

**PROJECT TITLE: ECOSYSTEM BASED PROTECTION OF THE COASTAL ZONE:
THE EFFECTIVENESS OF SEAGRASS MEADOWS IN COASTAL EROSION
MANAGEMENT**

FINAL REPORT



February 2023

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Abstract

Coastal ecosystems hold a specific, rich and unique biodiversity. They provide a variety of ecosystem services, which are directly linked to human wellbeing and environmental health. Anthropogenic pressures are, however, a threat to coastal ecosystems, and a rising sea level is posing further risks. The project aimed to document how the presence or absence of seagrass meadows influences biodiversity and sediment dynamics in the coastal zone, and how this drives the multi-functionality of the coastal zone. In the course of project implementation, the perception of the communities on the importance of seagrass meadows in terms of cultural functions, socio-economic functions and other immaterial services was assessed (Work Package 1). Two manuscripts were developed from this work package, and have been submitted for publication consideration. Given the widespread lack of knowledge with regard to how extensive seagrass meadows are in the WIO region, the inventory and mapping of seagrass meadows was carried out (as Work Package 2) in southern Mozambique (Maputo and Inhambane Provinces) and the entire coast of Tanzania (including Mafia, Unguja and Pemba Islands) to serve as the basis for developing monitoring and management strategies. The project managed to develop Geographic Information System (GIS) maps for the studied areas. Two manuscripts on seagrass mapping are in preparation as outputs.

To understand the multifunctional effects of implementing ecosystem-based actions, the secondary effects of biodiversity from the interplay between the shallow coastal zone and the terrestrial environment was evaluated (Work Package 3). Areas with and without intertidal seagrasses were compared to assess the terrestrial diversity (flora and fauna (macroinvertebrates)), and abiotic parameters (sediment grain size, organic matter content, carbonate content and sediment nutrients (N&P)). These parameters will be coupled with the stable isotope signatures of the sediment samples to better understand the functions of intertidal seagrass meadows in supporting the terrestrial environment. Two manuscripts are in preparation as outputs.

The effect of seagrass presence on sediment movement, water currents and biodiversity was assessed (Work Package 4). One manuscript is being prepared. To increase understanding on how to quantify the effects of ecosystem based coastal protection on long-term beach evolution, this project is in the process of building a Simulating Waves Nearshore (SWAN) model (Work Package 5). This model will help in the quantification of the contribution of the seagrass meadow to reducing the wave energy as well as provide spatial distribution maps of the wave energy wave, which will be used to identify areas and the required method for seagrass restoration.

The project also investigated the best practices for seagrass restoration with a view to providing technical guidelines on how seagrass can be restored in the WIO and informing evidence-based decision making for sustainable coastal management (Work Package 6). Findings from this work package produced two journal articles. Lastly, through Work Package 7, the information generated from this project was disseminated to various stakeholders to ensure awareness raising, community participation and evidence-based decision making. Information regarding the project team, activities and outputs was also communicated to a wider audience using the project website (<https://marinescience2.wixsite.com/seagrassprotect>).

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List of Symbols/Acronyms

ANN	Artificial Neural Network
BMU	Beach Management Unit
CBO	Community-Based Organization
COBIONET	Coastal biodiversity and food security in peri-urban
CTD	Conductivity, Temperature and Depth
DO	Dissolved Oxygen
EAME	Eastern African Marine Ecoregion
FETA	Fisheries Education and Training Agency
GPS	Global Positioning System
GIS	Geographical Information System
IPSN	Indo-Pacific Seagrass Network
MASMA	Marine and Coastal Science for Management
MBREMP	Mnazi Bay – Ruvuma Estuary Marine Park
MIMP	Mafia Island Marine Park
MPRU	Marine Parks and Reserves Unit
MSc	Master of Science
NGO	Non-Governmental Organization
NbS	Nature-based Solutions
NGT	Nominal Group Technique
NE	Northeast
ODV	Ocean Data View
PhD	Doctor of Philosophy
PI	Principal investigator
PC	Programme Committee
PVC	Polyvinyl Chloride
RCMRD	Regional Centre for Mapping of Resources for Development
RF	Radio Frequency
SAV	Submerged Aquatic Vegetation
SoAF	School of Aquatic Sciences and Fisheries Technology
SCP	Semi-automatic Classification Plugin
SE	Southeast
SVM	Support Vector Machines
SWAN	Simulating Waves Nearshore
TaCMP	Tanga Coelacanth Marine Park
TV	Television
UDSM	University of Dar es Salaam
UEM	University of Eduardo Mondlane
UNEP	United Nations Environment Programme
UTM	Universal Transverse Mercator
WIO	Western Indian Ocean
WIOMSA	Western Indian Ocean Marine Science Association
WIOSAP	Western Indian Ocean Strategic Action Programme
WP	Work Package

INTRODUCTION

Seagrasses are monocotyledonous flowering plants that habituate submerged areas of coastal waters. They provide a wide range of ecosystem services to coastal communities, including coastal protection (Ondiviela et al. 2014; Christianen et al. 2013), storage of sedimentary carbon (Mateo et al. 2006), pathogen reduction (Lamb et al. 2017) and the provision of nursery grounds for many species that support fisheries (Heck Jr et al. 1997; Nordlund et al. 2018). Despite their important ecological and socio-economic value, seagrasses are being lost at an annual rate of 7% worldwide due to global natural and anthropogenic threats, and by nearly 20% in the Tropical Indo-Pacific and Temperate Southern Oceans (Dunic et al. 2021). The global natural threats include rising ocean temperatures and extreme heat events, while the anthropogenic threats include, e.g., pollution from sewage outfalls, coastal development and destructive fishing practices (Waycott et al. 2009; Macreadie and Hardy 2018; Unsworth et al. 2018).

In East Africa, marine and coastal resources are vital for the livelihood and well-being of both coastal and inland inhabitants (EAME, 2004). For example, fisheries serve as one of the main large-scale commercial activities in the region. The high activities in the coastal zone, however, place significant pressure on coastal resources, resulting in reduction of water quality, loss of marine biodiversity, coastal erosion, and other services provided by marine and coastal zones (Halkos, 2011; Halkos and Matsiori 2018). Particularly, coastal erosion is to a large extent interlinked with the presence of seagrass meadows, since we today have strong evidence that the loss of seagrass meadows can accelerate coastal erosion when the anchoring effect of their roots and rhizomes disappears.

Climate change and coastal hazards are impacting coastal communities globally (Dolan and Walker 2006). Coastal erosion, sea-level rise and increased frequency and magnitude of storms and flooding events are major concerns facing coastal communities and the focus on adaptation strategies is increasing (Temmerman et al. 2013). There is a growing recognition of the need to utilize nature's own features for coastal defence and resilience, commonly referred to as nature-based solutions (NbS) (van der Meulen et al. 2022). Due to their cost-effectiveness, lower disturbance on sediment dynamics and additional ecosystem benefits, NbS for coastal protection are emerging as alternatives to hard or gray structures such as breakwaters, groynes and jetties (Temmerman et al. 2013; Spalding et al. 2014; Narayan et al. 2016; Nesshöver et al. 2017; Morris et al. 2018, 2020; van der Meulen et al. 2022). Since a natural system is inherently dynamic, NbS for coastal protection are suggested to be able to both adapt to environmental changes and self-repair following destructive hazards such as storms (Nordstrom et al. 2011, Morris et al. 2018, Hanley et al. 2019), although the timescales on which this occurs may be long and seasonally dependent (Bouma et al. 2014, Morris et al. 2020). Yet, the main rationale behind using NbS for coastal protection is its ability to strengthen coastal biodiversity and other ecosystem functions and services, as compared to artificial structures, which may accomplish the opposite (Morris et al. 2018). Coastal ecosystems are threatened globally and the increasing pressure from coastal development, climate change and associated sea-level rise has extensive negative impacts on coastal biodiversity and ecosystem functioning (Schlacher et al. 2008; Defeo et al. 2009; Waycott et al. 2009; Dugan et al. 2010; Hanley et al. 2014).

In the present MASMA-funded project, we took a comprehensive approach to developing nature-based solutions to mitigate against coastal erosion using seagrass meadows in order to

protect the shoreline. The project included seven work packages (WP) comprised of social science, natural science, geology, and coastal engineering to develop best practises for protecting the coast by working with nature instead of against it.

Below, we present each of the seven work packages and provide objectives, methodology or experimental details, results, and conclusions.

WORK PACKAGE 1

INVESTIGATE STAKEHOLDER AND CITIZEN NEEDS AND PERCEPTIONS OF COASTAL EROSION AND THE ECOSYSTEM SERVICES PROVIDED BY SEAGRASS MEADOWS.



PREAMBLE

Through this WP, we assessed the perceptions of the communities on the importance of seagrass meadows in terms of socio-economic and cultural functions, threats to seagrasses, the presence and main causes of shoreline erosion, and their perceptions with regard to mitigation measures against coastal erosion. This WP was expected to lead to improved awareness among stakeholders on coastal erosion and the role of seagrass and other marine habitats in protecting the coastline against waves and currents. This WP was implemented in both Tanzania and Mozambique. For Tanzania, the study was done in two municipal councils: Kinondoni in northern Dar es Salaam, and Kigamboni in southern Dar es Salaam. Streets (Mitaa) included in Kinondoni were Mbweni, Ununio and Kunduchi Pwani, while in Kigamboni Municipal Council, three streets, namely Kimbiji (Kizito Huonjwa), Puna Center and Buyuni (Kigamboni Municipal Council), were involved. For Mozambique, the study was conducted in southern Mozambique and included Inhambane Bay (Nhampossa and Guiduane Island) and Maputo Bay (Inhaca Island and Bairro dos Pescadores).

METHODOLOGY

For Tanzania, the fieldwork for this study was conducted from November 2019 to February 2020. The field work was preceded by a reconnaissance survey, which provided an opportunity for the enumerators to be identified and trained on the social research methods and the survey tools to be used. During the reconnaissance survey, the researchers visited each study site to familiarize themselves with the study area, introduce the study to the street leaders and collect some preliminary sociodemographic information and establish communication contacts for subsequent phases of the study. Furthermore, pre-testing of a questionnaire was administered to a few randomly selected fishers (about 5 per site) to discover the validity and reliability of questions and improvements were made accordingly. The primary data was collected through the Nominal Group Technique (NGT), key Informant interviews, a semi-structured questionnaire survey (Plate 1), and non-participant observation. A similar set of questionnaires was used for both countries.



Plate 1. Questionnaire interview at one of our sites in Mozambique

FINDINGS

Functions or importance of seagrasses

With regard to the functions or importance of seagrass habitats in the two countries (Figure 1), the communities had more or less similar perceptions. Strong affirmation of the importance of seagrass meadows in Tanzania is portrayed as adding natural beauty to coastal waters (97.8%), supporting fisheries production (94.4%), protecting the shoreline (87.0%), contributing to seawater clarity (73.1%), being used for medicinal purposes (66.9%) and providing of space for relaxation (swim and snorkel) (62.8%). For Mozambique, support for fisheries production ranked 99.7%, followed by coastal protection at 81.9%, adding natural beauty at 77.3%, and improve seawater clarity at 71.7%.

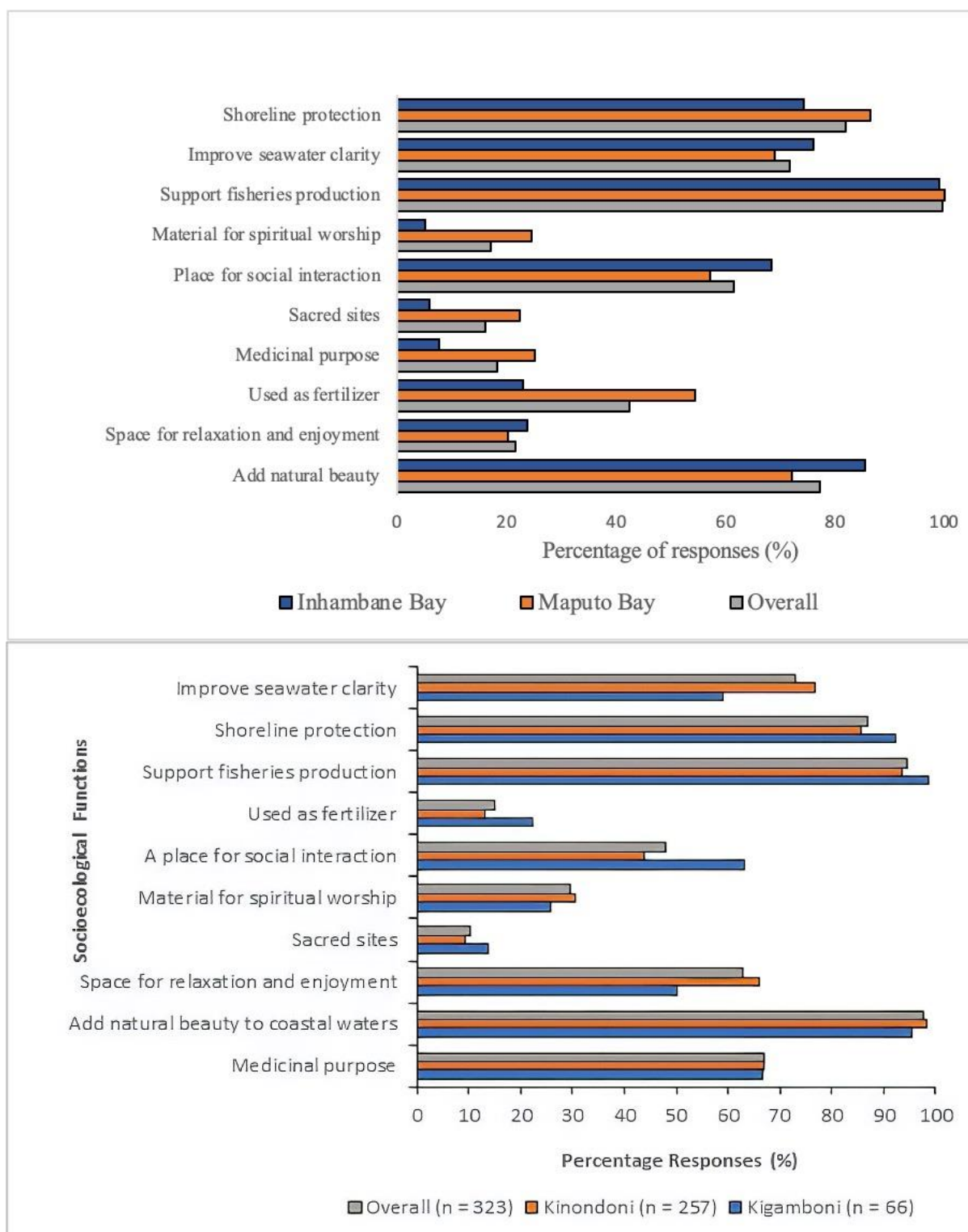


Figure 1. Fishing communities' perceptions on socio-ecological functions of seagrass meadows, for Mozambique (above figure) and Tanzania (below figure)

Threats to seagrasses

Regarding threats to seagrasses, in both countries, two similar issues were ranked highly by most respondents and these included destructive fishing practices and climate change. Overall, in Tanzania, destructive fishing practices and climate change were perceived as the major causes of seagrass degradation by 51.1% and 41.8% of respondents, respectively. In

Mozambique, most respondents (62.5%) pointed out climate change and destructive fishing practices (41.4%) as the major causes of the loss of seagrass meadows.

Presence of and main causes of shoreline erosion

In both countries, the majority of respondents declared shoreline erosion as the problem in their areas. When survey respondents were asked to reveal the main causes of erosion, overall, climate change with increased wave energy was perceived the leading driving force by majority (85.1% in Tanzania and 88.2% in Mozambique) as the main causative factor of coastal erosion.

Mitigation measures against coastal erosion

Regarding the community's perceptions of mitigation options for shoreline protection, there was a strong preference for habitat restoration (76.3%) over artificial infrastructure (63.5%) as measures for coastline protection in Mozambique. For Tanzania, the majority (66.6%) preferred the construction of artificial infrastructure, e.g., construction of walls and groynes, compared to those who preferred habitat (especially mangrove) restoration (48.6%). The majority of respondents in both countries expressed their positive willingness to participate in habitat restoration (Figure 2).

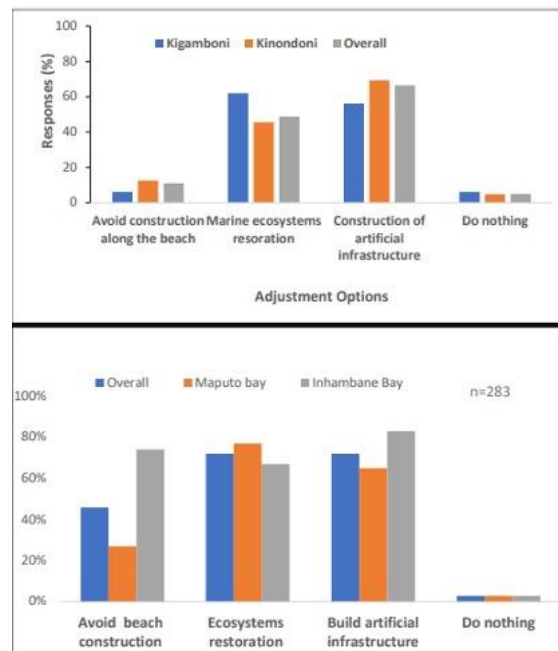


Figure 2. Proposed solutions for coastline protection for Tanzania (above) and Mozambique (below)

DISCUSSION

Seagrass meadows provide important ecosystem services to coastal communities, which include ecosystem-based adaptations for coastal protection; however, globally, seagrasses are among the least conserved marine ecosystems. The consequence is an overall decline, which is affecting a number of socio-economic and environmental benefits, including coastal protection. In order to develop and provide accurate and efficient decision-making processes and conservation actions, a good understanding of the importance of ecosystem services for people's livelihoods and wellbeing is key. Understanding local community perceptions can help us understand their attitudes and behaviour towards coastal marine conservation. The results demonstrated that respondents had a high level of awareness about the values of seagrass ecosystems. Fishermen for example, identified support to fisheries production, coastal protection, and maintenance of water quality as crucial services provided by seagrasses to

coastal communities. In general, respondents perceived that coastal erosion is occurring in the region and most respondents believe that it has accelerated in the last 20 years due to more frequent floods following cyclones. The majority of the respondents perceived climate change as the main cause of coastal erosion. In addition, coastal development and destructive fishing practices were recognized as the main anthropogenic causes of coastal erosion as seagrasses diminished. The objects respected by the coastal communities that are negatively impacted by coastal erosion relate to social activities, properties, sacred sites, current livelihood stability, and future development opportunities. The coastal communities in Mozambique proposed marine ecosystems restorations as the first measure to prevent coastal erosion. The coastal respondents also identified seagrass regulatory ecosystem services being central for their social and economic wellbeing and demonstrated a desire to participate in seagrass restoration in their region. In Tanzania, however, the majority of respondents perceived gray infrastructures as the best option for protecting the coast, followed by nature-based solution, i.e., coastal habitat restoration. This knowledge will support decision-makers and regulatory authorities in making evidence-based choices for coastal adaptation management by including nature-based solutions from seagrasses through protection and restorations. However, it is important seagrass conservation actions are implemented in accordance with the values, perspectives, and perceptions of coastal communities to safeguard their continued contribution to the many ecosystem services.

CONCLUSION

This found that the local communities have broad knowledge regarding seagrasses in their areas and are eager to be involved in initiatives to safeguard seagrass meadows. This study highlights the necessity of local communities' involvement in coastal management plans to ensure sustainable solutions to build resilience and stronger ecosystem-based adaptations against climate change.

The findings of this WP led to the preparation of two manuscripts, namely:

- “*Coastal communities’ perceptions on coastal erosion and ecosystem services of seagrass meadows in Dar es Salaam, Tanzania*” (by Shalli et al.); and;
- “*Community perceptions on the role of seagrass ecosystems for coastal protection*” (by Amone-Mabuto et al.).

WORK PACKAGE 2

INVENTORY OF SEAGRASS MEADOWS ALONG THE COASTS OF TANZANIA AND MOZAMBIQUE



PREAMBLE

The main objective of this WP was to conduct an inventory survey of seagrass meadows along the coasts of mainland Tanzania, Zanzibar and Mozambique. The main incentives of inventorying seagrass meadows were to understand the extent of spatial coverage of seagrasses along the two countries coasts. Since seagrass meadows play a critical structural and functional role in many coastal ecosystems across the globe, threats to seagrass ecosystems are both local and global, and to a large extent, they are driven by human-mediated factors such as eutrophication and habitat destruction. Given the widespread lack of seagrass management in the WIO, the inventory of seagrass meadow distribution and extent will serve as a foundation for developing management and monitoring strategies. Mapping of seagrass meadows along the coasts of Tanzania and Mozambique verified two complementary methodologies. GIS maps developed from this research will be provided as open source on the web, which means that additional projects elsewhere in the region can add on in order for maps to grow, develop, evolve and enhance in detail. Such information will be beneficial to seagrass management and other related habitats within the coastal and marine environment. In order to work out new and innovative methodologies for a fast and accurate mapping protocol for seagrass research, the project applied four different techniques, including remote sensing, the usage of web-based maps, ground-truthing, and the use of drones.

METHODOLOGY

For both Tanzania and Mozambique, seagrass mapping was done using both satellite images and field data. In addition, the Mozambique team used drone images. Ground-truth data, including GPS points for seagrasses and other marine habitats (coral reefs, rocks, mangroves, macroalgae and mud/sand flats) were used for training the software. It was evident that remote

sensing constitutes a robust approach for synoptic sampling and mapping of seagrass meadows over large areas.

For Tanzania, the mapping process followed three main steps:

- i) Field data source and management: Before the data collection exercise commenced, the scope and methodology for data collection and analysis had clearly been established. Presently, an online form for consistently collecting and recording field data has been created in Kobo Toolbox. The field survey form has already been launched in the area encompassed by the Dar es Salaam region. The GPS location and species composition of seagrass have been captured. The GPS location for other marine habitats such as coral reefs, rocky beds, mangroves and mud/sand flats have also been recorded in this area. Additional data representing seagrass cover have been extracted from the RCMRD GeoPortal (http://geoportal.rcmr.org/layers/servir%3Atanzania_seagrass).
- ii) Selection and subsetting of satellite images. A cloud-free Sentinel 2 image has been downloaded from the <https://glovis.usgs.gov/app> website. Important steps involved in remote sensing data pre-processing procedures, such as- i) Atmospheric correction, ii) Land and cloud mask, iii) Removal of sun glint (reflection) on the air-water interface and iv) Correction of water column effect (via Depth Invariant indices) - have been completed for Dar es Salaam.
- iii) The last step after these processes is image classification and validation of the classification output.

For Mozambique, a drone of the model DJI Phantom 4 Pro was used. Transects were conducted within the Pix4D application with 75% overlap on both axes. Flights altitude was 65 m. Orthomosaics were produced within Pix4Dmapper software version 4.5.6. This was followed by Orthomosaics Classification in QGIS using Semi- automatic classification Plugin (SCP). The flights were performed in *Zostera capensis* and *Halodule uninervis* dominated communities, covering about 800 ha of Inhaca Island. The drone was flown at a 65 m altitude, which resulted in a ground image resolution of 1.64 cm/pix. The mapping was performed during low tide, where both parallel and perpendicular orientations to the coastline were applied, primarily on the basis of the orientation of the distribution of the seagrasses. To optimize mapping, days with clear skies were chosen, avoiding windy days exceeding 5 km h⁻¹, and mapping with a reduced effect of the sun's angle, as recommended by Nahirnick et al. (2018). Orthomosaics were generated from the drone images and classified using the Semi-automatic Classification Plugin (SCP). Ground points were also collected along transects to document the habitat type, substrate conditions, and species, which aided the drone imagery classification.

FINDINGS

Seagrass species composition

A total of eleven seagrass species were observed in the surveyed coastal areas in Tanzania. The species include *Enhalus acorodides*, *Cymodocea rotundata*, *C. serrulata*, *Halophila ovalis*, *H. minor*, *H. stipulacea*, *Halodule uninervis*, *Halodule* sp., *Thalassia hemprichii*, *Thalassodendron ciliatum*, and *Syringodium isoetifolium*. Most species occurred in mixed meadows except for *T. ciliatum*, which occurred in large pure stands and occupied the deeper water zones.

From the drone imaging, eight species of seagrass were observed on the Mozambique coast, namely: *Zostera capensis*, *Halodule uninervis*, *Thalassia hemprichii*, *Cymodocea serrulata*,

Cymodocea rotundata, *Thalassodendron ciliatum*, *Syringodium isoetifolium*, and *Halophila ovalis*. The ground truthing demonstrated that the different seagrass species mostly co-occur with two to four species together and reside adjacent to coral reefs and mangroves.

Seagrass mapping

The average User, and Producer Accuracy for benthic habitat mapping based on RF, SVM and ANN algorithms for Tanzania are presented in Table 1. Out of the three machine learning classifiers, the RF outperformed SVM and ANN with an overall accuracy of 84.2% and Kappa statistic of 77.8%. Therefore, the predicted (classified) raster from the RF was selected as the reliable output for the benthic habitat classification on Tanzania's coast.

Table 1. User and Producer Accuracy for benthic habitat mapping based on RF, SVM and ANN algorithms.

Class	Producer Accuracy (%)			User Accuracy (%)		
	RF	SVM	ANN	RF	SVM	ANN
Coral	66.67	42.16	53.51	72.72	44.57	71.22
Rockbubbles	69.04	65.83	74.26	90.63	61.75	74.43
Sands	82.17	20.95	70.86	77.37	76.92	77.19
Seagrass	83.51	89.04	86.69	83.51	63.32	79.11
Water	93.33	59.72	71.88	91.33	72.88	73.92
Overall accuracy (%)	RF	SVM	ANN			
	84.2	63.4	76.6			
Kappa (%)	77.8	47.3	67.5			

Total seagrass areas and percent of seagrass cover by region or location for Tanzania are listed in Table 2. The total seagrass area for the entire Tanzanian coast was estimated at 2817.03 km². Pwani region had the most extensive seagrass cover of 1160.31 km² equivalent to 41.19%. Other areas with the most extensive seagrass cover were Pemba (15.12%), followed by Tanga (14.41%) and Unguja (13.85%). Dar es Salaam had the smallest (2.91%) seagrass patches. The spatial coverage of benthic habitats (seagrass meadows, coral reefs, rocks/rubbles, and sands) along Tanzanian coast is presented in Figure 3.

Table 2. Estimated seagrass coverage in Tanzania.

Region	Seagrass Area (km ²)	%
Tanga	405.80	14.41
Pwani	1160.31	41.19
Dar es Salaam	81.90	2.91
Lindi	213.56	7.58
Mtwara	139.23	4.94
Pemba	425.96	15.12
Unguja	390.27	13.85
Total	2817.03	100.00

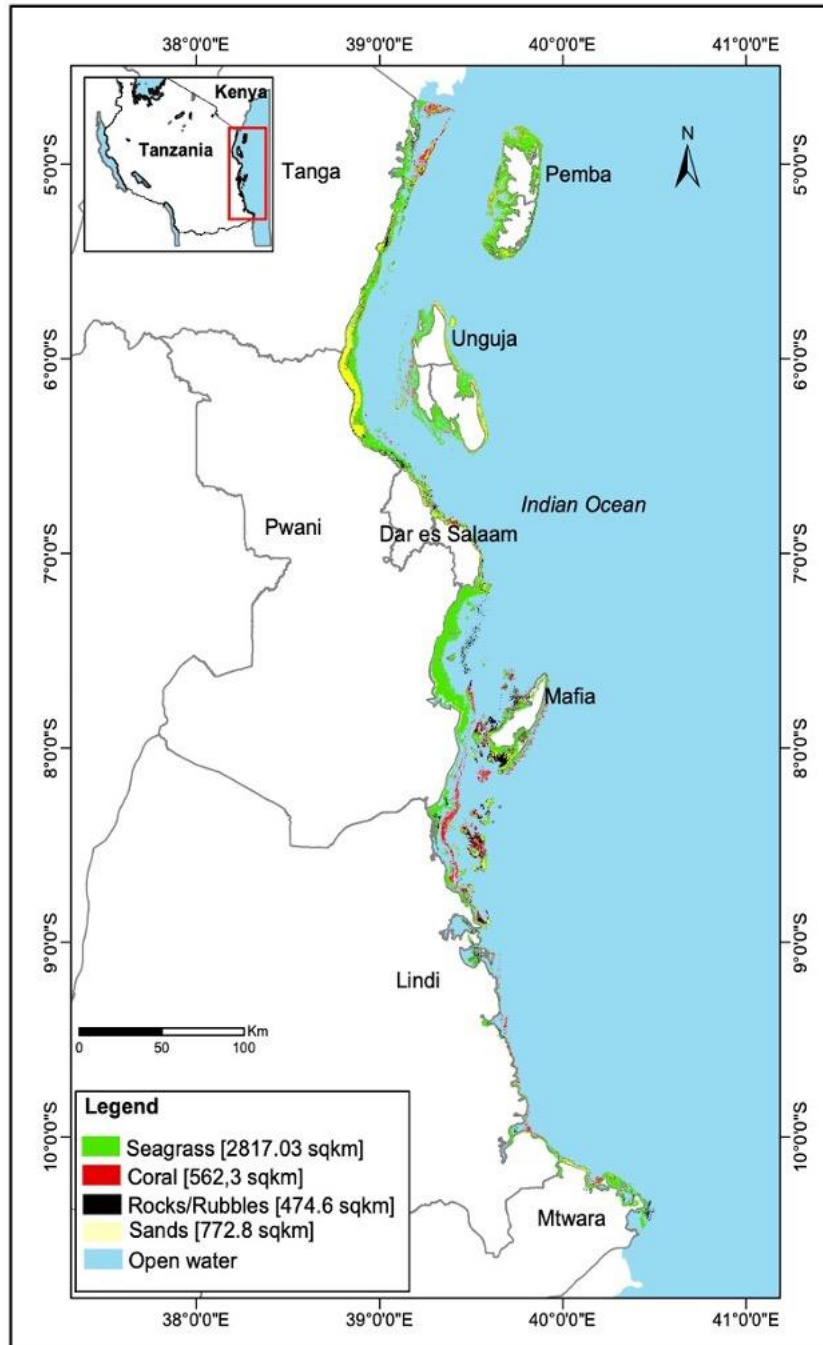


Figure 3. Spatial coverage of benthic habitats along Tanzanian coast (the results are based Random Forest classifier). Note, Rock/Rubble and Sand areas masked during image pre-processing are excluded from the statistics.

The spatial distribution of the seagrass cover in Mozambique is provided in Figure 4, Figure 5 and Figure 6. In Mozambique, the ground truthing demonstrated that the species mostly co-occurred as two to four species and occur in close connection with coral reefs and mangroves. The results from the mapping and classification of orthomosaics showed higher accuracy for the seagrass cover sand and mangrove classes; for coral reef and rock substrate, the classification had the lowest accuracy, even though it had great visibility in orthomosaic. The study demonstrates the effectiveness of drones in mapping and characterizing seagrass habitat in tropical waters.

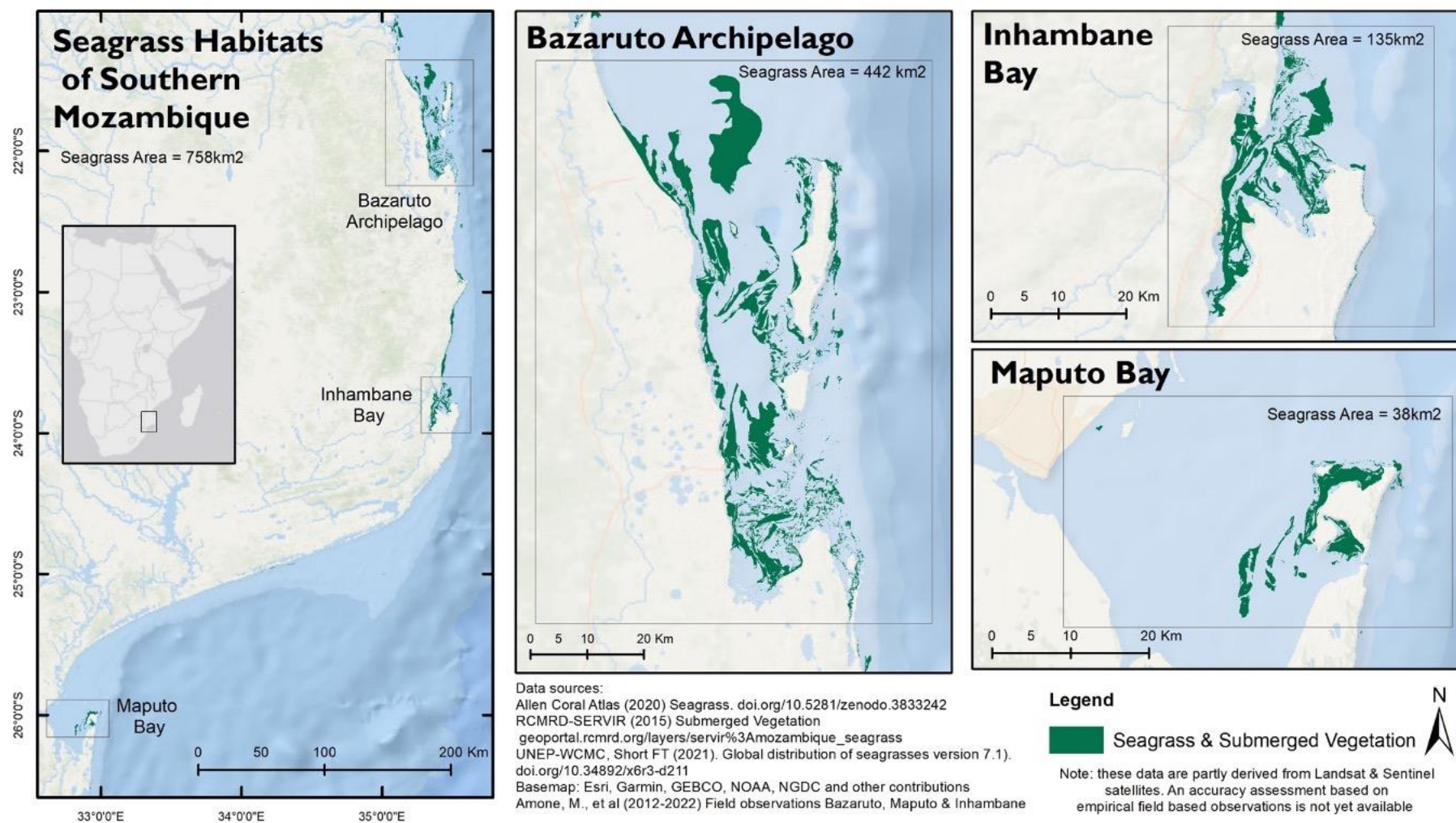


Figure 4. Seagrass coverage along the coast of Mozambique.

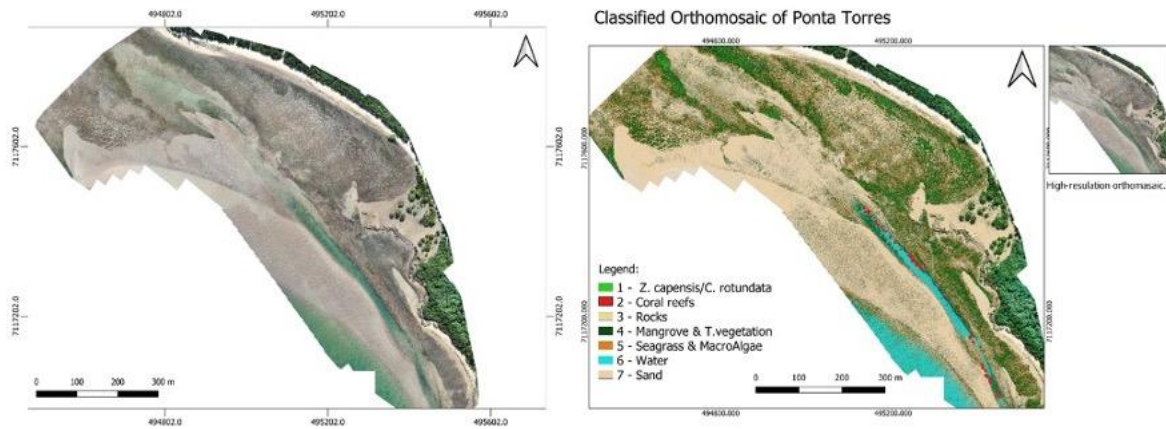


Figure 5. High-resolution orthomosaic (1.64cm/pix) for Ponta Torres, Inhaca, Mozambique generated by 646 overlapping images in real time from the drone showing seagrass occurrence and Thematic map from the same area generated after classification in Semi-automatic classification Plugin (SCP). Coordinate system: UTM

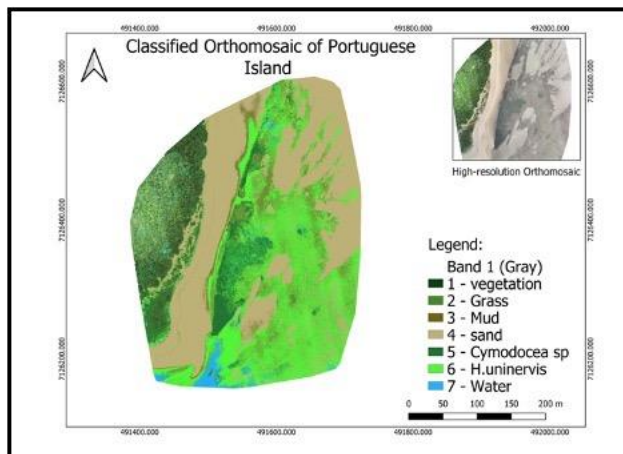


Figure 6. Seagrass occurrence for Portuguese Island, Inhaca, Mozambique.

DISCUSSION

This is the first comprehensive report on seagrass coverage along the coast of Mainland Tanzania and Zanzibar, and additional information for Mozambique. The seagrasses and other benthic habitats were successfully mapped using trained machine-learning technologies from spaceborne-captured imagery (Sentinel 2 sensor) or drone images. Results indicate that Tanzania has more seagrass areas, five times higher than previously reported by Traganos et al. (2022). However, caution needs to be observed during the interpretation of the results. First, the seagrass coverage does not account for health status and biomass. Secondly, similarly looking seaweeds, algae, and microalgal mats accounted for a tiny proportion of the training data and were hence removed in the subsequent classification. However, this might have induced classifications of seaweeds, algae, and microalgal mats into seagrasses, thus overestimating the seagrass area. Another potential source of error in the classification might arise from a slight temporal mismatch between the training (field) data and the aggregated median composite images, which might have introduced misclassification of pixels. Furthermore, field data recording was done preferentially on seagrass (40.3%). Although an independent test set was kept for final validation, spatially imbalanced training data might have introduced biases in the model training, a challenge that machine learning algorithms do not overcome well outside the training data. It was clear from the results of using different

methodologies that remote sensing is a powerful method for mapping at a larger scale, but with the satellite images provided today, the resolution is not high enough to distinguish between seagrass species. However, complementing with drone images and photos from drones produces high-resolution images that can be used for further analysis to differentiate down to the species level.

In this report, seagrass mapping in Tanzania and Mozambique was achieved using satellite data and drone images, coupled with thousands of field data. The findings of the present study revealed that the seagrass cover in Tanzania is around 2817 km². However, mapping seagrasses using remote sensing in coastal waters can be significantly improved by generating field data from a broader range of stakeholders, including fishermen/women, research institutions, and citizen scientists. This will ensure that different stakeholders contribute to the collation of in situ spot-check data for new and repeated field data collection and analysis over time. Furthermore, seagrasses are dynamic, varying from month to month and from metres to kilometers. Thus, continued monitoring and detailed assessment are inevitable.

CONCLUSION

The findings of the present study revealed that the seagrass cover in Tanzania is around 2817 km². This is the first comprehensive report on seagrass coverage along the coast of Tanzania.

Two manuscripts are in preparation from this WP:

- Lugendo et al. Spatially seagrass mapping across the entire coast of Tanzania.
- Amone-Mabuto et al. Seagrass macroscale mapping in southern Mozambique using extensive data points , satellite-based sources and drone application for *Zostera capensis* distribution.

WORK PACKAGE 3

EVALUATE SECONDARY EFFECTS ON BIODIVERSITY FROM THE INTERPLAY BETWEEN THE SHALLOW COASTAL ZONE AND THE COASTAL TERRESTRIAL ENVIRONMENT



PREAMBLE

Beaches rich in seagrass and algae are also rich in the fauna of crustaceans and insects in the supralittoral zone, and such trophic systems link the marine realm with the terrestrial realm. In the transition zone between land and sea, the two realms exchange not only sediment but also a variety of organic materials, inorganic nutrients and animals from both habitats move across the beach interface to feed (Defeo *et al.*, 2009; Mellbrand *et al.*, 2011). This WP links land and sea to identify additional ecosystem services as a response to ecosystem-based protection measures. The results help us understand the multifunctional effects of implementing ecosystem-based actions.

METHODOLOGY

Study design

We compared terrestrial and intertidal biodiversity (flora and fauna) and sediment characteristics (grain size, OM, carbonates, nutrients - N&P) at four sites (Buyuni, Kimbiji, Kunduchi and Mbweni) along the coast of Dar es Salaam. We included coastal areas with (Kimbiji and Kunduchi) and without (Buyuni and Mbweni) intertidal seagrasses and considered the Southeast (SE) and Northeast (NE) monsoons. Samples were taken 50 m landward - from the highest water mark – and 50 m seaward.

Physico-chemical parameters

Organic matter content was analyzed using the loss on ignition method and carbonates using the acidification method. Samples for sediment grain, organic matter and nutrients were collected using a corer, and analysed using standard procedures.

Terrestrial fauna

Invertebrates (mostly Arthropods—insects, arachnids, and crustaceans) were sampled at each site from three transects running from the low tide mark through high tide mark and beyond). The transects were 20 metres wide, with 3 trap lines 10 m apart. On each trap line, 10 pitfall traps were set, 10 m from one trap to the next. The area from one line of traps to the next formed a sampling station, denoted S1, S2 ... to S10. (Alternatively, the sampling stations were labeled S1L to S5L for the intertidal stations and S1U to S5U for the terrestrial stations). Each sampling station was 5 m by 20 m in size. Sampling of invertebrates was carried out within the sampling stations. Invertebrate collecting methods included the following:

1. Physical searching (hand picking on the surface, searching under debris, logs, sea drift, stones and vegetation) was carried out. Each “sample” consisted of all invertebrates collected during 5 minutes of active searching within each sampling station.
2. The sweep-net method was used to catch invertebrates on plants along the shore, flying insects, and disturbed invertebrates in seaweeds piled on the shore. Five minutes of active sweeping inside each sampling station comprised a “sample”.
3. Pitfall trapping – small (c. 100 ml) plastic cups were set in a three-line grid. Five sets of the traps (each set having 3 traps) were placed above the high water mark, 5 sets below the high water mark, and one set at the high tide mark. The distance between traps was 5 m. The traps were checked after 24 hrs.

Sorting and identification (to Order and Family level) took place at the Department of Zoology and Wildlife Conservation. Abundance, diversity (species richness and diversity index) and similarity index were computed and compared between sites.

Terrestrial plants

Transects of up to 50 m long were established in the terrestrial environment in continuation with those established in the shallow coastal zone. The modified Whittaker method was used in assessing terrestrial plants (Strogren, 1995). Contiguous plots of 10 x 10 m were established along the transect line. Within the larger plot, all trees were identified to species level, their numbers were enumerated and they were recorded in a notebook. Each shrub was identified to the species level and the number of individuals for each shrub species enumerated and recorded. Furthermore, four nested plots of 1 x 1 m were established within the 2 x 5 m subplots for assessing herbs and grasses. In this case, all species were identified to the species level and their percentage cover within the plot was estimated and recorded. Percentage cover was scored based on 0-100% scale, so a species that covered the entire 1 x 1 m plot was given a score of 100 and vice versa. Whenever identification of plants to species level was not possible in the field, samples were collected and pressed for further identification at the Herbarium of the University of Dar es Salaam. This was made possible by using relevant floras and keys or by matching preserved specimens.

FINDINGS

Physico-chemical parameters

Sediments from areas with seagrass meadows are rich in organic matter content, while those from areas with no seagrass are rich in carbonate (Figure 7). Carbonate content increased

seaward while organic matter content decreased seaward (Figure 8). Percentage organic matter content decreased seaward and was generally higher during the southeast than northeast monsoon. Percentage carbonate content increased seaward and was generally higher during the southeast than the northeast monsoon. Sites without seagrasses had a relatively higher percentage carbonate content than site with seagrasses.

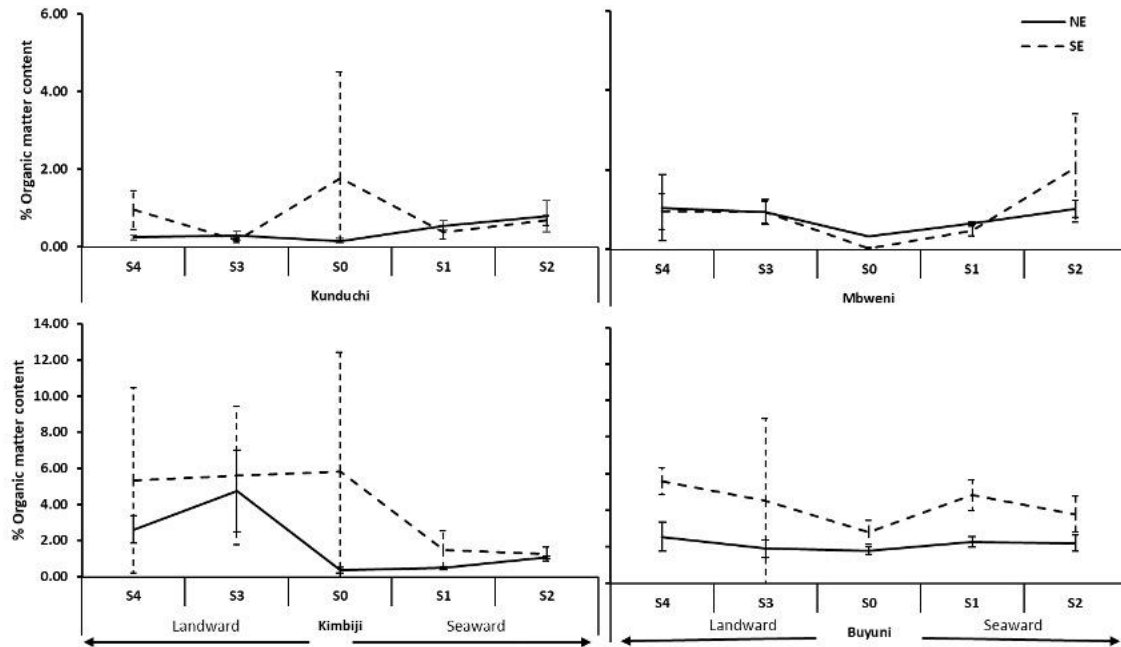


Figure 7. Percentage organic matter content seaward and landward of the shoreline (S0) at the study sites.

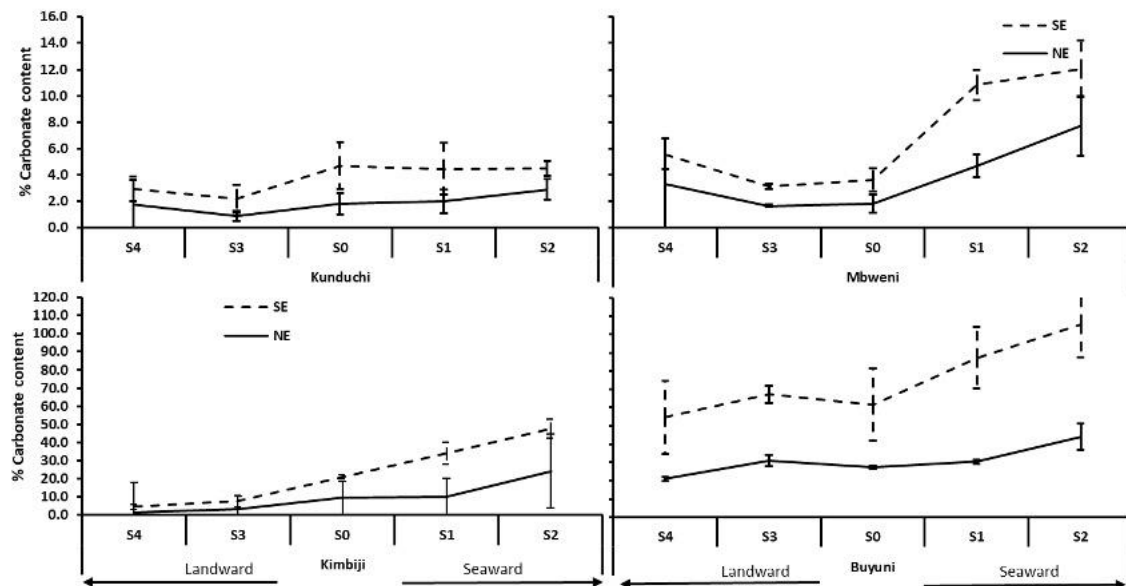


Figure 8. Percentage calcium carbonate content seaward and landward of the shoreline (S0) at the study sites.

Nitrate concentration in pore waters decreased seaward from terrestrial environment (Figure 9), nitrate concentration in terrestrial and marine environments were generally higher in the southeast than the northeast monsoon season.

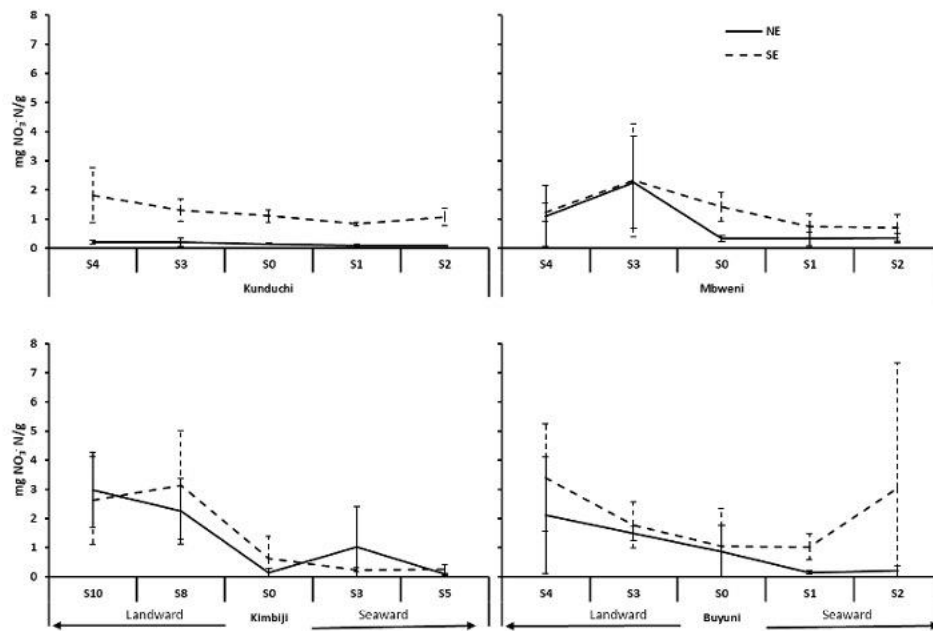


Figure 9. Nitrate concentrations seaward and landward of the shoreline (S0) at the study sites.

Phosphate concentration in pore waters generally increased both seaward and landward from the shoreline for Mbweni and Kimbiji, while it displayed a seaward decrease for the Buyuni site. Phosphate concentrations at Kunduchi remained more or less similar both landward and seaward of the shoreline. Similar to nitrates, the phosphate concentration in terrestrial and marine environments was generally higher in the southeast than the northeast monsoon season (Figure 10).

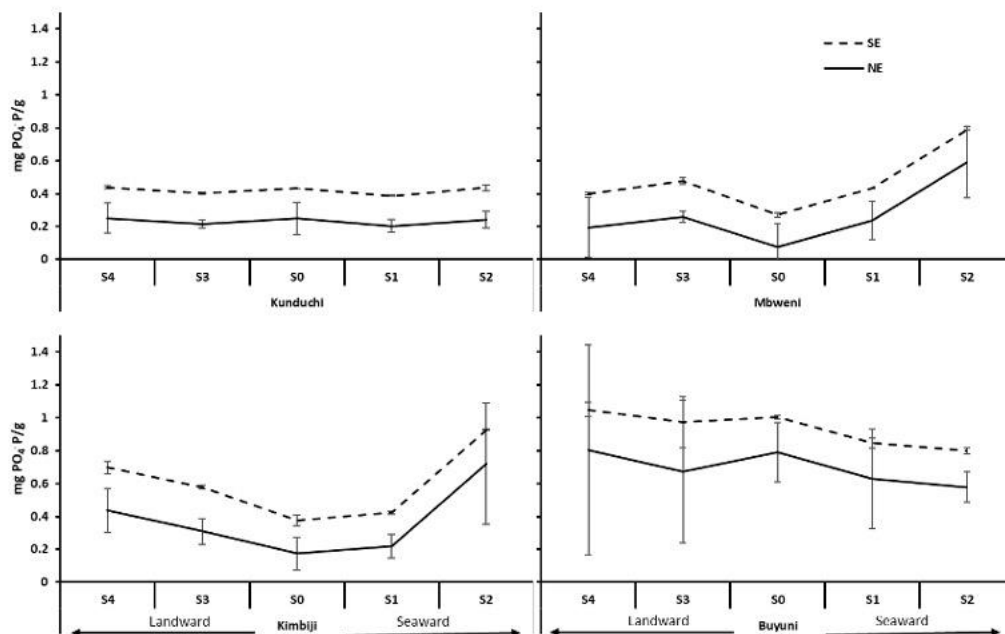


Figure 10. Phosphate concentration seaward and landward of the shoreline (S0) at the study sites.

Terrestrial fauna

A total of 256 samples were collected and yielded 3398 individual invertebrates. The highest abundance was obtained from Buyuni, followed by Kunduchi, Mbweni and the lowest

abundance was from Kimbiji. At the two sites where there were no seagrass beds nearby (Buyuni and Mbweni), two groups of detritivorous crustaceans, Amphipoda and Isopoda, were very abundant, inflating the total abundance at the sites (Figure 11). The difference in abundance was statistically significant (Kruskal-Wallis = 12.73, $p < 0.05$).

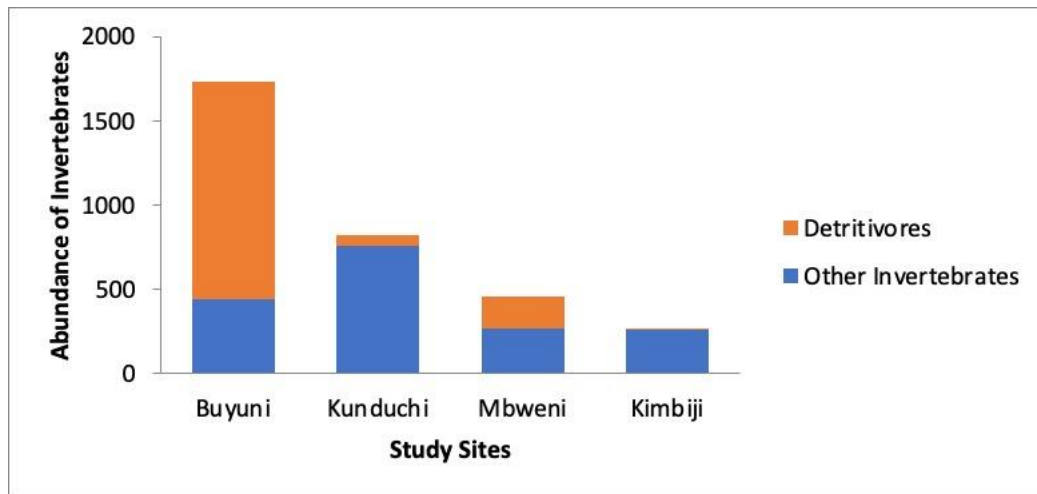


Figure 11. Abundance of Invertebrates collected from four sites during August-September 2020.

The supralittoral zone had a higher abundance compared to the littoral zone, with the exception of the Buyuni site (Figure 12). The difference was statistically significant (Mann-Whitney U = 5183, $p < 0.05$).

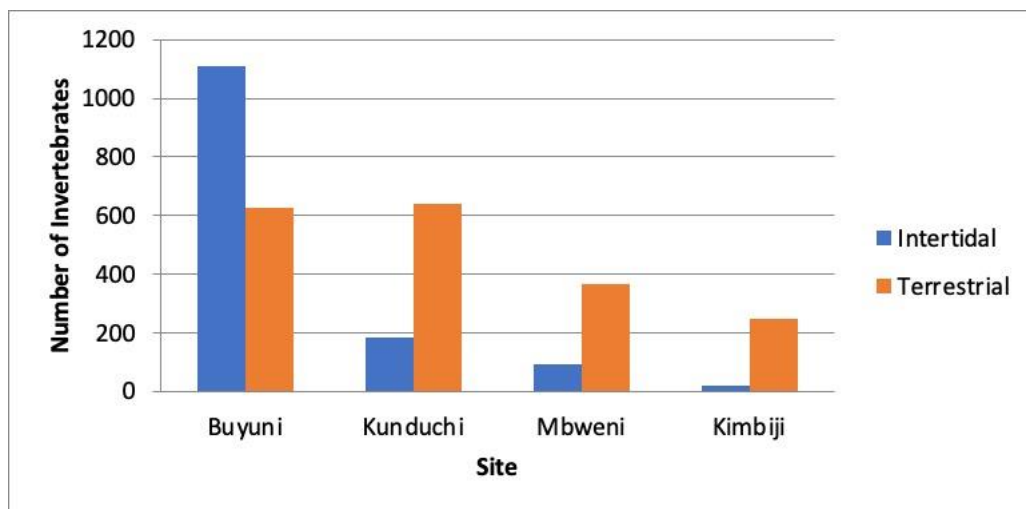


Figure 12. Comparison of abundance of Invertebrates collected from littoral (intertidal) and supralittoral (terrestrial) zones from four sites during August-September 2020.

Faunal diversity

A total of 26 Orders/Phyla were identified. The most abundant group was Order Amphipoda with 1242 individuals (36.55% of the total), followed by Order Hymenoptera (mostly small ants in Genus *Tetramorium*, Family Formicidae) (738 individuals, 21.72%), Order Coleoptera (487 individuals, 14.33%), Order Isopoda (337 individuals, 9.92%), Order Orthoptera (229 individuals, 6.74%) and Order Araneae (spiders, 140 individuals, 4.12%). The remaining groups were represented by less than 100 individuals, including 4 singletons (represented by a single specimen) and 2 doubletons.

The Diversity Index (Shannon-Wiener H') was highest at Mbweni and lowest at Buyuni (Table 3). The explanation may lie in the fact that at Buyuni, one group (Order Amphipoda) was extremely dominant, resulting in low evenness, hence the low diversity index. Kunduchi had the highest taxonomic richness. Jaccard's similarity index showed a fairly high similarity between all pairs of sites, ranging from $J = 0.5$ (Kimbiji vs Kunduchi) to $J = 0.67$ (Buyuni vs Kimbiji).

Table 3. Diversity of Invertebrate groups collected from four sites during August-September 2020.

	Buyuni	Kimbiji	Kunduchi	Mbweni
Taxa_(Orders)	16	14	19	12
Shannon_ H'	1.349	1.608	1.693	1.88
Evenness_ $e^{H/S}$	0.2408	0.3566	0.286	0.5461

Terrestrial plants

A total of 6128 individual plants (grasses, herbs and trees) were recorded. These belonged to 148 species. The distribution of the abundance of the plants is shown in Table 4. Overall, Kimbiji (54 species) had the highest total species richness, followed by Buyuni (47), Mbweni (43) and Kunduchi (20 species). The most common species included *Sporobolus virginicus*, *Ipomoea pes-caprae*, *Clerodendrum glabrum*, *Cyperus crassipes* and *Strychnos spinosa*. The diversity index was highest in Buyuni and lowest in Kunduchi. Buyuni an area without intertidal seagrasses exhibited highest diversity and relatively higher species richness, and indication that factors that influence macroinvertebrates in the terrestrial habitats adjacent to the coastal environment are other than the presence of seagrasses alone.

Table 4. Abundance and species diversity of plants at the four sampling sites

a) Abundance		b) Diversity			
Site	Abundance	Index	Buyuni	Kimbiji	Kunduchi Mbweni
Buyuni	1411	Species	47	54	20 43
Kimbiji	1689	Richness			
Kunduchi	1356	Shannon-Wiener H'	3.007	2.481	2.227 2.832
Mbweni	1672	Evenness	0.4305	0.2214	0.4637 0.3947

One manuscript is currently under preparation for this WP:

George et al. The interplay of sediment characteristics between terrestrial and marine ecosystems: Implications for carbon storage in marine coastal areas.

WORK PACKAGE 4

UNDERSTAND HOW SEAGRASS MEADOWS INFLUENCE COASTAL PROTECTION AND BIODIVERSITY

PREAMBLE

Seagrass meadows are highly productive ecosystems that perform numerous ecosystem functions, such as acting as a carbon sink, providing food, and nursery areas for commercially important fish species and prey (food) for the commercial fish species. This WP aimed at understanding how seagrass influences sediment movement, water currents and biodiversity, with a view to improving the knowledge of stakeholders on the importance of seagrass meadows in influencing coastal protection and biodiversity. In addition, the collected data will be used to calibrate and validate models to get a better understanding of how seagrass meadows influence processes.

METHODOLOGY

In Tanzania, we contrasted areas with and without intertidal seagrass meadows. The following parameters were determined: beach profiles, wave energy, sediment characteristics (grain size, OM, carbonates, nutrients – Nitrogen and Phosphate) and movements, sedimentation rates, water characteristics and biodiversity. Sedimentation rate was measured using sediment traps, sea bottom topography using a hand-held echo sounder and a hand-held GPS, shoreline profile using a theodolite and a vertical graduated staff. This study also compared nutrient (nitrate and phosphate) levels and oceanographic parameters (temperature, salinity, Dissolved oxygen and pH) between sites with seagrass (Kunduchi, Kimbiji and Puna) and sites without seagrass (Mbwani, Ununio and Buyuni) in Dar es Salaam, Tanzania. We also included the influence of the northeast and southeast monsoon seasons for the studied parameters.

Sediment grain size distribution

At each site, sediment samples were collected along 3 cross-shore transects that extended from the backshore sand dunes (above the high water-mark), through the beach slope and down to the tidal flat areas, with samples being taken during the southeast and northeast monsoon seasons. The backshore sand dunes samples (samples taken above the highwater mark) consisted of 5 samples, while the foreshore samples (samples taken below the highwater mark) consisted of 5 samples and one sample was taken at the highwater mark point, making a total of 11 samples along the transect. Along each transect, the separation distance between the samples was about 10 m and each transect was therefore about 110 m long.

Prior to the laboratory analysis of the samples, the samples were thoroughly washed with distilled water to remove the sea salt and then oven dried at 60 °C. The grain size distribution of the samples was determined by dry sieving, with representative fractions (about 100 g) of each sample being shaken through a set of sieves that spanned from -1 phi (2 mm) mesh size to 4 phi (0.063 mm) mesh size. The sieves were separated at 0.5 phi intervals. Determination of the grain size statistics (Mean grain size and sorting) of the sediment samples was accomplished using Folk and Ward (1957) and the spatial distribution of the grain size statistics was undertaken using a surfer computer software tool.

Oceanographic parameters

Measurements of various oceanographic parameters (namely: Seawater temperature, salinity, dissolved oxygen and fluorescence) were accomplished using a CTD machine. The CTD casts at each site were taken along three defined cross-shore transects, with about 3 CTD sampling sites at each transect. At each CTD sampling station, the CTD machine was slowly lowered from the boat and vertical CTD casts were taken along the water column. The CTD raw data were then processed and analysed using the Ocean Data View (ODV) analytical tool.

Sea bottom topography (bathymetry)

Determination of the sea bottom topography at all six Dar es Salaam study sites (Mbweni, Ununio, Kunduchi, Kimbiji, Puna and Buyuni) was accomplished using a hand-held echo sounder. The depth measurements at each site were taken along 4 (700 -1000 m long) cross-shore transects, with depth measurements being taken at approximately every 10 m. The locations of the sounding points were recorded using a hand-held GPS. The echo sounding data was finally corrected for the tides and then analysed using surfer computer software.

Beach profiles measurements

Beach profile measurements for each site were accomplished using a theodolite and a roughly 4-meter-long graduated staff. The intention here was to assess the seasonal pattern of beach morphological changes. At each site, measurements of beach elevation (levels) were taken along two cross-shore transects, with each transect extending from the shoreline for at least 250 m towards the offshore.

Exclusion experiment

In Mozambique, an exclusion experiment was conducted in Bairro dos Pescadores to study the recovery of seagrasses and epi- and infauna. Monitoring (seagrass shoot density and diversity, clam density and diversity, and environmental conditions inside the plots) was conducted in monthly basis.

FINDINGS AND DISCUSSION

Grain size characteristics

Grain size distribution data revealed that there were no marked seasonal differences in the grain size distribution parameters (mean grain size and sorting). However, there were considerable differences in the pattern of grain size distribution between the sites. Generally, the sediment size distribution (mean grain size and sorting) seemed to be controlled more by the physical setting of the sites than by the presence or absence of seagrass meadows. Generally, medium sand dominated the sediment along the coast of Dar es Salaam regardless of whether the site has seagrass meadows or not. Furthermore, considerable seasonal differences in sediment sorting were observed at the southern Dar es Salaam beach sites (Kimbiji, Puna and Buyuni), while, no such differences were observed at northern Dar es Salaam beach sites (especially Mbweni and Ununio). Kunduchi was an exception, showing patterns similar to those observed at the southern Dar es Salaam beach sites. This shows that the size distribution of sediments (mean grain size and sorting) in the Dar es Salaam area is probably controlled by the physical setting of these sites. Whereas the northern Dar es Salaam beach sites are all located in patch reef environmental settings, the southern Dar es Salaam beach sites are located in a lagoonal environmental setting.

Sea bottom topography

The results of the analysis of sea bottom topography (Figure 13) showed marked variation in the sea bottom topography between the northern Dar es Salaam sites and the southern Dar es Salaam sites. With the exception of the Mbweni site, the northern Dar es Salaam sites were characterized by relatively steeply sloping sea bottom topography, while the southern Dar es Salaam sites (with the exception of the Kimbiji site) were characterized by gently sloping sea bottom topography.

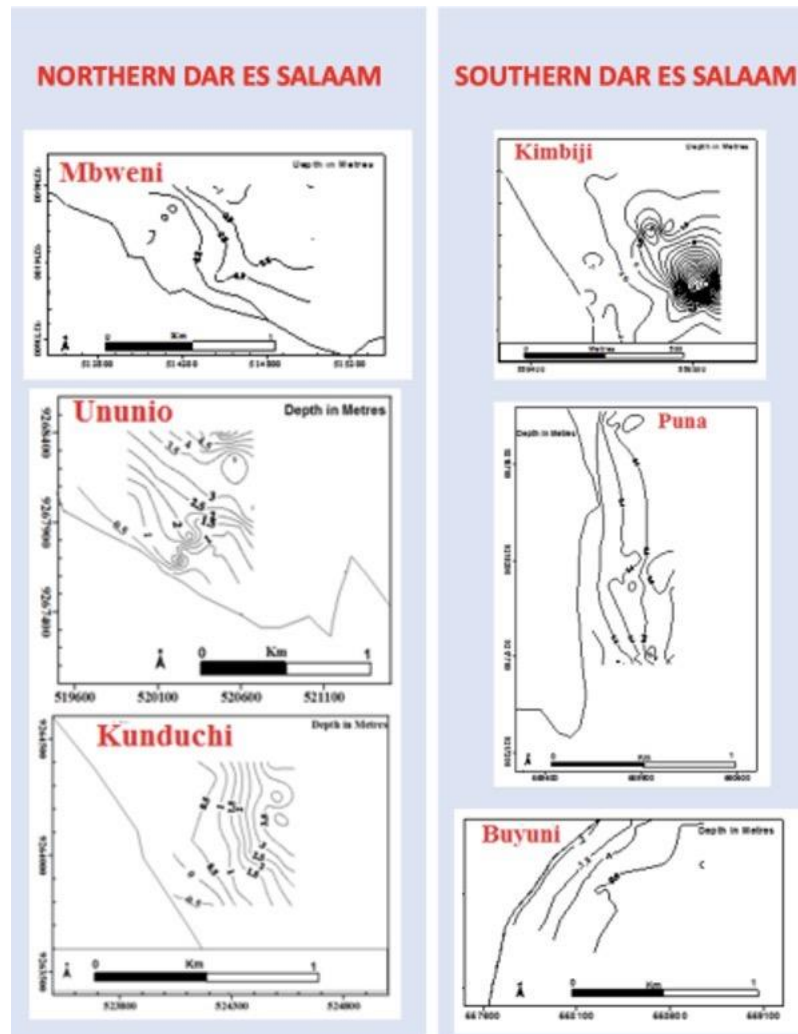


Figure 13. Bottom topography at the different study sites along the coast of Dar es Salaam.

Shoreline profiles

Shoreline profiles revealed that all sites had prominent depressions, with the deepest points lying more than 0.5 m below the mean bathymetric level (Figure 14). Some of these sites, such as Kunduchi, Kimbiji and Puna, also had prominent sand banks (positive relief features) with highest points lying more than 0.5 m above the mean bathymetric levels, while other sites (Mbweni, Buyuni) lacked such positive relief features. Those sites with both prominent positive and negative relief features (Kunduchi seemed to be the most highly potential sites for seagrass proliferation.

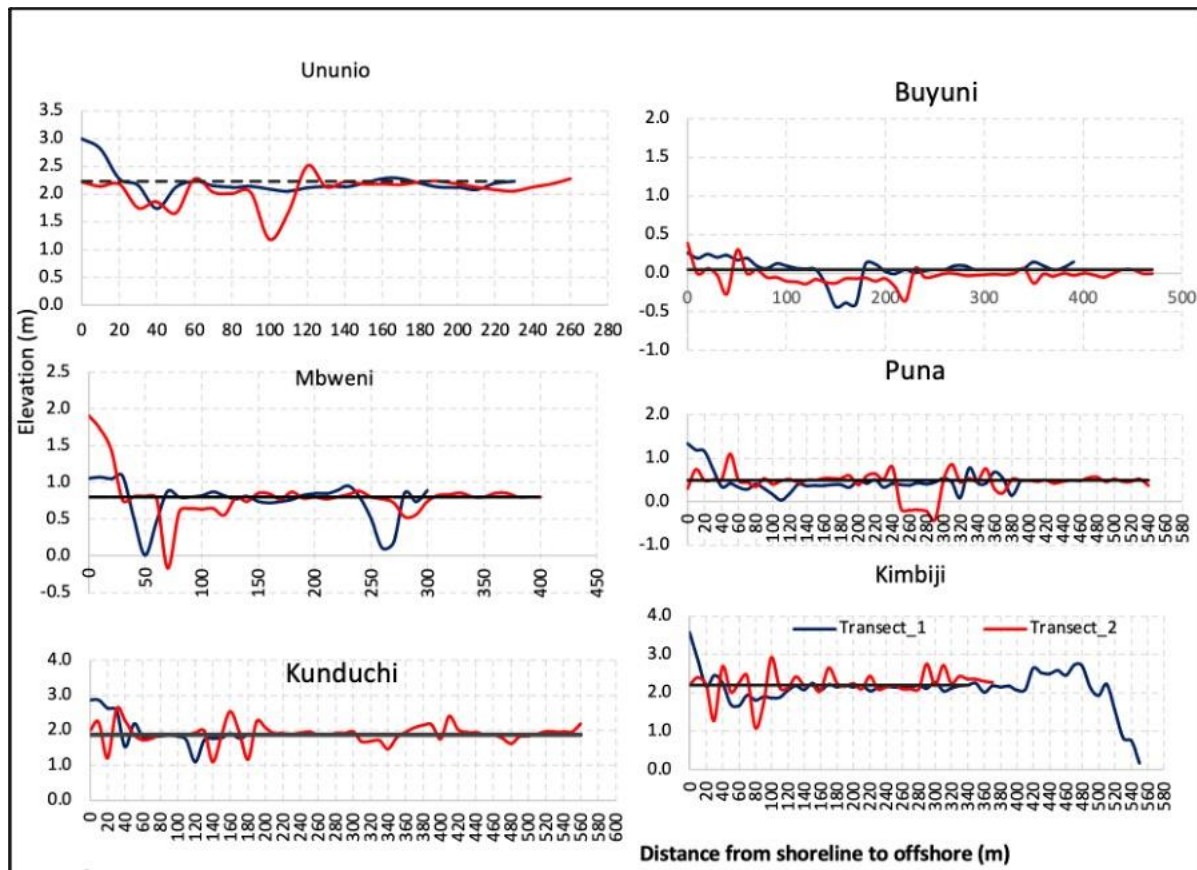


Figure 14. Shoreline profiles of the studied sites.

CTD Measured Oceanographic Parameters

The vertical profiles of DO at Kunduchi, Kimbiji, Buyuni and Puna were characterized by relatively higher DO levels at the surface, which tended to decrease with depth, while also showing depths of local DO maxima along the water column. By contrast, the vertical profiles of DO at Ununio and Mbweni indicated relatively lower values at the surface, which tended to increase with depth to a maximum value of about 7 mg/L. With the exception of Kunduchi and Puna, no considerable depth variation of sea water temperature was observed for the vertical profiles of sea water temperature at the investigated Dar es Salaam sites. Furthermore, the seawater temperatures at Kunduchi and Puna (25.7-26.6°C) were relatively lower compared to those observed at the other four sites (26.9-27.3°C). Although some profiles are observed, generally changes in pH with depth were very minimal (ranging from 0.01 to 0.001). With the exception of Ununio and Buyuni, the seawater salinity tended to show marked depth variation, with depths of local salinity maxima along the water column.

Total Suspended sediments

Suspended sediments are highest at Ununio, an intertidal area with no seagrass. Similarly, the sedimentation rate is highest at Buyuni, again an area with no seagrass.

Nutrient levels in the water column

Results indicate no clear trend in nitrate levels between areas with seagrass and those without. Highest nitrate levels were recorded at Mbweni (without seagrass), followed by Kimbiji (seagrass), and lowest at Buyuni (without seagrass). Similarly, no clear trend in phosphate levels was recorded between sites with seagrass and those without. Highest phosphate levels were recorded at Kunduchi (an area with seagrass) and low in all other sites.

Exclusion experiment

The exclusion experiment in Bairro dos Pescadores, Mozambique, resulted in a gleaning exclusion level classified as “Good” for the 6 months of experimentation. For recovery monitoring, a positive response in measured variables for both seagrass and invertebrate species was recorded. Significant results appeared after the fifth month of exclusion for *Halophila ovalis* and *Halodule uninervis* and after more than 6 months for *Zostera capensis*. It can be concluded that increasing the duration of exclusion results in an increase in invertebrate density for both edible and non-edible species.

CONCLUSIONS

The size distribution of sediments (mean grain size and sorting) in the Dar es Salaam area is probably controlled by the physical setting of these sites but not the presence or absence of seagrass meadows. The bottom topography does not determine the presence or absence of seagrass meadows in the coastal areas of Dar es Salaam. The coral reef features seem to either protect the seagrasses from wave erosion or enhance the functioning of the seagrasses for shore protection. The presence of seagrass meadows reduces suspended sediments in water column.

One manuscript is currently under preparation for this WP:

Shaghude, Y., Wegoro, J., Pamba, S., George, R., Shaghude, Y., Hollander, J., & Lugendo, B. (In prep). The role of seagrass meadows in modulating the sediment distribution and sea bottom topography of coastal intertidal areas: A case of Dar es Salaam seagrass sites. Important data to be used include: Bathymetric data, grain size distribution data, data on beach profiles.

WORK PACKAGE 5

BUILD NUMERICAL MODELS TO SIMULATE THE PHYSICAL IMPACTS OF ECOSYSTEM BASED COASTAL PROTECTION

PREAMBLE

Global climate change is contributing to elevated sea levels, increased coastal erosion and flooding. This accelerating trend has profound effects on coastal and urban areas, globally and the Eastern African region is no exception (Almström & Larsson, 2008). Previous actions to protect shorelines have not fully explored the efficiency and sustainability of ecosystem-based protection measures, particularly the effectiveness of seagrass meadows in retaining sediments and protecting shorelines. This study is part of a trans-disciplinary project that is investigating how coastal resilience can be strengthened against coastal erosion and flooding by combining terrestrial and marine ecosystem-based protection. The project aims to identify and evaluate ecosystem services provided by seagrass meadows for humans and the improved biodiversity in the Western Indian Ocean.

This WP assessed the wave attenuation effect of seagrass meadows, or submerged aquatic vegetation (SAV), using the numerical model XBeach (Roelvink et al., 2009). Field measurements of vegetation, bathymetry, and SAV were conducted at the three case study sites, Kimbiji, Kunduchi, and Puna, located on the coast of Tanzania (Figure 15). Additionally, the XBeach model is used to showcase the potential of wave dampening from SAV.

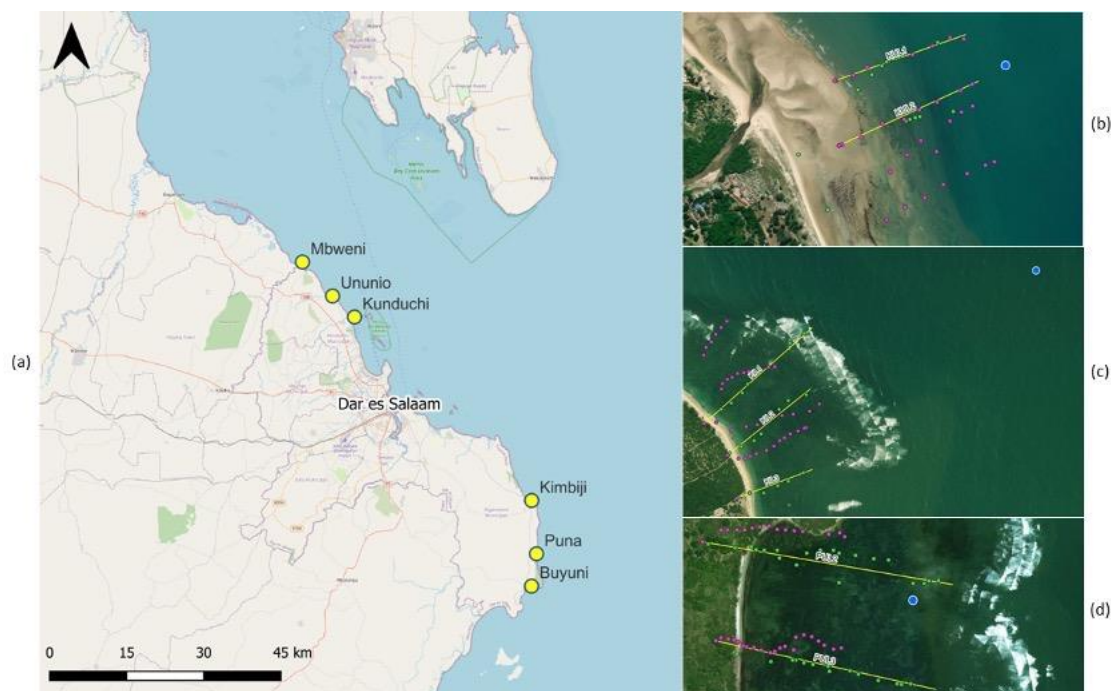


Figure 15. (a) Overview of the six locations included in wave and bathymetry measurements. The panels on the right show zoom-ins of the Kunduchi site (b), the Kimbiji site (c), and the Puna site (d). The two yellow lines show the transects for the simulations and the dots mark the bathymetry (pink) and vegetation (green) measurement points.

METHODOLOGY

The effect on wave propagation from vegetation can be assessed through several methods. For this study, the XBeach numerical model was selected as a tool for exploring the effects of the vegetation at the three case study sites. The XBeach model setups were based on field measurements of bathymetry, vegetation, and waves at the three case study sites. For each site, two transects were simulated in XBeach. The effect of the vegetation was assessed by comparing the mean wave height for a scenario with and without vegetation.

XBeach

XBeach is an open-source, depth-averaged, two-dimensional, process-based numerical model originally developed for simulating dune erosion during storm events (Roelvink et al., 2009). Since the first version, its capabilities have continuously been improved and extended to new applications. Today, XBeach is a widely recognized model for nearshore hydrodynamic and morphological modelling within the coastal engineering community. The model has been validated in numerous scientific publications. Wave dampening from vegetation was included in XBeach by the expression of wave dissipation due to vegetation by Mendez and Losada (2004). Additionally, the vegetation effect on infra-gravity waves and mean flow are included using the drag force. XBeach's capability of simulating wave attenuation by vegetation has, for instance, been verified by van Rooijen et al. (2015). To evaluate the wave-dampening effect of submerged vegetation (SAV), two identical model setups were made for each transect, one with and one without SAV. The difference in wave height between the simulations for each transect indicates.

Input data

To simulate the three case study sites, data were collected for bathymetry, SAV, and wave measurements. Bathymetry was surveyed using a single-beam echo sounder at six locations, Buyuni, Kimbiji, Kunduchi, Mbweni, Puna, and Ununio. An inventory of SAV was carried out in November 2022 at three locations: Kimbiji, Kunduchi, and Puna. Wave measurements were conducted from March to May 2021 at the six locations included in the bathymetric survey. Waves were measured using a pressure sensor (RBRduo³) deployed offshore the SAV fields. Waves were sampled in five minutes bursts. The deployment depth of the sensor ranged from 1.7m to 8.5m.

Model setup

The XBeach model is able to simulate two dimensions. However, this study is focused on wave propagation in a cross-shore direction. Hence, the one-dimensional version of XBeach has been used for the simulations. For each simulation it is necessary to specify input files, the minimum required input files are (example of these files can be seen in the XBeach manual, <https://xbeach.readthedocs.io/>):

- **Parameter-file:** A file containing model settings and non-default parameters using keywords
- **Grid-files:** Two files specifying the coordinates in cross-shore (x) and alongshore (y) direction.
- **Bathymetry-file:** a file specifying the depth in each grid-cell
- **Wave-file:** Input-file for the offshore wave boundary conditions.
- **Vegetation grid file:** Coordinates of the vegetation
- **Vegetation characteristics file:** Each type of vegetation is described in this file.

In general, default parameters were used since no data for calibration or validation have been available. The bed level was retrieved from the bathymetric survey and the still water level of 0.0 m was assumed for all simulations. The wave boundary conditions were defined in the simulations using a JONSWAP spectrum based on the highest measured significant wave height and period at each site.

The description of the SAV in the simulations was based on the field inventory of vegetation. Each specific patch of vegetation was described separately in the model. Within the patch, there could be multiple types of vegetation. Therefore, the vegetation parameters for each patch were determined by a weighted average of the number of stems of the specific species.

FINDINGS

For Kimbiji, there was an overall 2% reduction in the wave height due to wave dissipation from the vegetation. This can be explained by the shallow depths limiting the wave height by breaking waves. In Kunduchi, the vegetation reduced the wave heights by approximately 3-4% in transect KUL1. The dissipation is reduced as the depths become very shallow near the shore. However, the vegetation has only a small dissipating effect (about 2%) on the waves for the KUL2-transect in Kunduchi. This can be explained by the limited presence of vegetation along this transect. In Puna, the vegetation is more abundant compared to the other sites. Results from the simulation of the transect PUL1 show the largest wave attenuation effect of the simulated transects. Waves are dissipated by up to 6%. At transect PUL2 in Puna, the vegetation has a limited effect on wave dissipation. The wave heights are reduced by up to 2% (the increased wave attenuation at a distance of 700m is due to numerical instabilities by the land boundary in the XBeach-model). Despite the vegetation coverage being similar to PUL1, the wave dissipation is significantly lower. This can be explained by the vegetation being shorter and less dense in PUL2 compared to PUL1, demonstrating the importance of vegetation height for the functions of seagrasses in dissipating waves.

DISCUSSION

The findings from the simulations show, in general, a very limited wave-dissipating effect from vegetation at the three sites. It is only at transect PUL2 in Puna that the wave dissipation exceeds 5%. The low dissipation effect can be explained by the vegetation characteristics of the sites and wave heights, which are limited mainly by the shallow depths of the transects. The vegetation at the sites is characterized by being short in length, having a small leaf area, and having a moderate number of stems.

To showcase the potential of vegetation for wave dissipation, two additional scenarios have been simulated based on the KUL1 transect in Kunduchi. In the first scenario, a 100 m long meadow of vegetation with a height of 30 cm, stem width of 3 mm, and 300 stems per square meter, is simulated. The depth of the meadow ranges from about 0.5 to 1 m. In this scenario, the wave dissipation from the vegetation is reducing the wave height as the waves propagate through the vegetation (Figure 16). However, as the depth decreases, the wave height is limited by wave breaking and the effect of the vegetation on waves diminishes.

In Figure 17, findings from a second scenario are presented using the KUL1-transect. In this case, the real vegetation characteristics have been used, with the exception that the vegetation coverage has been modified to cover the entire profile. In such a scenario, waves are dissipated throughout the profile. The wave attenuation increases with decreasing depths because the vegetation becomes larger relative to the water depth.

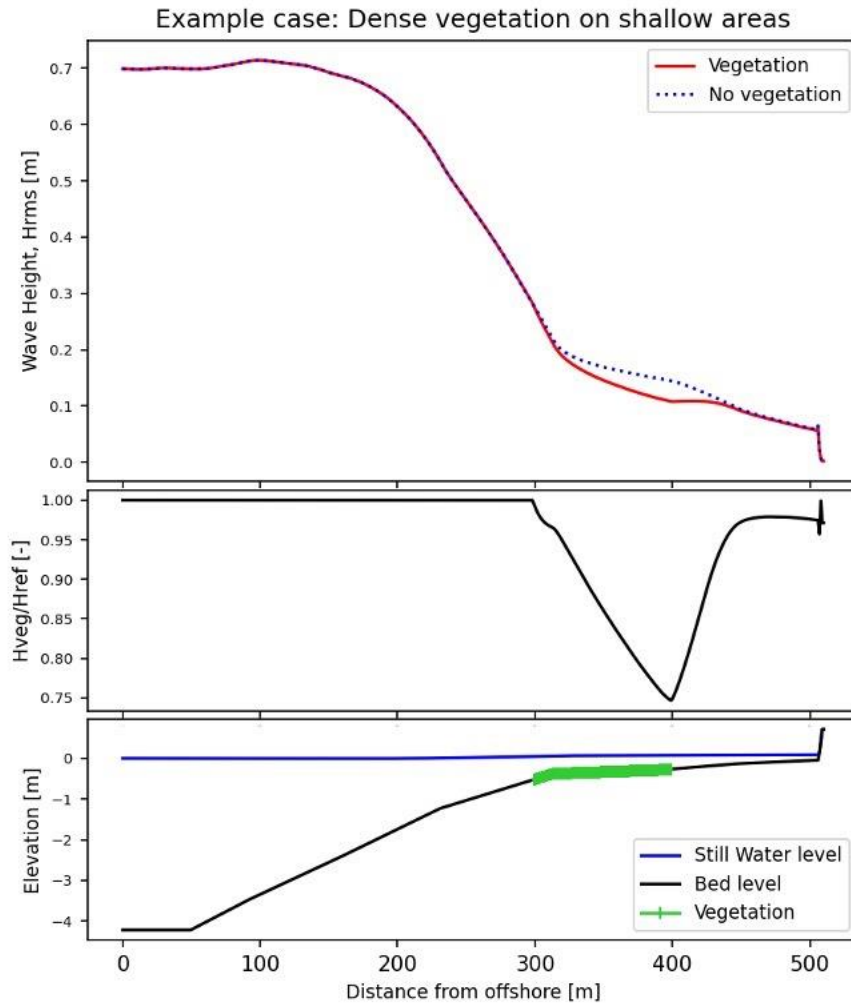


Figure 16. Showcasing how dense vegetation with a length of 100 m would impact the wave attenuation for a bottom profile identical to Kul1. Top: Mean wave height for simulation with vegetation (red line) and reference simulation without vegetation (dashed blue line). Middle: Wave attenuation along the transect, H_{veg}/H_{ref} . Lower: The bed level elevation (black line) taken from the bathymetry survey and localisations of vegetation (green line) according to field inventory. The blue line shows the mean still water level in the simulations.

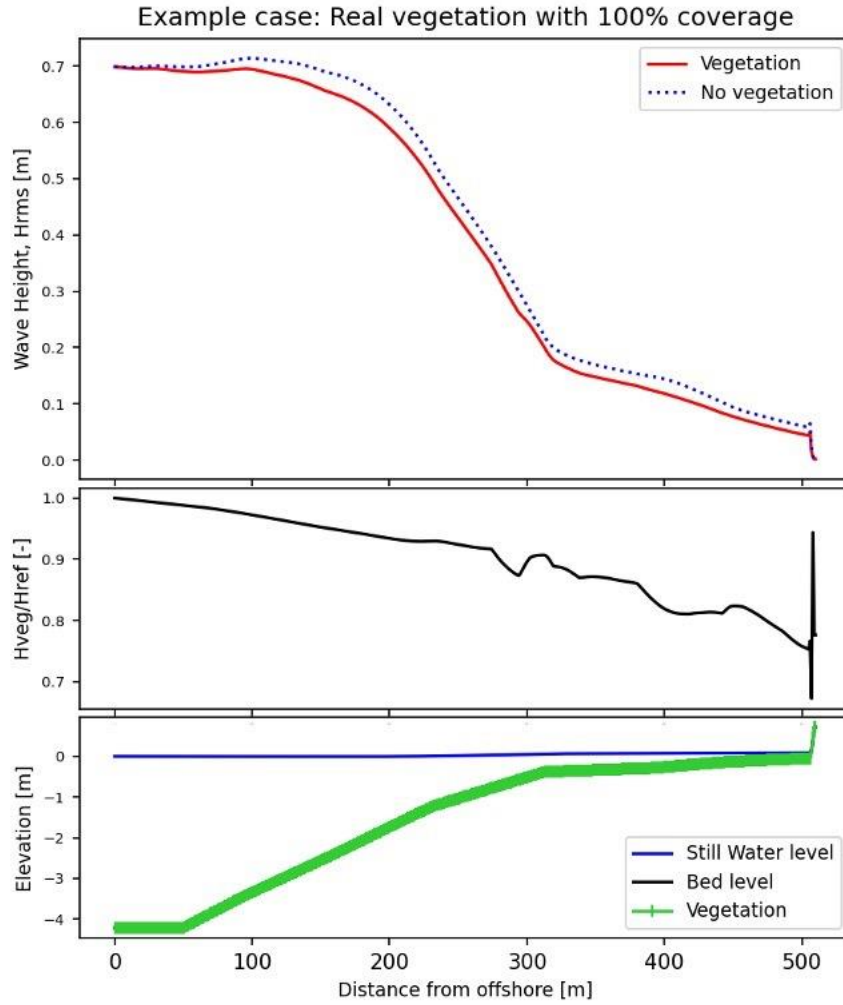


Figure 17. Showcasing the wave attenuation for the real vegetation in KUL1 if it would cover the entire bottom profile. Top: Mean wave height for simulation with vegetation (red line) and reference simulation without vegetation (dashed blue line). Middle: Wave attenuation along the transect, H_{veg}/H_{ref} . Lower: The bed level elevation (black line) taken from the bathymetry survey and localisations of vegetation (green line) according to field inventory. The blue line shows the mean still water level in the simulations.

The findings from this case study have shown that the effect of vegetation diminishes as the depth decreases. This is mainly explained by the dominant process for limiting wave heights in shallow water: wave breaking. As a rule of thumb, wave breaking occurs when the wave height at breaking relates to the water depth at breaking as $H_b/h_b = 0.78$, i.e., the wave height cannot exceed 78% of the water depth. In the case of a flat bed, where no breaking happens, the effect of wave attenuation from vegetation is sustained (Figure 18).

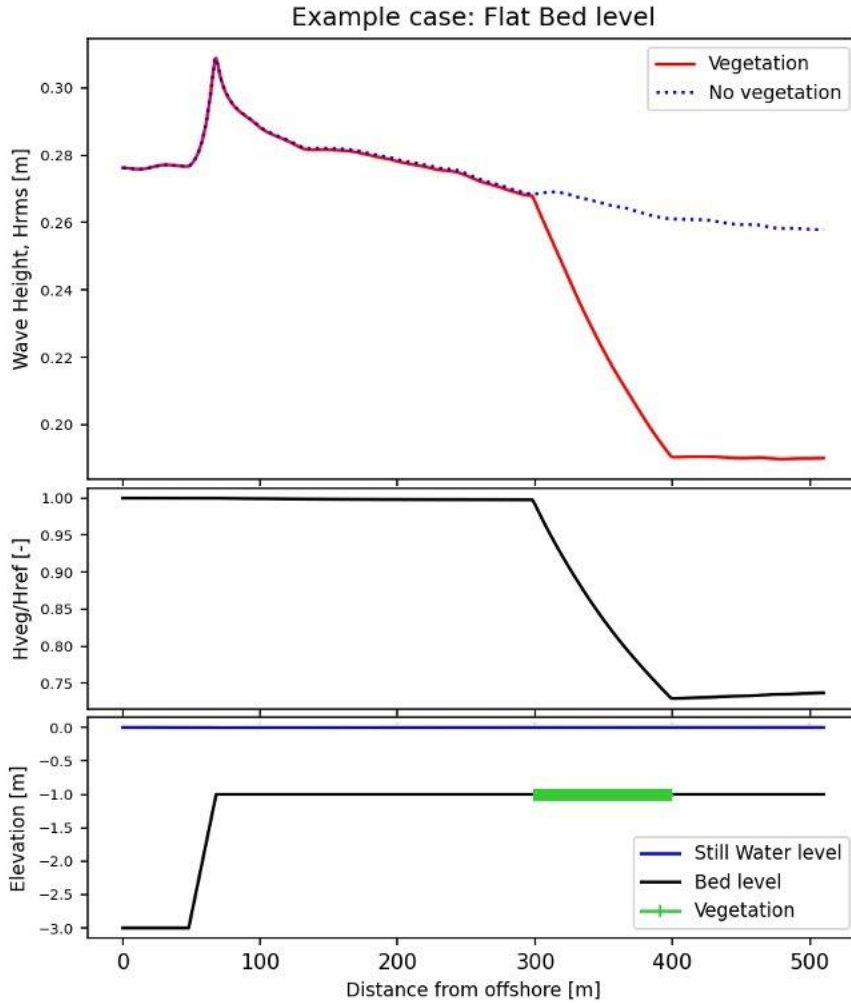


Figure 18. Showcasing the wave attenuation over vegetation for a flat bed. Top: Mean wave height for simulation with vegetation (red line) and reference simulation without vegetation (dashed blue line). Middle: Wave attenuation along the transect, H_{veg}/H_{ref} . Lower: The bed level elevation (black line) taken from the bathymetry survey and localisations of vegetation (green line) according to field inventory. The blue line shows the mean still water level in the simulations.

CONCLUSION

Waves propagating over seagrass meadows will be attenuated due to the energy losses from the vegetation if the vegetation is sufficiently dense, high, and covers larger areas of the nearshore bottom. However, in this study, the vegetation at the three case study sites had a negligible effect on the wave height because the vegetation covered a small portion of the cross-shore profile, the vegetation was short in height for most of the vegetation patches, and in combination with the shallow depths that induce wave breaking, it had a negligible effect on the wave height. The wave dissipation from SAV can be increased by managing the SAV at the sites to promote growth and reduce activities damaging the SAV.

WORK PACKAGE 6

INVESTIGATE BEST PRACTICES FOR SEAGRASS RESTORATION



PREAMBLE

Seagrass meadows act as a natural coastal protection in exposed areas and therefore they are of interest. The WP aimed to increase the vegetative defense structure at shallow depths (between 2-5 m depth) at exposed sites. This was done by strengthening structural features of the vegetation (shoot density, biomass and coverage, etc.) by planting seagrass shoots at some sites, which will accelerate the natural recovery process of the seagrass and eventually optimize the natural spread of the restored meadow. We are at an advanced stage of producing a technical guide about seagrass restoration that includes environmental and ecological conditions in our local context. This knowledge can later be used for large scale restoration projects elsewhere in the region.

METHODOLOGY

Seagrass restoration in Tanzania

Seagrass transplanting experiments were conducted in the intertidal seagrass meadows of Puna along the coast of Dar es Salaam, Tanzania. The tidal pools were chosen and used as experimental plots at the study site. The area is characterized by neap and spring tides. During the low spring tides, the seagrass meadows in the upper intertidal zone are fully exposed to air and strong insolation, while those in the middle intertidal zone are partially exposed, as well as those in the lower intertidal and subtidal zones, which remain submerged. The site had bare tidal pools within seagrass meadows in the middle intertidal, lower intertidal and subtidal zones, which were caused by human activities and natural seagrass recovery has not been possible. Three experimental plots within the study site were established within the tidal pools (depths ranging from 0.5-1 m during low spring tides). The pools were located at different parts

of the intertidal back-reef platform, ranging from the middle intertidal, lower intertidal and subtidal zones, to mimic the effect of water depth on the seagrass restoration success.

The plug and sprig seagrass planting methods were tested. With the plug method, 7 cm and 10 cm (internal diameter) PVC corers were employed to collect seagrass transplant units of low and high shoot density, respectively. The 7 cm and 10 cm plug transplants were planted on biodegradable hessian sacks filled with marine sediment that were installed in bare pools. Holes of equivalent size to PVC corers were made on the hessian sack to accommodate the plugs. For the sprig method, the shovel was used to collect sprigs from the donor meadow adjacent to the experimental plots. The sediment was removed from the collected seagrass transplants before they were bundled into transplant units (Plate 2) of 3 and 5 shoots using hessian jute strings. The sprig units were tied to a jute string on the PVC frame (Plate 2) measuring 0.5 m x 0.8 m consisting of two rows of jute strings tied from side to side at 0.3m spacing. The PVC frames were fixed into the sediment using U-shaped iron rods of 40 cm in length at the middle intertidal, lower intertidal and subtidal zones. The leaves of the sprigs were kept above ground, while the other below-ground parts and frames were completely buried in the sediment. The average initial shoot density of the sprigs was 9 and 15 shoots for low and high densities, respectively. The transplants' survival rates, shoot and rhizome growth rates and shoot and internode plastochrone intervals were monitored as indicators of restoration success. Physico-chemical variables affecting growth parameters such as the sediment organic matter, water nitrate and phosphate, temperature, water turbidity and salinity were also monitored on a monthly basis.



Plate 2. Seagrass (*Syringodium isoetifolium*) shoots (transplants) ready for planting (left) and tying of seagrass shoots for sprig method (right)

Seagrass restoration in Mozambique

The disturbance-and-recovery experiment

We performed an experiment on disturbance-and-recovery effects in *Zostera capensis* meadows on Inhaca Island, Southern . We undertook trials mimicking disturbance of meadows in terms of digging to collect clams, a common practice in Maputo Bay. Four large plots (4 × 20 m) were randomly chosen and demarcated within *Zostera capensis* meadows. Each plot was further divided in 16 subplots of 0.5 m² in two columns of 2 m apart to preserve the subplots during the sampling procedure. Two plots were subjected to the disturbance treatment at the start of the experiment and labelled 'digging plots', while two undisturbed plots were designed as 'control plots'. In order to assess the effects of digging and revolving sediment to seagrass recovery, shoot density (shoots per m²) was assessed at four sampling events: T1: 1

month after digging, T2: 3 months after digging, T3: 6 months after digging and T4: 12 months after digging. The findings indicated that once such anthropogenic impacts are halted, *Zostera capensis* restore itself after 12 months of impact exclusion.

Restoration of Zostera capensis

In addition, we also conducted seagrass restoration to test the effectiveness of replanting *Z. capensis* using the plug method with PVC tubes of a diameter of 4.5 and 7.5 cm. For the experiment, four plots (4 × 3.2 m) were determined at already degraded sites with no seagrass presence at the start of the experiment. The plots were divided between two subplots, where a total of 160 plugs (shoots with sediment) were transplanted, not far from the donor beds (distance < 100 m). An equal number of plugs (80) were transplanted with the 4.5 cm diameter tube and with the 7.5 cm tube, both with 50 cm length. The plugs were transplanted in rows perpendicular to the shore. Seagrass plugs were collected at donor meadows and fitted into the 10 cm long plug for the belowground plant structures such as rhizomes and roots to stay intact, and then transported to the restoration site using polyethylene containers. At the recipient areas, holes were made to accommodate the planting plugs. The seagrass restoration experiment focused on a comparison of the survival rate, epiphyte abundance and sediment composition at the same four sampling events as the disturbance experiment.

Restoration of Oceana serrulata

We also tested using another seagrass species, *Oceana serrulata* (former *Cymodocea serrulata*), around Inhaca Island, Sangala Bay: sediment-free methods (rod and finger methods) and seagrass with sediment methods (sod method). Maputo Bay is a wash of sedimentation given the underlining currents and winds that prompt the occurrence of several patchy areas prone to both constant transportation and erosion. This is pronounced especially on north Inhaca (Sangala) primarily colonized by the seagrass *oceana serrulata* which is a pioneer species in sand-accretion areas.

FINDINGS AND DISCUSSION

Seagrass restoration in Tanzania

The plug method revealed a higher median survival rate (median = 33.3%) than the sprig method (0.0%) which died off within the first two experimental months. It was also found that *Syringodium isoetifolium* transplants survived poorly in the sprig method (median = 0%), while the large diameter plug (10 cm) demonstrated a higher median survival rate (66.7%) than the smaller diameter (7 cm) plug (0.0%). Large-diameter plugs showed higher shoot and internode production than the smaller-diameter plugs, which were noted as plastochrone intervals. The study also revealed a strong effect of water depth, where survival and growth parameters decreased with increased water depth. Finally, the study found a number of significant correlations, both positive and negative, between growth parameters and the measured environmental factors – and revealed that most of the measured environmental parameters were influenced by the local weather conditions and the monsoon seasonal cycle. The study illustrates that the restoration technique is strongly related to restoration success, providing clear guidance for future seagrass restorations in high-energy coasts in the Western Indian Ocean. The progress of planted shoots soon after planting (left) and 6 months afterwards (right) is presented in Plate 3.



Plate 3. Progress of planted shoots soon after planting (left) and 6 months afterwards (right).

Seagrass restoration in Mozambique

Zostera capensis

The survival rate of seagrasses differed significantly between the two plug sizes, with a higher survival rate in the 7.5 cm diameter PVC tube treatment across all sampling periods for the 7.5 cm tube with an average of 75% of the shoots survived (Figure 19).

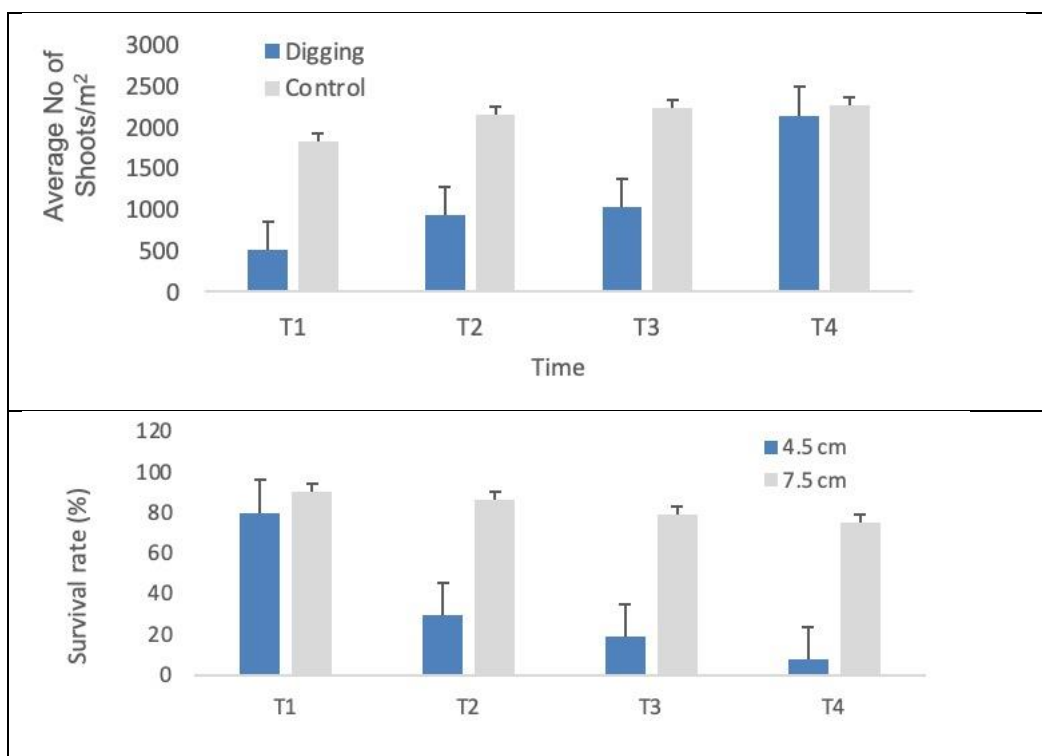


Figure 19. Average seagrass shoot density (shoots/m²) in Digging and Control plots (top) and Average survival rate of *Z. capensis* using 4.5 cm versus 7.5 cm plug size across the time intervals of T1-T4.

The effectiveness of *Zostera capensis* replanting using three different methods: sediment-free-methods (staple and finger) and seagrass with sediment method (plug)—by measuring the survival rate of planted seagrass was also tested. Survival rates did not differ significantly from the replanting occasion for all methods, with nearly more than 75% of survivors at each plot until the first year of planting. After that, the shoot method showed the best results, with a survival rate of over 70% of (ongoing analysis). It is clear from the study that a combination of both impact exclusions and active restoration is bound to produce the best results of seagrass

management actions. The findings from this study will further guide appropriate management to build the best practice in seagrasses meadows restoration and awareness.

Oceana serrulata (formerly *Cymodocea serrulata*)

The rod method recorded the highest survival rate of over 60%. The project has accomplished restoring nearly 2 ha of seagrasses with 150 000 modules of 3-6 shoots of *Oceana serrulata*. One of the meadows returned to near climax stage six months after planting; however, plants appear to be behaving differently in winter when compared to summer (Figure 20). Monitoring of the restoration has targeted mainly the metrics based on calculating seagrass percentage cover, shoot density, canopy height and biomass of both the restored and donor sites (ongoing analysis).

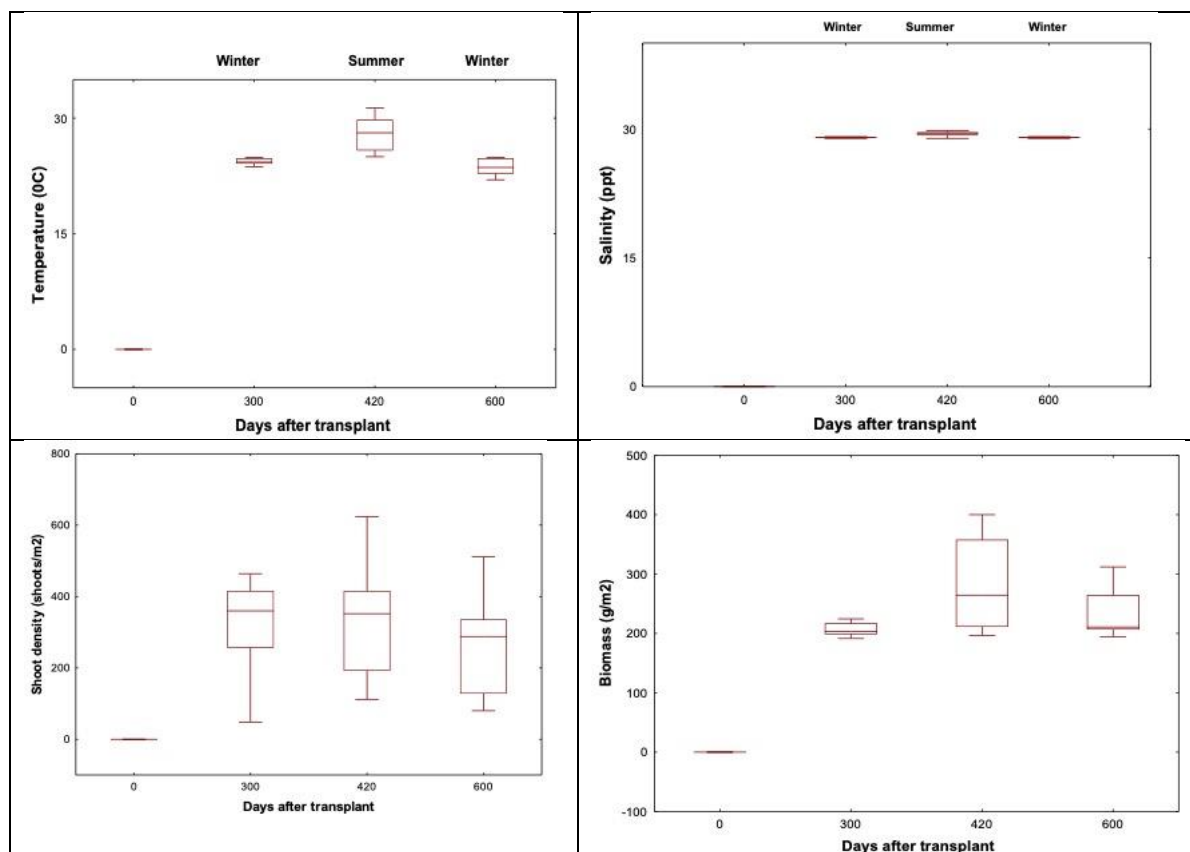


Figure 20. Shoot density and biomass of planted *Oceana serrulata* during winter and summer.

Findings of this WP were published in two peer review journal articles:

1. Wegoro, J., Pamba, S., George, R., Shaghude, Y., Hollander, J., & Lugendo, B. (2022). Seagrass restoration in a high-energy environment in the Western Indian Ocean. *Estuarine, Coastal and Shelf Science*, 278, 108119. <https://doi.org/10.1016/j.ecss.2022.108119>.
2. Amone-Mabuto, M., Hollander, J., Lugendo, B., Adams, J. B., & Bandeira, S. (2022). A field experiment exploring disturbance-and-recovery, and restoration methodology of *Zostera capensis* to support its role as a coastal protector. *Nordic Journal of Botany*, e03632. <https://doi.org/10.1111/njb.03632>.

WORK PACKAGE 7

DISSEMINATION

Findings of this research project have so far been disseminated through publications, participation in scientific conferences and through stakeholder engagements including workshops, trainings and demonstrations. Various dissemination materials were produced including banners, brochures, stickers, news articles, and video clips.

The findings of this project were also presented during the 11th and 12th WIOMSA Symposia. Furthermore, the findings of this project were disseminated through stakeholder workshops. A high-level stakeholders workshop (Plate 4) conducted in Tanzania involved a range of participants, including resource managers (fisheries and marine park officers); scientists from research institutes, training agencies and universities; local leaders and resource management organisation such as the Beach Management Unit (BMU); and Non-Government Organizations (NGOs) such as the World Wildlife Fund (WWF), Sea Sense, Wildlife Conservation Society, and SOA Tanzania. During the workshop, dissemination materials, including banners, brochures and stickers, were presented to the participants. Local communities to participants.

In addition, a low-level stakeholder workshop (Plate 5) was conducted to raise awareness on the importance and threats to seagrasses, as well as seagrass restoration. This low-level stakeholder workshop was followed by a demonstration on how seagrass restoration can be conducted (Plate 6). The demonstrations were done at Puna site, and about 50 participants, including BMU leaders from seven streets along the Dar es Salaam coast (Mbweni, Ununion, Kunduchi, Mjimwema, Kimbiji, Puna and Buyuni), resource managers, and NGOs, participated. The launching of the demonstrations was graced by Hon. Fatma Nyangasa, the District Commissioner of Kigamboni District, Dar es Salaam.



Plate 4. Participants of the high-level stakeholders workshop.



Plate 5. Participants of the low-level stakeholders workshop



Plate 6. Seagrass restoration demonstration with Hon. F. Nyangassa Kigamboni DC (left) inaugurating the event at Puna site, Dar es Salaam.

In Mozambique, 10 local communities were trained on seagrass restoration, to raise awareness about the importance of seagrass, create ownership and reflect about the threats to seagrasses, as well as the risks of reducing their importance for their livelihoods, which depend on wealthy seagrass meadows.

Newspaper articles as well as video clips demonstrating seagrass restoration were produced. Some of the video clips are listed below.

- Seagrass Restoration at Inhaca Island, Mozambique (<https://www.youtube.com/watch?v=GzwMP-gc2MY>)
- Seagrass restoration in Tanzania “*NYASI BAHARI KUPANDWA KIGAMBONI KWA MARA YA KWANZA TANGU DUNIA IUBWE*”. (<https://www.youtube.com/watch?v=noNHcSexjmg>) and
- “*WAVUVI WILAYANI KIGAMBONI WATAKIWA KULINDA NA KUHIFADHI NYASI BAHARI*” (<https://www.youtube.com/watch?v=McXlGvpkGUA>)
- <https://www.instagram.com/reel/CjIA0xvo9Bp/?igshid=MDJmNzVkMjY=>
-

For the first time in history, comprehensive seagrass maps for the entire Tanzanian coast (including Zanzibar) have been produced through this project.

Two reports were produced through this project, as shown below:

- Mabula, M. (2022). Seagrass mapping in Tanzania. A consultancy report.
- Björn Almström (2023) XBeach simulation of wave propagation over submerged vegetation – a case study from Tanzania.

The project also has a website <https://marinescience2.wixsite.com/seagrassprotect>

OUTCOMES AND IMPACTS OF THE PROJECT

We are pleased to report that the project has had a significant impact on the communities and the general public through its various activities and outputs, as follows:

- The project's first and most important impact is on capacity building. The project supported a total of five postgraduate students, including one PhD candidate (Manuela Amone-Mabuto) from Eduardo Mondlane University, Mozambique, who will be completing her studies at the end of 2023, and four master's students, three from Mozambique (Maria Cuambe, Maria Americo, Tsiaranto Fanoro) and one (January Wegoro) from Tanzania;
- The project engaged local communities during implementation and dissemination, and as a result of this project, a local community-led organisation (A-Tanyi) responsible for seagrass conservation was formed in Mozambique. Due to increased awareness of the importance of and threats to seagrasses, the BMUs in Kigamboni, Dar es Salaam, are committed to abandoning destructive fishing methods in order to conserve seagrasses, as well as protecting seagrass meadows from degradation. The BMUs are in regular communication with the project team, providing regular updates on monitoring activities conducted on seagrass meadows. Plans by the BMUs are also underway to invite the project team to speak with pupils at primary schools in their respective areas, in order to raise awareness about seagrasses;
- New collaborations with other institutions are likely to be formed to expand the work on seagrasses. Currently, ZAFIRI and SUZA have expressed an interest in working together to raise funds for seagrass awareness and restoration along Zanzibar's coast. In addition, WWF Tanzania and Sea Sense have expressed an interest in collaborating with the Tanzanian project team on the production of the booklets, including the Seagrasses of Tanzania (Nyasibahari za Tanzania);
- Some colleges that deal with coastal and marine resources have plans to include seagrass conservation and restoration in their curricula. For example, the Fisheries Education and Training Agency (FETA) has stated their intention to include seagrass restoration in one of their curricula when reviewing their programmes;
- The Kigamboni District Council in Dar es Salaam intends to engage the project team on a regular basis in raising awareness about the importance of seagrasses, threats to them, and how to conserve them;
- The seagrass cover maps have been requested by marine parks and reserves to guide seagrass monitoring in the parks. TNC Tanzania has requested to use the seagrass cover maps as inputs to Marine Spatial Planning, particularly for the Tanga coast in Tanzania; and;
- In addition to preparing a booklet about the Seagrasses of Tanzania in Kiswahili, we are in the final stages of preparing a Seagrass Restoration Guide based on our research findings. The guide will be available in both Kiswahili and English. We anticipate that the booklet and restoration guides will be extremely useful in raising awareness about seagrasses and guiding community-led seagrass restoration in Tanzania and Mozambique.

RECOMMENDATIONS

Based on the findings, the following recommendations are made.

- Seagrass meadows are important to local communities mainly in terms of supporting fisheries and shoreline protection. However, what we learned from the stakeholder feedback is that the general public is generally not very aware of the existence, importance and threats to seagrass meadows. **Therefore, it is recommended that awareness raising be done regularly among stakeholder groups, including resource users and high-level stakeholders, as most of them are also decision and policy makers.**
- According to the findings of this study, Tanzania's coast contains extensive seagrass meadows, with an estimated area of 2817 km². This is the first comprehensive report on seagrass coverage off Tanzania's coast. **In order to quantify any spatial changes and have time-scale data for proper seagrass management and conservation, ongoing monitoring, including periodic mapping, is recommended.**
- The coral reef features seem to either protect the seagrasses from wave erosion or enhance the functioning of the seagrasses for shore protection. **It is therefore recommended that adjacent coastal habitats to seagrass meadows be protected in order for them to continue providing ecosystem services.**
- The XBeach model confirmed that the efficiency of seagrass vegetation in reducing wave energy and protecting shorelines from erosion is determined by its density, height, and area cover. **To ensure the effectiveness of seagrass meadows in shoreline erosion protection, it is highly recommended to promote seagrass growth and reduce activities that harm them, through awareness raising, seagrass protection and active restoration where necessary.**
- The plug method (of 10 cm diameter) is bound to produce better results than smaller diameter plugs or the sprig method when restoring seagrass in areas with relatively strong waves, and is thus recommended. Furthermore, techniques like using sediment-filled hessian bags to stabilise sediment and provide a growing sediment matrix, especially in areas with very soft mud or rubble substrates, can improve restoration success and are thus recommended. In addition, there are currently few studies on the impact of transplant extraction on donor meadows. **Follow-up on donor meadows is thus recommended in order to understand the recovery rates of the patches produced during transplant collection.**
- Stakeholder involvement during project inception, implementation, and dissemination of project findings are critical steps to ensure stakeholder ownership of the project, participation in the project, and increased uptake of research findings. **WIOMSA should ensure that future projects involve stakeholders at all stages of the project.**

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ANNEXES/APPENDICES

List of publication/manuscript and awareness materials produced in connection with the project (attach them)

The publications produced by this research project include the following:

- Wegoro, J., Pamba, S., George, R., Shaghude, Y., Hollander, J., & Lugendo, B. (2022). Seagrass restoration in a high-energy environment in the Western Indian Ocean. *Estuarine, Coastal and Shelf Science*, 278, 108119. <https://doi.org/10.1016/j.ecss.2022.108119>.
- Amone-Mabuto, M., Hollander, J., Lugendo, B., Adams, J. B., & Bandeira, S. (2022). A field experiment exploring disturbance-and-recovery, and restoration methodology of *Zostera capensis* to support its role as a coastal protector. *Nordic Journal of Botany*, e03632. <https://doi.org/10.1111/njb.03632>.
- *Seagrass Restoration in Mozambique. How It Began*, an article that was published in WIOMSA-Magazine-Issue-12_December2020: (https://www.wiomsa.org/publications/wiomsa-magazine-issue-no-12-december-2020/wiomsa-magazine-issue-12_december2020/)
- *Seagrass restoration successful in Tanzania*, an article that was published in WIOMSA Science News (<https://blog.wiomsa.net/2021/07/22/wiomsa-sciencenews-seagrass-restoration-successful-in-tanzania/>)
- *Concerns as tonnes of seagrass get lost*, an article that was published in THE CITIZEN newspaper on Tuesday, October 04, 2022. <https://www.thecitizen.co.tz/tanzania/news/national/concerns-as-tonnes-of-seagrass-get-lost-3972506>.

Manuscripts in preparation

- Shalli, M.S., Hollander, J., Wegoro, J., Pamba, S., George, R., Shaghude, Y., Amone-Mabuto, M., Bandeira, S., & Lugendo, B. Coastal Communities' Perceptions on Coastal Erosion and Ecosystem Services of Seagrass Meadows in Dar es Salaam, Tanzania. (*Resubmitted after review*)
- Amone – Mabuto, M., Mubai, M., Bandeira, S., Shalli, M.S., Adams, J.B., Lugendo, B.R., & Hollander, J.: Community perceptions on the role of seagrass ecosystems for coastal protection. (*in revision*)
- Lugendo et al. Spatially seagrass mapping across the entire coast of Tanzania. (*in prep.*)
- George, R., Pamba, S., Shaguge, Y., Hollander, J., Wegoro, J., & Lugendo, B. The interplay of sediment characteristics between terrestrial and marine ecosystems: Implications for carbon storage in marine coastal areas. (*in prep.*)
- Amone-Mabuto, Manuela, Duncan Hume, António Beleza, Frederick Assante, Salomão Bandeira (*in prep.*). Seagrass macroscale mapping in southern Mozambique using extensive data points , satellite-based sources and drone application for *Zostera capensis* distribution. (*in prep.*)
- Amone-Mabuto, Manuela, Daniela Carvalho de Abreu, Johan Hollander, Salomão Bandeira, Janine Adams (*in prep.*) Differences in macrofauna assemblages in natural and restored seagrass beds. (*in prep.*)
- Cuambe, Maria Alberto , Manuela Amone Mabuto ^{1,2}, Maria Américo¹, Jeremias Nhaca^{1,2}, Ilario Timba^{1,3}, Salomao Bandeira¹. Seagrass restoration metrics: Case of *Oceana serrulata* (former *Cymodocea serrulata*) in Mozambique. (*in prep.*)
- Shaghude, Y., Wegoro, J., Pamba, S., George, R., Shaghude, Y., Hollander, J., & Lugendo, B. (*In prep.*) The role of seagrass meadows in modulating the sediment distribution and

sea bottom topography of coastal intertidal areas: A case of Dar es Salaam seagrass sites. Important data to be used include: Bathymetric data, grain size distribution data, data on beach profiles. (*in prep.*)

Booklets in preparation

- A Restoration Guide for Seagrass Meadows in High Energy Intertidal and Subtidal Environments.
- Muongozo wa urejeshaji wa nyasibahari.
- Nyasibahari za Tanzania

Banners, leaflets and stickers

- Muongozo wa urejeshaji wa nyasi bahari kakika mazingira ya bahari yenye mawimbi
- Restoration guide for seagrass meadows in high energy intertidal and subtidal environments.
- Umuhimu wa nyasibahari katika fukwe za Tanzania
- 600 stickers distributed to various stakeholders.

Two reports were produced from this research project, as shown below:

- Mabula, M. (2022) Seagrass mapping in Tanzania. A consultancy report.
- Björn Almström (2023) XBeach simulation of wave propagation over submerged vegetation – a case study from Tanzania.

NEWS ARTICLES



The Citizen - 4th October 2022



The Citizen - 4th October 2022

Brochure



Chuo Kikuu cha Dar es Salaam
IDARA YA SAYANSI AKUA NA
TEKNOLOJIA YA UVUVI
(DASFT)



Washiriki wa Mradi

Watafiti kutoka Chuo Kikuu cha Dar es Salaam, Idara ya Sayansi Akua na Teknolojia ya Uvuvi (DASFT) na Taasisi ya Sayansi ya Bahari (IPSS) watachirikiana na watafiti kutoka Taasisi ya Utafiti wa Uvuvi Tanzania (TAFRI).



Wafadhili wa Mradi

Mradi huu unafadhiliwa na Umoja wa Wanasayansi za Bahari wa Ukanda wa Magharibi mwa Bahari ya Hindi (WOMSA).



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Ufanisi wa Nyasi bahari

Katika Kudhibiti Mmnyoko wa Fulewe katika
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