Western Indian Ocean JOURNAL OF Marine Science

Volume 20 | Issue 2 | Jul – Dec 2021 | ISSN: 0856-860X

Western Indian Ocean
JOURNAL OF
Marine Science

Published biannually

Aims and scope: The *Western Indian Ocean Journal of Marine Science* provides an avenue for the wide dissemination of high quality research generated in the Western Indian Ocean (WIO) region, in particular on the sustainable use of coastal and marine resources. This is central to the goal of supporting and promoting sustainable coastal development in the region, as well as contributing to the global base of marine science. The journal publishes original research articles dealing with all aspects of marine science and coastal management. Topics include, but are not limited to: theoretical studies, oceanography, marine biology and ecology, fisheries, recovery and restoration processes, legal and institutional frameworks, and interactions/relationships between humans and the coastal and marine environment. In addition, *Western Indian Ocean Journal of Marine Science* features state-of-the-art review articles and short communications. The journal will, from time to time, consist of special issues on major events or important thematic issues. Submitted articles are subjected to standard peer-review prior to publication.

Manuscript submissions should be preferably made via the African Journals Online (AJOL) submission platform (http://www.ajol.info/index.php/wiojms/about/submissions). Any queries and further editorial correspondence should be sent by e-mail to the Chief Editor, wiojms@fc.ul.pt. Details concerning the preparation and submission of articles can be found in each issue and at http://www.wiomsa.org/wio-journal-of-marine-science/ and AJOL site.

Disclaimer: Statements in the Journal reflect the views of the authors, and not necessarily those of WIOMSA, the editors or publisher.

ISSN 0856-860X

Cover image: Humpback whale mother-calf pair at Sainte Marie channel, Madagascar. © Cétamada association (Madagascar), 2017

Seagrass restoration trials in tropical seagrass meadows of Kenya

Jacqueline Uku[1]*, Lillian Daudi[1], Charles Muthama[1], Victor Alati[1], Alex Kimathi[1], Samuel Ndirangu[1]

[1] Kenya Marine and Fisheries Research Institute, PO Box 81651, 80100, Mombasa, Kenya

* Corresponding author: juku988@gmail.com

Abstract

The degradation of seagrasses is becoming prevalent in the Western Indian Ocean (WIO) region due to anchor damage, sea urchin herbivory, extreme events such as cyclones and floods and anthropogenic factors such as pollution and sediment inflows. Consequently, there have been numerous efforts to advance the restoration of degraded seagrass beds in several countries in the region. In Kenya, experimental restoration efforts were started in 2007 in response to seagrass habitat degradation due to sea urchin herbivory. Although the initial efforts experienced challenges, there were lessons learned which provided insights into subsequent restoration work using different techniques. In this paper, insights are provided into three types of restoration techniques; the sod technique, the seagrass mimic technique, and the Hessian bag technique. In the case of the sod technique, *Thalassodendron ciliatum* showed a decline from 20 ± 1.7 shoots sod^{-1} in the first three weeks to 7 ± 4.4 shoots sod^{-1} at the end of the experimental period of the study, while *Thalassia hemprichii* sods showed an increase from 28 ± 3.4 shoots sod^{-1} to 32 ± 2.7 shoots sod^{-1} over the same period. For the Hessian bag method, the expectation was that the pilot site would be filled with the transplanted seagrass species, *Thalassia hemprichii*, but the findings showed that different species including *Halodule uninervis*, *Syringodium isoetifolium*, *Halophila stipulacea*, *Cymodocea rotundata*, and *Cymodocea serrulata* colonized the area. This indicated that it was not possible to restore the area to its original status, but that the area could be rehabilitated. The costs of restoration have also been assessed as well as community participation in such initiatives. These findings provide insights for restoration efforts in Kenya and provide a baseline for future work.

Keywords: *Thalassodendron cililatum*, *Thalassia hemprichii*, rehabilitation, sods, mimics, Hessian bag

Introduction

Seagrasses are widely distributed in shallow coastal areas throughout the world with over 60 described species, 12 genera and four families (Short *et al*., 2007; Orth *et al*., 2006). Seagrasses have been traditionally used for roof covering, as medicine, fertilisers, and their seeds as a food source (de la Torre-Castro and Rönnbäck, 2004). They provide shelter for breeding, nursery and feeding grounds for herbivorous fish, dugongs and turtles (Björk *et al*., 2008). They also support a diverse assemblage of plant and animal species which include macroalgae that grow as epiphytes on the stems and leaves of the seagrasses (Uku, 2005), and invertebrates that include sea cucumbers, sea urchins, shrimps and lobsters (Ochieng and Erftemeijer, 2003). Due to these attributes they function as an important food source and support the livelihoods of local communities. Seagrass beds are important in sediment stabilization, nutrient cycling, shoreline protection, enhancement of water transparency, biological system support and carbon sequestration because of their slow decomposition rate (Muthama and Uku, 2003; Orth *et al*., 2006; Juma *et al*., 2020). They therefore have a high economic value (Costanza *et al*., 1997; Björk *et al*., 2008) which is further elaborated by Mtwana Norlund *et al*. (2016) who highlighted ecosystem services and values associated with water purification, provision of cultural artefacts, coastal protection, fertilizer and pharmaceutical uses.

http://dx.doi.org/10.4314/wiojms.v20i2.6

In recent years, seagrass beds have been altered due to frequent anthropogenic and natural disturbances (Waycott *et al*., 2009; Paulo *et al*. 2019). Anthropogenic threats that have led to the decline of seagrasses globally include pollution, dredging, destructive fishing activities, aquaculture, invasive species introduction and overfishing of predators, among others (Waycott *et al*., 2009). Climate change effects include rising sea levels, increase in sea temperature and flooding, leading to a rate of seagrass loss of approximately 7 % per year and this places seagrasses at the same level as mangroves and corals as the most threatened ecosystems on earth (Waycott *et al.,* 2009). In Kenya, the loss of seagrasses over time has been documented to be from 0.29 % yr^{-1} in 2000 to 1.59 % yr^{-1} in 2016, which is lower than the global rate of loss (Harcourt *et al*., 2018), but has the potential to increase due to the increasing threats in these systems. These threats affect seagrass beds and their ability to provide ecosystem services including their ability to sequester carbon.

Seagrass beds have been degraded in Kenya due to sea urchin herbivory (Eklof *et al*., 2008) and this has implications on the functionality of these important critical habitats. Further to this, some of the seagrass species within the coastline of Kenya fall among those that are considered threatened on a global scale, such as *Zostera capensis* (Short *et al*., 2011). The loss in these critical habitats threaten critical ecosystem functions such as nutrient cycling, photosynthesis, carbon sequestration, sediment stabilization and key fisheries and biodiversity that are supported by these ecosystems (Irving *et al*., 2014). In Kenya and Mozambique, loss of seagrass cover has been documented to lead to a loss of fauna, and decreased sediment stabilization leading to erosion exposure in degraded areas (Eklof *et al*., 2008; Amone-Mabuto *et al*., 2017).

Seagrass meadows take several years for natural recovery from disturbances, with some species like *Posidonia spp.* taking up to 100 years to cover a cleared substratum (Kirkman and Kuo, 1990). Therefore, in an attempt to enhance recovery times, various restoration methods have been developed (Irving *et al*., 2014, Paulo *et al*., 2019). Two approaches can be undertaken to restore ecosystem services. This can be done through (i) the reduction of the threats facing these ecosystems, or (ii) by physically restoring the ecosystems through harvesting seagrasses from a donor site and transplanting these plants in the degraded area. Physical restoration efforts have been undertaken worldwide with some successes and failures reported (Paling *et al*., 2009; Bayraktarov *et al*., 2016).

Conservation and restoration of seagrass beds can be enhanced by transplantation of plants from natural seagrass beds (Paling *et al.,* 2001). Their restoration, usually conducted in areas affected by eutrophication, coastal construction and mechanical damage from boat propellers and fishing nets (van Katwijk *et al*., 2016), is expected to lead to recolonization and creation of new meadows (Paling *et al*., 2007; van Katwijk *et al*., 2016). Restoration has been undertaken in several parts of the world with the most successful work being undertaken in Australia by Murdock University (van Keulen *et al.,* 2003; Paling *et al.,* 2003,) using the species *Posidonia spp.* and *Amphibolis griffithii* (Black, den Hartog) (Paling *et al.,* 2001). Seagrass transplantation has also been conducted on a large scale using mechanically transplanted sods with the help of specially designed underwater seagrass harvesting and planting machines with a capacity of planting of up to 18 sods day^{-1} (Paling *et al*., 2001). Such restoration efforts have been performed world-wide to compensate or mitigate seagrass losses and have been shown to enhance the associated ecosystem services (Orth *et al*., 2020; Tan *et al*., 2020; UNEP, 2020).

Several lagoons in Kenya including the Diani – Chale lagoon have been affected by seagrass degradation. The area is dominated by tourist activities and the seagrass beds form artisanal fishing grounds. Available information shows extensive seagrass decline especially for the dominant species, *Thalasodendron ciliatum* Forskal den Hartog (Uku *et al*., 2005). This decline was attributed to the proliferation of the sea urchin, *Tripneustes gratilla* (L.) (Eklof *et al*., 2008). The rapidly increasing rate of seagrass degradation compared to the low rate of natural recovery has increased the demand for seagrass restoration in Kenya. This widespread seagrass loss led to the experimental trials of restoration using different methods with varying measures of success.

In this paper the prospects of seagrass restoration efforts in Kenya are described through the evaluation of trials of seagrass restoration in the country, and recommendations are made on the methods that are suitable for restoration. Experiences are shared in seagarass restoration experiments conducted on the south coast of Kenya, in Diani and Wasini, from 2007 to 2015. It was attempted to determine the following aspects of restoration in these experiments: (i) which species of the 11 seagrasses found in the degraded areas could be used for restoration; (ii) which time of the year is best suited for seagrass restoration; and (iii) which restoration method yields the best outcome. Over this period, areas were worked in that were impacted by natural degradation caused by sea urchin herbivory and an area that was impacted by anthropogenic degradation caused by boat anchorage and trampling.

This paper is aimed at sharing some of the lessons learnt in the seagrass restoration pilot studies carried out in Kenya whose methodologies could potentially be used in other areas of the WIO Region.

Methods

Data has been compiled in this paper from three restoration trials conducted in Kenya between 2007 and 2015. All the trials occurred on the south coast of Kenya, which had been greatly impacted by sea urchin herbivory. By the time the trials were being undertaken the seagrass herbivory had halted and the sea urchin numbers had declined. The trials consisted of different planting techniques, in shallow subtidal areas, and different monitoring frequencies. The frequency of monitoring for the different techniques was varied and in some cases the only data available was for the initial planting effort versus the final monitoring of the transplanted seagrasses.

To test for success of the rehabilitation technique, the survival rate was determined, as explained in the different transplantation techniques, and also documented colonization by other seagrass species. In most of the restoration work, regular monitoring was not possible due to financing gaps and the measure of restoration success was based on the site assessments at the start and end of the experimental period that varied with the different methods used.

Seagrass transplantation using the sod technique

The experimental work using the sod technique was conducted in 2007 in Diani. Three experimental seagrass plots of 10 m^2 within the Diani lagoon were established. The plots were separated by 20 meters from each another. The three plots of 10 m^2 were planted with seagrass making a total area of 300 m^2 (0.03 ha). The sod/plug technique was used following a protocol developed by van Keulen *et al.* (2003). Although the initial intention was to establish equal replicates of *Thalassodendron ciliatum* and *Thalassia hemprichii* plots, the final work yielded two plots of planted *Thalassodendron ciliatum* sods and one plot of *Thalassia hemprichii* sods, therefore covering a final area of 0.03 ha.

The two species were selected due to their previous occurrence in the study site. Each sod/plug consisted of bundles of viable shoots, with attached rhizomes, which were collected from healthy beds and transported to the recipient sites to be transplanted within 2 hours. The sods were collected using a corer of 18 cm diameter and planted by carefully fitting them into prepared holes. The sods were planted 1m apart and there were approximately 20 shoots per sod. The planted sods were initially monitored weekly for shoot density, canopy height and the number of sods remaining during each visit (Fig. 1). Recovery success was measured in terms of percentage survival of

A

B

Fig. 1. (a) A sod retrieved from a healthy area and (b) sods planted within the degraded area.

transplanted sods by counting the number of remaining sods during every field visit. The initial monitoring was conducted over three weeks during the North East Monsoon (NEM) which is represented by calmer sea conditions, while the rest of the monitoring was conducted within the South East Monsoon (SEM) season which is represented by rough sea conditions.

Restoration using plastic seagrass mimics

Plastic seagrass mimics resembling *Thalassia hemprichii* were set up in the Diani lagoon in 2008 to undertake a three-week experiment on colonization of degraded areas by epiphytic meiofauna (Daudi *et al*, 2013). The mimics had an average plant surface area of 146.8 cm^2 (SE ± 17.3). The mimics were anchored into the sediment using stay rods with an oval eye and cable ties were used to secure them to the rods (Fig. 2). A total of six mimics were set in each plot providing a total 18 mimics in the experimental restoration site of 0.03 ha. Although the seagrass mimics were set up for the assessment of colonization by epiphytic meiofauna, they yielded results that enhanced understanding of the potential for the use of artificial seagrasses in the rehabilitation process (Tuya *et al.*, 2017). The mimics were harvested after 21 days to collect associated epiphytic meiofauna and the findings of this work have been published in Daudi *et al.* (2013).

A

B

Fig. 2. (a) Seagrass mimics anchored with an oval eyed metal rod and (b) *Halophila ovalis* observed around the seagrass mimics.

Seagrass transplantation of seedlings using the modified Hessian bag method

The use of the Hessian bag technique was undertaken on the south coast at Wasini Island in 2015. The seagrass seedlings were harvested using a PVC corer from healthy *T. hemprichii* meadows in Mkwiro (*Nyuma ya maji*), approximately 8 km from the restoration site. The harvested sods were carefully transported to the restoration site within two hours of harvest to avoid desiccation. The sods were further processed by separating them into individual *T. hemprichii* seedlings.

The method used was a modification to the biodegradable Hessian bag protocol by Irving *et al.* (2014). In the original method, the Hessian bags were filled with sand and placed on the substrate to provide an anchorage for recruits of *Amphibolis antarctica* (Labill.) Asch. In the present study, the Hessian bags (jute bags), which were 1 m wide and 1.2 m long, were cut open lengthwise on one side and the bottom and flattened out before the planting process. They were punched with small holes using dive knives and the seedlings were planted in these holes. The bags were anchored in the restoration site using mangrove poles and 50 bags were joined to make an area of approximately 0.012 ha. A spacing interval of 20 cm for the seedlings was used. Each plant unit consisted of approximately three shoots with attached rhizomes grouped together as a cluster. Fifty jute sack bags were used with each sack having approximately 40 planted seedlings (Fig. 3). This resulted in approximately 2000 seedlings over a surface area of 0.012 ha.

Community engagement in the seagrass restoration work

Members of the fishing community from the nearby Beach Management Units (BMU) were included in the survey and establishment of the transplantation plots in all the seagrass restoration work. In Wasini, as the restoration effort was within their co-management area (CMA), more effort was made to involve the BMU members fully. The project design was disclosed to the community members at the onset of the work. The members selected the restoration site. As a follow up, 30 community members from the Beach Management Unit were trained in the establishment and monitoring of the experimental site. They also had the responsibility of safeguarding the site from other threats. As the technical team was unable to visit the site as envisioned, the community members from the BMU were expected to provide an in-kind contribution by monitoring the site and providing feedback on what they saw.

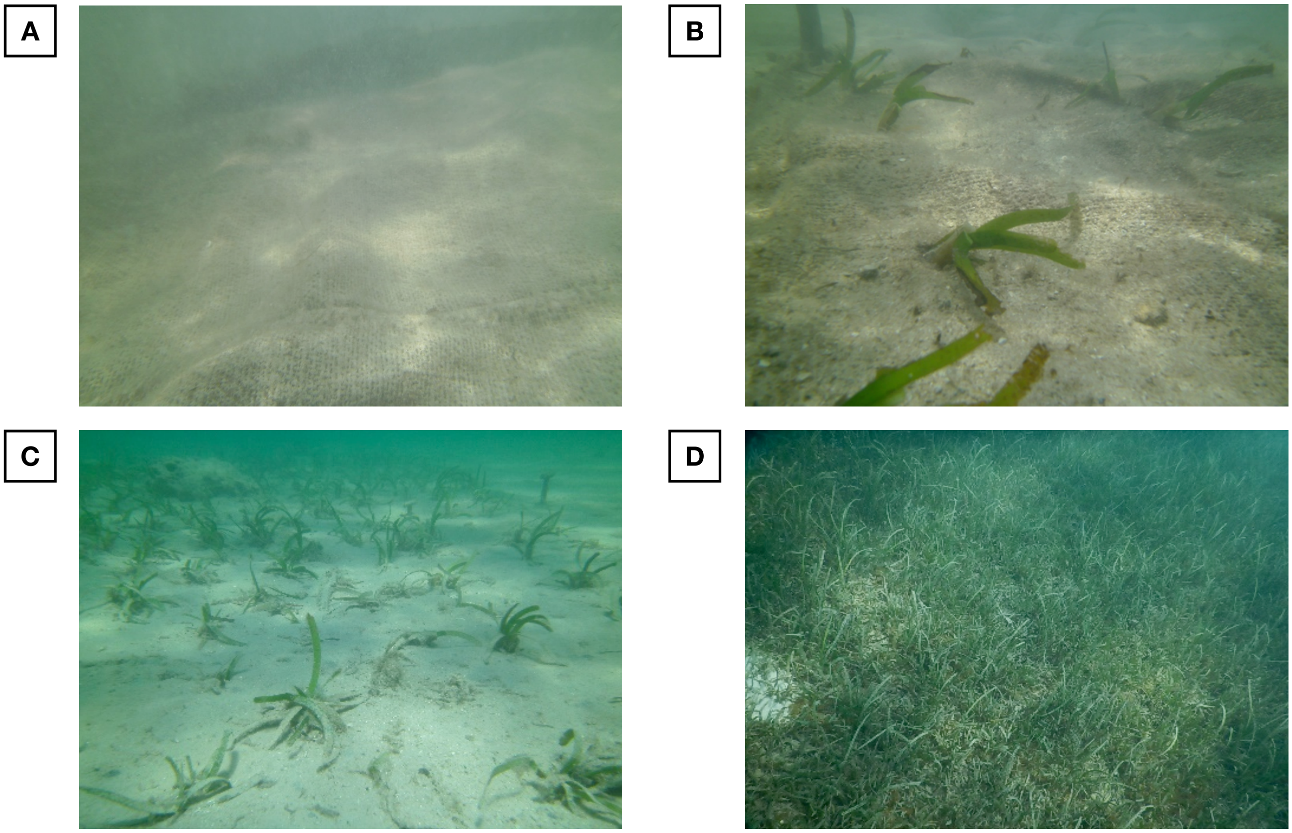

Fig. 3. (a) Hessian/Jute bags anchored for planting seedlings, (b) freshly planted *T. hemprichii* seedlings, (c) healthy growing *T. hemprichii* 6 months after establishment of the site, and (d) rehabilitated area colonized by other seagrass species in the restoration site in Wasini.

Results

The survival of seagrasses using the sod technique in Diani

The survival of the entire sod was estimated in Diani. The sod survival of *T. ciliatum* ranged between 26 ± 0.9 sods plot^{-1} to 5 ± 2.9 sods plot^{-1} while that of *T. hemprichii* ranged from 22 sods plot^{-1} to 15 sods plot^{-1} during the monitoring period which was in the first three weeks after transplantation, and later in the 32nd week after transplantation, Sod survival in the first three weeks was significantly higher than the last six weeks of monitoring for both species (Mann Whitney U=0.00; $p<0.05$ (Fig. 4). *T. ciliatum* experienced a high rate of loss of sods at 81 % whereas for T. *hemprichii* the loss was much lower from the first week to the 37th week of the experiment. Significant differences were observed between shoots per sod for the two species with a decrease in the number of shoots per sod for *T. ciliatum,* from 20 ± 1.7 shoots sod^{-1} in the first three weeks to 7 ± 4.4 shoots sod^{-1} at the end of the experimental period (Fig. 5). Monitoring from week 32 however showed a general switch between the two species with an increase in the number of shoots per sod for *T. hemprichii* and a decline of the same for *T. ciliatum* (Fig. 5). *T. hemprichii* increased from 28 ± 3.4 shoots sod^{-1}at the start of the experiment to 32 ± 2.7 shoots sod^{-1}.

The canopy heights were highest for *T. ciliatum* (17 cm) at the beginning of the experiment but reduced continuously over time up to approximately 7 cm at the end of the monitoring period, showing a reduction of about 60 % (Fig. 6). Contrary to this, *T. hemprichii*, which recorded initial canopy of approximately 7 cm, showed an increase in canopy height of 8 cm at the end of the experiment. Significant differences were observed for canopy height between both species as well as between the different monitoring periods (Mann-Whitney U=5050 for differences between species and U=1791.5, U=433.5 for *T. ciliatum* and *T. hemprichii*, respectively).

Seagrass restoration using mimics in Diani

Follow up observations of the seagrass mimics showed that none of the seagrass mimics were uprooted in Diani. Observations, though not quantitative, indicated that the mimics were surrounded by the pioneer seagrass species *Halophila stipulacea* (Forsskål)

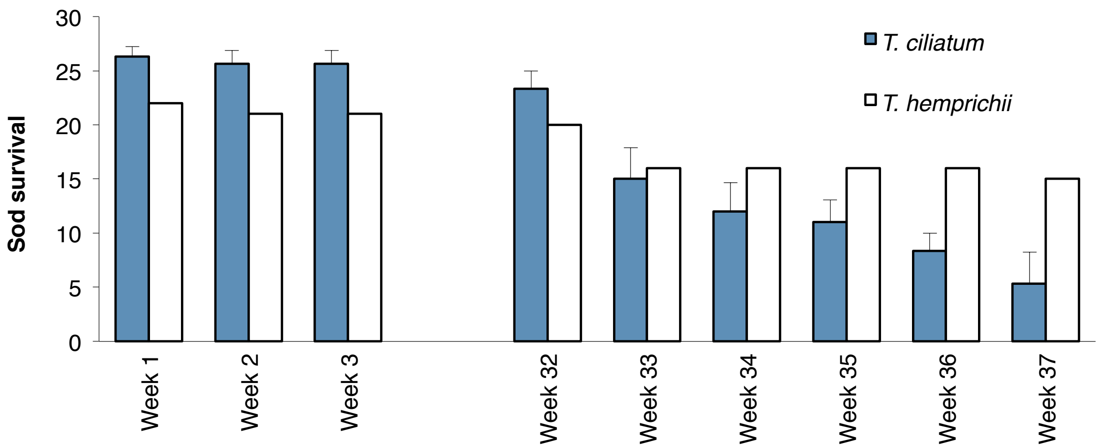

Figure 4. Variation in sod survival of *T. ciliatum* and *T. hemprichii* for the monitoring period (Note that as there was only one plot for *T. hemprichii* there is no standard error for this species).

Ascherson towards the end of the three weeks of deployment. These observations indicated that the mimics were important in stabilizing sediments around them thus allowing colonization by the pioneer species.

Seagrass restoration using seedlings on Hessian bags in Wasini

Approximately 2000 seedlings of *T. hemprichii* were planted in the study area at Wasini. Due to the disruption in funding, the site was not monitored as it should have been by the technical team. The community members reported the recolonization by associated epiphytes and seagrasses six months after replantation. They also reported instances of herbivory of the shoots but did not estimate the quantity of the loss of shoots. The community monitoring was irregular and not as rigorous as was anticipated.

An assessment conducted three years later in 2018, revealed colonization by other seagrass species other than the replanted species, *T. hemprichii*, and seagrass cover was documented to be approximately 75 % in the area that was previously bare of seagrasses. The new colonizing species included *Halodule uninervis* (Forskål) Ascherson (29 % cover), *Syringodium isoetifolium* (Ascherson Dandy) (39 % cover) and *Halophila stipulacea* (Forskål) Ascherson (7 % cover). *Cymodocea rotundata* Ehrenberg & Hempr. ex Ascherson and *Cymodocea serrulata* (R. Br.) Ascherson & Magnus, were also noted at the site. The spread of the species around the restored area showed a wider expanse of spread of these species, though the coverage was not estimated.

The costs of restoration using the different methods

Table 1 shows the associated costs of restoration which need to be considered when adopting such activities.

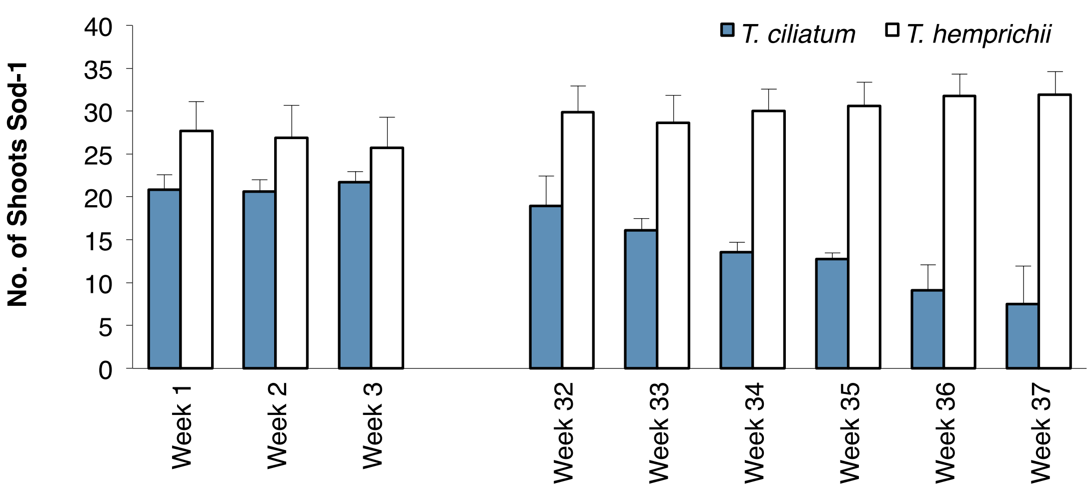

Figure 5. Variation in the number of shoots per sod of *T. ciliatum* and *T. hemprichii* for the monitoring period.

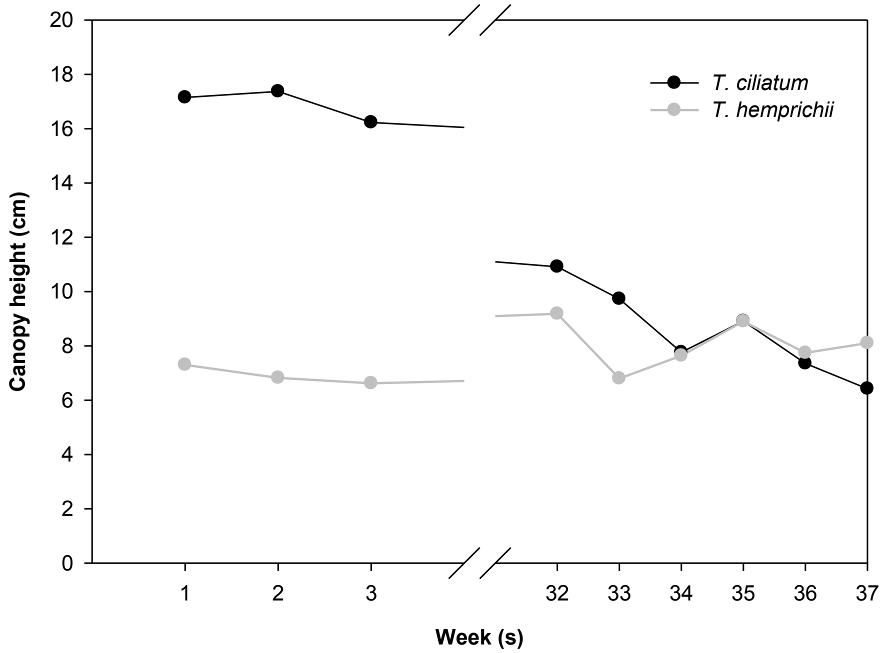

Figure 6. Canopy height for *T. ciliatum* and *T. hemprichii* during the monitoring period.

The costs include the costs of manpower through technical expertise from researchers, community participation from local fishermen, materials/equipment, and the costs of monitoring and evaluation. The costing does not consider the time spent doing the work for the fishers who monitored the sites as part of their fishing effort. The highest cost incurred was for the Hessian bag method (Table 1).

Discussion

Seagrass restoration using the sod method

Restoration using the sod technique has been documented to yield higher chances of transplant success (van Katwijk *et al.*, 2009) and this was expected from this work for the two species used. However, the sods were impacted by the effect of seasonality. Planting of the sods was carried out during the NEM season and this represented the period of stable sod survival for both *T. ciliatum* and *T. hemprichii*. This is a result of the calm weather conditions that are normally associated with this season. On the other hand, the SEM season is characterized by rough sea conditions that destabilized the planted sods and this was evident in this study with lower survival of sods in July/August 2008. Van Katwijk *et al.* (2009) indicate that the outcome of transplantation of seagrasses is dependant on hydrodynamic stressors and disturbances while Diego *et al.* (2019) indicate that transplants

Table 1. Cost estimates for the seagrass restoration work.

Site	Year	Planted area	Plant material used	Cause of degradation	Approximate costs of rehabilitation (costs in USD for the restored area)
Diani	2007 to 2008	0.03 ha	Sods/Plugs (*Thalassodendron ciliatum, Thalassia hemprichii*)	**Urchin herbivory (natural causes)**	Technical support = 2,609 Community costs = 862 Equipment costs = 2,529 Costs per ha = 200,000
Diani	2008	0.03 ha	Seagrass mimics	**Urchin herbivory (natural causes)**	Technical support = 500 Equipment costs = 360 Costs per ha = 28,667
Wasini	2015	0.012 ha	Seedlings using Hessian/ Jute bags (*Thalassia hemprichii*)	**Boat propeller damage and trampling (Anthropogenic causes)**	Technical support = 6,373 Community costs = 760 Equipment costs = 2,667 Costs per ha = 817,000

did not survive winter conditions and strong storms in Marine Park Professor Luiz Saldanha in Portugal. The timing of planting is critical and the NEM is most appropriate for planting seagrass rehabilitation meadows in the WIO region which is influenced by the monsoonal seasonal variations. Sods must be planted at the onset of the low energy NE monsoon season when there are no strong winds and waves, as the seagrass roots and rhizomes need to have time to stabilize in order to ensure success.

The sod technique in this study showed greater success for *T. hemprichii* suggesting that this species was more successful for transplantation using the sod method and was more resilient to seasonal environmental changes. The increasing shoots observed for *T. hemprichii* also suggests a more successful vegetative reproduction mode for this species than for *T. ciliatum.* In this assessment, the sod method provided a loose anchorage for *T. ciliatum* and the shoots were carried off easily by wave action. It can only be postulated in this paper that the success of *T. hemprichii* could be due to their growth form and adherence to sandy substrates on shallow intertidal flats, while *T. ciliatum* favors growth on mixed sandy and rocky or hard substrates in deeper infra-littoral zones (Aleem, 1984; Gullstrom *et al*., 2002). *T. cilatum* sods may have also required additional anchorage to enable them to settle on the substrate as demonstrated by van Katwijk (2016). Further to this, the stocking density may also have had an influence as more shoots were contained in the *T. hemprichii* sods compared to the *T. ciliatum* sods. *T. ciliatum* was originally the dominant species at the restoration site, and its loss from the areas may have led to seabed erosion (Ekloff *et al.,* 2008) and altered the sediment to the extent that anchorage by this species, which has shallow rhizomes (Ekloff *et al*., 2008), was not possible.

Seagrass restoration using mimics

Although the experiment using the seagrass mimics was set up to address a different set of questions, it provided insights on the opportunity that the mimics can provide for the settlement of sediments in bare sand areas. The mimics promoted the settlement of pioneer species such as *Halophila stipulacea* (Forsskål) Ascherson. This demonstrates an opportunity for use as technique in areas that may be too rough for the sod technique and Hessian bag method and yet require rehabilitation. It is further recommended that instead of metal anchors, biodegradable material such as bamboo can be considered as this can be bent to provide strong anchors on the substrate (Calumpong and Fonseca, 2001). Tuya *et al*. (2017) also demonstrated the usefulness of artificial seagrasses in increasing the survival of transplanted seagrass as they functioned as a shield against herbivory. In some instances, such seagrass mimics can be used to stabilize sediments and allow for the establishment of seagrasses through natural recovery (UNEP, 2020).

Seagrass restoration using the Hessian bag technique

Given the success of *T. hemprichii* restoration using the sod technique in 2007, it was decided to use this species in the work undertaken using the Hessian bag method in Wasini in 2015. Irving *et al*. (2014) developed the Hessian bag method for facilitating recruitment of *Amphibolis antarctica* seedlings *in situ*, where bags were filled with sediment from donor beds and deployed in restoration sites. This method was modified in the current study to use vegetative shoots rather than filling the bags with sand. Since the donor bed was further away from the transplantation site, this also ensured that it was not necessary to depend on donor meadows as a source of seed as was the case in Irving *et al*. (2014). The Hessian bag served as anchoring material for the planted seedlings to prevent them from being uprooted due to waves and currents. The bag also facilitated the trapping of sediments which served as a substrate for root and rhizome development. From this study it is recommended that this modified method is adopted as it is convenient for transplantation of *T. hemprichii* seedlings in shallow subtidal sites which have a sandy substrate and could also be applied to other species with similar morphological characteristics. Further, the Hessian bag method is environmentally friendly as the sisal material disintegrates in the water and the mangrove poles are eventually uprooted and disintegrate. As the bags and mangrove poles can easily be found locally and since they are biodegradable they do not harm the environment. Further success in this area was achieved through the removal of the threat from boat anchor damage and trampling by the introduction of mooring buoys in the area outside of the seagrass beds.

The Hessian bags provided settling substrate for colonization by pioneer species and other intermediate species such as *H. uninervis*, *S. isoetifolium*, *H. stipulacea*, *C. rotundata* and *C. serrulata* apart from *T. hemprichii* which was the transplantation species.

The costs of restoration

The overall cost of transplantation using the different methods in these experiments was within the reported costs of seagrass restoration projects of USD 630,000 per hectare reported by Calumpong and Fonseca (2001), although the Hessian bag technique was slightly higher. The Hessian bag method required a large amount of manpower to establish a plot and more work needs to be done to reduce the costs of using this method. Further investigations using the mimic method, for a longer duration of time, may yield a much cheaper and cost-effective restoration approach.

Conclusions

The experimental restoration work showed that there are key aspects that need to be considered to ensure the success of seagrass restoration projects. These include the following:

1. Seasonal stressors are important as demonstrated by the success achieved in the sod establishment method during the calmer NEM period;
2. More work is needed to determine a better approach to the restoration of climax species such as *T. ciliatum* in shallow subtidal areas;
3. Site selection is also critical as it is important that sites are sheltered from high wave action to provide the transplanted seagrass with an opportunity for settlement and spread;
4. Identification and removal of the stressors is important and crucial in providing for re-establishment of seagrass areas (Katwijk, *et al.* 2016) that have been stabilized, as demonstrated through the Hessian bag method where anchoring buoys were introduced, and in the sod method where the work was undertaken when the sea urchin numbers had declined;
5. Preservation of seagrass beds is critical to ensure that there are donor communities from which to obtain seed materials;
6. There is need to monitor the restored areas over long time periods and to share the costs with communities to ensure lower costs of the work. In this study the science support covered the technical aspects of restoration while the community support entailed monitoring of the sites. However, this work revealed the need for repeated training and greater technical oversight in order to ensure that monitoring data is correctly documented by community members;
7. Seagrass restoration success can be hindered by costly and time consuming methods of restoration, absence of a scientific method (such as the use of controls) which may affect evaluation of success, site selection, bioturbation caused by marine organisms, the size of the area targeted, and elevated tidal and wind driven current energy, among other factors (Bell, *et al.*, 2008). Controls should be set in sites that are similar in nature to the restoration site and should be monitored alongside the restoration site; and
8. In this study, the expectation was that the pilot site using the Hessian bag technique would be filled with the transplanted seagrass species, *Thalassia hemprichii*, but the findings showed that different species colonized the area thus indicating that it was not possible to restore the area to its original status. It was however, still rehabilitated with seagrasses. Long term monitoring (beyond 5 years) is required to monitor the colonization process and determine whether the original state is ever achieved.

In summary, if scaled up with consideration of the lessons learnt, this seagrasss restoration trial using successfully tested restoration techniques would contribute to Kenya's efforts towards the sustainable development goal of supporting ecosystem rehabilitation efforts where feasible. Globally such efforts contribute towards the achievement of SDG 14.2 which indicates that by 2020, marine and coastal ecosystems should be sustainably managed and protected to avoid significant adverse impacts, including by strengthening their resilience, and taking action for their restoration in order to achieve healthy and productive oceans. In light of this global target, the findings of the seagrass restoration work in Kenya provide several insights into the processes that can be adopted for the future in this field.

Acknowledgements

The authors wish to thank WIOMSA for the MARG I grant to Charles Muthama, which supported the experimental trials using the sod methodology in 2008. The seagrass mimic work formed part of a MSc thesis by Lillian Daudi under the Flemish Interuniversity Council scholarship program of Master of Science in Ecological Marine Management (ECOMAMA, Free University of Brussels). The work using the Hessian bags was supported through the World Bank funded Kenya Coastal Development Project (2010 – 2017). We are also grateful to the community members led by the Mvuleni and Wasini Beach Management Units that participated in these experimental studies.

References

Aleem, A (1984) Distribution and ecology of seagrass communities in the Western Indian Ocean. Deep-Sea Research 31: 919-933

Amone-Mabuto M, Bandeira S, da Silva A (2017) Western Indian Ocean Journal of Marine Science 16 (2):13-25

Bayraktarov E, Saunders M, Abdullah S, Mills M, Beher J, Possingham H, Mumby P, Lovelock C (2016) The cost and feasibility of marine coastal restoration. Ecological Applications 26 (4): 1055-1074

Bell S, Tewfik A, Hall M, Fonseca M (2008) Evaluation of seagrass planting and monitoring techniques: Implications for assessing restoration success and habitat equivalency. Restoration Ecology 16 (3): 407-416

Björk M, Short F, Mcleod E, Beer S (2008) Managing seagrasses for resilience to climate change. IUCN, Gland, Switzerland. 56 pp

Calumpong H, Fonseca M (2001) Seagrass transplantation and other seagrass restoration methods. In: Short FT, Coles RG (eds) Global seagrass research methods. pp 425-443

Costanza R, d'Arge R, de Groot R, Farberk S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill R, Paruelo J, Raskin R, Suttonkk P, van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387: 253-260

Daudi L, Uku J, De Troch M (2013) Role of the source community for the recovery of seagrass associated meiofauna: a field colonisation experiment with seagrass mimics in Diani Beach, Kenya. African Journal of Marine Science (35): 1-8

de la Torre-Castro M, Rönnbäck P (2004) Links between humans and seagrasses—an example from tropical East Africa. Ocean & Coastal Management 47 (7-8): 361-387

Eklöf J, de la Torre-Castro M, Gullström M, Uku J, Muthiga N, Lyimo T, Bandeira S (2008) Sea urchin overgrazing of seagrasses: a review of current knowledge on causes, consequences, and management. Estuarine Coastal and Shelf Science (79): 569-580

Gullström M, de la Torre Castro M, Bandeira, S, Björk M, Dahlberg M, Kautsky N, Rönnbäck P, Öhman M (2002) Seagrass ecosystems in the Western Indian Ocean. Ambio 31 (7): 588-596

Harcourt W, Briers R, Huxham M (2018) The thin(ning) green line? Investigating changes in Kenya's seagrass coverage. Biology Letters 14 (11): 20180227

Irving A, Tanner J, Collings G (2014) Rehabilitating seagrass by facilitating recruitment:

Improving chances for success. Restoration Ecology 22 (2): 134-141

Juma G, Magana A, Michael G, Kairo J (2020) Variation in seagrass carbon stocks between tropical estuarine and marine mangrove-fringed creeks. Frontiers in Marine Science 7: 696

Kirkman H, Kuo J (1990) Pattern and process in southern Western Australian seagrass. Aquatic Botany 37: 367-382

Muthama C, Uku J (2003) Macrofaunal assemblages of littoral seagrass communities. Recent Advances in Coastal Ecology. African Studies Centre Research Report 70: 51-63

Mtwana Norland L, Koch E, Barbier E, Creed J (2016). Seagrass ecosystem services and their variability across genera and geographical regions. PLoS ONE 11 (10): e016309 [https://doi.org/10.1371/journal.pone.0163091]

Ochieng C, Erftemeijer P (2003) The seagrasses of Kenya and Tanzania. In: Green E, Short F (eds) World atlas of seagrasses. University of California Press, Berkeley, California. pp 82-92

Orth R, Curruthers T, Dennison W, Duarte C, Fourqurean J, Heck K, Hughes A, Kendrick G, Kenworthy W, Olyarnik S, Short F, Waycott M, Williams S (2006) A global crisis for seagrass ecosystems. BioScience 56: 987-996

Orth R, Lefcheck J, McGlathery K , Aoki L, Luckenbach M, Moore K, Oreska M, Snyder R, Wilcox D, Lusk B (2020) Restoration of seagrass habitat leads to rapid recovery of coastal ecosystem services. Science Advances 6 (41) [doi: 10.1126/sciadv.abc6434]

Paling E, Van Kuelen M, Wheeler K, Phillips J, Dyhrberg R (2001) Mechanical seagrass transplantation in Western Australia. Ecological Engineering (16): 331-339

Paling, E, van Keulen, M, Wheeler K, Phillips J, Dyhrberg, R (2003) Influence of spacing on mechanically transplanted seagrass survival in a high wave energy regime. Restoration Ecology 11 (1): 56-61

Paling E, van Keulen M, Tunbridge D (2007) Seagrass transplanting in Cockburn Sound, Western Australia: A comparison of manual transplantation methodology using *Posidonia sinuosa* Cambridge et Kuo. Restoration Ecology 15 (2): 240-249

Paling E, Fonseca M, van Katwijk M, van Keulen M (2009) Seagrass restoration. In: Perillo G, Wolanski E, Cahoon D, Brinson M (eds) Coastal wetlands: An integrated ecosystem approach. Elsevier. pp 687-713

Paulo D, Cunha A, Boavida J, Serrao E, Goncalves E, Fonseca M (2019) Open coast seagrass restoration. Can we do it? Large scale seagrass transplants. Frontiers in Marine Science 6: 52

Short F, Carruthers T, Dennison W, Waycott M (2007) Global seagrass distribution and diversity: A bioregional model. Journal of Experimental Marine Biology and Ecology 350 (1-2): 3-20

Short F, Polidoro B, Livingstone S, Carpenter K, Bandeira S, Bujang S, Calumpong H, Carruthers T, Coles R, Dennison W, Erftemeijer P, Fortes M, Freeman A, Jagtap T, Kamal H, Kendrick G, Kenworthy W, Hafie Y, Zieman J (2011) Extinction risk assessment of the world's seagrass species. Biological Conservation 144 (7): 1961-1971

Tan Y, Dalby O, Kendrick G, Statton J, Sinclair E, Fraser M, Macreadie P, Gillies C, Coleman R, Waycott M, van Dijk K, Vergés A, Ross J, Campbell M, Matheson F, Jackson E, Irving A, Govers L, Connolly R, McLeod I, Rasheed M, Kirkman H, Flindt M, Lange T, Miller A, Sherman C (2020) Seagrass restoration is possible: Insights and lessons from Australia and New Zealand. Frontiers in Marine Science 7: 617

Tuya F, Vila F, Bergasa O, Zarranz M, Espino F, Robina R (2017) Artificial seagrass leaves shield transplanted seagrass seedlings and increase their survivorship. Aquatic Botany 136: 31-34

Uku J, Ndirangu S, Muthama C, Kimathi A (2005) An evaluation of the effect of sea urchin herbivory in the Diani-Chale lagoon. Preliminary report No 1. A KMFRI/CORDIO collaborative project report. 8 pp

UNEP-Nairobi Convention/WIOMSA (2020) Guidelines on seagrass ecosystem restoration for the Western Indian Ocean Region. UNEP, Nairobi. 63 pp

van Katwijk M, Bos A, De Jonge V, Hanssen L, Hermus D, De Jong D (2009) Guidelines for seagrass restoration: importance of habitat selection and donor population, spreading of risks, and ecosystem engineering effects. Marine Pollution Bulletin 58 (2): 179-188

van Katwijk M, Thorhaug A, Marba N, Orth R, Duarte M, Kendrick G, Althuizen I, Balestri E, Bernard G, Cambridge M, Cunha A, Durance C, Giesen W, Han Q, Hosokawa S, Kiswara W, Komatsu T, Lardicci C, Lee K, Meinesz, A, Nakaoka M, O'Brien K, Paling E, Pickerell C, Ransijn A, Verduin J (2016) Global analysis of seagrass restoration: the importance of large-scale planting. Journal of Applied Ecology 53 (2): 567-578

van Keulen M, Paling E, Walker C (2003) Effect of planting unit size and sediment stabilization on seagrass transplants in Western Australia. Restoration Ecology 11 (1): 50-55

Waycott M, Duarte C, Carruthers T, Orth R, Dennison W, Olyarnik S, Calladine A, Fourqurean J, Heck K, Hughes A, Kendrick G, Kenworthy W, Short F, Williams S (2009) PNAS 106 (30): 12377-12381