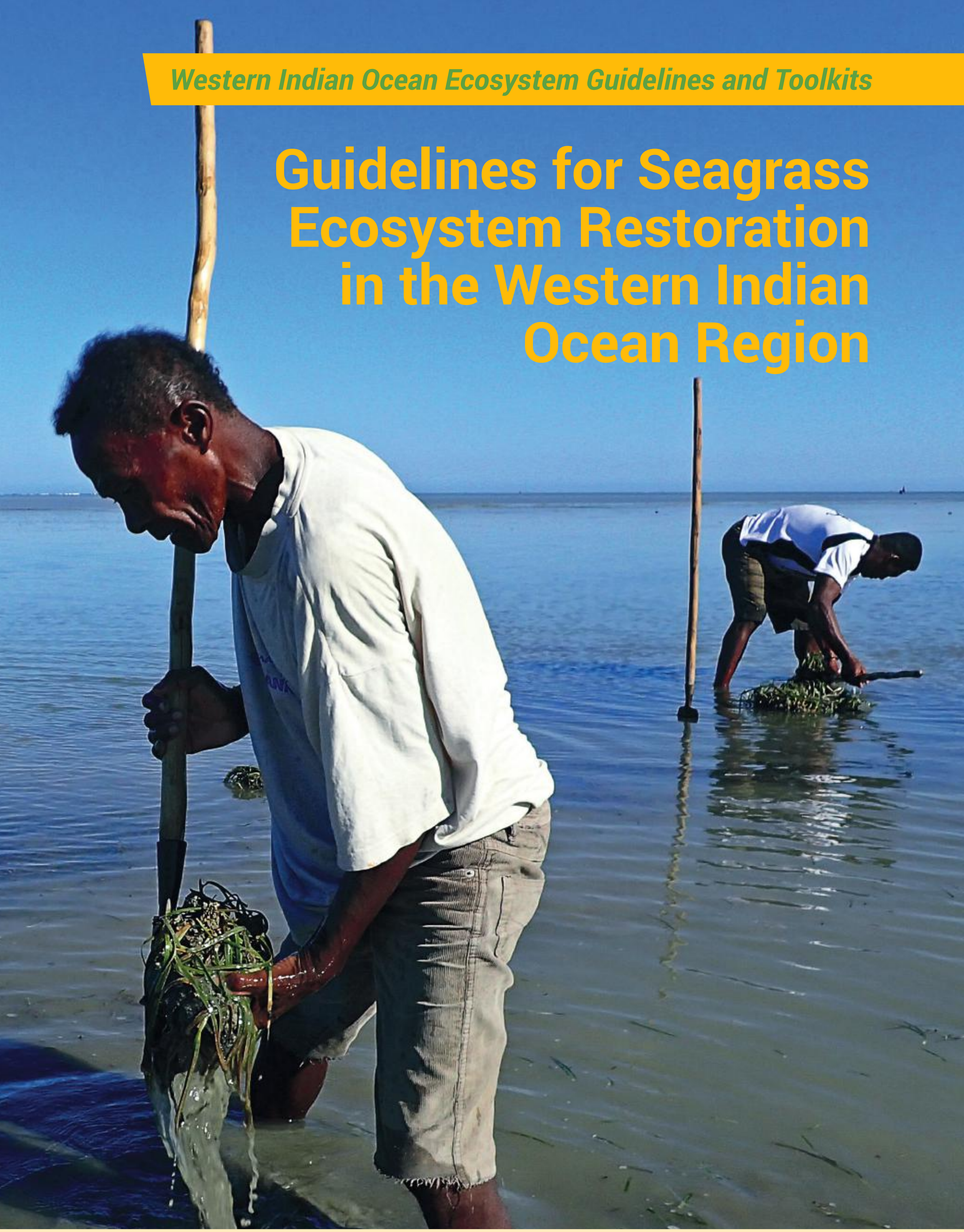
Western Indian Ocean Ecosystem Guidelines and Toolkits

Guidelines for Seagrass Ecosystem Restoration in the Western Indian Ocean Region



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Western Indian Ocean Ecosystem Guidelines and Toolkits

Guidelines for Seagrass Ecosystem Restoration in the Western Indian Ocean Region

Published by the United Nations Environment Programme/Nairobi Convention Secretariat.

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Citation:
UNEP-Nairobi Convention/WIOMSA (2020). Guidelines for Seagrass Ecosystem Restoration in the Western Indian Ocean Region. UNEP, Nairobi, 63 pp. A digital copy of this report is available at: www.nairobiconvention.org/; www. wiomsa.org

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ISSN: 2714-1942

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Preface

Seagrasses in the WIO region cover extensive areas of nearshore soft bottoms along ~12,000 km of coastline from the intertidal to depths of more than 30m (Gullström *et al*., 2002; Ochieng and Erftemeijer, 2003; Bandeira and Gell, 2003). Seagrass meadows in the region often occur in close connection with coral reefs and mangroves. Mixed seagrass beds are common (especially in Kenya, Mozambique and Tanzania), but monospecific meadows also occur.

The seagrass beds in the WIO region harbor a highly diverse array of associated plant and animal biodiversity. Due to their high primary production and complex habitat structure, seagrass beds support a variety of benthic, demersal and pelagic organisms. Many fish and shellfish species, including those of commercial interest, are attracted to seagrass habitats for foraging and shelter, especially during their juvenile life stages. Seagrass beds in the WIO region also support sizeable populations of two endangered species that feed on seagrasses, i.e. the green turtle *Chelonia mydas* and the dugong *Dugong dugon*. These marine meadows also support fisheries as nursery, breeding and feeding grounds.

Due to the complex architecture of the leaf canopy in combination with the dense network of roots and rhizomes, seagrass beds stabilize bottom sediments and serve as effective hydrodynamic barriers reducing wave energy and current velocity, thereby reducing turbidity and coastal erosion (Donatelli *et al*., 2019). Further, seagrass beds trap large amounts of nutrients and organic matter in the bottom sediment. Through microbial decomposition, seagrass biomass enters the marine food web as detritus and thus supports productivity through the recycling of nutrients and carbon. More recently, seagrass meadows have been acknowledged for their considerable carbon storage potential, and it has been estimated that globally as much as 19.9 Pg[1] of organic carbon are stored in seagrass meadows.

Seagrasses in the WIO region are under a range of threats, ranging from sedimentation from upland deforestation and erosion in river catchments, trampling and heavy concentration of fishing and tourist activities, eutrophication and physical damage from anchors, propeller scarring and boat groundings to overgrazing by sea urchins. Underlying drivers behind some of these threats include rapid demographic growth, poverty, lack of education and awareness, inadequate law enforcement, and climate change. Continued seagrass degradation across the region makes a business case for restoration efforts to ensure these critical ecosystems continue to provide their inherent goods and services.

To facilitate capacity building and promotion of seagrass restoration in the Western Indian Ocean (WIO) region, the Nairobi Convention, in collaboration with Western Indian Ocean Marine Science Association (WIOMSA), have supported the development of these Guidelines on Seagrass Ecosystem Restoration for the region. The Guidelines are practical and concise and are designed for adoption and direct application by seagrass restoration practitioners and other interested parties in the region.

The inclusion of comprehensive descriptions of seagrass ecosystems, identification of restoration sites, practical methods that can be used in the protection and restoration of these sites, and how to develop a Seagrass Restoration Management Plan that includes a monitoring framework makes this resource an essential addition to the tools available to address pressing environmental needs in the WIO.

The development of these Guidelines has followed a process that has resulted in them being endorsed by the countries of the WIO; an important aspect if they are to be actively utilized in the region. They provide a practical resource that will allow countries to build on experiences from else-

1 Pg = petagram; one Pg =10^{15} grams=one billion metric tonnes

where in the region and the world and enhance the quality and standard of ecosystem assessment and monitoring in the WIO.

I encourage practitioners in the WIO to make use of this resource and to actively contribute to improving and updating these Guidelines based on experiences gained through the WIOSAP demonstration projects. I would like to congratulate all those that have been involved in their collaborative development and have no doubt that these Guidelines will be of great use in the future.

Kerstin Stendahl
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Acronyms and abbreviations

BuDs	Buoy-Deployed Seeding system
CBO	Community Based Organizations
EIA	Environmental Impact Assessment
GPS	Global Positioning System
NGO	Non-Governmental Organization
Pg	Petagram; one Pg = 10^{15} grams = one billion metric tonnes
PVC	Polyvinyl chlorides
SCUBA	Self-Contained Underwater Breathing Apparatus
SER	Seagrass Ecosystem Restoration
TERFs	Transplanting Eelgrass Remotely with Frames
Tg	Teragram; one Tg = 10^{12} grams
WIO	Western Indian Ocean
WIOMSA	Western Indian Ocean Marine Science Association
WIOSAP	'Strategic Action Programme for the protection of the Western Indian Ocean from land-based sources and activities'

Acknowledgements

The following people are kindly acknowledged for their contributions to the preparation and review of these Guidelines: Salomão Bandeira, Jacqueline Uku, Lilian Daudi, Charles Muthama, Emma Gibbons, Leah Pettitt, Marieke van Katwijk, John Statton, Gary Kendrick, Marion Cambridge, Jason Tanner, Andrew Irving, Bob Orth, Michelle Waycott, Korjent van Dijk, Gildas Todinanahary, James Kairo, Blandina Lugendo, Marcos Pereira, Agnes Muthumbi and C.N. Paupiah. The funding received from the Global Environmental Facility-funded WIOSAP and the SIDA Partnership Projects is gratefully acknowledged, as are the expert reviewers who gave their time to ensure that a comprehensive and acceptable product resulted from this work. Finally, WIOMSA, through the MASMA programme, is thanked for their invaluable input in managing the development of the draft Guidelines and the final preparation of the document for publication.

Photo credits: Bob Orth (plates 14 and 15), Jacqueline Uku, Lilian Daudi and Charles Muthama, KMFRI (plate 20), Jason Tanner and Andrew Irving (plate 18), John Statton (plate 19), Kat Ryan, Department for Environment and Water (plate 7), Leah Pettitt and Emma Gibbons, Reef Doctor (plate 17), Luca van Duren (plate 13), Marjolijn Christianen (plate 4 - left), Paul Erftemeijer (plates 2, 3, 4 - right, 5, 6 - top and bottom left, 8, 9, 10, 11, 12 and cover photo), Salomão Bandeira (plate 1), Savanna Barry, University of Florida (plate 6 - bottom right) and , Wim Giesen (plate 16).

Glossary

Apical: arising from superior, distal or extreme end (tip).

Benthic: living in or on the seafloor (sediment).

Bioturbation: physical disruption of the seafloor by animal activity.

Biogeographical region: area of animal and plant distribution of similar or shared characteristics (distinct from other such regions).

Blue carbon: carbon captured by the world's oceans and coastal ecosystems (stored in the biomass and sediments).

Cohesive sediment: sediment containing a significant proportion of fine clay particles, which causes the sediment to bind together.

Compensatory mitigation: creation or restoration of a wetland or seagrass area or the purposes of offsetting a permitted loss of a similar wetland or seagrass area.

Demersal: living near or at the seafloor.

Herbivory: consumption/grazing of living plant tissue by animals.

Life history (strategies): characteristic aspects of an organism's reproductive development and behaviour, as well as its demographic characteristics such as generation time and life span, population density and population dynamics.

Mitigation: the restoration, creation or enhancement of a seagrass area to compensate for permitted seagrass loss.

Monospecific: consisting of a single species.

Opportunist: a species that is able to colonise, reproduce and gain significant, persisting biomass when conditions are good but also has the ability to rapidly recover from seed when necessary.

Peat pot: technique whereby small sods (plugs) of seagrass are removed and placed into commercially viable, small cups or pots (constructed of compressed peat) for ease of stacking,handling, transportation and outplanting.

Pelagic: living in the water column of the open sea.

Pioneer (species): species of seagrass with a growth strategy that enables it to rapidly colonise un-vegetated seafloor, usually with high investment in sexual reproduction, low resistance to disturbance but able to recover rapidly from seed-bank.

Rehabilitation: efforts that aim to improve conditions but not necessarily returning seagrass of the same species, abundance or equivalent ecosystem function.

Relocation: salvage operations to rescue seagrass patches that would otherwise be lost under the footprint of planned developments and move them to other areas.

Remediation: action of remedying something, in particular of reversing or stopping environmental damage or otherwise unwanted change.

Remedial planting: corrective action of planting new seagrass planting units during a restoration program to replace previously planted units that died.

Resilience: capacity of an ecosystem to respond to a perturbation or disturbance by resisting damage and fast recovery.

Restoration: any process that aims to return a seagrass system to a pre-existing condition (whether or not pristine).

Rhizome: underground stem, usually growing horizontally.

Salvage: rescuing seagrass from an area where activities are planned that will destroy that seagrass.

Secchi (disk): a circular, white and black or coloured disk lowered into a body of water to estimate the clarity of the water by measuring the depth at which it disappears.

Secondary succession: plant community which develops on sites from which a previous community has been removed.

Seed bank: an accumulation of dormant seeds in the sediment which may germinate at a later time.

Seedling: young plant that has germinated from a seed.

Shoot: a single plant unit that arises from the rhizome.

Shoot density: number of leaf shoots per surface area (generally 1 m^2).

Sod(s): section of seagrass-covered sediment held together by its roots and rhizomes (also referred to as terfs or plugs), excavated for the purpose of transplanting.

Spathes: bracts at the base of a seagrass flower that will contain the ripening seeds after fertilisation (can break off and float to aid in seed dispersal).

Sprig(s): seagrass fragment (or stem) bearing leaves, rhizome and roots, taken from a seagrass meadow with the purpose of restoration.

Tidal elevation: relative elevation or bathymetric position where plants are found in relation to the fluctuating water levels caused by the tide, usually in relation to an agreed reference point like Chart Datum (CD) which is usually the lowest astronomical tide level.

Transplantation: planting of seagrass shoots or sods derived from another seagrass area into a restoration site.

1. Introduction

1.1 Background

These *Guidelines on Seagrass Ecosystem Restoration* (SER) are intended to serve as a tool in support of seagrass restoration opportunities in the Western Indian Ocean (WIO) Region. The Guidelines were developed in response to increasing incidents of seagrass degradation across the region, either through direct anthropogenic pressures and/or climate change related impacts. The initiative is part of a wider, GEF-funded 'Implementation of the Strategic Action Programme for the protection of the Western Indian Ocean from land-based sources and activities' (WIOSAP) by the United Nations Environment Programme (Nairobi Convention). It is anticipated that these guidelines will offer necessary technical guidance on seagrass restoration for the implementation of demonstration projects across the region under the broader objective of reducing stress on seagrass ecosystems from land-based sources and activities.

The *Guidelines* comprise best practice approaches and methodologies for seagrass restoration and are based on a thorough review of global scientific and grey literature on seagrass restoration methods and documented experiences from experimental, small-scale pilot projects and large-scale restoration programs around the world.

The *Guidelines* have been tailored for practical applicability (fit-for-purpose) to the WIO region by considering locally relevant drivers of seagrass decline, dominant seagrass species, environmental settings, management contexts, logistic and economic constraints specific to the WIO region, and three case studies from within the region (see Case Study 1).

1.2 Objectives of the Guidelines

The objective of preparing these WIO-specific guidelines is to help practitioners in the region to focus on what is most likely to work for them when planning a seagrass restoration project and to assist them to better match the vast array of available restoration methods and approaches to their particular local situation. This will prevent failures due to a repeat of approaches that don't work and avoid haphazard seagrass restoration activities without key consideration of the lessons learnt from methods tested elsewhere and their workability in the region.

1.3 Target readership

The Guidelines are intended for stakeholders in seagrass restoration in the WIO region, including resource managers, restoration practitioners, scientists, students, non-governmental organizations (NGOs) and communities. The guide is written in a language style that is easily understandable and transferable. It integrates and makes use of existing global literature and guidelines/protocols/manuals on seagrass restoration, complemented by the practical experience from seagrass research and restoration projects in the WIO region.

1.4 Process followed in the development of the Guidelines

The process followed in the development of these *Guidelines* was rigorous and initiated in April 2018 at a meeting of the Nairobi Convention Focal Points in Madagascar. The need for various guidelines and the process to be followed in their development was discussed. As a first step, the Secretariat was requested to prepare Terms of Reference for a consultant to develop a working draft of these Guidelines. These ToRs were approved by the Project Steering Committee (PSC) at a meeting in Kenya held in August 2018, and a consultant was recruited in the 3rd quarter of 2018. Progress on the process was reported to a meeting of Focal Points and regional experts in December 2018 in Mozambique, while active development of these Guidelines proceeded from January 2019. This included consultation with regional experts and review of the draft *Guidelines* by the Secretariat and Contracting Parties.

CASE STUDY 1.

Seagrass *Zostera capensis* restoration experiment using a 'plug' method on tidal flats in Maputo Bay (Mozambique)

The aim of this seagrass restoration study was to assess effects of sediment digging for clam collection on *Zostera capensis* recovery and compare survival of experimentally transplanted seagrass plugs using PVC tubes to restore disturbed areas. The study was conducted on tidal flats in Maputo Bay, Mozambique (Plate 1). The effectiveness of replanting *Z. capensis* was tested using PVC tubes of two diameters (7.5 cm and 4.5 cm). Seagrass community structure, shoot density, fauna abundance, epiphytes and grain size were investigated at the start (before planting) and at 14, 45, 75 and 175 days after planting. A total of 160 plugs were transplanted in eight plots (80 plugs with the 4.5 cm tube and 80 plugs with the 7.5 cm tube) and monitored for survival, shoot density and epiphyte abundance. Seagrass at donor sites recovered rapidly (% cover restored within ~two weeks and other ecological attributes in subsequent weeks). After three months, survival of planted seagrass at restoration sites differed significantly between the plug method, being high for 7.5 cm diameter PVC tubes (60 %) and low (<10 %) for 4.5 cm tubes. While *Z. capensis* recovered rapidly from the disturbance caused by clam harvesting, this species is impacted by a range of other pressures in Maputo Bay. Initial results of the experiment are promising and indicate that the use of PVC corers (7.5 cm not 4.5 cm) to relocate seagrass plugs may prove to be appropriate for (small-scale) *Z. capensis* restoration in Maputo Bay (Mabuto *et al.*, 2008).

Plate 1. Photographic impression of the ongoing seagrass restoration project at Maputo Bay (Mozambique) using cores of seagrass for the transplantation of *Zostera capensis* on intertidal flats affected by clam digging.

The *Guidelines* were validated during the Science to Policy meeting attended by Focal Points, experts and partners in May 2019, during which further technical and policy input were given. The updated *Guidelines* were launched at the PSC meeting held in June 2019, which approved: (i) adoption for wider regional application; (ii) testing; (iii) revision as appropriate after testing, subject to feedback from different stakeholders; and (iv) application in capacity building around seagrass restoration. The PSC approvals were followed by professional editing, layout/design, publication and dissemination.

2. Seagrass Ecosystems in the WIO Region

The Western Indian Ocean (WIO) region encompasses the Comoros, France (Réunion), Kenya, Madagascar, Mauritius, Mozambique, Seychelles, Somalia, South Africa and Tanzania. Seagrasses in the WIO region cover extensive areas of nearshore soft bottoms along ~12,000 km of coastline from the intertidal to depths of more than 30 m (Gullström *et al.*, 2002; Ochieng and Erftemeijer, 2003; Bandeira and Gell, 2003). Seagrass meadows in the region often occur in close connection with coral reefs and mangroves. Mixed seagrass beds are common (especially in Kenya, Mozambique and Tanzania), but monospecific meadows also occur.

2.1 Seagrass species

A total of 12 seagrass species[2] have been documented from the WIO region (Plate 2). Two of the most common species are *Thalassia hemprichii* and *Thalassodendron ciliatum*, both forming extensive beds in most parts of the region. *Thalassia hemprichii* is usually found in more protected habitats or on intertidal flats, whereas *Thalassodendron ciliatum*[3] normally inhabits exposed or semi-exposed subtidal sandy habitats (such as the reef lagoons along parts of the Kenyan coast) (Plate 3). *Halophila ovalis*, *Cymodocea rotundata*, *Cymodocea serrulata*, *Syringodium isoetifolium* and *Halodule uninervis*

Seagrasses of the Western Indian Ocean region

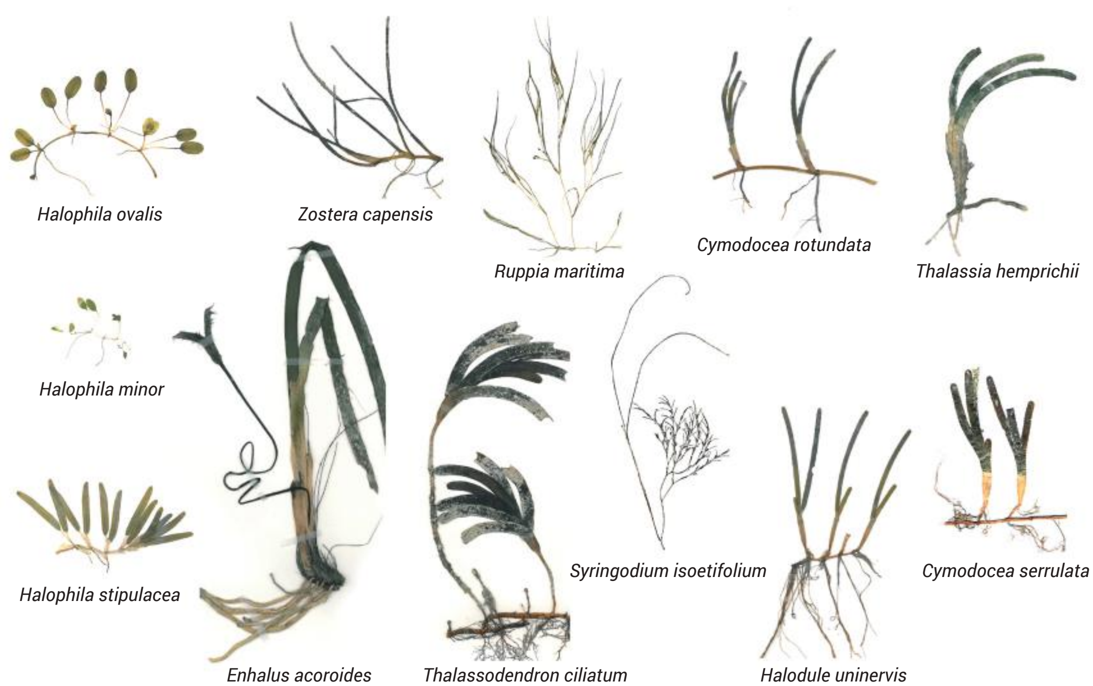

Plate 2. Seagrass species of the WIO region (scans of dried herbarium specimen; note flowering parts in specimen for *Ruppia maritima, Enhalus acoroides* and *Syringodium isoetifolium*).

2 Several other seagrass (*Halodule pinifolia, Halodule wrightii, Halophila ovata, Hlophila decipiens* and *Halophila beccarii*) have been reported for the region, but these may constitute misidentifications or need further confirmation. Taxonomy here follows Waycott et al. (2004).

3 A new *Thalassodendron* species (*T. leptocaule*) was recently described from rocky habitats in southeast Africa, but the distribution of this new species in the WIO region is not yet well-understood.

are also common throughout most of the region. *Enhalus acoroides*, *Halophila stipulacea* and *Halophila minor* (a member of the *Halophila ovalis* complex) appear to be restricted to northern Mozambique and Tanzania and some locations in Kenya. *Zostera capensis* (which is listed in the IUCN Red List as endangered) is only common in southern Mozambique and South Africa, where large monospecific stands may occur, but the species has also been recorded from Kenya. *Ruppia maritima*[4] is common in estuaries in South Africa but also occurs in coastal lakes in southern Mozambique and Madagascar.

It is noticeable in many intertidal and subtidal areas that the seagrass beds comprise a patchwork of different shoot densities. In some places, there may be extensive and dense beds stretching for hundreds of meters, but along fringes of lagoons, the lower and upper intertidal and other areas, there may be a patchwork of dense, completely bare and newly growing patches. Such a cycle of bare sand to dense shoot density areas are commonly related to how the seagrass root system adapts to waves, desiccation and other physical influences.

2.2 Ecosystem functions and values

The seagrass beds in the WIO region harbor a highly diverse array of associated plant and animal biodiversity. Due to their high primary production and complex habitat structure, seagrass beds support a variety of benthic, demersal and pelagic organisms. Many fish and shellfish species, including those of commercial interest, are attracted to seagrass habitats for foraging and shelter, especially during their juvenile life stages. Seagrass beds in the WIO region also support sizeable populations of two endangered species that feed on seagrasses, i.e. the green turtle *Chelonia mydas* (Plate 4) and the dugong *Dugong dugon*.

The great importance of East African seagrass ecosystems for fisheries is gradually emerging from an increasing research effort on the role of the seagrass meadows in this region as nursery, breeding and feeding grounds for marine fish and crustacean species of economic importance such as shrimps (*Penaeus*) and spiny lobster (*Panulirus*). Harvesting of bivalves and other invertebrates for food from intertidal seagrass areas is a locally important economic activity (e.g. Tanzania and Mozambique).

Due to the complex architecture of the leaf canopy in combination with the dense network of roots and rhizomes, seagrass beds stabilize bottom sediments and serve as effective hydrodynamic barriers reducing wave energy and current velocity, thereby in turn reducing and coastal erosion. Further, seagrass beds trap large amounts of nutrients and organic matter in the bottom

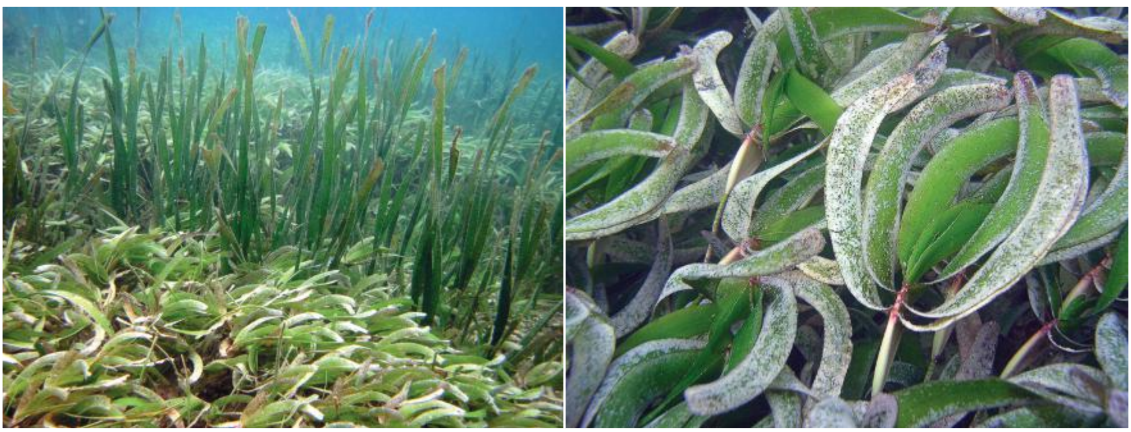

Plate 3. Impressions of typical seagrass meadows in the Western Indian Ocean, here showing a mixed stand of *Thalassodendron ciliatum* and *Enhalus acoroides* (left), and a close-up of *Thalassodendron ciliatum* (right).

4 *Ruppia maritima* has often been described as a freshwater plant species with a pronounced salinity tolerance. It is included here as a true seagrass species, in line with recent seagrass guidebooks and key literature.


Plate 4. Seagrass meadows in the WIO region serve a range of important ecosystem services, including as feeding grounds for endangered species such as Green turtles (left) and sustaining local fisheries (right).

sediment. Through microbial decomposition, seagrass biomass enters the marine food web as detritus and thus supports productivity through the recycling of nutrients and carbon.

More recently, seagrass meadows have been acknowledged for their considerable carbon storage potential. It has been estimated that globally , as much as 19.9 Pg of organic carbon are stored in seagrass meadows. Organic carbon in seagrass sediment accumulates from both *in situ* production and sedimentation of particulate carbon trapped from the water column. Carbon accumulation in marine sediments provides long-term storage of organic carbon and has been referred to as "blue carbon" to distinguish it from carbon in terrestrial sinks. Seagrass meadows cover only 0.1 % area of the world's ocean floor yet account for 10–18 % of the total oceanic carbon burial, accumulating carbon at rates of 48 to 112 Tg C yr$^{1.}$

The huge economic benefits that seagrass ecosystems provide to the WIO regional economy through these various ecosystem functions have been estimated to represent a total economic value of some USD 20.8 billion (Obura *et al.*, 2017).

2.3 Drivers of decline

Seagrasses in the WIO region are under a range of threats (Eklöf, 2008; UNEP, 2009; Nordlund, 2012; Lugendo, 2015). Sedimentation from upland deforestation and erosion in river catchments are affecting seagrass areas in the Comoros and northern Kenya. Trampling and heavy concentration of fishing and tourist activities are an issue along parts of the coasts of Mozambique, Mauritius and Kenya (Bandeira and Gell, 2003; Daby, 2003; Ochieng and Erftemeijer, 2003; Plate 5). Eutrophication and physical damage from anchors, propeller scarring and boat groundings have affected seagrasses near urban centres such as Dar es Salaam (Tanzania), Mombasa (Kenya) and Maputo (Mozambique). Destructive effects of certain types of fishing gear on seagrasses, such as beach seining, are commonly reported from Tanzania, Mozambique and southern Madagascar (Gullström *et al.*, 2002). Digging to collect intertidal bivalves is common on intertidal seagrass meadows near Maputo (Mozambique), where it has affected seagrasses and associated biodiversity (Bandeira and Gell, 2003). Seaweed farming in Zanzibar (Tanzania) is causing short- and long-term effects on seagrass growth and abundance (through shading, removal, trampling and boat mooring), which is affecting local fish catches (Eklöf *et al.*, 2006). Impacts on seagrasses due to herbicide leakage and sugar industry runoff have been documented from Mauritius. Overgrazing by the white-spined sea urchin *Tripneustes gratilla* due to overfishing of its predators has been implied as a potential cause of seagrass decline along parts of the Kenyan coast (Alcoverro and Mariani, 2002).

Underlying drivers behind some of these threats include rapid demographic growth, poverty, lack of education and awareness, inadequate law enforcement, and climate change (Anemone-Mabuto *et al.*, 2017). Rapid coastal development

Plate 5. Impact of tourism industry on seagrasses. Seagrass cover declined in front of a Mombasa north coast beach hotel.

(involving dredging, clearing and pollution) and oil pollution (including the risk of oil spills) have not yet caused dramatic impacts on seagrasses in the WIO region to date (see Case Study 2). However, emerging economic growth and population demographics are likely to put an increasing pressure on the coastal and nearshore environment in the region in the years to come. For example, recent plans for major port developments in Kenya and Tanzania that will involve considerable dredging activities and the proposed installation of gas pipelines in Northern Mozambique following the recent discovery of large natural gas reserves are likely to pose further risks of impacts on seagrasses and their associated livelihood benefits in the WIO region (Erftemeijer and Lewis, 2006).

2.4 The case for seagrass restoration

The rationale for seagrass restoration is to restore damage to or rehabilitate a seagrass ecosystem that has been altered to such an extent that it can no longer sufficiently self-correct or self-repair. This is generally in response to the observation (e.g. through remote sensing, mapping and/or field investigations) that there has been significant degradation or loss of seagrass in certain areas. While the highest priority should always be given to avoid such degradation and loss, this is not always possible or practical (e.g. when the cause of seagrass loss is outside management control), and seagrass restoration through active intervention may then be necessary. The ultimate goal of seagrass restoration would be to not only re-vegetate damaged or degraded areas but also to restore the lost ecosystem services these areas used to provide. In some cases, seagrass restoration may be considered to re-introduce a seagrass species that was lost completely from an area.

2.5 Incorporating seagrass restoration into policy frameworks

There are benefits to considering the incorporation of seagrass restoration as a management tool into regional and national policy frameworks and decision-making contexts. Some

CASE STUDY 2.

Susceptibility and clean-up of seagrass beds impacted by oil spills

By *Matthew D. Richmond*

In the Western Indian Ocean, seagrass beds are mainly located in the mid - to lower - shore of inlets and bays, subtidal lagoons and shallow, sheltered low-energy areas protected by reefs or coastal barriers. Their locations make them vulnerable to oil spills, because these areas tend to be where uncontained oil tends to accumulate. The seagrass ecosystem is sensitive to oil, particularly because of the associated fauna inhabiting the sediment, canopy and leaf surfaces or using the seagrass beds as nursery or feeding grounds. Spills reaching the shore during low tide are more likely to impact intertidal seagrass beds, but once the tide has risen, oil would typically float up and be transported further up the shore. Seagrass systems situated at deeper depths are less likely to be affected by long-term exposure to spilled oil. Effects of petroleum products on seagrass ecosystems (Figure 1) may include:

- Direct mortality of organisms due to smothering, fouling, asphyxiation or poisoning
- Indirect mortality due to the death of food sources or destruction or removal of habitat
- Mortality of juvenile fish and invertebrates using seagrass beds as nursery grounds
- Incorporation of sub-lethal amounts of petroleum fractions into body tissue of biota
- Reduction market value of harvested shellfish due to absorption of hydrocarbons
- Incorporation of potentially carcinogenic substances into the food chain

Depending on the degree of oiling, short-term effects on the seagrass plants can be expected when the above-ground plant parts (leaves and leaf sheaths) are in direct contact with floating oil. A recent review of available case studies

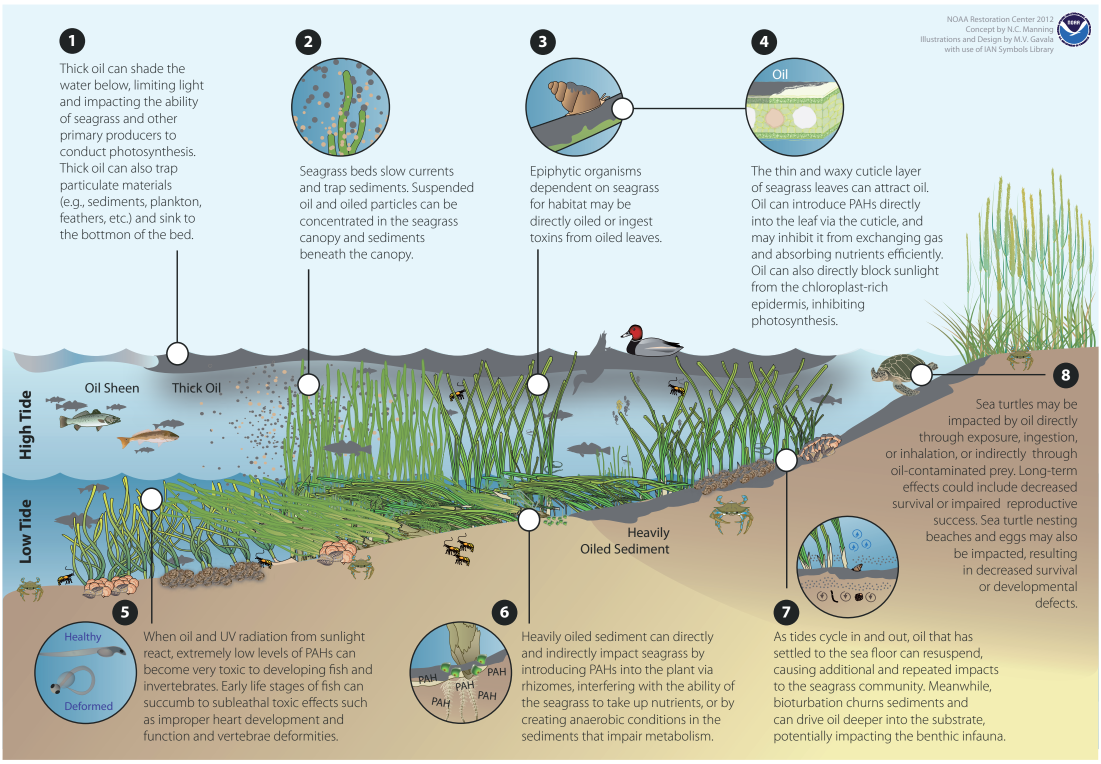

Figure 1. Potential impacts of oil spills to seagrass and associated organisms. (Source: NOAA Restoration Centre 2012, cited in Kenworthy *et al.*, 2017).

found the effects of oil spills on seagrass beds to be inconsistent. At many sites, there was little or no evidence of significant long-term or persistent effects, unless the beds had been completely covered with oil or below-ground plant parts were affected by oil penetration into the sediment. As long as the seagrass and its root system is not seriously affected, meadows are generally able to recover quite rapidly.

When an oil spill situation develops that is projected to reach and potentially impact seagrass beds, it is important that shoreline responders carefully select spill-combat methods aimed at effectively preventing oil from reaching the seagrass. If a spill evolves to the point where clean-up will be required, the aim should be to contain the oil it so that it may be rapidly collected and removed from the system. Responders should mark 'no-go' areas for clean-up crews, where seagrass beds occur adjacent to other marine and coastal habitats that are in the process of clean-up. Whatever chemical, mechanical or manual clean-up methods are used, operations must be well-supervised and documented. In tropical environments, where evaporation rates are very high, natural cleaning and low pressure flushing are the preferred responses to stranded oil in seagrass beds. Removal of sediment, burial, indiscriminate cutting and burning of oiled vegetation, use of sinking agents, steam cleaning or high pressure flushing are all to be avoided. Only removal of the bulk of the free-phase oil should be attempted, leaving any remaining oil to weather naturally to minimise physical damage to the seagrass structure. There are no documented cases that indicate the need for active restoration (planting) of seagrasses following an oil spill.
The use of dispersants can increase stress to seagrass plants and pose additional damage to the seagrass system, though the toxicity of the dispersants and the resulting dispersed oil depends on the species exposed. Appropriate preparations for oil spills include comprehensive oil spill contingency planning and pre-impact baseline assessments of vulnerable seagrass areas in close vicinity to oil refineries, major ports or oil terminals.

Some further reading: Fonseca *et al.,* (2017); Kenworthy *et al.,* (2017).

countries in the WIO region have already done so quite specifically. The National Strategy and Action Plan of Biological Diversity of Mozambique, for example, makes specific mention of the importance of seagrasses and gives due attention to the need for restoration of degraded ecosystems (MITADER, 2015). In Kenya, environmental restoration is anchored in the 1999 Environmental Management and Coordination Act (National Council for Law, 2018) and a 'Coral Reef and Seagrass Ecosystems Conservation Strategy 2014-2018' has been developed, which specifically promotes the development and implementation of seagrass restoration protocols and activities along with dedicated monitoring and evaluation programs (Kenya Wildlife Service, 2013). Such policy instruments are also strategically important during environmental impact assessments, when setting compensation for environmental damage or negotiating blue carbon offsets. Seagrass restoration does not stand alone but is part a suite of management options and tools for environmental conservation, protection, management and rehabilitation. This is important, especially when considering the wider context of the need to address the underlying causes of seagrass decline and protect seagrasses from land-based sources and activities (GESAMP, 2001).

3. Seagrass Restoration – General Considerations

The widespread loss of seagrass meadows worldwide, coinciding with the growing knowledge and awareness of the resource value of these systems, has led to increasing attention on seagrass restoration. A range of methodologies having been developed and tested in a variety of environments, with varying degrees of success and plenty of lessons to learn from.

Seagrass restoration or rehabilitation may be recommended when the seagrass ecosystem has been altered to such an extent that it can no longer sufficiently self-correct or self-renew. Under such conditions, normal processes of secondary succession or natural recovery from damage are inhibited in some way. Unfortunately, for a long time the practice of seagrass restoration has emphasized planting seagrasses as the primary tool in restoration, rather than first assessing the reasons for the loss of seagrasses in an area and working with the natural recovery processes that all ecosystems have (see Case Study 3). Seagrass restoration may also be considered where there is a need to re-introduce a seagrass species that was lost from an area.

In other cases, seagrass restoration is sometimes conducted as a form of compensatory mitigation by creating seagrass meadows in areas that appear suitable for growth, in an attempt to substitute (commonly referred to as an 'offset') for unavoidable loss of healthy seagrass elsewhere due to the 'footprint' of a certain development (e.g. port expansion or land reclamation). This may be an obligatory requirement as part of environmental permit approvals under a principle of 'no-net-loss'. Such mitigation may include seagrass relocation or salvage operations (see below). However, it is emphasized here that seagrass restoration should never be considered the first alternative when planning for the mitigation of coastal development projects or to justify mitigation as a compensation measure for economic activities.

Another purpose for seagrass restoration, suggested more recently in response to concerns over climate change, could be to plant seagrasses for 'blue carbon farming' or to reduce ocean acidification, but this has not yet been tried anywhere.

3.1 Terms and definitions

In the context of this manual, the term 'seagrass *restoration*' has been adopted to mean any process that aims to return a seagrass system as much as possible to a pre-existing condition (whether or not this was pristine), with consideration of natural recovery processes. This broader definition includes *rehabilitation* efforts that aim to improve conditions but not necessarily return seagrass of the same species, abundance or equivalent ecosystem function. The term 'seagrass *transplantation*' is used to describe the planting of seagrass shoots or sods derived from another seagrass area into a restoration site, while the term 'seagrass *relocation*' is used to describe salvage operations to rescue seagrass patches that would otherwise be lost under the footprint of planned developments and move them to other areas.

3.2 Common sense considerations

If seagrass is not growing somewhere, there are two possibilities: [1] it has never grown there because the conditions at the site are unsuitable, or [2] it used to grow there in the past but it disappeared due to an adverse (human or natural) impact. In both cases, the environmental conditions are apparently not suitable for seagrass at present. As such, it would not make much sense to plant seagrass at such sites and expect any of these transplants to survive. Instead, the underlying cause(s) of the seagrass loss needs to be addressed first by improving the environmental conditions.

Once conditions have significantly improved or returned back to what they were before the disturbance, seagrass generally comes back by itself, gradually recovering its former cover and

CASE STUDY 3.

Passive seagrass restoration at Port Manatee, Florida (USA)

Restricting boating access from certain areas (damaged by propeller scarring) in Tampa Bay, Florida through regulatory measures and the installation of demarcation buoys (prohibiting all entry, transit, anchoring or drifting within the restricted areas) resulted in significant (4.5 ha) and successful seagrass recovery (through 'passive' restoration) at relatively low costs (USD 300,000 for buoys and three years of enforcement patrols and maintenance) (Swingle, 2003).

The passive approach by far exceeded the disappointing results (very low or no survival) of a simultaneous (~USD 5 million) mechanical seagrass relocation approach that had used a 'giga-unit sod' transplanting machine (Plate 6) to salvage and relocate ~11,000 large sods from a port expansion zone into a nearby ~4 ha relocation site (Cuba, 2003). Whilst capable of relocating viable plant material along with suitable sediments, the condition of the donor material and the poor suitability of the receiving habitat (marginal) contributed to the overall poor success of the mechanical approach. This case demonstrates that – where feasible – reversal of seagrass degradation by addressing the root cause(s) in order to facilitate natural recovery can be one of the most cost-effective approach for large scale seagrass restoration.

Plate 6. Seagrass salvage and restoration work at Tampa Bay (Florida): Top: 'Giga-unit sod' transplanting machine. Bottom (left): intertidal area from where 1x1 m seagrass sods have been removed with the 'giga-sod' machine (see frame for reference of scale). Bottom (right): demarcation buoys used to prohibit all entry, transit, anchoring or drifting within restricted areas to allow seagrass to recover from boating damage.

ecological functioning with time (Vaudrey *et al.*, 2010). The only potential bottleneck to such natural recovery could be recruitment limitation (a lack of supply of seeds or fragments), either due to barriers to connectivity with adjacent (unaffected) meadows or due to the absence of any significant populations remaining nearby from which the site could be re-populated. In such cases, it would make sense to bring seagrass seeds or plant material from elsewhere to restore some vegetative cover (see Case Study 4). When such revegetated patches are large enough, they will eventually be capable of sustaining themselves, expanding and gradually recolonizing the site.

Inappropriate site selection and a lack of planning (given little or no consideration to why the seagrass disappeared in the first place) are among the most frequently cited reasons for failure of seagrass restoration attempts (Box 1). Please refer to Chapter 8 for suggestions on how to develop a Seagrass Restoration Management Plan.

3.3 Hierarchy of approaches to seagrass restoration and management

For the most cost-effective and meaningful approach to seagrass restoration, the following four-step hierarchy of interventions is recommended, in order of priority:

STEP 1: REMOVING CAUSES OF FURTHER DECLINE

The objective is to prevent ongoing loss and reverse degradation of seagrasses by addressing the drivers of decline. This may include a variety of approaches, such as: the establishment of marine protected areas (MPAs); imposing boating access-restrictions; banning the use of trawling; beach-seining and other destructive fishing gear in seagrass areas; installation of anti-trawler devices; improving watershed and catchment management practices; investing in waste-water treatment systems to reduce eutrophication (e.g. Greening and Janicki, 2006; Vaudrey *et al.*, 2010); adopting a thorough EIA process; and avoiding seagrass areas in site selection for ports, reclamation, industry, aquaculture, pipelines and other infrastructure.

STEP 2: ASSISTING NATURAL RECOVERY

This involves active approaches to create/restore conducive conditions that will facilitate and support or speed up the natural recovery of seagrass vegetation and its associated ecosystem functions and biodiversity. This may include hessian bags or geotextile applications (to stabilize the substrate, trap recruits and facilitate successful establishment), restoration of tidal exchange (when restricted or blocked), management of freshwater inflow (e.g. in hypersaline estuaries), hybrid engineering measures such as bunds, sand bars, mussel ridges or oyster reefs (to create

Box 1. Common reasons for failure of seagrass restoration attempts

- Inappropriate site selection
- Uprooting of transplants due to strong flows, high wave energy or swell
- Sediment instability causing erosion or smothering and burial of seedlings
- Poor water quality (turbidity, eutrophication, low light)
- Algal blooms and/or excessive epiphyte growth
- Inadequate anchorage of transplants (washed away)
- Poor planning (no reversal of threats, lack of consideration for site selection)
- Too shallow (desiccation) or too deep (insufficient light)
- Excessive bioturbation (e.g. by polychaetes or stingrays) uprooting transplants
- (Over)grazing of transplants (e.g. by sea urchins or amphipods)
- Disease (e.g. fungal attack on seeds or seedlings)
- Too small-scale (poor resilience, insufficient self-facilitation)
- Lack of donor material or seed stock (e.g. no flowering)
- Damage from human activities, storms, floods or spills
- Large-scale application of unproven technology (insufficient testing)
- Unrealistic expectations (re: costs, scale, duration, chances of success)

CASE STUDY 4.
Translocation of a *Ruppia tuberosa* seed bank in the Coorong

The ecological health of the Coorong, a coastal lagoon system in South Australia, was devastated by a long-term drought from 2006 to 2010 and upstream over-abstraction of water from the Murray River. Decreased water levels and extreme salinities resulted in a rapid decline of *Ruppia tuberosa*. Despite recent improvements in environmental conditions in the Coorong, *R. tuberosa* populations in the two main lagoons of the Coorong have not naturally returned on a large scale, due to a severely exhausted seed bank. Lake Cantara, a small nearby saline lake within the Coorong National Park, has an established and healthy population of *R. tuberosa* that largely survived the drought and acted as the donor site for this seed bank translocation project.

Ruppia tuberosa seeds are about 1 mm in size, black and tear-dropped shaped, and can be found in high densities in the top layer of the lake bed sediments. Seeds were collected in late summer and early autumn, when Lake Cantara was dry (Plate 7). A small excavator was used to scrape off the top 15 mm of bare sediment containing the seeds. Track mats were used to reduce the impact of the excavator. The seed was collected in strips, with even-width gaps to promote faster recovery of the *R. tuberosa* seed bank in Lake Cantara.

The sediment was transported in bags to translocation sites in the Coorong. 'Planting' was carried out during exposure of the mudflats along the Coorong (South) Lagoon when water levels were low. Planting sites were chosen based on water level predictions, as *R. tuberosa* in the Coorong is known to grow best at water depths between 30 cm and 100 cm. Planting involved lightly agitating the mudflat surface, scattering the seed sediment, and then pressing it into the soil. Deeper sections of mudflats had shallow water cover even at planting time, so the seed sediment was scattered directly into the water and local wave action kept it in place. A total of 280 tonnes (14,080 bags) and 450 tonnes (30,100 bags) of sediment were translocated in 2013 and 2014, respectively. An estimated area of ~20 ha and ~41 ha were restored during the two years. The restoration efforts were successful in that *R. tuberosa* did recolonise the areas transplanted. While the restoration helped recovery of *R. tuberosa* in the Coorong, water levels did not rise high enough to allow completion of the reproductive cycle at the re-vegetated sites and densities of seeds and turions (wintering buds that remain dormant at the lake bottom) remained low compared to historical values (Collier *et al.*, 2016).

Plate 7. Stages in the *R. tuberosa* translocation program 2014/2015: (a) harvesting seeds in sediments at Lake Cantara, (b) stores of sediments containing seeds, (c), placement of stored sediments and (d), spreading actions.

calmer conditions), or infilling of larger and deeper excavated injuries from boat groundings or propeller scars through regrading with sediment-filled biodegradable geotextile tubes.

STEP 3: OVERCOMING RECRUITMENT BOTTLENECKS

There may be evidence of recruitment limitation, for example, barriers to connectivity, lack of seed banks, near-total loss of vegetation over large areas with very limited or no remaining local sources to replenish from, or if sexual reproduction in the dominant seagrass species is a very rare event. In such cases, there is need for intervention to overcome the bottlenecks to recruitment (Erftemeijer *et al.*, 2008; Statton *et al.*, 2017). Such interventions may include seed-based methodologies and efforts to restore connectivity (e.g. installation of culverts, establishment of MPA networks, re-opening of dammed estuaries). Other approaches that could be considered include the prohibition (or strict management) of significant disturbances (e.g. dredging) during sensitive reproductive periods (such as flowering or seed germination of key seagrass species). Interventions to overcome bottlenecks to successful seedling establishment, such as sediment instability caused by excessive bioturbation (e.g. by altering the sediment composition of the top layer or by the addition of shell material) would also fall into this category.

STEP 4: ACTIVE RESTORATION BY PLANTING ('GARDENING')

This is undertaken only when steps 1-3 above have been implemented and natural recovery is still slow or unsuccessful, whereby manual transplanting of shoots/fragments or relocation of plugs, sods or excavated mats of seagrass may be considered. Manual planting is also often carried out in compliance with off-set requirements for unavoidable damage (footprint) as part of permit approvals for major coastal developments or port expansions. Planting of seagrasses may also be conducted to establish demonstration projects (for education or research purposes) as proof-of-concept to reintroduce a species lost from an area, for blue carbon farming, or to engage local communities to enhance environmental awareness.

4. Restoration Methods

A plethora of methods for seagrass restoration have been developed and tested over the past few decades. Seagrass restoration is a relatively young discipline with new methods, innovative ideas and approaches being developed all the time. There are several excellent manuals, guidelines and reviews that describe and review a wide range of seagrass restoration methods in detail. Particular mention deserve the work by Mark Fonseca (Fonseca, 1994; Fonseca *et al.*, 1998; Fonseca *et al.*, 2002), Bob Orth (Orth and Marion, 2007; Orth *et al.*, 2007), and the late Robin R.R. Lewis III (Lewis, 1987; Treat and Lewis, 2006). Useful recent reviews include: Calumpong and Fonseca (2001) and Van Katwijk *et al.* (2016).

Development and implementation of appropriate methods requires experience and familiarity with species' growth habits and life histories. Numerous methods have been shown to establish seagrass successfully; however, familiarity with handling and planting methods, as well as the ability to work in or under the water, are essential. Most experience with these methods has been gained on temperate seagrass species, especially in the USA (Fonseca *et al.*, 1998) and Australia (Statton *et al.*, 2018). By comparison, seagrass restoration in tropical regions is still in its beginning stages (apart from some great work in Florida and earlier pilots in the Caribbean) and certainly has not yet been done successfully on a large scale. Seagrass restoration in the WIO region is still in its infancy, but some first small-scale trials have been initiated recently in Kenya, Madagascar and Mozambique.

4.1 Manual transplanting

Planting methods in deeper waters will require the use of SCUBA equipment, experienced boat operators and trained SCUBA divers. Shallow waters may allow for the restoration works to be carried out by snorkelling, provided that the water depth is shallow enough to allow a snorkelling person to reach the bottom while holding his/her breath. Intertidal areas are often easily accessible on foot during low tide (provided they are not extremely muddy) and may as such offer the least logistical challenges to the planting activities. In all cases, it is important to clearly mark the planting areas, so its boundaries are clearly visible (e.g. with poles or buoys).

All planting methods require available 'wild stock' as a source and are labour-intensive. While this can easily translate in high costs (per area) - especially in western economies, where labour-costs are typically high - this may not necessarily be so in major parts of the WIO region or in restoration programs that involve local communities and/or volunteers.

Planting projects typically involve either sediment-free seagrass units, seagrass sods with sediment and intact rhizome/root systems, or seeds/fruits.

4.1.1 Sediment-free methods

Sediment-Free Methods

Advantages: Sediment-free methods have the have the advantage of reducing the burden of carrying (heavy) associated sediment.

Disadvantages: The main disadvantage of this approach is its labour-intensiveness (thus limiting the spatial scale of the restoration) and the use of metal staples, which is sometimes criticised, but these can be removed later (and re-used) or substituted for a biodegradable alternative (e.g. bamboo skewers).

For most sediment-free methods, plants are dug up using a shovel (or other device), the sediment is shaken off from the roots and rhizomes and the plants are placed in flowing seawater tanks, floating pens or similar for holding until made into 'planting units' (see Plate 8 for general morphology). It is important to ensure the presence of growing rhizome tips in individual planting units as these provide a source of new shoots and horizontal growth, a means of colonizing of new areas. For vegetative stock, a minimum of at least one shoot (with growing tip) per planting unit is recommended. However, benefits can be derived from the clonal nature of the plant if a larger number of short shoots per length of rhizome is preserved (e.g. preferably three shoots per rhizome fragment in *Thalassia*). Plants should be collected and planted on the same day, kept in water with the same ambient temperature and salinity, and kept as moist as possible when out of the water. In a few cases, artificial seagrass mimics have been used with the aim of temporarily creating more stable conditions to allow for the establishment and recovery of natural seagrass plants in between the mimics.

Seagrass should be planted either directly into the bed (as sprigs) or anchored using one of a variety of devices such as rods, pegs, rings, nails, stones, shells, rebar, skewers or staples. U-shaped metal staples or robust wire hooks (e.g. fencing wire) are the most common anchoring devices that have been used successfully in sediment-free seagrass planting programs to date (Plate 9). Plants are attached to the staples by inserting the rhizome + root portion of the plant fragments under the 'bridge' of the staple and securing the plants with a paper- (not plastic-) coated metal twist-tie. The twist-tie is secured around the plants at the base so that the leaves will extend from under the staple up into the water column when planted. A small strip of paper has been used to protect the rhizomes from the twist-tie by wrapping the group of plants with the paper and then inserted into the sediment so that the roots and rhizomes are buried. Loosening the sediment with a utensil such as a dive knife facilitates placing the roots into the sediment. Consideration of the orientation of the plants and angle of the staples or wire hooks can be important in high energy environments so that the plants are not displaced by the dominant current flow.

One person can lay out the planting units beforehand at the desired spacing, while a second person follows and installs them. The step of attaching plants to staples can be prepared beforehand but is time consuming. In areas with low wave energy and current velocity, groups of plants may be stapled to the bottom without attaching them to the staples beforehand. When negative buoyancy is not required, the metal sta-

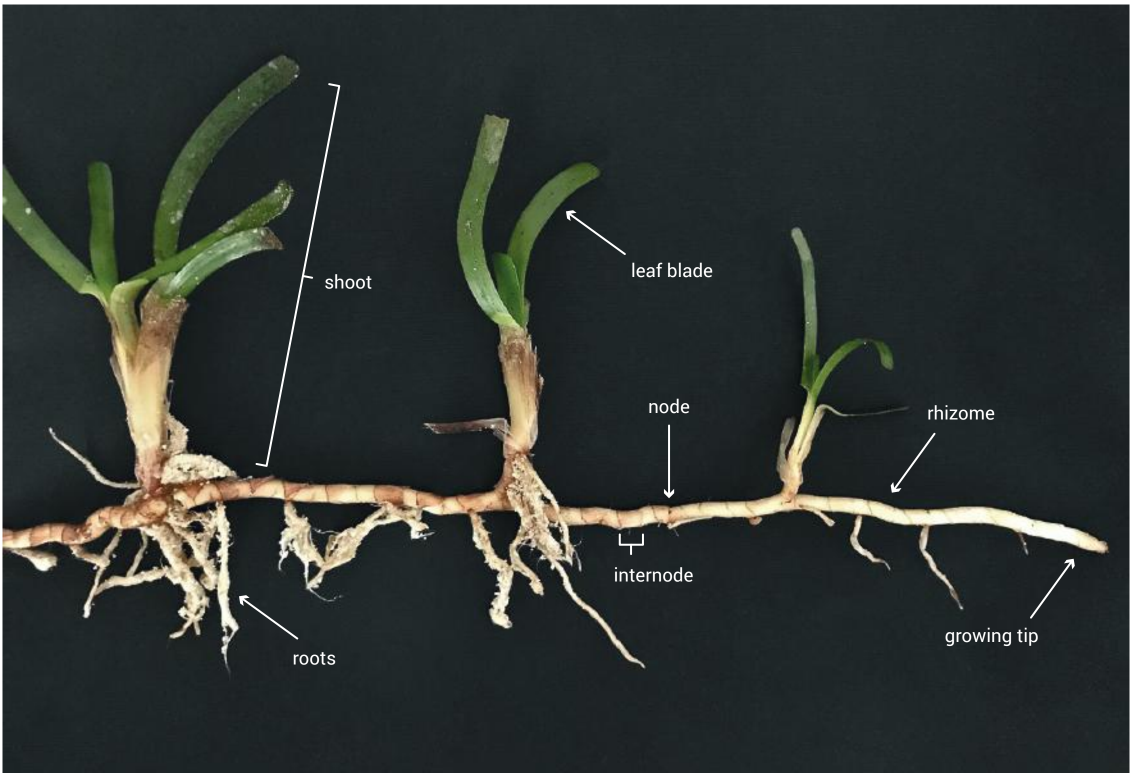

Plate 8. Diagram showing the general morphology of a seagrass plant.

Plate 9. Demonstration of the staple method, showing the attachment of a seagrass shoot to the staple (left) and insertion of the staple into the sediment during planting.

ples may be substituted by bamboo skewers (bent into a 'V'). The staples or wire hooks can be retrieved once plants have established themselves successfully, and then be reused again for further planting (e.g. in the next year).

Plants have also been woven into biodegradable mesh fabric (e.g. hessian bags[5]) that is attached to the sediment surface as a planting unit (Wear *et al.*, 2010; Plate 10). This method has been applied successfully to restore seagrasses in mooring scars in Western Australia and degraded meadows in Kenya (see Case Study 10).

In a recent, more innovative technique developed in the USA, plants were tied with paper strings (leaves up, roots down) to the bottom of frame-deployed systems (TERF units) that can be deployed from small boats in deeper waters without the use of divers. The frames help to protect the plantings from biological and physical disturbance and are held down at the bottom with bricks or metal pins and marked at the surface with buoys (Plate 11). Later, the cage systems can be removed once the plants have successfully rooted and their paper ties have decomposed.

Plate 10. Demonstration of weaving seagrass shoots into biodegradable hessian mesh material.

5 Alternatively, sediment-filled hessian bags can be placed as 'mattresses' along the edge of healthy seagrass systems and left for natural colonization by surrounding seagrasses. Once the mattresses have an even and dense seagrass coverage, they can be transferred to a restoration site. Trials of this method - though not 'sediment-free' - to relocate *Halophila ovalis* and *Halodule uninervis* in Dubai and Abu Dhabi showed potential.

4.1.2 Seagrass-with-sediment methods

Seagrass-With-Sediment Methods

Advantages: Relatively easy, generally less labour-intensive (per area) and yielding higher survival than sediment-free methods.

Disadvantages: The main disadvantage of these methods is the logistical challenge posed by the weight of the sods/plugs, which can be quite heavy to carry around (depending on their size) over longer distances, especially with deeply rooted species or when the donor bed is far away from the planting site.

Within this method there are different extremes, depending on the volume of seagrass to be planted (Plate 12). The sod or turf technique represents planting the larger volumes, consisting of planting a shovel-full of seagrass with sediment (including benthic fauna) and rhizomes/roots intact. The only equipment needed are shovels and some sort of (large) basins to hold the sods. However, if the donor site is far away, transporting the sods may present a logistical problem as the weight of the material can be a physical burden. Deeply rooted species, such as *Enhalus acoroides* and *Thalassia hemprichii*, may require removal of a tremendous amount of sediment to harvest the belowground plant structures intact. Furthermore, harvesting an entire sod may constitute a significant perturbation in the donor meadow, which may inhibit its recovery.

The plug method utilizes tubes as coring devices to extract the plants with the sediment and rhizomes intact. The core tubes can be made of any diameter PVC plastic pipe with caps for both ends to initially create a vacuum and keep sediments from washing out the bottom. The tube is inserted into the sediment, capped (which creates a vacuum), pulled from the sediment and capped at the other end to avoid losing the plug. This is relatively easy in soft but cohesive sediments with smaller, thinner-leaved seagrass species, but becomes more challenging in coarser substrates with tougher seagrasses (e.g. *Thalassodendron*) with dense root systems and taller, tougher leaves. where care must be taken to avoid excessive leaf shearing. When the donor bed is far away from the planting site, many tubes are needed, which adds to the cost and logistical burden (due to the combined weight).

Various modifications to these sod and plug methods have been made by different restoration programs to suit site- and project-specific conditions, scales and goals. Sod pluggers have been tried to extrude 3 x 3 inch plugs of seagrass into peat pots (transported on floating trays) for ease of sod planting, a method that showed some potential for shorter-leaves species (in high density) such as *Halodule*, *Halophila* and possibly *Ruppia* species, although there can be some challenges with squeezing out air trapped in the peat pots underneath the sods and with the ripping down the sides of the peat pots once at the bottom (to allow

Plate 11. Demonstration of an adapted version of the frame method (as successfully tested in Kenya), whereby seagrass plants are tied to a metal frame that is placed and secured on the seafloor to restore damaged areas.

Plate 12. Demonstration of 'seagrass-with-sediment' methods, showing sod with shovel (left) and two sizes of plugs with corers (centre and right).

rhizome spread). In Qatar, a large seagrass relocation program near a major port development used metal trays to salvage 50 x 50 cm sods of *Halodule uninervis* (harvested by snorkelers from meadows on fine muddy sediments) that were transported on self-made floating barges (constructed of pallets and old car tires) pulled behind a small boat between the donor site and the relocation site, where they were placed in similarly-sized depressions in the sediment (made with the same metal trays), a program that had some (albeit limited) success (Whitehead, 2015).

4.1.3 Seed-based methods

Seagrass-Based Methods

Advantages: Relatively easy, suitable for large-scale application.

Disadvantages: Dependency on seed-availability (and its timing), and the generally low % survival. The latter can, however, be easily compensated for by broadcasting (very) large numbers of seeds (as available).

Seed-based restoration techniques hold great promise for large-scale restoration of some seagrass species, especially in low-energy areas where seeds can settle and germinate and seedlings successfully establish without being washed away. Particular success in seed-based restoration has been achieved with eelgrass (*Zostera marina*) in Chesapeake Bay (USA), where approximately 215 ha have been restored with seeds using a variety of techniques (Orth *et al.*, 2012) (see Case Study 5). Seed-based techniques have also been tested successfully for some other seagrass species, including *Posidonia* spp. in the Mediterranean and Australia (see Case Study 9) and *Ruppia* spp. in the USA and South Australia (see Case Study 4).

Direct broadcasting of seagrass seeds appears to be the easiest and most cost-effective method. The major cost in this method is obtaining and storing the seeds. This is done through the collection of fertile (seed-containing) shoots or mature fruits shortly before they would be

Plate 13. Demonstration of the Buoy-Deployed Seed Bags (BuDs) method, showing individual bag-with-buoy units filled with seed-containing flowering shoots and spathes (left) and their field deployment on an intertidal flat (right).

released. The collected shoots are then maintained alive in large seawater tanks for several weeks until most seeds have been released (see Case Study 5). The seeds are separated from other organic debris by winnowing and sieving and stored until required for a restoration project.

An alternative approach for species that produce seeds contained within spathes on flowering shoots (e.g. *Zostera* spp.) is to harvest large quantities of fertile shoots prior to seed release and to place these in mesh nets (suspended from buoys) - also referred to as buoy-deployed seed bags (BuDs) - anchored at the restoration site (Plate 13). Allowing for natural seed release with time, as the seeds ripen they fall out of the nets onto the seafloor where they germinate. While this method may be suitable for community-based restoration projects in areas without access to facilities required to separate seeds from other plant material, it is more costly and time consuming because of the large number of buoys, nets and anchoring devices and boat required.

Irrespective of the methodology used for seed-collection and broadcasting, the percentage of broadcasted seeds that survive and become established as seedlings is generally low (<10 %) and sometimes very low (1-2 %). However, in areas where it takes little effort to collect seeds during the reproductive season (for seagrass species in which mass flowering and fruiting is common, such as *Zostera* spp.), it is quite easy to broadcast very large numbers of seeds to compensate for this low survival. For the smaller seagrass species, in order to obtain a few hundred seedlings per m^2, it is generally required to broadcast several thousand seeds per m^2. Impacts on the donor meadows from harvesting such large quantities of seeds have, however, rarely been shown to be significant. To enhance the success of seed germination and seedling establishment on dynamic intertidal flats, innovative seed-injecting devices have been developed for use in an eelgrass restoration program in the Dutch Waddensea (Van der Eijk, 2017).

A disadvantage of seed-based approaches is their dependence on the availability of seeds, which may be low or poorly understood. This is potentially an issue in parts of the WIO region, where the timing, intensity and frequency of flowering and seed production for most seagrass species are still largely unknown.

4.2 Mechanical transplanting

Mechanical Methods

Advantages: Potentially suitable for large-scale application.

Disadvantages: High initial investment costs, (high-tech) operational and maintenance requirements, not always cost-effective.

In an effort to scale up restoration efforts and reduce costs on a per hectare basis, a number of mechanical methods have been developed that make use of heavy equipment or machinery for the collection of plant material and seeds or for

CASE STUDY 5.
Eelgrass restoration in Chesapeake Bay using adult plants and seeds

Over the past four decades, a large-scale eelgrass (*Zostera marina*) restoration program has been implemented in Chesapeake Bay and adjacent coastal bays of Delmarva Peninsula (USA) (Marion and Orth, 2010; Orth *et al*., 2010; Orth *et al*., 2012). Restoration was first initiated in 1978 following widespread eelgrass loss and degradation in the bay due to deterioration of water quality. Major efforts were made to improve water quality through the installation of waste water treatment plants and improved watershed management. While eelgrass showed good recovery in Chesapeake Bay itself, there was no recovery in the adjacent coastal bays.

Both manual and mechanized techniques were used in efforts to restore eelgrass at a number of different locations using either adult plants or seeds, highlighting the importance of the timing of transplanting, labour requirements and initial success. Much of the earliest transplant work was conducted in a variety of locations with different vegetation histories and water quality characteristics, which allowed issues related to habitat requirements to be examined.

Planting eelgrass in autumn rather than spring was optimal, offering the plants a longer initial growing period to become established. Techniques utilizing adult plants (e.g. mesh mats with bare rooted shoots, sods and cores of eelgrass and sediment, bundles of bare rooted shoots with anchors, and single rooted shoots without anchors) were generally successful, with the manually planted single shoot method being both successful and requiring the least time. Mechanized planting with a planting boat had lower initial plant survivorship with no significant savings of time.

Plate 14. Buoy-deployed seed bag method (including assemblage and deployment), one of the methods used to restore eelgrasses at Chesapeake Bay (USA).

Techniques using seeds, such as manual seed broadcasting from a small boat, use of burlap bags to protect seeds, and buoy-deployed seed bags (Plate 14) had varying degrees of success. The highest seedling establishment noted where seeds were protected in burlap bags. The main challenges with seeds relate primarily to their low survival rate (generally between 5 and 10 %) and seed treatment and storage conditions affecting their viability.

Despite having some of its own challenges, the broadcast of seeds is one of the least labour-intensive techniques used to date in the program and is currently proving highly successful in restoring eelgrass to Virginia's seaside coastal bays (Plate 15). For the past 20 years, over 72 million seeds were broadcasted into 215 ha of seaside bays. This natural enhancement of these environments is simple, fast, and effective. The 215 ha of seeded plots have since spread naturally into ~3,640 ha of eelgrass throughout the seaside bays.

Plate 15. Mechanical harvesting of seed stock from donor areas, seed processing in tanks at the lab, and handling of seeds ready for casting out, usually from a small boat.

planting. Examples of these include a modified mechanical plant harvester operated behind a boat used to harvest reproductive eelgrass shoots for seed collection from Chesapeake Bay, USA (Marion and Orth, 2010), a modified backhoe device to salvage and relocate sods of intertidal *Zostera noltii* in the Dutch Westerschelde (Suykerbuyk *et al.*, 2016) (see Case Study 6), and a submarine mechanical device ('Ecosub') used to cut and plant sods of *Posidonia* spp. and *Amphibolis* spp. at deep sites of high wave energy coast near Cockburn Sound in Western Australia (Paling *et al.*, 2001). Two other examples are the use of 'giga unit sod' transplanting machines used to salvage and relocate sods of tropical seagrasses from Tampa Bay in Florida, USA (Swingle, 2003; see Case Study 3) and the 'Safebent' method with a transplanter (Model Optimal 880) modified for use in the sea and equipped with a very long arm shovel operated from a jackup that was used for the mechanical relocation of *Posidonia oceanica* sods in Monaco (Descamp *et al.*, 2017). Due to the high investment costs and some project operational challenges, the relevance of these mechanical seagrass restoration methods for application in the WIO region is questionable.

Different restoration methods may be more or less suitable for different seagrass species, depending on their morphology and life history strategy (Table 1), though the suitability and effectiveness of most of these restoration methods have not yet been tested for most species in the WIO region to date.

As can be seen from Table 1, for several WIO species, there is not much known about their response to different restoration techniques, and these represent suitable research areas for the future. However,

CASE STUDY 6.

Relocation of large sods of intertidal *Zostera noltii* eelgrass using a modified excavator in The Netherlands

Eelgrass relocation at the Eastern Scheldt, the Netherlands, involved a modified excavator driven onto the intertidal mudflats along the dikes to scrape off large sods (~2 m^2) of dwarf eelgrass (*Zostera noltii*) with soft (muddy) sediment (toplayer). The sods were stored, transported and then re-instated in comparable habitats further away. The reason the eelgrass vegetation along the dikes was salvaged was to make way for major dike renovations along a particularly vulnerable stretch of coast, needed to cope with sea-level rise. The harvested sods of eelgrass were relocated to eight recipient sites located further away from the dikes (Plate 16). In total, 2600 m^2 of eelgrass sods were mechanically transplanted to six intertidal flats over the course of five years (2007-12).

This project had some promising results, achieving mixed successes with the relocation depending on location, with an overall survival of 43 % of the sod transplants after five years at an overall total cost (including monitoring) of about USD 8.6 million per hectare (Suykerbuyk *et al.*, 2016). At four of the six intertidal flats, transplanted sods showed low survival and gradually decreased in size over time. The lack of success at those sites may partly be attributed to site conditions at the receiving habitat, notably local desiccation patterns, but may partly be due to unpredictable natural variability, as the researchers showed. The other two sites showed extensive eelgrass colonization around the sod transplant areas (in some years), which are still surviving and healthy up to the present day (Suykerbuyk *et al.*, 2016).

Plate 16. Photographic impression of the sod relocation method at the intertidal sites in the Eastern Scheldt, showing the modified backhoe scraping technique and transplant relocation.

it can be seen that restoration of the common intertidal species *Thalassia* has shown promise using the passive technique (as for several other species), as well as through use of sprigs and seedlings. Seed-based techniques have worked well and showed promising results for *Ruppia* and *Zostera*.

Table 1. Suitability of different seagrass restoration methods by species. [Legend: tick marks (√) indicate that a method has been tested on a species (or its sister species); question marks (?) indicate that a method has not yet been tried but is potentially suitable for that species. Shading indicate that a method has shown to be particularly suitable (green) or unsuitable (red) when tested for a species].

	Thalassia hemprichii	*Thalassodendron ciliatum*	*Enhalus acoroides*	*Cymodocea rotundata*	*Cymodocea serrulata*	*Syringodium isoetifolium*	*Halodule uninervis*	*Halophila ovalis*	*Halophila minor*	*Halophila stipulacea*	*Zostera capensis*	*Ruppia maritima*
	T.h.	*T.c.*	*E.a.*	*C.r.*	*C.s.*	*S.i.*	*H.u.*	*H.o.*	*H.m.*	*H.s.*	*Z.c.*	*R.m.*
Passive restoration:												
Removal of threats (anchors, fishing, etc.)	√	?	?	?	?	?	√	√	?	?	√	√
Sediment-free methods:												
Sprigs planted (shoot-method)	?		√	?	?	√	√	√		?	√	?
Sprigs anchored (staple method)	√		√	?	√	?	√	?		?	√	?
Sprigs on mats or frames (TERFs)	√			?	?	?	?	√		?	√	?
Seagrass with sediment methods:												
Plugs (by cores)	?	?		?	?	√	√	√	?	?	√	√
Sods (by shovel)	√	?		?	?	√	√	?	?	?	?	?
Sods (by trays)							√	?	?	?	?	?
Sods (in peat pots)							√	√	?	?	√	?
Seed-based methods:												
Manual broadcast	?		?					?			√	?
Fertile shoots (BUDs-method)						?	?				√	?
Seeds in bags with sediment								?	?	?		√
Seedlings:												
Collected from beach wrack or lab-reared	√	?	√	√	√	?	?	√		?	?	?
Mechanical methods:												
Mechanical seed harvester											√	
Mechanical shoot planter*												
Mechanical sod harvester/planter	√						√				√	

* tried on *Posidonia coriacea* and *Amphibolis* spp. in Australia with inconclusive results

5. Restoration Site Identification

Inappropriate site selection is by far the most important cause of failure of seagrass restoration projects worldwide. If there is no seagrass (or just sparse seagrass) at a proposed restoration site, you have to ask yourself: why? Simply transplanting seagrasses to such sites (regardless of the method applied) or even attempting the use of seeds, will not, in and of itself, ensure the successful establishment of a new seagrass bed as long as the initial stressors remain. As highlighted earlier, these may include some of the following: poor water quality, excessive bioturbation, heavy sea urchin grazing, beach seine fishing, boat traffic, high waves or currents. The stressors need to be clearly identified and eliminated or at least reduced (Case Study 7), which can be expensive. However, without addressing the stressors, seagrass restoration is unlikely to produce any significant successful results at such sites.

Important aspects to consider when selecting suitable sites for seagrass restoration include:

- habitat suitability (environmental conditions conducive to seagrass growth)
- level of (human) disturbance (from activities and/or developments that can affect seagrass health and survival)
- previous experience (success at similar sites)
- advice from local area specialists (people that know the area well)
- practical considerations (e.g. access, distance, as well as logistical, institutional and legal considerations)
- proximity to existing seagrass meadows
- evidence of historical seagrass presence at the site, recent incidental sightings of seagrass colonisation in or near the area
- presence of other habitats nearby that are known to facilitate stability and offer positive feedback (e.g. reefs, mangroves, oyster beds) and that would help sustain successful seagrass restoration in the longer term.

Habitat suitability for seagrasses is largely determined by the tolerance limits of the individual seagrass species for environmental variables, such as:

- water temperature
- salinity
- light availability (a function of water depth and turbidity)
- flow velocity
- wave exposure
- low tide exposure to air (desiccation)
- substrate conditions (composition and stability)

This may require specialist advice based on a review of specific literature and *in situ* assessment and/or modelling of environmental conditions. However, most seagrass species will probably do well in relatively shallow subtidal waters of 'normal' salinity (~30-35 ppt), low turbidity, adequate light (~15-20 % of Surface Irradiance), stable sediments, or in non-polluted areas, sheltered from excessive wave energy or extreme flow conditions.

It is not advisable to plant seagrasses in areas with no history of seagrass growth or in areas where the underlying causes of seagrass degradation and loss have not been addressed. Similarly, there will be a low probability of success in areas where seagrass loss has caused 'irreversible' negative feedback resulting in an alternative stable state (Suykerbuyk *et al.*, 2016). Seagrass restoration sites should have similar depths to nearby healthy meadows and not be subject to chronic storm damage. Sites that undergo rapid and extensive natural recolonization by seagrasses should not be selected for restoration.

Seagrass restoration is sometimes required as compensatory ('offset') mitigation for damage to seagrass beds, e.g. from pipeline trenching or port expansion. Other sites that are sometimes considered for restoration include damage to seagrass meadows from boating activities, such as from propellers, anchoring and boat groundings.

Planting areas for compensatory mitigation may be classified as either on-site or off-site. On-site plantings are conducted within the area of disturbance on impacted sites, whereas off-site plant-

CASE STUDY 7.

Community-based seagrass restoration trial at Beravy, Toliara (Madagascar)

This ongoing seagrass restoration trail was initiated in February 2019 by Reef Doctor, an NGO based in Ifaty, south-west Madagascar. It is part of a project by the local community of Beravy in partnership with Vezo Miaro (Young Fishermen Association). Seagrass beds in Beravy have been in decline, primarily due to sediment run-off from land, which consequently smothered the seagrasses. The land-to-sea runoff of sediment was caused by deforestation of nearby mangroves and agricultural activities on adjacent land, uses that are also being addressed in the project. The ultimate goal is to restore seagrass areas degraded by sedimentation to contribute to long-term sustainability of coastal ecosystems and support community development in the Bay of Ranobe.

Each month, 1,200 sods (30 x 30 cm) of seagrass are transplanted into damaged and degraded areas in the tidal zone of the bay (Plate 17), dug out by spade from a healthy nearby seagrass beds of *Cymodocea serrulata*, *Cymodocea rotundata* and *Halodule uninervis*. As of May 31, 2019, seagrasses have been transplanted into two sites with a combined total area of 0.2 ha. The ultimate target is to have transplanted 36,000 sods of seagrass (Reef Doctor, 2019).

Survival of the transplanted seagrass patches is being monitored to assess the success of the methodology. The percentage cover of selected patches are being surveyed every three months, as well as the overall survival rate across all transplants. Initial results are encouraging (Reef Doctor, 2019). Evaluation of these regular monitoring results allows for adaptation of the restoration approach and methodology along the way and for the establishment of an optimal transplantation method.

Plate 17. Photographic impression of the ongoing seagrass restoration project at Beravy, Tuliara (Madagascar) using spades for the excavation of seagrass sods for transplantation into degraded areas.

ings are conducted at some distance from the impacted sites. There are usually few (if any) off-site locations available (unless newly engineered as part of an integrated design for a development) that can support seagrass growth or involve habitat substitution, i.e. replacing one (existing) habitat type with another (i.e. seagrass).

5.1 Checklist of criteria for site selection

The following are lists of the minimal parameters that should be considered when verifying that a potential site is a candidate for restoration and that a donor site is an appropriate site from which material (plants with roots and/or seeds) can be taken.

Restoration sites:

- Historical seagrass distribution (aerial photography, maps, datasets, literature)
- Current seagrass distribution (mapping, fieldwork, evidence of loss/decline/scars/damage)
- Proximity to natural seagrass beds (donor sites or source of natural recruitment)
- Has the cause of seagrass decline been reversed?
- Has seagrass restoration been successful previously at similar sites (pilots?)
- Substrate / sediment composition/thickness (suitable for seagrass?)
- Sediment instability (significant erosion or burial that could hamper restoration)
- Bioturbation (high levels of bioturbation could frustrate restoration success)
- Water depth and tidal characteristics (similar to nearby natural seagrass beds)
- Light availability (meeting minimum light requirements)
- Water quality (turbidity, nutrients[6], organic matter, pollutants, phytoplankton and epiphyte loads)
- Salinity and temperature (within tolerance limits of target species)
- Wave / storm exposure (not exceeding tolerance limits of seagrasses)
- Tidal elevation (risk of desiccation during low tide exposure)
- Legal issues (permission)
- Constraints imposed by structures, dredged channels or human activities
- Restoration of sites with evidence of a high likelihood of natural recovery should be avoided (e.g. presence of viable seed bank, high numbers of seedlings, significant rhizome expansion from adjacent seagrass areas)

Donor sites:

- Extensive enough (for the harvesting of sufficient plant material or seeds
- In good health condition (to offer high quality material/viable seeds)
- Located within the same biogeographical area
- Nearby (to minimize transportation costs and logistical constraints)

Relatively simple GIS applications can further assist in site selection by providing a higher level overview of the wider area under consideration on which many datasets and other information can be presented. The resulting maps can also be used for presentations to communities and stakeholders, sharing the process on how and why sites were selected or not. Three of the mapping categories often developed through GIS include:

- *Exclusion mapping*: mapping of areas that are not suitable, inaccessible, earmarked for development, having potential user conflicts, or currently already covered by seagrass meadows or other valuable ecosystems;
- *Suitability mapping*: model-assisted mapping of habitat suitability for seagrasses based on environmental conditions such as light availability, depth, substrate type, water quality, current velocity, wave exposure, salinity and temperature; and
- *Logistical mapping*: practical considerations, such as road access, proximity to a jetty or marina, travel distances, proximity between donor and restoration site, need for SCUBA or boat etc.).

6 A few studies suggest that addition of nutrients in the sediment (slow-release fertiliser) can sometimes help to stimulate healthy growth of transplanted seagrasses (e.g. in fine-grained carbonate silt environments in Caribbean and Florida). Addition of fertiliser showed no beneficial effects in most other studies worldwide.

6. Principles of Best Practice – A Restoration Protocol

6.1 Guiding principles for restoration planning

The following six principles emerged over the past few decades of seagrass restoration practice worldwide as critical considerations to guide any successful seagrass restoration approach (see Treat and Lewis, 2006; Van Katwijk *et al.*, 2016):

- **Large-scale approach:** Many seagrass restoration projects in the past have been unsuccessful because their spatial scale was too small. One of the problems with a small-scale approach is that the (re)planted seagrass patches are too small to sustain themselves over time. Research suggests that restored seagrass patches of one hectare or larger are better able to withstand adverse conditions, overcome negative ecological feedbacks and survive over longer time scales than smaller patches or groups of small patches (Van Katwijk *et al.*, 2016; Paolo *et al.*, 2019). This seems at least in part to be due to self-facilitation through substrate stabilisation and self-seeding. Simply put: for successful restoration, it is better to think in terms of scales of hectares rather than square metres.

- **Working with nature:** Unlike the small scale at which active human effort - through 'gardening' approaches - is capable of restoring seagrass meadows, nature itself is able to recover at much larger scales through natural regeneration within relatively short timeframes. For this, two requirements will have to be met: [1] environmental conditions have to match (again) the ecological requirements of the seagrass species, and [2] natural recruitment (from a persistent seed bank, through seed dispersal, or through inflow of viable seedlings or plant fragments from nearby unaffected seagrass areas) should be sufficient to enable recolonization (see Case Study 8). Restoration approaches would benefit from capitalizing on this 'free-of-charge' service that nature provides through focusing their main effort on restoring environmental conditions and recruitment and then letting 'mother nature' and 'father time' do the rest (a.k.a. '*working with nature*').

- **Site selection:** Inappropriate site selection is by far the most important cause of failure of seagrass restoration projects worldwide. Key aspects to consider include:
  - ¤ suitability of environmental conditions (meeting the requirements for healthy seagrass growth, notably emersion and desiccation effects, nutrient limitation or overload, light requirements and site turbidity, currents, wave exposure, salinity and temperature tolerances, and substrate stability)
  - ¤ level of disturbance or developments that can affect seagrass survival
  - ¤ local area specialists' advice
  - ¤ logistical considerations (site access, distances)
  - ¤ nearby presence of existing seagrass meadows
  - ¤ evidence of historical seagrass presence
  - ¤ recent sightings of seagrass colonisation nearby

  Donor sites from which to harvest plant material or seeds need to be extensive enough, in good health, and located within the same biogeographical region, preferably in close proximity to minimize transportation costs and logistical constraints.

- **Spreading of risk:** To maximize chances of restoration success, it is often necessary to spread the risk of poor survival or loss of transplants by spreading the restoration efforts in space and time. Loss of seedlings, transplants and seeds is likely to be higher at dynamic sites that are exposed to strong currents, waves or tidal flows or experience excessive bioturbation, but these can be important areas to revegetate if the project goal is to improve sediment stability. Mortality and loss of seedlings and transplants can also occur due to storms, desiccation (intertidal) and seasonal fluctuations in salinity and temperature. Thus, the timing of planting is also important with respect to seasons and tides. The origin of donor material may also contribute to variability in success. Other (unknown) factors and the complexity of processes involved may further contribute to the unpredictability of success in seagrass transplantation. The effect of all these factors can be reduced by spreading and replicating the timing and location of the restoration activities over different sites and at different times and by using source material from different donor locations (which also helps to maintain genetic diversity and resilience). Simply put: to minimize risks, it is better not to collect and plant all material at one time and at one location, but to vary and repeat restoration activities in space and time. Another way of spreading risk is to use multiple species of seagrass in the restoration rather than just one (so long as all species selected are appropriate for the tidal level), particularly in regions with high biodiversity. In a recent seagrass restoration experiment in Sulawesi (Indonesia), transplant survival and coverage at restoration sites increased with the number of species transplanted (Williams *et al.*, 2017), achieving better results with transplanting multiple species together than with a single target species.

- **Keeping costs (per unit area) low:** It is of critical importance that the limited financial means that are available for restoration of sensitive marine environmental assets (especially in the WIO region) are used as effectively and efficiently as possible on successful projects (Treat and Lewis, 2006). There is general scepticism and perception worldwide that ecosystem restoration projects are costly and often have only minimal success. In order to achieve an as high as possible return for investment (of both labour and costs), it is therefore of paramount importance to keep the costs for each and every step of the restoration process as low as practically and technically feasible. This will allow for the greatest possible restoration outcome (in terms of hectares). However, a comprehensive feasibility study and thorough site selection prior to any restoration project remain essential to increase the success rate of any restoration project. Where possible, close collaboration with existing research and monitoring programmes can help to reduce overall costs of ancillary investigations.

- **Minimizing impacts on donor sites and avoiding species introductions:** If the seagrass restoration approach involves the use of donor material from elsewhere, it is critical that proper consideration is given to minimise impacts from the harvesting of the material (whether seeds, plants or sods) at the donor sites and to avoid the unintentional introduction of exotic or invasive species (plants and animals) into the restoration site.

6.2 Other practical considerations

- **Choice of species and donor material:** The obvious consideration would intuitively be to plant the same species (or mixture of species) as those lost from the site, which applies to most restoration projects. However, it may sometimes be better to plant a different species if site conditions have changed to an alternative state. A different species (e.g. a pioneer or opportunist) may then be better adapted to the changed conditions than the species that originally dominated the site. Donor material would ideally come from within the same biogeographical area or region. The use of material from multiple donor sites is sometimes considered to enhance and/or preserve genetic diversity. By all means, plant material should always be handled with extreme care and kept wet at all times, as most seagrasses have very little resistance to desiccation.

CASE STUDY 8.
Facilitating *Amphibolis* seedling recruitment with artificial substrates

The coastal waters off Adelaide (South Australia) have seen a significant loss of >6,000 ha of seagrasses since 1949, primarily due to overgrowth by epiphytic algae resulting from anthropogenic nutrient inputs and turbidity. Despite substantial improvements in water quality since the late 1990's, natural recovery of seagrasses (especially of *Amphibolis antarctica*) has been slow, with high levels of sand movement hampering the successful establishment of seedlings. Initial restoration efforts focused on adapting techniques used elsewhere, such as transplantation of shoots, sprigs and laboratory-reared seedlings, but the success and scale of these efforts was limited. During these initial studies, hessian matting was used around the transplants to stabilize the sediment. While ultimately unsuccessful in this goal, it was observed that seedlings of the seagrass *A. antarctica,* which have a miniature 'grappling hook' on their base, naturally became entangled in the hessian material, thus facilitating their establishment. Following this observation, a range of techniques were tested using hessian and other materials to entangle *A. antarctica* recruits and allow them to become established. Standard hessian sacks filled with sand were eventually selected for subsequent work. These bags can simply be dropped off a boat and do not require any further manipulation by divers (Plate 18).

May to August was shown to be the best period for bag deployment to coincide with the natural dispersal of seedlings and maximise recruitment success. *A. antarctica*'s structural characteristics (stem density and length) were similar to those in natural meadows five years after bag deployment. Early deployments started to coalesce into larger patches by 2013 and have now formed several larger patches where the locations of individual bags can no longer be distinguished (Tanner *et al.*2014).

Plate 18. *Amphibolis antarctica* recruitment facilitation approach showing: (a) *Amphibolis* seedling with close-up of grappling hook (see arrow) to assist anchorage; (b) recently deployed sand bags laid out for monitoring; (c) 6-month old deployment covered in *Amphibolis* seedlings; (d) restored *Amphibolis* patch showing coalescence from ~40 bags.

CASE STUDY 9.

‘Seeds for Snapper’: Collection, processing and broadcast delivery of *Posidonia australis* seeds

Cockburn Sound is a natural embayment approximately 16 km long and 7 km wide, SW of Perth, Western Australia. Cockburn Sound has seen a 77% decline in *Posidonia australis* seagrass cover (~2,000 ha) since 1967, largely due to the effects of eutrophication, industrial development and sand mining. In small, localised areas, natural recruitment has been successful, but many other parts have not been able to recruit and recover naturally. A number of techniques have been trialled in an attempt to develop efficient and cost-effective methods to regenerate seagrass meadows, including transplanting large sods, cores, transplanting sprigs and seedlings. However, cost and labour-intensiveness have a factor prohibiting the application of many of these methods at larger scales, while the availability of plant material and impact on existing meadows has proven prohibitive for others.

Many species of seagrass produce an abundance of seed (100’s-10 000’s m^{-2}) that offer a significant source of planting units, which like seed collection in terrestrial environments and unlike clonal material, can be obtained without direct negative impact on the donor vegetation. The overall objective of this pilot study was to develop a large-scale collection, processing and remote seafloor delivery process for the restoration of *P. australis*, a species with non-dormant, directly developing seeds (Plate 19).

Plate 19. (a) Mature *Posidonia australis* fruit prior to collection; (b) harvested fruits in 100 L cooler for transport to lab; (c) processing fruit after collection; (d) after processing, seeds are clean and ready for delivery to field sites; (e) seeds scattered on surface of sediment (200 seeds m^{-2}); (f) close up of seeds settled on the sea floor; (g) 1 year old established seedlings; (h) seedlings established in high density; (i) two year old seedling with multiple shoots.

To address this objective, the following, more specific aims for this species were pursued by developing technologies to: (1) collect fruit at maturity from source meadows using purpose built nets, (2) process collected fruit to obtain pure seeds in temperature controlled holding tanks by agitation via aeration to obtain large quantities of seed material that settle on the bottom of the holding tank, and (3) trial approaches to effectively and efficiently deliver seeds to the restoration site, which included; a) diver assisted, precision seeding by scattering seeds close to the sea-floor, and (b) remote, broadcast seeding from a boat. One of the major benefits of using the broadcast seeding method, as opposed to transplanting sprigs and shoots, is that seeds are negatively buoyant and naturally fall to the seafloor. Hence, there is no requirement for expensive and labour-intensive diving operations, especially when considering deeper sites or when there is low water visibility.

Pilot scale trials have shown good success (Statton *et al.*, 2017). *Posidonia australis* was seeded at densities of 200 seeds m^{-2} into three 25 m^2 replicate plots at four locations in Cockburn Sound. Seedling establishment success varied from 1 % (two seedlings m^{-2}) to 10 % (20 seedlings m^{-2}) after two years. At 18 months, seedlings have begun to produce new shoots and by 24 months, established seedlings had three to five shoots and had begun horizontal expansion over the sea-floor. This initial success is now being scaled up in an innovative community-based approach by enlisting the help and involvement of local recreational fishermen in a program known as 'Seeds for Snapper' (https://ozfish.org.au/seeds-for-snapper/). In this program, 40-50 local recreational fishers volunteered to release one million seagrass seeds (collected and provided by scientists) back into the sea in a massive effort to restore the lost seagrass meadows of Cockburn Sound. This will increase the scale of seeding and ability to restore locations that are difficult to access (deep, turbid, turbulent, or diver-restricted locations), while helping to identify and overcome critical environmental factors limiting seedling establishment. Preliminary assessments show that establishment success is around 14-38 seedlings m^{-2}, equivalent to 7-19 % (Statton *et al.*, 2017).

- **Selection of restoration method:** A plethora of restoration methods and techniques have been developed over the past few decades, and most of them probably work well for most seagrass species on which they have been tested, provided that site-selection has been given adequately consideration. The desired scale of the restoration outcome and costs (versus available budget) can be important considerations in selecting the method of choice. In the end, practical logistics, convenience with regards to the local conditions at the site and familiarity and/or preference of the practitioner add further to the choice considerations.

- **Community participation:** Community-based projects are projects that take place in community settings with the involvement of local coastal communities from design to implementation. Such projects recognize local knowledge and other contributions made by community partners (or other local stakeholders) to project success. Effective community participation can greatly contribute to achieving local ownership and long-term sustainability of the outcome of a seagrass restoration project beyond the initial intervention. This will be particularly so when the community is (made) aware of the values of the restored seagrass ecosystem as a fish habitat and coastal protection asset and thus its contribution to securing a better livelihood and future. It can also play a factor when weighing skill and experience against costs for the implementation of restoration objectives. Similar considerations apply to the decision to involve citizen volunteers (see Case Study 9). In all cases, there is a need to carefully manage realistic expectations of the outcome of the restoration efforts and maintain transparent communication.

- **Stakeholder engagement and the role of government:** In most projects, it can be beneficial to engage stakeholders in the planning and implementation of a seagrass restoration project (in addition to community participation). Examples include NGOs, CBOs, local businesses, dive operators, MPA management and park rangers, port authorities, the tourism and hotel industry and so forth. The contribution of non-governmental and community-based organisations can be particularly valuable and important in the WIO region. Municipalities and other local authorities and government representatives should be contacted for the necessary permits and may be able to facilitate access and offer data and logistical support.

- **Multidisciplinary approach:** It can sometimes be valuable to seek the advice and/or involvement of experts from different disciplines (e.g. geologists, engineers), as a multidisciplinary approach may sometimes be required to address the complex challenges at a project location in order to accomplish restoration success.

- **Spacing of planting units:** The choice of appropriate spacing of planting units will depend on the method and species. Practical experience with eelgrass restoration in the USA suggests that optimal spacing generally ranges between 0.5 and 2 m. Obviously, the closer planting units are together, the more rapidly they will close up the gap over time (or attain a desired % cover or patchiness similar to what was there before). However, the benefit of increased rate of coalescence is soon offset by the substantially higher costs due to the number of planting units involved. For example, a 100m x 100m (1 ha) planting area planted at 2.0, 1.0 or 0.5 m spacing would require 2,500, 10,000 or 40,000 planting units respectively. Similar considerations apply for seed-based techniques, but the relatively low percentages of successful germination and seedling survival reported for such methods need to be kept in mind.

- **When to seed/transplant:** When planning for the restoration, seasonal changes in weather (e.g. avoid periods of heavy rainfall or disturbance by storm waves) and site conditions (e.g. water quality) that may affect growth and survival of the planting units (or seedlings) and thus restoration success need to be considered. When working on intertidal flats, timing of the fieldwork should consider the tidal conditions, as this will determine accessibility and could pose safety issues for participating community members and volunteers. Periods of equinoctial spring tides, when the lower intertidal zone is exposed and there may be extreme solar insolation and a heightened risk of desiccation, should be avoided. Availability of donor material may also vary seasonally, especially in the case of seeds (or fertile shoots) for species with distinct reproductive seasonality.

- **Realistic timeframes:** It is important to set realistic timeframes for successful seagrass restoration projects. Proper planning before implementation (incl. site selection and permits) will often take more time (months) than initially realised, but it always pays off in the end. Depending on the methodology and scale, the restoration work itself can take up several days or weeks (or more) and may be repeated multiple times, either within the same year or in consecutive years. Evaluating success should not be done too soon after initial planting. It is best practice to monitor the success, growth and survival of the transplanted seagrass for a period of several years following planting (five years, as used in the USA, is a good yard stick, but this can be reduced for fast-growing pioneer species (e.g. *Halophila* spp.). Restoring a reasonable seagrass cover may be accomplished within a few years (or even sooner in fast-growing species), but the full recovery of ecosystem functions is likely to take much longer. This timeframe is often under-estimated and should be made clear to all participating entities, stakeholders and other interested parties.

- **Planning a restoration schedule:** Careful and thoughtful planning is crucial to the success of any seagrass restoration project and generally involves most of the following steps/considerations:
  - damage assessment (size/scale and cause of seagrass damage / loss)

- determination of adequate remediation approach (which first and foremost will involve measures to reverse habitat degradation)
- cost-benefit analysis of potential intervention options
- scale considerations
- seasonal perspectives
- species life history characteristics
- selection of planting stock
- pre-planting site surveys at donor and restoration sites
- assessment of pre-damage species composition, cover, distribution and extent, as well as other historical perspectives
- identify restoration goals and performance criteria
- evaluate permit requirements and other legal considerations
- site selection
- obtain transplant stock (plants, sods or seeds)
- choice of planting method, species and spacing
- evaluation of the best timing for the transplanting (or seed-broadcasting)
- developing success criteria and indicators
- implementation of the actual restoration works
- monitoring of plantings (plant performance and survival)
- remedial planting and site maintenance (this may include interventions to address substrate instability by reducing bioturbation or reducing wave and current scour, as required)
- interpretation of results
- evaluation of success
- sharing of lessons learnt

- **Cost considerations:** Seagrass restoration is expensive. However, if successful, regained ecosystem services may compensate and eventually surpass these initial investment costs. The true costs of any seagrass restoration project include the costs of mapping and ground-truthing, planting (sprigs or sods) or sowing (seeds), monitoring, community participation, contractor involvement and government oversight. Typical (all-inclusive) costs for seagrass restoration worldwide range from USD <590,000 to >910,000 per hectare, but community-based projects in the WIO region (depending on their scale) are likely to be much cheaper.

  Seed-based restoration, projects assisting natural recovery, and restoration initiatives involving local communities or citizen volunteers are generally the cheapest, while projects involving site remodification, engineering measures (e.g. substrate modification) and/or those involving the use of SCUBA (in deeper waters) or heavy equipment (e.g. modified backhoe and seed harvesting or sod planting/relocation machines) are generally more expensive (up to >1 million USD per hectare). It is highly recommended to include a thorough cost-benefit analysis prior to any decision about a restoration project, weighing the costs of different restoration methods (as well as those of additional habitat enhancements and other mitigating measures) against the benefits of increased scale of success.

- **Monitoring and evaluating success:** Monitoring of the progress and success of the restoration (although labour-intensive and expensive) is an essential component of any seagrass restoration project. Appropriate and sufficiently robust monitoring is critical to ensure that any contracted work was performed to specifications and was in compliance with regulatory permit requirements (where applicable). In any situation, monitoring of planting performance using standard methods provides the basis for 'mid-course' corrections (e.g. remedial plantings and/or other project modifications) and to derive lessons learnt for improved planning of subsequent projects elsewhere. Hence monitoring and evaluation is an iterative process, adapting and changing where necessary. There is general consensus that seagrass restoration monitoring programs should run for at least five years, with quarterly monitoring in the first year followed by bi-annual (and eventually annual) monitoring in the remaining years.

7. Restoration Monitoring

7.1 Introduction

Implementing a systematic monitoring plan to document the progress, challenges, effect of remedial measures and ultimate degree of success of the restoration is an essential component of any seagrass restoration project.

Although monitoring can be labour-intensive and expensive, a systematic and statistically robust monitoring program using standard methodologies is indispensable to ensure that any contracted work was performed to specifications and in compliance with regulatory permit requirements (where applicable). In any situation, appropriate monitoring of planting performance provides the basis for 'mid-course' corrections (e.g. remedial planting, site modifications). It is also critical for deriving valuable lessons for improved planning of future seagrass restoration initiatives elsewhere.

Monitoring of performance of plantings and restoration success should always be linked to agreed standards and pre-defined metrics. Success should be evaluated against clearly-defined success criteria that are preferably quantitative and scientifically valid. Success criteria can be as simple as the extent of restored area (in hectares) or a desired percent seafloor coverage (% cover or shoot density) of the vegetation and its persistence over time. In more recent projects, criteria often also include measures and indicators of the functional attributes (e.g. fauna colonisation, associated biodiversity, role in sediment stabilisation, nursery function, carbon burial etc.) of the restored habitat in comparison with similar natural (local) reference sites. It is important to consider including measurements of some general environmental variables (e.g. temperature, salinity and turbidity), which may help to explain and attribute a disappointing outcome of the restoration efforts at certain locations to environmental conditions that are beyond the control of the restoration team (such as severe rainfall, river floods, heat waves, frost, major storms or even cyclones). Seagrass restoration monitoring programs are best run for a duration of at least five years, with quarterly monitoring in the first year followed by bi-annual (and eventually annual) monitoring in the remaining years. The timing of monitoring events should be selected with consideration of the spring-neap tidal cycle and seasonality of weather (e.g. monsoons, rainy season, summer-winter). In the case of once-a-year monitoring, it is best to select the time of year when the seagrass is at the peak of its growth and development (maximum standing crop). The results of the monitoring during the first year (ideally quarterly) will help to define the best timing of monitoring in subsequent years. This may also be helpful in selecting the best timing for aerial photography or drone-assisted monitoring (as appropriate, e.g. in areas where access is more difficult) for follow-up monitoring of the long-term persistence of the restored areas in subsequent years.

7.2 Monitoring Indicators

Monitoring specifications typically include most (or some) of the following indicators:

- ***Survival:*** The % of the number of transplanted sprigs, sods or broadcasted seeds that survived.

- ***Aerial coverage:*** A random sample of the surface area (in m^2) covered per planting unit should be recorded until coalescence (when individual planting units have grown together and become indistinguishable). By counting the total number of surviving planting units, they may then be multiplied by the average area per planting unit to determine the total area covered at the restoration site.

- ***Shoot density:*** A random assessment should be done of the density of shoots (by counting). Alternatively, a visual estimate can be made of the % cover of the replanted patches, which can then be compared against known shoot densities of a reference series of samples taken within the same general area to estimate shoot density. It is also important to be aware that the visible % cover of seagrass, a reflection of the amount of leaf matter, may vary considerably during the year or even according to tides, depending on grazing, desiccation and growth cycles, even though the actual shoot density may not have changed. Early stage planting units may show an artificially high shoot density when expressed per m^2 when they are still associated with the anchor (or staple), but eventually planted patches spread out more naturally in a way that is more similar to natural colonisation. Shoot density is recommended in addition to aerial cover, because it is a more accurate means of assessing the asexual reproductive vigour of the plantings (how well they have established and spread). Shoot density can vary quite significantly between locations (as a function of site suitability) and seasonally (which needs to be taken into consideration when interpreting monitoring data in comparison with those from reference sites or against data from previous monitoring campaigns).

- **Photography/video:** Repeated photography of restoration plots (best from standardised positions) and video transects of restored areas can be an additional (attractive) way of providing useful and potentially semi-quantitative records of progress of any seagrass restoration project. Such material is also very useful for public awareness and for use in presentations aimed at keeping the participating entities informed on progress.

- **Ecosystem functions:** Where desirable and identified as intrinsically valuable indicators of project success, quantitative measures of selected ecosystem functions (as predefined at the onset of the restoration), such as associated biodiversity, water quality, sediment stability, nursery ground, fish densities, carbon storage can be incorporated in the monitoring program as appropriate.

7.3 Monitoring Reports

Monitoring reports should (at a minimum) contain the following information:

- Dates, times and geographic (GPS) locations of monitoring activities
- Observations on the sea state and tide at the time of monitoring
- Quantitative data on the measured attributes (survival, coverage, density, photographs/videos, ecosystem functions) for each transplantation plot/site
- Data and observations on environmental variables and weather for the monitoring period
- Interpretation of the data, supported by statistical analysis (as appropriate)

8. Seagrass Restoration Management Plan

Seagrass restoration is unlikely to succeed if it simply means transplanting seagrasses without adequate site assessment and consideration of the underlying causes of seagrass loss at the site. To ensure a successful seagrass restoration project, a generalised planning protocol should be followed which would generally include the following basic steps and considerations (Figure 2):

8.1 Project planning phase:

- ***Goals and objectives:*** Establish clear goals and objectives for the restoration project prior to initiating any restoration activities.

- ***Pre-planting studies:*** Mapping of seagrass distribution and delineation of degraded areas in need of restoration. Study the potential sites to be restored and determine: the seagrass bed history (species composition, cause of loss), exposure to environmental stressors (especially air, waves and currents), substrate type, evidence of significant siltation or erosion, presence of bioturbation and other animal disturbances. For seed-based restoration approaches, phenological studies may be required to identify the timing of flowering and seed production of the different species and/or the presence of seed banks.

- ***Community and stakeholder involvement:*** Involvement and participation of local communities, stakeholders and/or citizen volunteers in seagrass restoration projects should be considered. It can help reduce costs, offer a source of local labour, contribute to ensuring long-term persistence and sustainability of the restored seagrass areas, and improve the success of the restoration efforts by offering an opportunity to incorporate local (traditional) knowledge of the area into the planning and design of the restoration approach. Early engagement of the community is critical in achieving their meaningful and effective participation, which should be sustained throughout all phases of the restoration project.

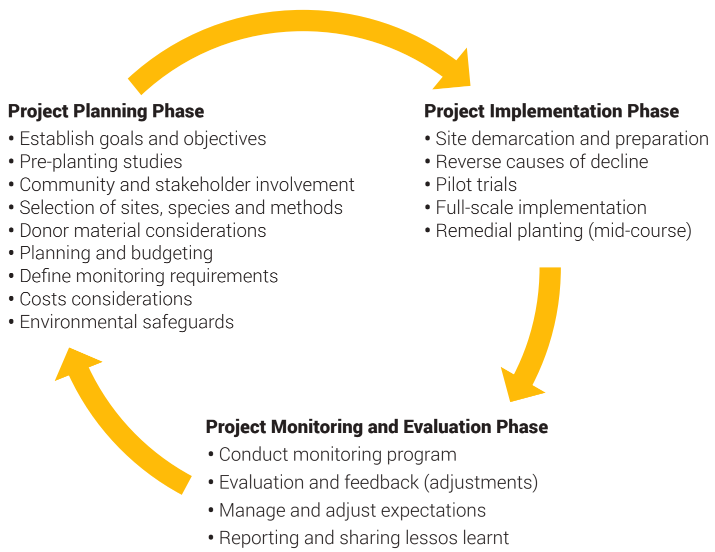

Figure 2. Basic steps and considerations of a seagrass restoration management plan.

- ***Selection of sites, species and planting method:*** Site selection for seagrass restoration should consider the suitability of environmental conditions in meeting the requirements for healthy seagrass growth. Species selected for the restoration should be derived from the historical community composition and be well-adapted to current site conditions. The selection of planting methods should be based on an assessment of their suitability to the species and conditions at the site, the goals and desired outcome and spatial scale of the project, and a thorough (participatory) cost-benefit analysis of different options.

- ***Donor material:*** Locate a donor bed that satisfies the requirements for the collection of appropriate quantities of seagrass material for transplanting into the restoration site. For vegetative methods, this should be near enough for transplanting of the plants or sods on the same day (and not more than that). For sediment-free plant material and/or seed-based methods, consideration should be given to meet the needs for storage of the material (in moving seawater at ambient temperature and salinity). Efforts should always be made to minimise disturbance of the donor sites (as general guidance: keep removal of plant material within <10 % of the vegetation at the donor area) as it can be frustrating for all persons involved in the restoration effort if there is significant (new) damage to a healthy donor bed due to the harvesting of material for the restoration, especially if the restoration is ultimately unsuccessful. Fortunately, in most projects impacts to donor beds are generally small in scale and usually show rapid recovery.

- ***Planning and budgeting:*** Determine the timeframe and budget by evaluating typical staffing and equipment requirements. A minimum of seven to nine people is generally required for intertidal and shallow subtidal sediment-free planting. Time for planning, pre-trip preparations and mobilisation and demobilisation (including travel) should also be incorporated in planning and budgeting. The time and resources required for monitoring and reporting of restoration success should also be budgeted for.

- ***Monitoring requirements:*** Define methods, success criteria and frequency (and duration in years) for long-term monitoring. Include donor population monitoring (to determine recovery from impacts of harvesting of plant material for the restoration).

- ***Costs:*** Consider all the aforementioned potential project costs, including site delineation, reports, mobilisation and demobilisation, planting operations, monitoring, remedial planting, overheads (perhaps including insurance), mapping, staffing, transport and food/drinks for volunteers, and so forth. Think of long-term sustainable financing options that could ensure sufficient funds to cover all works, including the monitoring and evaluation phase.

- ***Environmental safeguards:*** Assess potential environmental impacts of the restoration works, both at the donor site and the restoration site (including the risk of introducing invasive species if donor material is brought in from elsewhere) and consider practical ways in which these can be minimised.

8.2 Project implementation phase:

- ***Site demarcation and preparation:*** Carefully delineate the plots to facilitate both the transplanting and the monitoring of the restoration areas. This phase may also include some modifications to site conditions (as appropriate and feasible) to prepare the site for restoration and enhance chances of its success.

- ***Reversal of causes of decline:*** Make every effort to ensure that local threats (bioturbation, herbivory, sediment instability, adverse human activities) and known causes of decline and degradation to the seagrasses at the restoration site are understood and reversed (reduced to a level as low as reasonably practical).

- ***Pilot trials:*** Initiate with small-scale or pilot restoration trials first, prior to engaging in large-scale restoration projects (see Case Study 10). Small pilot projects can help to test the suitability of different methods (including anchoring techniques and site remedial measures, such as sediment conditioning or creation of engineered sand-bars or shellfish reefs) for the species and conditions of the local site, and to get familiar with the handling of the plant material and equipment, time requirements, practical aspects, logistics and challenges) before scaling up the project for application at larger spatial scales (Tanner *et al.*, 2014).

- ***Full-scale implementation:*** A large-scale restoration effort may eventually be necessary because a critical mass of plants/area planted is required to ensure longer-term persistence of the restored areas. In such cases, it is important to spread the trials and planting phases over different sites and times of the year to accommodate unforeseen circumstances, poor understanding of site complexities, and other unpredictable factors that may affect performance and success (Suykerbuyk *et al.*, 2016).

- ***Remedial planting:*** Corrective measures (mitigation of unwanted developments or local interferences) may sometimes be necessary at a certain stage during on ongoing restoration project. This may include remedial planting as a 'mid-course' correction, based on observations made during the monitoring program (e.g. unexpected or below expectation levels of survival of transplants). Sometimes, this may include interventions that help to modify site conditions (as appropriate and feasible) to improve chances of a successful outcome of the restoration. As explained above, the process should be iterative – modifying or adjusting the plan as lessons are learned or new information or approaches emerge.

8.3 Project monitoring & evaluation phase:

- ***Monitoring:*** This is conducted through following a monitoring plan (see previous chapter) with proponents needing to be prepared to conduct site modification and/or remedial planting if survival is below expectation.

- ***Managing and adjusting expectations:*** It is important to manage realistic expectations of the outcome of restoration efforts. To achieve, this a clear communication strategy is critical. If there is a restoration pilot trial, then it needs to be viewed as it is, i.e. an experiment and learning process, to be scaled up and modified over time, with transparent sharing and learning of failures and unexpected developments along the way to determine what works and what doesn't. The outcome of a pilot trial will define whether a full restoration program is worth pursuing. Expectations may be too high if people expect and conclude that a particular restoration approach will be successful without any prior learning experience and/or proven demonstration of success under similar circumstances (or from earlier pilot trials at the site).

- ***Reporting and sharing of lessons learnt:*** Publication of the results and sharing of experiences is essential and offers an opportunity for others to accommodate the lessons learnt into the planning and design of new restoration projects at other locations in the future.

8.4 Recommendations for research:

Whilst the primary goal of restoration should not be to advance science but to accomplish an increase in seagrass area, the following research topics are recommended to fill existing critical knowledge gaps that would benefit the outcome of seagrass restoration efforts in the WIO region:

- Investigate seasonality of flowering, seed production and seed bank formation in WIO seagrass species

- Evaluate the appropriateness of different restoration methodologies for the different seagrass species in the WIO region
- Conduct a cost-effectiveness evaluation of different restoration methods (based on pilot projects) for large-scale application in seagrass restoration programs in the WIO region.

CASE STUDY 10.

Community-based seagrass bed restoration trials at Diani and Wasini Island, Kenya

A number of preliminary seagrass restoration studies and small-scale pilots were initiated along the Kenyan coast beginning in 2007. Experimental trials of seagrass restoration were conducted following incidences of seagrass decline due to excessive sea urchin herbivory at Diani. This first seagrass transplantation trial off Diani Beach was conducted using the sod method and the climax species *Thalassodendron ciliatum* and *Thalassia hemprichii.* Although this trail did not bear strong results, it provided insights into restoration processes and yielded good indicators for follow-up and lessons learned on site selection and optimization of transplantation techniques.

Further experimental work in a research project using artificial seagrass mimics provided insight in the process of (meio-) faunal colonisation, sediment trapping and establishment of pioneer seagrass seedlings within the restoration plots (Mutisia, 2009).

In April 2015, a promising community-based seagrass restoration project was started at Wasini Island to restore degraded seagrass areas (Daudi *et al.*, 2015; Plate 20). A major component of this project focused on the training of local community members in seagrass restoration. The training included an overview of the importance of coastal ecosystems to ocean health and local community livelihoods, the reasons for seagrass restoration, procedures for restoration and practical training in restoration techniques.

The project successfully trained 30 local community members and implemented a mapping of healthy and degraded seagrass areas at Wasini Island. Approximately 2.3 ha of seagrass habitat was restored using *Thalassia hemprichii* shoots and seedlings collected from a nearby donor site. Seedlings were planted using hessian bags for anchoring and to stabilize the sediments at the site. The long-term growth, performance and survival of the restored seagrass areas is being monitored by the communities. The encouraging initial results of this trial and its methodology will be used for the planning of further participatory seagrass restoration activities along the Kenyan Coast.

Plate 20. Community-based seagrass restoration project at Wasini Island, involving the planting of seagrass seedlings using hessian bags for anchorage and sediment stabilisation (right), after advance consultation and planning by the local community (left).

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The Nairobi Convention through the GEF-funded project, Implementation of the Strategic Action Programme for the protection of the Western Indian Ocean from land-based sources and activities (WIOSAP), in collaboration with WIOMSA, are facilitating the production of a series of regional Guidelines. The first three volumes are on Seagrass Ecosystem Restoration, Mangrove Ecosystem Restoration and Assessment of Environmental Flows in the WIO Region.

The participating countries in the WIOSAP include Comoros, Madagascar, Mauritius, Seychelles, Mozambique, Kenya, Tanzania, France (not a beneficiary of GEF funds), Somalia and South Africa. The Goal of the WIOSAP is to: 'Improve and maintain the environmental health of the region's coastal and marine ecosystems through improved management of land-based stresses'. The specific objective of the WIOSAP is 'To reduce impacts from land-based sources and activities and sustainably manage critical coastal-riverine ecosystems through the implementation of the WIOSAP priorities with the support of partnerships at national and regional levels.'