub.: 1-202 ISBN 2-905540-30-3, Marseille, France.

Bouma, T.J., de Vries, M.B., Low, E., Kusters, L., Herman, P.M.J., Tanczos, I.C., Temmerman, S., Hesselink, A., Meire, P., van Regenmortel, S., 2005. Flow hydrodynamics on a mudflat and in salt marsh vegetation: identifying general relationships for habitat characterisations. Hydrobiologia 540, 259–274.

Cambridge, M.L., Bastyan, G.R., Walker, D.I., 2002. Recovery of *Posidonia* meadows in Oyster Harbour, southwestern Australia. Bull. Mar. Sci. 71, 1279–1289.

Calumpong, H.P., Fonseca, M.S., 2001. Seagrass transplantation. In: Short, F.T., Coles, R.G., Short, C.A. (Eds.), Global Seagrass Research Methods. Elsevier, Amsterdam, pp. 425–444.

Cappo, M., Alongi, D.M., Williams, D.M., Duke, N., 1998. A review and synthesis of Australian fisheries habitat research. Australian Institute of Marine Science, Townsville.

Chisholm, W., in preparation. The Stability of Shallow Coastal Sediments with and without Seagrasses. PhD Thesis, Murdoch University.

Christensen, P.B., McGlathery, K.J., 1995. Transplantation of Eelgrass. National Environmental Research Institute, Silkeborg.

Coles, R., 1996. Coastal management and community coastal resource planning in the Asia Pacific region. A Report of Churchill Fellowship Sponsored Overseas Study. April – July 1996, The Winston Churchill Memorial Trust, Canberra.

Costanza, R., d'Arge, R., de Groots, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.

Cunha, A.H., Santos, R.P., Gaspar, A.P., Bairros, M.F., 2005. Seagrass landscape-scale changes in response to disturbance created by the dynamics of barrier-islands: a case study from Ria Formosa (Southern Portugal). Estuar. Coast. Shelf Sci. 64, 636–644.

Curiel, D., Rismondo, A., Solazzi, A., Marzocchi, M., Scattolin, M., 1994. Valutazione dello stato di qualità dei popolamenti a fanerogame marine in laguna di Venezia e sperimentazione di reimpianto a *Cymodocea nodosa, Zostera marina* e *Zostera noltii*. Biol. Marit. Mediterr. 1, 407–408.

Curiel, D., Scarton, F., Rismondo, A., Marzocchi, M., 2005. Pilot transplanting project of *Cymodocea nodosa* and *Zostera marina* in the lagoon of Venice: results and perspectives. Boletino Museo civ. St. Naturali Venezia 56, 25–40.

Davis, R.C., Reel, J.T., Short, F.T., Montoya, D., 2006. Costs and success of large-scale Eelgrass (*Zostera marine* L.) plantings in New England (New Hampshire and Maine). In: Treat, S.F., Lewis III., R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 103–114.

Davis, R.C., Short, F.T., Burdick, D.M., 1998. Quantifying the effects of bioturbation by green crabs (*Carcinus maenas*) on eelgrass (*Zostera marina*) transplants using mesocosm experiments. Restor. Ecol. 6, 297–302.

den Hartog, C., 1971. The dynamic aspect in the ecology of sea-grass communities. Thalassia Jugoslavica 7, 101–112.

Duarte, C.M., 1995. Submerged aquatic vegetation in relation to different nutrient regimes. Ophelia 41, 87–112.

Duarte, C.M., 2002. The future of seagrass meadows. Environ. Conserv. 29, 192–206.

Duarte, C.M., Fourqurean, J.W., Krause-Jensen, D., Olesen, B., 2006. Dynamics of seagrass stability and change. In: Larkum, A.W.D., Orth, R.J., Duarte, C.M. (Eds.), Seagrasses: Biology, Ecology and Conservation. Springer, Dordrecht, pp. 271–294.

Duarte, C.M., Sand-Jensen, K., 1990. Seagrass colonization: patch formation and patch growth in *Cymodocea nodosa*. Mar. Ecol. Prog. Ser. 65, 193–200.

Eleuterius, L.N., 1987. Seagrass: A neglected coastal resource. In: Lynch, M.P., McDonald, K.L. (Eds.), Proceedings of the Tenth National Conference. Estuarine and Coastal Management: Tools of the Trade, October 1986, vol. 2. New Orleans, LA. pp. 719–724.

Fong, T.C.W., 1999. Habitat preservation or transplantation: which is better for Hong Kong seagrass conservation? Porcupine! (Hong Kong University) 20, 12–14.

Fonseca, M.S., 1992. Restoring seagrass systems in the United States. In: Thayer, G.W. (Ed.), Restoring the Nation's Marine Environment. Maryland Sea Grant College, College Park, Md., Publ. UM-SG-TS-92-06.

Fonseca, M.S., 1994. A Guide to Planting Seagrasses in the Gulf of Mexico. Texas A&M Sea Grant College Program, TAMU-SG-94-60l, College Station, Texas.

Fonseca, M., 2006. Wrap-up of seagrass restoration: success, failure and lessons about the costs of both. In: Treat, S.F., Lewis III., R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 169–175.

Fonseca, M.S., Julius, B.E., Kenworthy, W.J., 2000. Integrating biology and economics in seagrass restoration: how much is enough and why? Ecol. Eng. 15, 227–237.

Fonseca, M.S., Kenworthy, W.J., Courtney, F.X., Hall, M.O., 1994. Seagrass planting in the Southeastern United States: methods for accelerating habitat development. Restor. Ecol. 2 (3), 198–212.

Fonseca, M.S., Kenworthy, W.J., Courtney, F.X., 1996. Development of planted seagrass beds in Tampa Bay, Florida, USA. I. Plant components. Mar. Ecol. Prog. Ser. 132, 127–139.

Fonseca, M.S., Kenworthy, W.J., Thayer, G.W., 1998. Guidelines for the Conservation and Restoration of Seagrasses in the United States and Adjacent Waters. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Coastal Ocean Office, 1315 East-West Highway, Silver Spring, Maryland 20910. 222pp. http://www.cop.noaa.gov. Accessed date 30 January, 2008.

Fonseca, M.S., Robbins, B.D., Whitfield, P.E., Wood, I., Clinton, P., 2002. Evaluating the effect of offshore sandbars on seagrass recovery and restoration in Tampa Bay through ecological forecasting and hindcasting of exposure to waves. Tampa Bay Estuary Program, St. Petersburg, Florida.

Fonseca, M.S., Thayer, G.W., Kenworthy, W.J., 1987. The use of ecological data in the implementation and management of seagrass restorations. Fla. Mar. Res. Publ. 42, 175–187.

Fortes, M.D., 1988. Mangrove and seagrass beds of East Asia: habitats under stress. Ambio 17, 207–213.

Fortes, M.D., 1990. Seagrasses: A Resource Unknown in the ASEAN Region. International Center for Living Aquatic Resources Management, Manila.

Fortes, M.D., Sour, K., Xiaoping, H., Kuriandewa, T.E., Tien, N.V., Vibol, O., Montaño, N.E., Almonte, T., Satumanatpan, S., 2006. The UNEP/GEF seagrass demonstration sites in South China Sea: milestones in seagrass research and coastal resource management in Southeast Asia. In: The East Asian Seas Congress, 12-16 December 2006, Haikou City, Hainan Province, PR China. Partnerships in Environmental Management for the Seas of East Asia - EAS Congress Secretariat, PO Box 2502 Quezon City, 1165, Philippines.

Frederiksen, M., Krause, J.D., Holmer, M., Laursen, J.S., 2004b. Spatial and temporal variation in eelgrass (*Zostera marina*) landscapes: influence of physical setting. Aquat. Bot. 78, 147–165.

Frederiksen, M., Krause-Jensen, D., Holmer, M., Laursen, J.S., 2004a. Long-term changes in area distribution of eelgrass (*Zostera marina*) in Danish coastal waters. Aquat. Bot. 78, 167–181.

Fredette, T.J., Fonseca, M.S., Kenworthy, W.J., Wyllie-Echeverria, S., 1985. An investigation of eelgrass (*Zostera marina*) transplanting in San Francisco Bay, CA. U.S. Army Corp. of Engineers, San Francisco District, California, 33pp.

Genot, I., Caye, G., Meinesz, A., Orlandini, M., 1994. Role of chlorophyll and carbohydrate contents in survival of *Posidonia oceanica* cuttings transplanted to different depths. Mar. Biol. Berlin 119, 18–29.

Giesen, W.B.J.T., van Katwijk, M.M., den Hartog, C., 1990. Eelgrass condition and turbidity in the Dutch Wadden Sea. Aquat. Bot. 37, 71–85.

Glémarec, M., LeFaou, Y., Cuq, F., 1997. Long-term changes of seagrass beds in the Glenan Archipelago (South Brittany). Oceanol. Acta 20, 217–227.

Gobert, S., Cambridge, M.L., Velimirov, B., Pergent, G., Lepoint, G., Bouquegneau, J.M., Dauby, P., Pergent-Martini, C., Walker, D.I., 2006. Biology of *Posidonia*. In: Larkum, A.W.D., Orth, R.J., Duarte, C.M. (Eds.), Seagrasses: Biology, Ecology and Conservation. Springer, Dordrecht, pp. 387–408.

Gonzalez-Correa, J.M., Bayle, J.T., Sanchez-Lizasa, J.L., Valle, C., Sanchez-Jerez, P., Ruiz, J.M., 2005. Recovery of deep *Posidonia oceanica* meadows degraded by trawling. J. Exp. Mar. Biol. Ecol. 320, 65–76.

Gordon, D.M., 1996. Status of seagrass restoration: Review of international literature. LeProvost, Dames and Moore, Perth, Western Australia.

Green, E.P., Short, F.T. (Eds.), 2003. World Atlas of Seagrasses. University of California Press in association with UNEP-WCMC, Berkeley, California.

Greening, H., 2006. Implementation, regulatory and research priorities for seagrass restoration: results from the Seagrass Restoration Workshop, March 11–12, 2003. In: Treat, S.F., Lewis III., R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 165–168.

Haddad, K.D., 1989. Habitat trends and fisheries in Tampa and Sarasota Bays. In: Tampa and Sarasota Bays: Issues, Resources, Status and Management. NOAA, Washington, DC, NOAA Estuary-of-the Month Seminar Series, No. 11, 113–128.

Harmsen, G.W., 1936. Systematische Beobachtungen der Nordwest-Europäischen Seegrasformen. Ned. Kruid. Arch. 46, 852–877.

Hily, C., van Katwijk, M.M., den Hartog, C., 2003. The seagrasses of Western Europe. In: Green, E.P., Short, F.T. (Eds.), World Atlas of Seagrasses, UNEP. University of California Press, Berkeley, pp. 48–58.

Hopkins, E., White, M., Clarke, A., 1998. Restoration of fish habitats: fisheries guidelines for marine areas. Rep FHG002, Department of Primary Industries, Queensland.

Jaubert, J.M., Chisholm, J.R.M., Ducrot, D., Ripley, H.T., Roy, L., Passeron-Seitre, G., 1999. No deleterious alterations in *Posidonia beds* in the Bay of Menton (France) eight years after *Caulerpa taxifolia* colonization. J. Phycol. 35, 1113–1119.

Johansson, J.O.R., Lewis III., R.R., 1992. Recent improvement of water quality and bioindicators in Hillsborough Bay, a highly impacted subdivision of Tampa Bay, Florida. USA. In: Vollenweider, R.A., Marchetti, R. Viviani, R. (Eds.), Symposium on Marine Coastal Eutrophication, Bologna (Italy), 21–March 24, 1990. Elsevier, Amsterdam. pp. 1199–1216.

Kelly, N.M., Fonseca, M., Whitfield, P., 2001. Predictive mapping for management and conservation of seagrass beds in North Carolina. Aquat. Conserv.: Mar. Freshw. Ecosyst. 11, 437–451.

Kenworthy, W.J., Fonseca, M.S., 1992. The use of fertilizer to enhance growth of transplanted seagrasses *Zostera marina* L. and *Halodule wrightii* Aschers. J. Exp. Mar. Biol. Ecol. 163, 141–161.

Kenworthy, W.J., Haunert, D.E., 1991. The light requirements of seagrasses: proceedings of a workshop to examine the capability of water quality criteria, standards and monitoring programs to protect seagrasses. National Oceanic and Atmospheric Administration, Tech. Memo. NMFS-SEFC-287. Beaufort, NC, 181pp.

King, D.M., Bohlen, C.C., Adler, K.J., 1993. Watershed management and wetland mitigation: a framework for determining compensation ratios. University of Maryland System Draft Report #, UMCEES-CBL-93-098, College Park, MD.

Kirkman, H., 1989. Restoration and creation of seagrass meadows with special emphasis on Western Australia. Environmental Protection Authority, Perth, WA.

Kirkman, H., 1998. Pilot experiments on planting seedlings and small seagrass propagules in Western Australia. Mar. Pollut. Bull. 37, 460–467.

Kirkman, H., 1992. Large-scale restoration of seagrass meadows. In: Thayer, G.W. (Ed.), Restoring the Nation's Marine Environment. Maryland Sea Grant College, College Park, MD, pp. 111–140.

Kirkman, H., 1997. Seagrasses of Australia, Australia: State of the Environment Technical Paper Series (Estuaries and the Sea). Department of the Environment, Canberra.

Kitting, C.L., Wyllie-Echeverria, S., 1992. Seagrasses of San Francisco Bay: Status, management and conservation needs. In: Yosemite Centennial Symposium Proceedings, National Park Service N.P.S. D-374, Denver Service Center, Denver, CO, pp. 388–395.

Kruk-Dowgiallo, L., 1991. Long-term changes in the structure of underwater meadows of the Puck Lagoon. Acta Ichthyol. Piscat. 21, 77–84.

Langridge, T.M., 2002. The effect of sediment stabilisation on water flow and the survival of naturally-recruited and transplanted seagrass seedlings. Honours Thesis, Murdoch University, 97pp.

Larkum, A.W.D., den Hartog, C., 1989. Evolution and biogeography of seagrasses. In: Larkum, A.W.D., McComb, A.J., Shepherd, S.A. (Eds.), Biology of Seagrasses. A Treatise on the Biology of Seagrasses with Special Reference to the Australian Region. Elsevier, Amsterdam, pp. 112-156.

Lenzi, M., Palmieri, R., Porrello, S., 2003. Restoration of the eutrophic Orbetello lagoon (Tyrrhenian Sea, Italy): water quality management. Mar. Pollut. Bull. 46, 1540–1548.

Lewis III., R.R., Marshall, M.J., Bloom, S.A., Hodgson, A.B., Flynn, L.L., 2006. Evaluation of the success of seagrass mitigation at Port Manatee, Tampa Bay, Florida. In: Treat, S.F., Lewis III., R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 19–40.

Lipkin, Y., Beer, S., Zakai, D., 2003. The seagrasses of the eastern Mediterranean and the Red Sea. In: Green, E.P., Short, F.T. (Eds.), World Atlas of Seagrasses, UNEP. University of California Press, Berkeley, pp. 65–73.

Livingston, R.J., 1987. Historic trends of human impacts on seagrass meadows in Florida. Fla. Mar. Res. Publ. 42, 139–152.

Lord, D.A., Paling, E.I., Gordon, D.M., 1999. Review of Australian rehabilitation and restoration programs. In: Butler, A.J., Jernakoff, P. (Eds.), Seagrass in Australia. Strategic Review and Development of an R & D Plan. CSIRO Publishing, Collingwood, Victoria, pp. 65–115.

Marbá, N., Duarte, C.M., 1995. Coupling of seagrass (*Cymodocea nodosa*) patch dynamics to subaqueous dune migration. J. Ecol. 83, 381–389.

Marbá, N., Duarte, C.M., Cebrian, J., Gallegos, M.E., Olesen, B., Sand Jensen, K., 1996. Growth and population dynamics of *Posidonia oceanica* on the Spanish Mediterranean coast: Elucidating seagrass decline. Mar. Ecol. Prog. Ser. 137, 203–213.

Martinet, J.F., 1782. Verhandeling over het wier der Zuiderzee. Verh. Hollandsche Maatsch. Wetenschappen 20, 54–129.

Martins, I., Neto, J.M., Fontes, M.G., Marques, J.C., Pardal, M.A., 2005. Seasonal variation in short-term survival of *Zostera noltii* transplants in a declining meadow in Portugal. Aquat. Bot. 82, 132–142.

McNeese, P.L., Kruer, C.R., Kenworthy, W.J., Schwarzschild, A.C., Wells, P., Hobbs, J., 2006. Topographic restoration of boat grounding damage at the Lignumvitae Submerged Land

Management Area. In: Treat, S.F., Lewis III., R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 131–146.

Meinesz, A., Caye, G., Locques, F., Macaux, S., 1990. Analyse bibliographique sur la culture des phanerogames marines. Posidonia Newsl. 3, 1–67.

Meinesz, A., Molenaar, H., Bellone, E., Loquès, F., 1992. Vegetative reproduction in *Posidonia oceanica*: I. Effects of rhizome length and transplantation season in orthotropic shoots. Mar. Ecol. 13, 163–174.

Meinesz, A., Molenaar, H., Caye, G., 1993. Transplantations de phanerogames marines en mediterranee. Boll. Oceanol. Teor. Applic. 11, 183–190.

Milano, G.R., Deis, D.R., 2006. Biscayne Bay seagrasses and recent restoration efforts. In: Treat, S.F., Lewis III., R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 115–130.

Milchakova, N.A., 2003. The seagrasses of the Black, Azov, Caspian and Aral Seas. In: Green, E.P., Short, F.T. (Eds.), World Atlas of Seagrasses, UNEP. University of California Press, Berkeley, pp. 59–64.

Milchakova, N.A., Phillips, R.C., 2003. Black Sea seagrasses. Mar. Pollut. Bull. 46, 695–699.

Millennium Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Molenaar, H., Meinesz, A., 1995. Vegetative reproduction in *Posidonia oceanica*: survival and development of transplanted cuttings according to different spacings, arrangements and substrates. Bot. Mar. 38, 313–322.

Molenaar, H., Meinesz, A., Caye, G., 1993. Vegetative reproduction in *Posidonia oceanica*. Survival and development in different morphological types of transplanted cuttings. Bot. Mar. 36, 481–488.

Montin, G.J., Dennis III, A.B., 2006. A shallow water technique for the successful relocation and/or transplantation of large areas of Shoalgrass (*Halodule wrightii*). In: Treat, S.F., Lewis III., R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 41–48.

Moore, K.A., Wilcox, D.J., Orth, R.J., 2000. Analysis of the abundance of submersed aquatic vegetation communities in the Chesapeake Bay. Estuaries 23, 115–127.

Munkes, B., 2005. Eutrophication, phase shift, the delay and the potential return in the Greifswalder Bodden, Baltic Sea. Aquat. Sci. 67, 372–381.

Nakamura, Y., 2005. Development of restoration technology of tidal flats and eelgrass fields by using mesocosm experimental facilities. In: Yokohama International Workshop for Revival of the Tokyo Bay Ecosystem, Yokohama, Japan. pp. 91–97.

Nakase, K., Shimaya, M., 2001. Restoration technology of seagrass beds. In: EMECS 2001 Executive Committee (Ed.), The Fifth International Conference on the Environmental Management of Enclosed Coastal Seas, November 19–22, 2001, Kobe.

National Oceanic and Atmospheric Administration, Damage Assessment and Restoration Program, 1997. Habitat Equivalency Analysis: An Overview. Policy and Technical Paper Series, No. 95–1, 18pp. http://www.darrp.noaa.gov/library/pdf/heaoverv.pdf

Neckles, H.A., Short, F.T., Barker, S., Kopp, B.S., 2005. Disturbance of eelgrass *Zostera marina* by commercial mussel *Mytilus edulis* harvesting in Maine: dragging impacts and habitat recovery. Mar. Ecol. Prog. Ser. 285, 57–73.

Noten, T.M.P.A., 1983. Detached shoots of *Zostera noltii* Hornem. as a means of dispersal: a transplantation experiment. Proc. Int. Symposium Aquat. Macrophytes, Nijmegen, 18–September 23, 1983.

Olsen, J.L., Stam, W.T., Coyer, J.A., Reusch, T.B.H., Bilingham, M., Boström, C., Calvert, E., Christie, H., Granger, S., La Lumiére, R., Milchakove, N., Outdot-Le Secq, M., Procaccini, G., Sanjab, B., Serråo, E., Veldsink, J., Widdicombe, S., Wyllie-Escheverria, S., 2004. North Atlantic phylogeography and large-scale population differentiation of the seagrass *Zostera marina* L. Mol. Ecol. 13, 1923–1941.

Orth, R.J., Bieri, J., Fishman, J.R., Harwell, M.C., Marion, M.C., Moore, K.A., Nowak, J.F., van Montfrans, J., 2006b. Perspectives on two decades of Eelgrass (*Zostera marine* L.) restoration using adult plants and seeds in Chesapeake Bay and the Virginia coastal bays, USA. In: Treat, S.F., Lewis III., R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 1–18.

Orth, R.J., Carruthers, T.J.B., Dennison, W.C., Duarte, C.M., Fourqurean, J.W., Heck, K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Olyarnik, S., Short, F.T., Waycott, M., Williams, S.L., 2006a. A global crisis for seagrass ecosystems. BioScience 56, 987–996.

Orth, R.J., Moore, K.A., 1981. Submerged aquatic vegetation of the Chesapeake Bay; past, present, and future. Trans. N. Am. Wildl. Nat. Resour. Conf. 46, 271–283.

Ostenfeld, C.H., 1908. On the ecology and distribution of the grass-wrack (*Zostera marina*) in Danish waters. Rep. Dan. Biol. Stn. 16, 1–62.

Oudemans, C.A.J.A., Conrad, J.F.W., Maats, P., Bouricius, L.J., 1870. Verslag der Staatscommissie inzake de wiermaayerij. Verslag aan den Koning over de Openbare Werken in het Jaar 1869, Van Weelden en Mingelen, Den Haag, pp. 199–231.

Paling, E.I., van Keulen, M., 2002. Seagrass restoration in Australia. In: Seddon, S., Murray-Jones, S. (Eds.), Proceedings of the Seagrass Restoration Workshop for Gulf St. Vincent 15–May 16, 2001. South Australian Department for Environment and Heritage and SARDI Aquatic Sciences, Adelaide, pp. 100–108.

Paling, E.I., van Keulen, M., Tunbridge, D.J., 2007. Seagrass transplanting in Cockburn Sound, Western Australia: a comparison of manual transplantation methodology using *Posidonia sinuosa* Cambridge et Kuo. Restor. Ecol. 15, 430–439.

Paling, E.I., van Keulen, M., Verduin, J., Horn, L., in preparation. Broad-scale manual transplantation of *Posidonia australis* for harbour mitigation in Cockburn Sound, Western Australia.

Paling, E.I., van Keulen, M., Wheeler, K.D., 1998. Project S2, Phase 2: Seagrass rehabilitation in Owen Anchorage, Western Australia. Annual report: August 1997–June 1998. Marine and Freshwater Research Laboratory, Murdoch University.

Paling, E.I., van Keulen, M., Wheeler, K., Phillips, J., Dyhrberg, R., 2003. The influence of spacing on mechanically transplanted seagrass survival in a high energy regime. Restor. Ecol. 11, 56–61.

Paling, E.I., van Keulen, M., Wheeler, K.D., Phillips, J., Dyhrberg, R., 2001a. Mechanical seagrass transplantation on Success Bank, Western Australia. Ecol. Eng. 16, 331–339.

Paling, E.I., van Keulen, M., Wheeler, K.D., Phillips, J., Dyhrberg, R., Lord, D.A., 2001b. Improving mechanical seagrass transplantation. Ecol. Eng. 18, 107-113.

Park, J.I., Lee, K.S., 2007. Site-specific success of three transplanting methods and the effect of planting time on the establishment of *Zostera marina* transplants. Mar. Pollut. Bull. 54, 1238–1248.

Pergent-Martini, C., Pasqualini, V., Pergent, G., Ferrat, L., 2002. Effect of a newly set up wastewater-treatment plant on a marine phanerogam seagrass bed – A medium-term monitoring program. Bull. Mar. Sci. 71, 1227–1236.

Philippart, C.J.M., 1994. Interactions between *Arenicola marina* and *Zostera noltii* on a tidal flat in the Wadden Sea. Mar. Ecol. Prog. Ser. 111, 251–257.

Pickerell, C.H., Schott, S., Wyllie-Echeverria, S., 2005. Buoy deployed seeding: Demonstration of a new eelgrass (*Zostera marina* L.) planting method, Ecol. Eng. 25, 127–136.

Plus, M., Deslous-Paoli, J.M., Dagault, F., 2003. Seagrass (*Zostera marina* L.) bed recolonisation after anoxia-induced full mortality. Aquat. Bot. 77, 121–134.

Powell, G.V.N., Kenworthy, W.J., Fourqurean, J.W., 1989. Experimental evidence for nutrient limitation of seagrass growth in a tropical estuary with restricted circulation. Bull. Mar. Sci. 44, 324–340.

Procaccini, G., Buia, M.C., Gambi, M.C., Perez, M., Pergent, G., Pergent-Martini, C., Romero, J., 2003. The seagrasses of the western Mediterranean. In: Green, E.P., Short, F.T. (Eds.), World Atlas of Seagrasses, UNEP. University of California Press, Berkeley, pp. 48–58.

Pulich Jr., W.M., White, W.A., 1991. Decline of submerged vegetation in the Galveston Bay system: chronology and relationships to physical processes. J. Coast. Res. 7, 1125–1138.

Ralph, P.J., Tomasko, D., Moore, K., Seddon, S., Macinnis-Ng, C.M.O., 2006. Human impacts on seagrasses: eutrophication, sedimentation and contamination. In: Larkum, A.W.D., Orth, R.J., Duarte, C.M. (Eds.), Seagrasses: Biology, Ecology and Conservation. Springer, Dordrecht, pp. 567–593.

Ranwell, D.S., Wyer, D.W., Boorman, L.A., Pizzey, J.M., Waters, R.J., 1974. *Zostera* transplants in Norfolk and Suffolk, Great Britain. Aquaculture 4, 185–198.

Reed, J., Schwarz, A., Gosai, A., Morrison, M., 2004. Feasibility study to investigate the replenishment/reinstatement of seagrass beds in Whangarei Harbour – Phase 1. Rep AKL2004-33. National Institute of Water and Atmosphere Research Ltd., New Zealand.

Reed, J., Schwarz, A., Morrison, M., 2005. Feasibility study to investigate the replenishment/reinstatement of seagrass beds in Whangarei Harbour – Phase 2. Rep AKL2005. National Institute of Water and Atmosphere Research Ltd., New Zealand.

Reise, K., Kohlus, J., 2008. Seagrass recovery in the Northern Wadden Sea? Helgol. Mar. Res. 62, 77-84.

Reigersman, C.J.A., Houben, G.F.H., Havinga, B., 1939. Rapport omtrent den invloed van de wierziekte op den achteruitgang van de wierbedrijven, met Bijlagen. Provinciale Waterstaat in Noord-Holland, Haarlem.

Rismondo, A., Curiel, D., Solazzi, A., Marzocchi, M., Chiozzotto, E., Scattolin, M., 1995. Sperimentazione di trapianto a fanerogame marine in laguna di Venezia: 1992–1994. Soc. Ital. Ecol. 16, 683–685.

Rollon, R.N., de Ruyter van Steveninck, E.D., Van Vierssen, W., Fortes, M.D., 1998. Contrasting recolonisation strategies in multi-species seagrass meadows. Mar. Pollut. Bull. 37, 450–459.

Ruggiero, M.V., Procaccini, G., 2004. The rDNA ITS region in the Lessepsian marine angiosperm *Halophila stipulacea* (Forssk.) Aschers. (Hydrocharitaceae): intragenomic variability and putative pseudogenic sequences. J. Mol. Evol. 58, 115–121.

Sánchez-Lizaso, J.L., Fernández-Torquemada, Y., González-Correa, J.M., 2006. Efectividad de los transplantes de *Posidonia oceanica* efectuados en el entorno del puerto deportivo Luis Campomanes (Altea), WWF, Universidad de Alicante, Spain.

Sargent, F.J., Leary, T.J., Crewz, D.W., Kruer, C.R., 1995. Scarring of Florida's seagrasses: Assessment and management options. Florida Department of Environmental Protection, St. Petersburg, FL. FMRI Technical Report TR-1. 46pp.

Schiewer, U., Plinski, M., Andrushaitis, G., 1999. Discharge areas – a comparison between three regions in the southern Baltic. Limnologica 29, 274–281.

Seddon, S., 2004. Going with the flow: facilitating seagrass rehabilitation. Ecol. Manage. Restor. 5, 167–176.

Seddon, S., Miller, D., Venema, S., Tanner, J., 2004. Seagrass rehabilitation in metropolitan Adelaide. I. Transplantation from donor beds. Rep SARDI Aquatic Sciences Publication No. RD04/0038, SARDI Aquatic Sciences, south Australia.

Seddon, S., Wear, R., Venema, S., Miller, D., 2005. Seagrass rehabilitation in Adelaide metropolitan coastal waters. II. Development of donor bed independent methods using *Posidonia* seedlings. Rep SARDI Aquatic Sciences Publication No. RD04/0038-2; SARDI Research Report Series No. 110, SARDI Aquatic Sciences. South Australia.

Short, F., Burdick, D., 1996. Quantifying eelgrass habitat loss in relation to housing development and nitrogen loading in Waquoit Bay, Massachusetts. Estuaries 19, 730–739.

Short, F.T., Davis, R.C., Kopp, B.S., Gaeckle, J.L., Burdick, D.M., 2006. Using TERFS and site selection for improved Eelgrass restoration success. In: Treat, S.F., Lewis III., R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 59–68.

Short, F.T., Davis, R.C., Kopp, B.S., Short, C.A., Burdick, D.M., 2002. Site-selection model for optimal restoration of eelgrass *Zostera marina* in the Northeastern US. Mar. Ecol. Prog. Ser. 227, 253–267.

Siebert, T., Branch, G.M., 2007. Influences of biological interactions on community structure within seagrass beds and sandprawn-dominated sandflats. J. Exp. Mar. Biol. Ecol. 340, 11–24.

Stowers, J.F., Fehrmann, E., Squires, A., 2006. Seagrass scarring in Tampa Bay: impact analysis and management options. In: Treat, S.F., Lewis III., R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 69–78.

Suzuki, M., 2002. Tidal flat restoration in Japan: a grassroots perspective. 17th Session of the Global Biodiversity Forum. Global Biodiversity Forum, IUCN, Geneva, Switzerland.

Taisei Corporation, 2006. Replanting eelgrasses by the Natural Reproduction Method. Taisei CSR Report 2006, Corporate Planning Office, Taisei Corporation, Tokyo, 32pp.

Talbot, F., Wilkinson, C., 2001. Coral Reefs, Mangroves and Seagrasses: A Sourcebook for Managers. Australian Institute of Marine Science, Townsville.

Thom, R.M., Hallum, L., 1991. Long-term changes in the areal extent of tidal marshes, eelgrass meadows and kelp forests of Puget Sound. U.S. Environmental Protection Agency, Seattle, WA, EPA910/9-91-005. 55pp.

Thorhaug, A., 1987. Philippines seagrass transplantation trials. Rep W/S5594, Food and Agriculture Organization of the United Nations.

Townsend, E.C., Fonseca, M.S., 1998. Bioturbation as a potential mechanism influencing spatial heterogeneity of North Carolina seagrass beds. Mar. Ecol. Prog. Ser. 169, 123–132.

Treat, S.F., Lewis III., R.R. (Eds.), 2006. Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida.

Turner, S.J., 1995. Restoring seagrass systems in New Zealand. Water Atmos. 3, 9–11.

Turner, S.J., Schwarz, A.M., 2006. Management and Conservation of Seagrass in New Zealand: An Introduction, Science & Technical Publishing. New Zealand Department of Conservation, Wellington.

Uhrin, A.V., Hall, M.O., Merello, M., Fonseca, M.S. in press. Evaluation of the Success of Mechanized Transplanting of Two Tropical Seagrasses. Marine Fisheries Review.

UNEP, 2004. Seagrass in the South China Sea. Rep UNEP/GEF/SCS Technical Publication No. 3–14, UNEP/GEF.

UNEP, 2006. Reversing environmental degradation trends in the South China Sea and Gulf of Thailand. Report of the Seventh Meeting of the Regional Working Group for the Seagrass Subcomponent. Rep NEP/GEF/SCS/RWG-SG.7/3, -39, UNEP/GEF Bangkok, Thailand.

Unsworth, R.E., Bishop, R.C., 1994. Assessing natural resource damages using environmental annuities. Ecol. Econ. 11, 35–41.

USNRC, 1992. Restoration of aquatic ecosystems. Science, technology and public policy. Committee on Restoration of Aquatic Ecosystems. US National Research Council, National Academy Press, Washington, DC.

Valentine, J.F., Duffy, J.E., 2006. The central role of grazing in seagrass ecology. In: Larkum, A.W.D., Orth, R.J., Duarte, C.M. (Eds.), Seagrasses: Biology, Ecology and Conservation. Springer, Dordrecht, The Netherlands, pp. 463–501.

van der Heide, T., van Katwijk, M.M., Geerling, G.W., 2006. Een verkenning van de groeimogelijkheden van ondergedoken Groot zeegras (*Zostera marina*) in de Nederlandse Waddenzee. Radboud University. Nijmegen, The Netherlands.

van der Heide, T., van Nes, E.H., Geerling, G.W., Smolders, A.J.P., Bouma, T.J., van Katwijk, M.M. (2007) Positive Feedbacks in Seagrass Ecosystems: Implications for Success in Conservation and Restoration. Ecosystems 10, 1311–1322.

van Katwijk, M.M., Geerling, G.W., Rašín, R., van 't Veer, R., Bos, A.R., Hermus, D.C.R., van Wieringen, M., Jager, Z., Groeneweg, A.H., Erftemeijer, P.L.A., van der Heide, T., de Jong, D.J., 2006. Macrophytes in the western Wadden Sea: monitoring, invasion, transplantations, dynamics and European policy. In: Laursen, K., Marencic, H.et al. (Eds.), Proceedings of the 11th International Scientific Wadden Sea Symposium, Esbjerg.

van Katwijk, M.M., Hermus, D.C.R., 2000. Effects of water dynamics on *Zostera marina*: transplantation experiments in the intertidal Dutch Wadden Sea. Mar. Ecol. Prog. Ser. 208, 107–118.

van Katwijk, M.M., Hermus, D.C.R., de Jong, D.J., Asmus, R.M., de Jonge, V.N., 2000. Habitat suitability of the Wadden Sea for restoration of *Zostera marina* beds. Helgol. Mar. Res. 54, 117–128.

van Katwijk, M.M., van Pelt, S., Dankers, N., 2002. Herintroductie van Groot zeegras in de westelijke Waddenzee (2002–2006). Inventarisatie van bestaande kennis, selectie van locaties en plan van aanpak. Report Department of Environmental Science, University of Nijmegen.

van Keulen, M., Paling, E.I., Ridd, P., Fotheringham, D., Verduin, J.J., 2005. Seagrass rehabilitation and sediment dynamics. In: AMSA 2005: Marine Biodiversity, Biodiscovery and Biosecurity: Discovering and Protecting our Oceans' Bounty. Darwin, Northern Territory, 10–13 July, 2005.

van Keulen, M., Paling, E.I., Walker, C.J., 2003. Effect of planting unit size and sediment stabilization on seagrass transplants in Western Australia. Restor. Ecol. 11, 50–55.

van Katwijk, M.M., Schmitz, G.H.W., Gasseling, A.M., van Avesaath, P.H., 1999. The effects of salinity and nutrient load and their interaction on *Zostera marina* L. Mar. Ecol. Prog. Ser. 190, 155–165.

van Katwijk, M.M., Schmitz, G.H.W., Hanssen, L.S.A.M., den Hartog, C., 1998. Suitability of *Zostera marina* populations for transplantation to the Wadden Sea as determined by a mesocosm shading experiment. Aquat. Bot. 60, 283–305.

van Katwijk, M.M., Wijgergangs, L.J.M., 2004. Effects of locally varying exposure, sediment type and low-tide water cover on *Zostera marina* recruitment from seed. Aquat. Bot. 80, 1–12.

Walker, D.I., Kendrick, G.A., McComb, A.J., 2006. Decline and recovery of seagrass ecosystems - the dynamics of change. In: Larkum, A.W.D., Orth, R.J., Duarte, C.M. (Eds.), Seagrasses: Biology, Ecology and Conservation. Springer, Dordrecht, pp. 551–565.

Western Australian Environmental Protection Authority, 2004. Benthic primary producer habitat protection for Western Australia's marine environment. Rep Guidance Statement 29, ii+25, Environmental Protection Authority.

Wilson, J., 2004. Is *in vitro* propagation of seagrasses the solution to transplanting problems? Seagrass 2004. Townsville, Queensland, 25–September 27, 2004.

Yoshida, T., Ito, A., Mori, S., 2001. The *Zostera marina* bed creation method by the sowing sheet. In: EMECS 2001 Executive Committee (Ed.), The Fifth International Conference on the Environmental Management of Enclosed Coastal Seas, November 19–22, 2001, Kobe.

Zaitsev, Y.P., Alexandrov, B.G., Berlinsky, N.A., Zenetos, A., 2002. The Black Sea – an oxygen-poor sea. In: Künitzer, A. (Ed.), Europés biodiversity/biogeographical regions and seas. European Environment Agency, Copenhagen, Denmark, pp. 1–23.

Zieman, J.C., Wood, E.J.F., 1975. Effects of thermal pollution on estuaries, with emphasis on Biscayne Bay, Florida. Chapter. 5, In: Wood, R.E., Johannes, E.J.F. (Eds.), Tropical Marine Pollution. Elsevier, New York.