BLUE CARBON

SUBTIDAL CARBON STOCKS OF SEAGRASS BEDS IN GAZI BAY, KENYA

TECHNICAL REPORT

Acknowledgement

This technical report is a part of carbon stock assessment of blue carbon ecosystems in Gazi Bay, Kenya. The work was conducted by KMFRI while elemental carbon analysis was carried at CSIRO, Australia. We thank all the teams that participated in the fieldwork, laboratory and data analysis. Preparation of this report was supported through UN's Blue Forest Project, to whom we are grateful

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Cover: Sub-tidal seagarsses in Gazi bay, Kenya. Photo by: Derrick Omollo

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Technical Report

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Abbreviations and Acronyms

AGB	Above ground biomass
BGB	Belowground biomass
CSIRO	Commonwealth Scientific International Research Organization
C	Carbon
IPCC	Intergovernmental panel for climate change
KMFRI	Kenya Marine and Fisheries Research Institute
LOI	Loss on Ignition
PVC	Poly Vinyl Chloride
PES	Payment for Ecosystem Services
SCUBA	Self-Contained Underwater Breathing Apparatus
WIOMSA	Western Indian ocean Marine Science Organization

Conversion Table

Value (grams)	Unit	Name
10^3	Kg	Kilogram
10^6	Mg	Megagram (tonne)
10^9	Gg	Gigagram
10^{12}	Tg	Teragram
10^{15}	Pg	Petagram
10^{18}	Eg	Exagram
10^{21}	Zg	Zettagram

One Gigatonne = 1000 Teragrams
One hectare = 10,000 square meters

Glossary

Autochthonous carbon	Carbon produced and stored in the same environment it is produced
Allochthonous carbon	Carbon produced in one location and deposited in another
Intertidal zone	The area of seashore which is covered during high tide and exposed during low tide
Carbon stock	Total amount of organic carbon stored in a blue carbon ecosystem of a known size
Seagrass	Submerged flowering plants that live in fully marine and estuarine environments
Seagrass meadow	Beds formed by seagrasses that grow either as mixed species or single species
Subtidal zone	Refers to the area along the sea shore where the seabed is below the lowest tide

1.0 INTRODUCTION

1.1 Background information

Seagrasses and associated blue carbon systems, such as mangroves and salt marshes, are important as natural carbon sinks as well as in provision of critical ecosystem goods and services (Nelleman *et al*., 2009; Fourqurean *et al*., 2012). However, around the world seagrass ecosystems are threatened by habitat conversions, pollution and climate change (Fourqurean *et al.*, 2012; Duarte *et al*., 2013). When lost or degraded, these seagrass ecosystem not only halt taking in carbon but more importantly they release the already stored carbon back to the atmosphere; leading to climate change (Pendleton *et al.*, 2012).

Whereas there have been significant efforts to quantify the carbon storage in seagrass meadows globally, global seagrass carbon estimates are largely based on data from few species and from specific regions such as Australia, the Mediterranean, and North America, lacking estimates from coastal regions with extensive seagrass meadows in Africa and Asia and at the same time, much of the available data is from intertidal seagrasses due to ease of access to these shallower meadows (Githaiga *et al* 2016). This potentially puts in doubt the accuracy of the global carbon stock and therefore undermines the climate regulatory role of seagrasses.

Carbon stock assessments of blue carbon ecosystems in Gazi bay have tended to focus on mangrove forests (Tamooh et al., 2008; Langat et al., 2014). These studies contributed to the development of Mikoko Pamoja - the first community type project in the world to restore and protect mangroves through sale of carbon credits (https://www.planvivo.org/mikoko-pamoja). Due to the connectivity of marine ecosystems, there is an opportunity to expand Mikoko Pamoja into seagrass beds of the bay. This will, however, require estimation of carbon baselines in seagrass and estimation of their carbon sequestration levels.

Past estimation of seagrass carbon in Gazi have focused on the intertidal areas as well as in the mangrove fringed creeks of the bay (Githaiga et al 2017, Juma et al 2020), Understanding the carbon stocks in the subtidal areas, which is the core of this study, fills the gap on the total ecosystem carbon of seagrass beds in bay.

1.2 Objectives of the Study

The overall objective of the study was to assess total ecosystem carbon in the seagrass beds of Gazi Bay. More specifically, the objectives were:

i. To determine the composition, distribution and abundance of seagrass species in sub tidal areas of Gazi Bay, Kenya.
ii. To determine the vegetation carbon stocks in the above- and below ground components of sub-tidal seagrass beds meadows in the bay
iii. Use data in (ii) to determine total ecosystem carbon stocks of seagrasses in the bay.

2.0 STUDY APPROACH AND METHODOLOGY

2.1 Description of the Study area

This study was conducted in Gazi Bay (4°25'S, 39°31'E) located in the south coast of Kenya; 55km from Mombasa city (Fig.1). The bay is a tropical semi-enclosed shallow coastal water system (Kitheka, 1996), with a total surface area of approximately 17 km^2 (Coppejans, 1992). The sub tidal areas in Gazi cover approximately 470ha.

The characteristic features of Gazi bay are the two main creeks – the eastern (or Kinondo) and western creeks; the fringing mangrove forests, and a huge intertidal area. There are two seasonal rivers flowing into Indian Ocean at Gazi bay - river Kidogoweni and Mkurumudzi. This is in addition to several seepage points (Signa *et al.* 2017) that provide the Bay with freshwater input.

According to Koppen climate classification (Peel et al., 2007), the climate of Gazi Bay may be classified as tropical wet/dry. The climate is heavily influenced by South East monsoon winds (Kuzi), which are associated with heavy rains and blows from March to August. This is followed by the North East monsoons (Kazkazi) from November to March that is associated with dry period. Annual total rainfall in Gazi ranges from 1000 mm to 1600 mm. Temperature ranges from 22 to 34°C during North Easterly Monsoon, and from 19 to 29 °C during the South Easterly Monsoon seasons (Chia and Kirkman 2000). Humidity is high, and averages 80% all year round (Kitheka 1996).

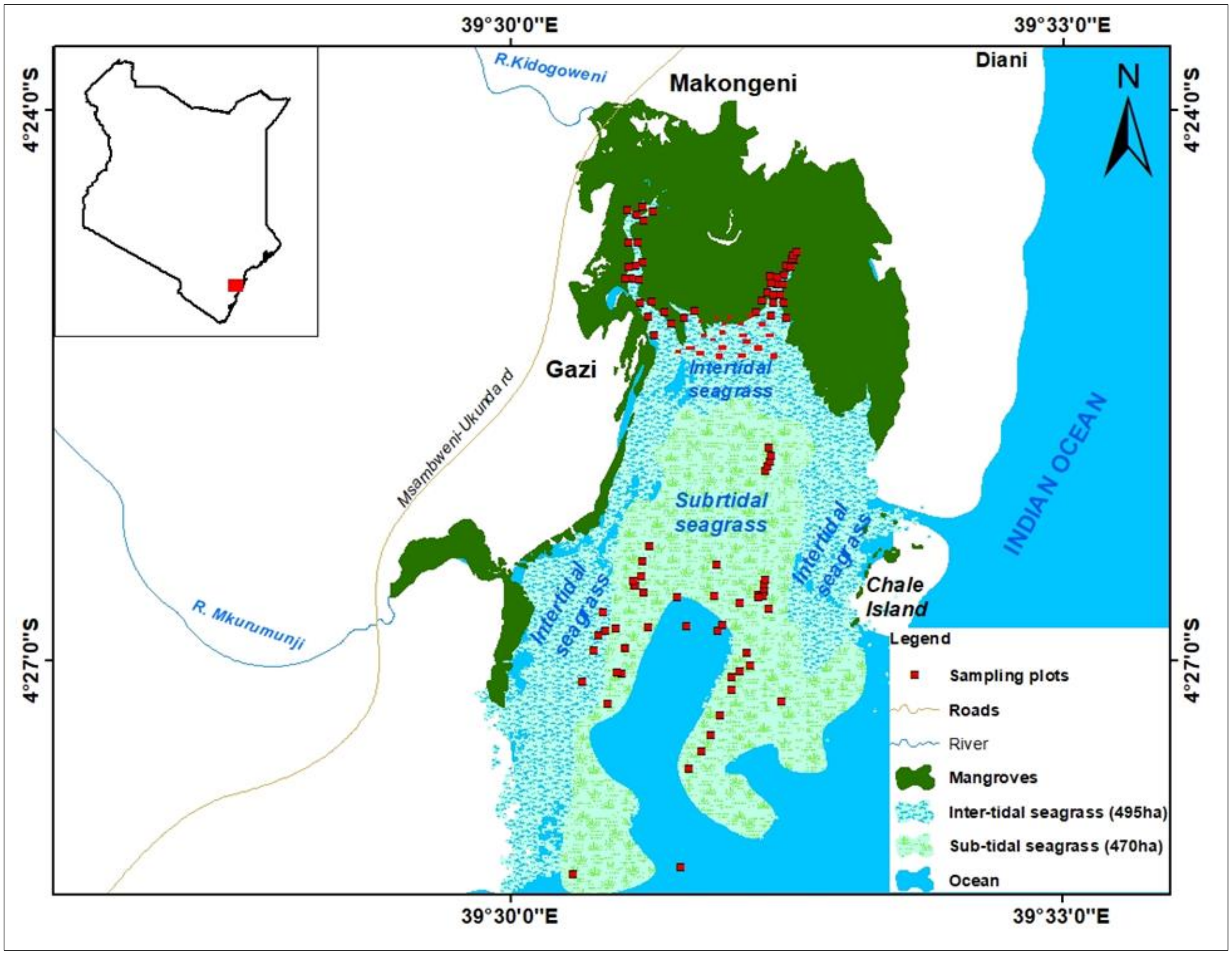


Figure 1: Sub tidal seagrasses in Gazi bay showing sampling points

2.2 Sampling design

Systematic random sampling design was used to identify 40 sampling stations within the subtidal areas of Gazi bay. In each station, sample collection was done within 0.25m^2 plots with two replicates. Three SCUBA divers collected seagrass and sediment samples during spring low tide while the sorting and packing of the collected samples was done on the boat. Measurements of physio-chemical water parameters were done *in-situ,* during low tides. Total dissolved solids (mg/L), water temperature (˚C), salinity and p.H were measured using the YSI Professional Plus handheld multiparameter meter W14-05. Depth was measured using a dive computer.

2.2.1 Seagrass vegetation assessments

Vegetation assessment was carried out in square quadrat of $0.25m^2$. All the above ground shoots within the quadrat were identified, harvested using scissors, and packed in pre-labeled zip lock bags, and taken to the laboratory. In the lab the shoots were counted and length of 10% of the total shoots measured using the procedures described in Waycott *et al*., (2004). Thereafter, the shoots and leaves were scrapped gently with a scalpel to remove epiphytes.

2.2.2 Determination of vegetation carbon stocks

The harvested shoots were then used to determine the above ground carbon content by oven drying them at 60°C for 72 hrs. Samples for below ground carbon determination were obtained through coring with a PVC corer (6 "internal diameter, 1m long). The corer was physically pushed into the sediment up to a depth of 50 cm or point of refusal, retrieved and the sediment taken to the boat. The roots, rhizomes, and necromass were then washed and sieved to separate from the sediment matrix and put into labeled ziploc bags for transport to the laboratory. Roots, rhizomes, and necromass were further rinsed without separation into species and oven-dried at 60^0C for 72hrs to constant weight. Standing stock (both above and belowground) was converted to its carbon equivalent by multiplying biomass with 0.34 as described by (Howard et al., 2014).

2.2.3 Determination of sediment organic carbon

In determination of sediment organic matter, two additional PVC corers (7.5cm internal diameters, 1m long) were used. These corers were pushed to a depth of 50cm into the sediments then covered on top with a stopper. The cores were retrieved and the bottom covered by a cap, and returned to the boat for extraction. The sediment samples were then sliced into 5cm subsamples and stored in pre-labeled ziplock bags and taken to the laboratory. Sediments were then oven-dried at 60°C for 72 hrs to constant weight.

The dry samples were then homogenized and sieved to remove shells and roots. The samples were further divided into duplicate sub-samples of 5g each for the determination of organic carbon content using the Loss on Ignition (LOI) technique (Howard *et al.,* 2014). Organic carbon content in the ashed samples was obtained using the carbon conversion factors for seagrass soils (Fourqurean *et al.*, 2012; Howard *et al.,* 2014).

(% C_{org}= 0.43*x%LOI-0.33) r^2= 0.96 for seagrass soils with % LOI >0.2 and

(%C_{org}= -0.21+0.40*%LOI) r^2= 0.87 in seagrass soils with % LOI <0.2, Soil carbon density was calculated for all the sections in each corer and summed up to obtain total carbon in the cores sampled. Total carbon stock of the entire subtidal area was obtained through extrapolation by multiplying the average carbon value the area of the study site and reported in MgC.

2.2.4 Data analysis

Statistical analysis was done in R console version 4.0.4 (R Core Team 2021). Assumptions of normality and homogeneity of response variables (AGB, BGB and Total carbon) were tested for normality using the Shapiro Wilk test. Where this was not met, data was log transformed. Asymptotic Wilcoxon rank sum test was used to determine the variation in above and below ground carbon stocks within the sub-tidal seagrasses meadows of the bay. A t- test was used to determine if there is significant difference in the total carbon stocks between mono-specific and mixed specific seagrass meadows.

3.0 RESULTS

3.1 Physio-chemical characteristics of sub-tidal areas of Gazi bay

Mean water depth in the sub tidal area was 3.4±0.2 m, (range: 1.2-7.4 m) during low spring tide while the mean temperature was 28.6±0.06 °C; (range: 27.9-29.3 °C). Salinity ranged between 35-36.6 ppt in the sub-tidal area with a mean value of 35.3±0.17ppt, while mean pH was 7.8±0.02 (range: 7.5-8.07). Turbidity ranged between 34580-35815mg/l with a mean value of 35002.5±47.03 mg/l.

3.2 Species composition, distribution and abundance

Nine seagrass species belonging to three families namely *Zosteracea*, *Hydrocharetacea* and *Cymodoceaceae* were encountered in the subtidal areas of Gazi bay. The most dominant species are, *Thalassia hemprichii, Thalassodendron ciliatum, Syringodium isoetifolium* and, *Halodule uninervis; while the least dominant species are Enhalus acoroides* and *halophila ovalis* (Table 1).

Table 1: Frequency of seagrass species in sub tidal zone of Gazi Bay

Species	Frequency	%
Cymodocea rotundata	5	6.25
Cymodocea serulata	12	15
Enhalus acoroides	2	2.5
Halodule uninervis	8	10
Halophila ovalis	1	1.25
Halophila stipulacea	7	8.75
Syringodium isoetifolium	8	10

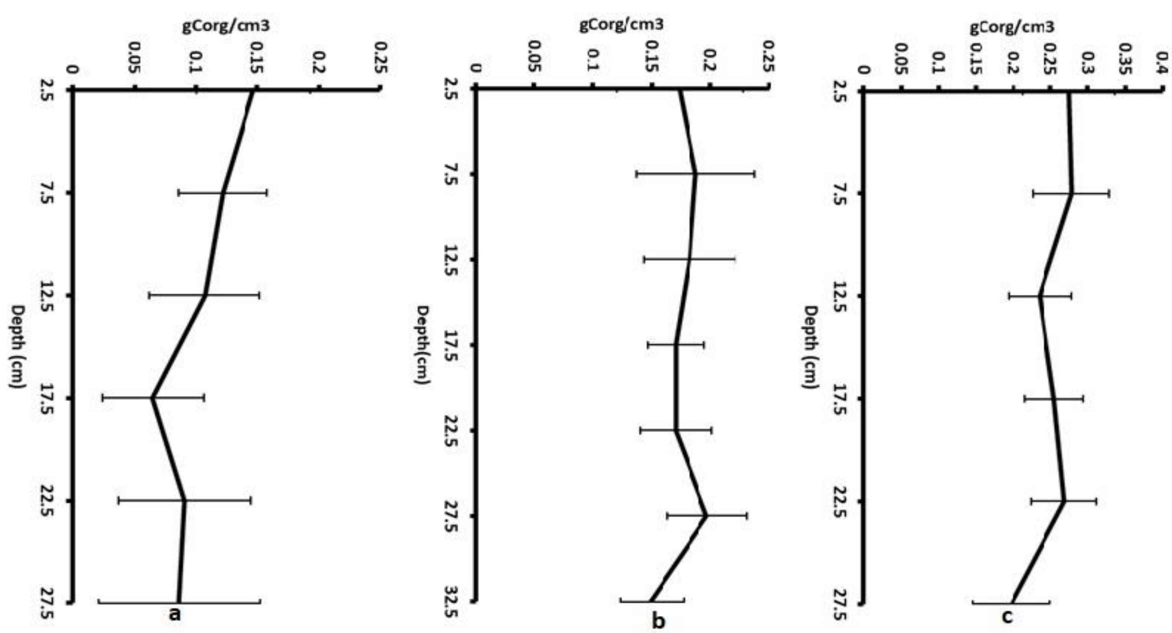
Thalassia hemprichii	23	28.75
Thalassodendron ciliatum	14	17.5

3.3 Seagrass vegetation carbon

Mean above- and below ground vegetation carbon in sub tidal seagrass meadows were 0.54±0.06 $MgCha^{-1}$ (range: 0.15 - 2.1 $MgCha^{-1}$) and 5.06±0.66 $MgCha^{-1}$ (range: 0.51 and 23.16 $MgCha^{-1}$) respectfully. Mean vegetation carbon was 5.60±0.66 $MgCha^{-1}$; (range: 0.84-23.89 $MgCha^{-1}$); giving a total vegetation carbon of seagrasses in the bay of 2631 Mg C. There was a significance differences ($W = 48$; $p < 0.001$) between above and below ground vegetation carbon stocks within the sub-tidal seagrasses meadows of the Bay.

3.4 Sediment carbon stock in sub tidal seagrass meadows

Mean sediment carbon stock in sub tidal seagrass area was 225.98±15.84 Mg C ha^{-1}. Carbon values ranged between 40.14 and 386.25 $MgCha^{-1}$. There was a significance differences ($t = -2.36$; $p = 0.02$) between monospecific (*Syringodium isoetifolium*, *Cymodocea serulata* , *Thalassia hemprichii*, *Halodule uninervis*, *Thalassodendron ciliatum*, *Halophila ovalis*) and mixed (*Syringodium isoetifolium* and *Thalassia hemprichii*; *Halodule uninervis* and *Thalassia hemprichii; Cymodocea serulata* and *Thalassia hemprichii; Enhalus acoroides*, *Thalassia hemprichii* and *Syringodium isoetifolium; Thalassia hemprichii*, *Syringodium isoetifolium* and *Cymodocea rotundata*) seagrass meadows. Carbon concentrations in this pool tend to increase by one unit across the 5-10 cm depth and then decrease significantly with depth (Fig. 3). Total sediment carbon stored in the subtidal areas of Gazi bay is estimated at 103,796 Mg C.



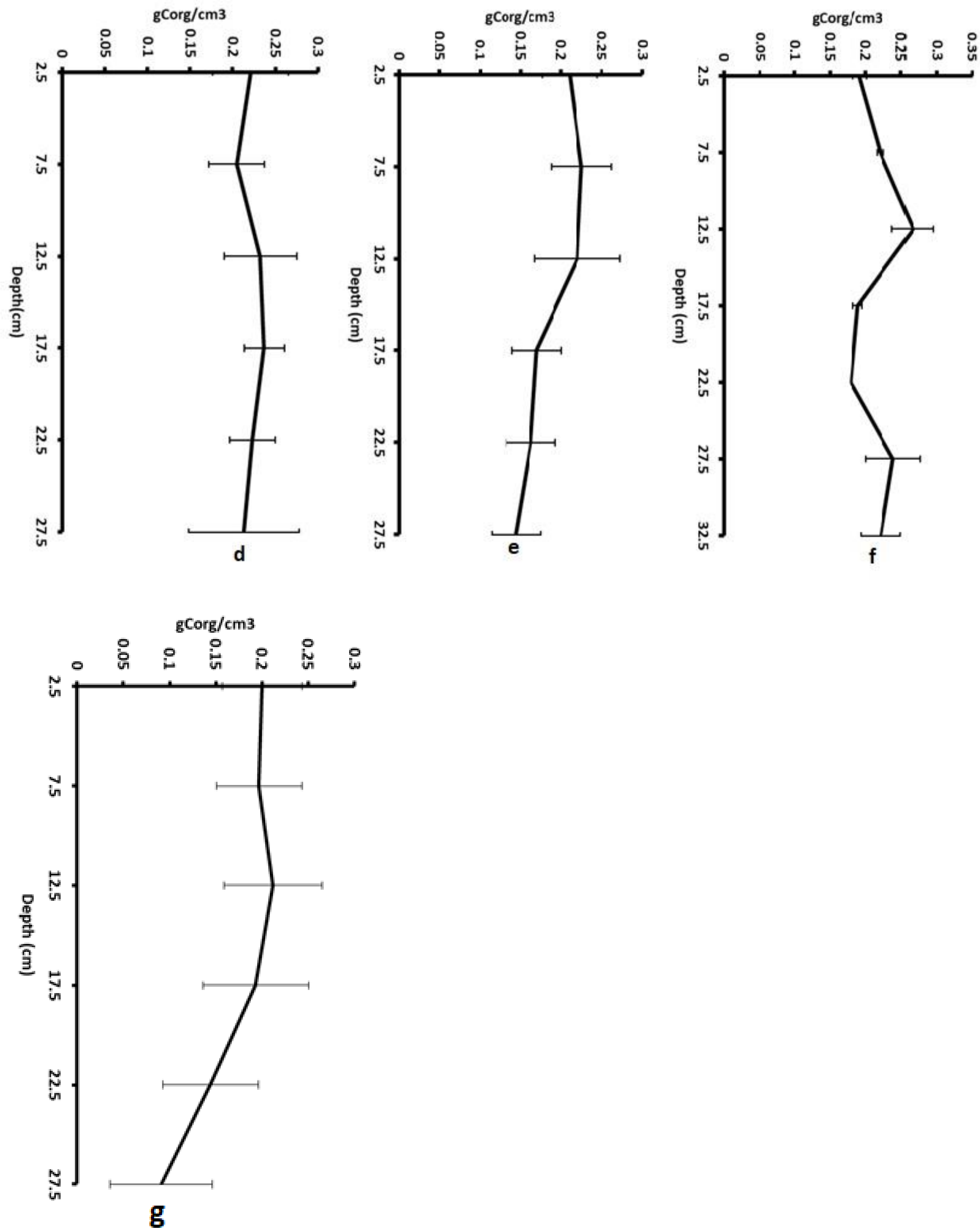


Figure 2; Depth profile of seagrasses sediment$_{Corg}$ in the subtidal areas of Gazi bay a). *Syringodium isoetifolium* b) *Cymodocea serulata* c) *Thalassia hemprichii* d) *Halodule uninervis* e) *Thalassodendron ciliatum* f) *Halophila ovalis* g) mixed meadows

3.5 Total seagrass ecosystem carbon in Gazi bay

Previous seagrass carbon assessment studies in the intertidal area (Githaiga et al., 2017) and in the mangrove-fringed creeks (Juma et al., 2020) of Gazi bay allows us to estimate total ecosystem carbon of seagrasses in the bay. The total ecosystem carbon in the bay is estimated at 249,821 Mg C (Table 2). Intertidal seagrasses contributes 47.95% of the total ecosystem carbon. This is followed by the subtidal seagrasses (43.57%) and lastly the seagrasses in the mangrove creeks that contributes less than 10% of the total ecosystem carbon (Fig.3).

Table 2: Total seagrass ecosystem carbon in Gazi bay, Kenya.

Habitat	Area(ha)	Vegetation carbon (Mg C ha-^{1})	Sediment Carbon (Mg C ha^{-1})	Total ecosystem carbon* Mg C
Eastern Creek	50	10.2 ± 0.6	258 ±90	13,420 (5.37)
Western creek	70	4.3 ± 0.3	107 ±21	7,769 (3.11)
Intertidal	495	5.9 ± 0.9	236 ± 24	119,790 (47.95)
Subtidal	470	5.6±0.7	226 ±16	108,842 (43.57)
Total				249,821

1.0 *number in parenthesis represent %

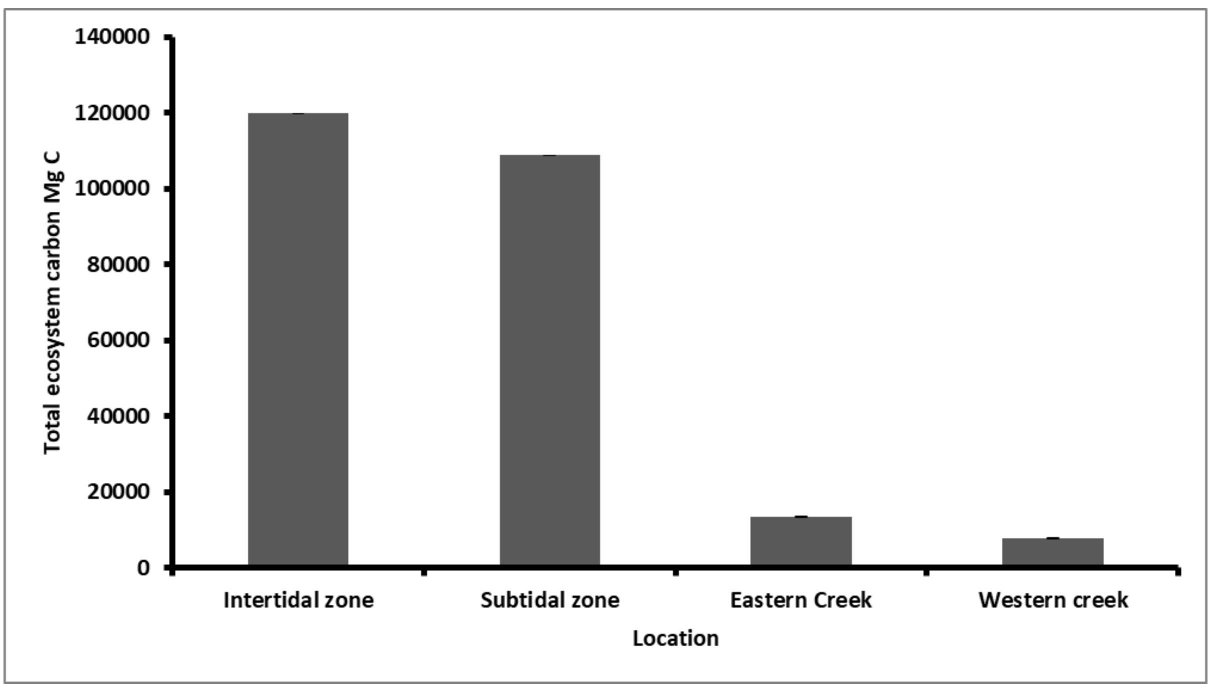


Figure 3: Carbon stocks in creeks, intertidal and subtidal seagrass meadows in Gazi Bay

4.0 DISCUSSION

4.1 Species composition distribution and abundance of Seagrasses in the sub tidal areas of Gazi Bay

This study established presence of nine seagrass species in the subtidal areas of Gazi bay. These were found occurring either as single or mixed stands. Previous studies (e.g. Copejans et al 1992; Githaiga et al., 2017; Juma et al 2020) reported 12 species of seagrass species in the bay. *Halodule wrightii*, *Halophila minor* and *Zostera capensis* were absent in the deeper zones of the bay confirming that they are intertidal species (Githaiga et al., 2017; Juma et al 2020).

Seagrass communities in Kenya are dominated by *Thalassodendron ciliatum*, *Thalassia hemprichi*, *Enhalus acoroides* and *Syringodium isoetifolium*. These species are slow growing, have high above ground to belowground biomass ratio and possess large roots and rhizomes. This makes them efficient in accumulating allochthonous material, stabilizing sediments and reducing re-suspension through reducing water motion thus inhibiting erosion and promoting deposition (Githaiga et al., 2017;Juma et al.,2020; Halim et al.,2020). Small pioneering species on the other hand are generally shallow rooted, have small diameter rhizomes, lower biomass and have higher turnover rates than climax communities. Human or biological disturbance to seagrass communities is known to cause dominance of pioneering species. This shift in species composition is beneficial as it allows for succession and bed re-establishment for large and persistent species (collier et al., 2007). However, shifts can sometimes lead to permanence and subsequently, the loss of seagrass ecosystem services and functions that enhance the biophysical functioning of sediments. This could further affect both primary and secondary productivity, sediment stability and ultimately compromise the capacity of seagrass meadows to act as long term carbon sinks.

4.2 Above ground and belowground biomass

Mean vegetation carbon of subtidal seagrasses in Gazi bay (5.60±0.66 Mg C ha^{-1}) was above the global average (2.51 ± 0.49 Mg C ha^{-1}) discussed by (Fourqurean *et al.*, 2012). Belowground biomass was significantly higher than aboveground biomass and is consistent with trends observed in previous studies in the bay (Githaiga et al., 2017; Juma et al., 2020). Large difference in above- and below-ground biomass is mostly associated higher disturbances of standing biomass and pressure such as grazing, higher turnover rates of aboveground biomass relative to belowground biomass and higher content of refractory matter in belowground biomass (Duarte and Chiscano, 1999; Govindasamy *et al.*, 2013). Variation among habitats is often attributed to differences in environmental conditions that influence seagrass growth such as light, temperature and nutrient supply. Studies investigating variation in biomass and production rates among habitats show that shallower meadows have higher production and biomass than deeper meadows (Collier et al., 2007).

4.3 Sediment carbon stocks in subtidal area of Gazi bay

Sediment C_{org} from subtidal seagrasses in the bay recorded a mean of 226±15.8 Mg C ha^{-1}. This is within the global range of 115.5 - 829.2 Mg C ha-1 (Fourqurean *et al.*, 2012). Much of this carbon may be allochthonous, given the relatively low standing biomass; further supporting export of organic matter into the subtidal areas from the mangrove forests and intertidal area through tidal action and flushing by the two channels (Bouillon *et al.,* 2007; Nieuwenhuizel and Kruyt, 1994; Hemminga and Mateo, 1996; Kennedy *et al.,* 2010).

The decrease in average sediment carbon density in creeks, intertidal and sub tidal areas (table.2) can be attributed to reduced light irradiance with increasing depth. In the creeks and the intertidal areas, seagrasses are exposed during low tide leading to increased exposure to photosynthetic active radiation. However, seagrasses in the subtidal zone are mostly submerged, and with reduced photosynthetic activities (Serrano *et al.*, 2014) culminating to low biomass increment. Through allocthonous process, some of the carbon stored in the seagrass meadows originates from the nearby mangroves and other terrestrial ecosystems (Signa *et al.*, 2017; Juma et al., 2020). The transport of organic matter and fine sediment from mangrove forest reduces with increased distance from the mangrove fringed creeks (Huxham et al., 2018) and this may also explain the reduced carbon concentrations in subtidal area when compared to other zones (table.2). This is supported by relatively high carbon concentration in meadows closer to the intertidal areas and very low organic carbon concentration observed in meadows closer to the coral reefs. The low carbon in coral reef areas could be because of the rocky substrate that prohibits extensive seagrass colonization and limits seagrass species expansion. Similar results were reported by (Serrano *et al.*, 2014) in seagrass meadows in Spain and Australia. Their study showed a fourfold decrease in C_{org} stocks from shallow to deep meadows of *Posidonia sinuosa* (averaging 7.0 and 1.8 kgm^{2}, respectively; top meter of sediment) and a 14-fold to 16- fold decrease from shallow (2 m) to deep (32 m) *Posidonia oceanica* meadows (200 and 19 kgm_2 average, respectively; top 2.7m of sediment). Similar trends are supported by (Dahl *et al.*, 2016; Lavery *et al.*, 2016) who reported that sediment factors (Dry Bulk Density, grain size, porosity) and water depth affect *Corg* storage. However, the findings of this study contradict findings by (Lavery et al., 2013) who did not find significant differences between the soil C_{org}

stocks in intertidal and subtidal habitats in Australia. Besides irradiance, shallow meadows are likely to be affected by increased hydrodynamic activities that facilitate erosion and transport of carbon into deep meadows. Also, the high temperatures are likely to enhance remineralization of organic matter if strong hydrodynamic action cause re-suspension and sediment exposure. Lavery *et al* (2013) further demonstrated enhanced carbon stocks in deep meadows of two meadows of *Posidonia sinuosa* and *Amphibolis antarctica*.

4.4 Total ecosystem carbon stocks of seagrasses bed in Gazi bay

Carbon density in the subtidal seagrass areas of Gazi bay is 226 ±16 $MgCha^{-1}$, giving a total ecosystem carbon of 108,842MgC. Sediment carbon pool contributes to 97% of the total ecosystem carbon (Table 2). Previous estimates by Githaiga *et al.*, (2017) reported 168,642 MgC as total seagrass ecosystem carbon in the Gazi bay. However, this study extrapolated carbon values from intertidal seagrass only, thus underestimating the total ecosystem carbon in the bay. Combining the subtidal carbon stocks with the intertidal (Githaiga et al., 2017) and mangrove fringed creeks (Juma et al 2020) gives the total carbon stored in seagrass meadows of Gazi bay as 244,775 Mg C (Table 2). Intergovernmental Panel on Climate Change (IPCC) and other studies provide a range of possible fates of 'near-surface carbon' upon conversion from 25% to 100% emissions to the atmosphere depending on land use types (IPCC, 2014). Using the low end of 25% emissions, potential carbon loss from seagrasses in Gazi bay is estimated at 9,216 Mg C ha^{-1}, equivalent to 33,822.72Mg $CO_2e\ yr^{-1}$.

5.0 CONCLUSION AND RECOMMENDATION

The current study has established that subtidal seagrasses in Gazi bay stores substantial amounts of carbon. Much of this carbon is allochthonous, particularly from adjacent mangrove ecosystem. The current carbon-offset project, Mikoko Pamoja, in Gazi is centered on mangrove forests. Every year (since 2013), community in Gazi have been trading 3000tCO2-eq into the voluntary carbon market. Income generated (of ca. US$24,000) is then used to support priority community projects in water and sanitation, education, and environment conservation ((https://www.planvivo.org/mikoko-pamoja). Our proposal is to expand Mikoko Pamoja to include seagrasses, as some of the carbon captured by mangroves is trapped here. Bundling marine ecosystem services in Gazi will generate climate, community and biodiversity benefits. This study complements previous carbon assessment in the intertidal seagrasses (Githaiga et al., 2017) as well as the seagrasses within the mangrove creeks (Juma et al., 2019). The study provides a better picture of seagrass distribution, abundance and carbon stocks within Gazi seascape for enhanced conservation and improved community livelihoods.

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7.0 APPENDIX

Plate 1: from top left ; Seastar and sea urchin in seagrass meadows; bottom , Harvesting seagrass samples underwater, sorting and packing of collected biomass and sediment samples