SPECIES COMPOSITION, DISTRIBUTION, AND ORGANIC CARBON STOCKS IN THE SUBTIDAL SEAGRASS MEADOWS OF GAZI BAY, KENYA

BY

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DECLARATION

I declare that this thesis is my original work and has not been submitted elsewhere for examination or award of a degree. Where other people's work has been used, this has been properly acknowledged and referenced in accordance with the University of Nairobi's requirements

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DEDICATION

This research thesis is dedicated to my beloved parents, Maurice Michael Omollo and Jecinta Atieno Ong'ech.

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LIST OF ABBREVIATIONS AND ACRONYMS

AGB	Above ground biomass
ANOVA	Analysis Of Variance
Bgb	Below ground biomass
C	Carbon
C_{org}	Organic carbon
CO_2	Carbon dioxide
DBD	Dry bulk density
GEF	Global Environment Facility
IPCC	Intergovernmental panel for climate change
LOI	Loss on Ignition
MARG	Marine Research Grant
PVC	Poly Vinyl Chloride
PES	Payment for Ecosystem Services
SAR	Sediment accumulation rate
SCUBA	Self-Contained Underwater Breathing Apparatus
WIO	Western Indian Ocean

GLOSSARY

Autochthonous carbon	Carbon produced and stored in the same environment it is produced
Allochthonous carbon	Carbon produced in one place and then deposited in another
Intertidal zone	The part of the coastline that is covered at high tide and exposed at low tide.
Carbon stock	The 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
Sub tidal zone	Refers to the area along the sea shore where the seabed is below the lowest tide

ABSTRACT

Seagrass beds occur in both intertidal and subtidal zones within shallow marine environments such as bays and estuaries globally. This important ecosystem support fisheries production, attenuate strong wave energies, human livelihoods and sequester large amounts of CO_2 that may help mitigate the effects of climate change. At present, there is increased interest globally to understanding how these ecosystems could help alleviate the challenges likely to face humanity and the environment in future. Unlike other blue carbon ecosystems; mangroves and saltmarshes, seagrasses are less understood especially on their contribution to the carbon dynamics. This is particularly true in regions with less focus and limited resources. Paucity of information is even more on the subtidal meadows that are less accessible. In Kenya much of the available information on seagrasses, is from Gazi Bay, where the focus has been on the extensive intertidal meadows. As such, like other regions there remains paucity of information on subtidal meadows. This limits our understanding of the overall contribution of seagrasses in carbon capture and storage. This study provides the first assessment of the species composition and variation in carbon storage capacity of subtidal seagrass meadows of the bay. Sampling was done in forty quadrats of $0.25m^2$ placed randomly along eight transects in each of the four zones in the subtidal area of the bay. In each sampling point, canopy cover and species composition were determined. Above-ground samples were obtained using the harvesting technique whereas below-ground and sediment samples were obtained through coring. Organic carbon content in biomass and sediment was determined using the Loss on Ignition (LOI) technique. Two-way ANOVA was used to test for significant differences in above, belowground biomass as well as sediment carbon among the dominant species as well as among the zones in subtidal zone. T-test was used to determine if there was variation in sediment carbon stocks between mono-specific and multispecific meadows.

Relationship between canopy cover, canopy height, percentage cover and biomass were tested using spearman’s rank correlation. Nine seagrass species were encountered in the subtidal area of the bay with *Thalassia hemprichii*, *Thalassodendron ciliatum*, *Cymodocea serrulata and syringodium isoetifolium* being the most dominant species. Aboveground biomass stocks were significantly lower than belowground biomass (t (43) =-6.817, p<.05) within the sub-tidal seagrass meadows of the bay. Aboveground biomass was significantly different among the dominant species (F $(_{3,16})$ = 4.967, p <.05), while belowground carbon stocks was not significantly different among species (F $_{(3,16)}$ = 1.108, p >.05). Mean sediment carbon stock in sub tidal seagrass area was 113. ±8 Mg C ha^{-1}. Sediment carbon was not significantly different among the four zones (F $_{(3,39)}$ = 0.35, p= 7.90), as well as among the four dominant species (F $_{(3,16)}$ = 0.958, p= .437). Shoot density (F $_{(3,16)}$ = 24.708, p<.05) and shoot height (F $_{(3,16)}$ =13.592, p<.05) showed significant variations among species whereas canopy cover did not vary among species. There was a positive relationship between canopy height and aboveground biomass (r $_{(38)}$ = .71, p< .001), as well as between belowground biomass and total biomass (r $_{(38)}$ = .98, p<.001). Conversely, shoot density and canopy height were negatively correlated (r $_{(38)}$ = -.34, p=.036). Salinity, depth, turbidity, temperature and pH were significantly different among the four zones in subtidal area with Zone A being the shallowest (2.2 ±0.6 m), highest temperature (28.9 ±0.4°C), most saline (35.8±0.5 ‰), most turbid (35340.5±370 mg/l) and had the highest pH (7.8 ±0.1) while zone D was the deepest (4.9±1.3 m), coolest (28.2±0.4°C), less saline (35.1±0.1 ‰), least turbid (34661.3±46 mg/l), and had the least pH (7.7±0.1). The total seagrass ecosystem carbon in the bay is about 196,721 Mg C with the intertidal seagrasses storing about 119,790 Mg C (61%), followed by the subtidal seagrasses 55,742 Mg C (28%) and seagrasses in the mangrove creeks storing 21,189 Mg C (11%). These results demonstrate the importance of seagrass meadows in storing carbon and provide a

wealth of information on the significance of blue carbon ecosystems in mitigating climate change, which highlights the need to preserve these ecosystems.

CHAPTER ONE

INTRODUCTION

1.1: Background Information

Seagrasses are marine angiosperms that are adapted to live in fully submerged marine and estuarine environment (Hartog and Kuo, 2001). They occur extensively in shallow coastal waters and can reach a depth of 50 meters where abiotic conditions favour photosynthesis. The meadows have a wide geographical distribution occurring in tropical and temperate waters where they form either mixed or mono-specific stands (Short *et al*, 1996; Short *et al.*, 2007). About 72 species of seagrasses exist globally belonging to four families*; Posidoniacea*, *Hydrocharitacea*, *Zosteracea* and *Cymodoceacea* (Hartog and Kuo, 2001; Short *et al.*, 2007). They are important components of the marine environment as they play significant ecological roles such as; providing nursery grounds for commercially important fish, mollusks and crustaceans; providing foraging grounds for fish and endangered marine organisms like turtles and dugongs; contribute to high productivity, nutrient stripping, shoreline stabilization (Costanza *et al.*, 1997; Christianen *et al.*, 2013) as well as carbon sequestration (Duarte, 2013).

Together with mangroves and saltmarshes, these vegetated marine ecosystems form the blue carbon ecosystems (Nellemann *et al.*, 2010; Fourqurean *et al.*, 2012). In the wake of global warming and climate change, their significance as natural sinks has been acknowledged and their conservation has become a priority (Kelleway *et al.*, 2020; Macreadie *et al.*, 2021). Carbon is stored in both above and below ground organs in these environments (Fourqurean *et al.*, 2012;

Duarte, 2013), with the sediment organic carbon constituting the majority of the total carbon stock (Kennedy, 2010; Fourqurean *et al.*, 2012; Githaiga *et al.*, 2017). Due to the realization of their important role as carbon sinks, there has been increased interest in research and in formulation of policies as countries earmark carbon investment opportunities (Nellemann *et al.*, 2010; Duarte, 2013; Macreadie *et al.*, 2014).

Seagrass meadows have large carbon sequestration capacity due to their extensive distribution (Nellemann *et al.*, 2010), with quantities amounting to 27.4 Tg C/year (Fourqurean *et al.*, 2012). Anaerobic conditions in the sediments facilitate consolidation of carbon through the slow decomposition rates (Fourqurean *et al.*, 2012; Dahl *et al.*, 2016; Mazarrasa *et al.*, 2018). In addition to accumulation of autochthonous carbon, seagrass meadows facilitate settlement of suspended particles in the water column through their canopies and thus promote sediment accumulation and stabilization (Duarte, 2013) which translates to the deposition of imported, allochthonous carbon from affiliate ecosystems (Kennedy, 2010). However, these meadows face degradation that results in loss of critical ecological goods and services (Orth, 2006). The degradation of the meadows contributes to global emission thresholds releasing up to 299 Tg C yr^{-1} that significantly contribute to global warming (Fourqurean *et al.*, 2012). Estimation of this ecosystem's carbon stock and hence its contribution in climate change mitigation is critical in raising global awareness on the value of its conservation and protection (Fourqurean *et al.*, 2012; Pendleton *et al.*, 2012).

The ability of seagrass species to store carbon varies significantly (Lavery, 2013). This is can be attributed to species specific differences in primary production, habitat conditions, belowground biomass, and type of the recalcitrant material that is resistant to decomposition as well as the capacity of their canopies to filter and accumulate allochthonous carbon (Lavery, 2013). Specific factors in their sediments that drive organic carbon protection also varies among species and locations (Mateo *et al.*, 2006; Kennedy, 2010). The diverse range of depositional environments and hydrodynamic factors acting on the sediments affect organic carbon preservation by determining the proportion of fine particles in the soils (Mazarrasa *et al.*, 2018). Seagrass have a wide latitudinal range and occur in environments with substantial temperature differences that potentially affect organic matter degradation and remineralization rates (Lavery, 2013; Mazarrasa *et al.*, 2018). Whereas there have been significant efforts to quantify the carbon storage in seagrass meadows globally, estimates of worldwide seagrass carbon rely heavily on data from a few species and certain areas, such as Australia, the Mediterranean, and North America (Githaiga *et al.*, 2016). At the same time, much of the available data is from intertidal seagrasses (e.g., an ISI Web of Science search reveals 27 peer reviewed articles on intertidal seagrass carbon stocks vs. 12 for subtidal seagrasses), with comparatively fewer studies examining the contribution of subtidal seagrass meadows to carbon storage (Lavery *et al.*, 2013; Green *et al*.,2018;Gullstrom *et al* .,2018;York *et al* .,2018). Partly, this is due to the difficulties (and financial costs) of conducting subtidal research and because poor water quality (e.g., turbidity) in many regions including the Western Indian Ocean which hamper accurate estimates of total seagrass extent and structure (Vanderkilft *et al.*, 2019; Githaiga *et al* 2017; Juma *et al.*,2020). As a result, it is common for substantial underestimates of the total ecosystem carbon stocks of seagrass ecosystems in many parts of the globe. Subtidal environments have lower irradiance due to diffusion through the water column than intertidal meadows (Serrano *et al.*, 2014; Lavery *et al.*, 2013; Serrano *et al.*, 2016; Mazarrasa *et al.*, 2018). This can result in lower primary production and biomass accumulation when compared to intertidal environments (Mazarrasa *et al.*, 2018; Serrano *et al.*, 2014). However, because subtidal meadows are subjected to more subtle and less variable environmental conditions, they are expected to have higher carbon stocks than intertidal meadows (Mazarrasa *et al*., 2018, Koch *et al*., 2006). Intermittent exposure to air, higher irradiance, and extreme tidal currents and wave action reduces carbon gains in seagrass tissue, as well as reducing deposition, increasing aeration, and promoting sediment erosion in intertidal meadows (Koch *et al*., 2006). As a result, subtidal meadows are expected to have higher carbon stocks and sequestration rates than intertidal meadows (Mazarrasa *et al*., 2018). There is a need to consider subtidal environments and understand habitat conditions that drive carbon storage within these environments, which will assist in obtaining accurate estimates. Recent work on carbon stocks at Gazi Bay (Githaiga *et al.*, 2017; Juma *et al.*, 2020) concentrated on the intertidal seagrasses. These factors are likely to either underestimate or overestimate the carbon stocks. In order to obtain accurate estimates, there is need to conduct carbon stock assessments in underrepresented species, regions and a wide range of habitats and understand the factors that drive this variability other than species composition (Lavery, 2013; Mazarrasa *et al.*, 2018).

The objective of this study was to assess the physico-chemical characteristics of the subtidal area, and to investigate the species composition, distribution and abundance in subtidal seagrass beds of Gazi Bay. It also aimed at estimating below, above ground and sediment carbon stocks in the subtidal region. Finally, this new information was used to calculate the total ecosystem carbon by pooling carbon stocks in subtidal seagrasses with estimates of intertidal and creek seagrasses from recent studies in the bay (Githaiga *et al.*, 2017; Juma *et al.*, 2020). Because of its high seagrass diversity and cover, Gazi Bay is one of Kenya's most important ecological sites. Gazi Bay contains all 12 species recognized along the East African coast, and their distribution extends from intertidal to subtidal areas, as well as sandy and rocky substrates. However, the bay's seagrass ecosystem is deteriorating, primarily due to beach seining practiced by small-scale artisanal fishermen, and it is not under any official protection by the law. The findings of this study on the carbon stocks of seagrasses in the bay will inform prospects for incorporating seagrasses into payment for ecosystem services schemes alongside mangrove ecosystems, improve biodiversity conservation, mitigate climate change, raise community awareness, and support the livelihood of the local community, whose main source of income is fishing.

1.2: Problem Statement

Seagrass are important carbon sinks. However, recent work on seagrass carbon stocks at Gazi Bay on the intertidal zone and focused more on the dominant species and within the creeks and the intertidal seagrass beds. Considering that, the subtidal grasses cover extensive areas, estimates of the organic carbon stocks on the seagrasses of the bay maybe inconclusive. Furthermore, the intertidal and sub-tidal regions of seagrass are different in terms of anthropogenic impacts and physical chemical factors, they have different capabilities of sequestering carbon. It is therefore important to extend the studies to the sub tidal meadows to have comprehensive estimates for the seagrasses of the bay. The limited understanding regarding seagrass extent, carbon stocks, and sequestration capacity is among the reasons seagrasses have not been included in Kenya's NDC. Mangroves have been included in the most recent submitted NDC targets of 2021. The results of these research will offer the opportunity to include seagrasses in the country's obligations to combating climate change and to guarantee the preservation of all blue carbon habitats.

1.3: Project Justification

The reality of climate change has intensified the urge to understand the role of ecosystems in the mitigation of greenhouses gases in the atmosphere and hence the value for their conservation. Gazi Bay has extensive seagrass meadows which are likely to contribute to carbon sequestration and thus provides an opportunity of harnessing its conservation through community initiative. Past studies on seagrass carbon in the region have focused on the intertidal meadows and the creeks. This study builds on previous studies by assessing above and below ground carbon stocks in the sub tidal seagrass meadows. Information on distribution, abundance and carbon stocks of seagrass beds will facilitate expansion of carbon offset to include seagrass beds. Furthermore, the findings of this study will be useful to the Kenyan government, particularly in terms of its efforts to meet its commitments to the Paris agreement 2015. As such an opportunity exists of incorporating seagrass ecosystems into nationally determined contributions (NDCs). Understanding the carbon storage capacity of subtidal seagrasses will help with the need for improved seagrass conservation policies, as well as with the provision of goods and services offered by these ecosystems. It will also help with the blue economy and the attainment of up to fourteen of the 17 SDGs.

1.4: Broad Objective

To determine the organic carbon stocks in the subtidal seagrass meadows of Gazi Bay, Kenya.

1.4.1: Specific Objectives

i. To assess the physico-chemical properties in the sub tidal zone

ii. To determine the composition, distribution and abundance of seagrass species in sub tidal seagrass meadows.

iii. To determine the above ground and below ground carbon stocks in subtidal sea grass

iv. To determine Sediment organic carbon stocks

1.4.2: Research Questions

i. What are the physico-chemical characteristics of the subtidal area?

ii. What is the composition, distribution, abundance of seagrass species in the sub-tidal zone?

iii. What is the aboveground and below ground carbon stock of subtidal seagrass meadows?

iv. How much carbon is stored in sediment carbon of seagrasses in the sub-tidal area?

1.4.3: Scope of the Study

The research looked at the composition, distribution, and abundance of seagrass species, as well as the quantity of organic carbon stocks, in the subtidal seagrass meadows of Gazi Bay in Kwale County, Kenya. For the measurement of above and below ground biomass, as well as sediment organic carbon content, 40 quadrats were created and 800 samples of shoots, roots, and sediments were collected. The study took place between the months of May and September of 2020.

CHAPTER TWO

LITERATURE REVIEW

2.1: Biology of Seagrass

Seagrasses are a group of flowering plants that live in the marine environment (Hartog and Kuo, 2001). They have evolved certain morphological and anatomical characteristics that allow them to carry out photosynthesis and pollinate underwater (Ackerman, 2007). They also possess a lacunae which allows transport of gases within their tissues (especially from leaves to roots). Furthermore, the presence of roots and rhizomes provide anchorage for seagrasses as well as allow uptake of nutrients and minerals from the sediment therefore supporting growth of the plants (Figure 1). The plants form an ecological group belonging to four families; *Cymodoceacea*, *Zosteracea*, *Posidoniacea* and *Hydrocharetacea*, twelve genera and over seventy species globally (Hartog and Kuo, 2001; Waycott *et al.*, 2007).

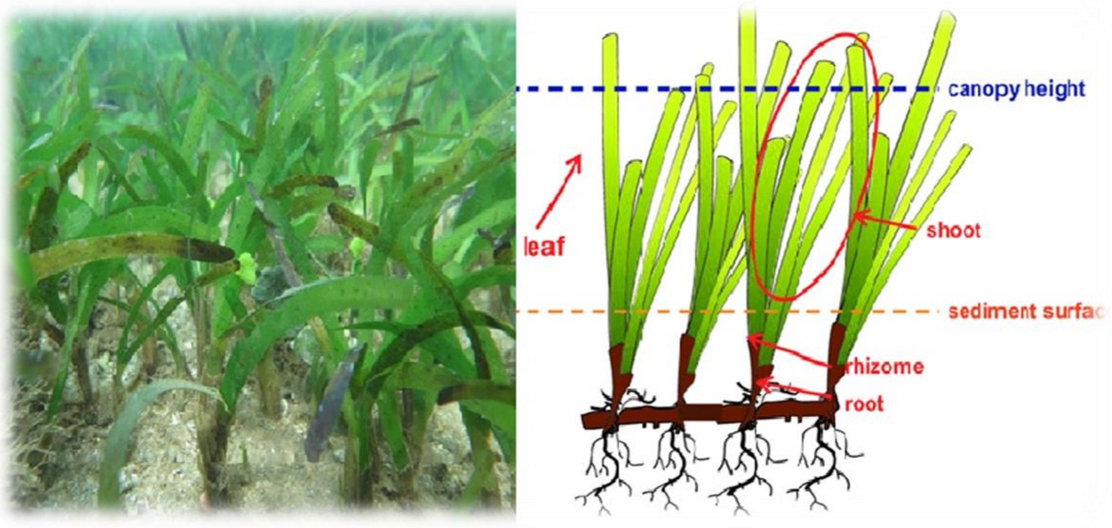


Figure 1: Seagrass meadow and various organs of seagrass; (Source: Waycott *et al*., 2004)

2.1.1: Ecosystem Goods and Services Provided by seagrass

Despite occupying only about 0.2 percent of the coastal oceans, seagrass ecosystem performs ecological functions valued at $ 19,004 ha^{-1}yr^{-1} (Duarte, 2002; Duffy, 2006). Fish and other marine species such as manatees, water birds, sea turtles, and dugongs use seagrass meadows as a habitat, as well as a feeding, hiding, and breeding site (Figure 2). They're also important for commercial fisheries in Florida (Jackson et al., 2001; Behringer et al., 2009; Nordlund et al., 2018), fish productivity (Tuya et al., 2014), and prawn fisheries (Coles et al., 1993; Blandon and Zu Ermgassen, 2014), which are valued at US$47.8 million yr^{-1}, US$103.74 million yr^{-1}, and US$1,150 ha^{-1} yr^{-1} respectively. Furthermore, they promote the outwelling of rich organic materials to nearby ecosystems such as mangroves and coral reefs, hence sustaining food webs in these environments (Hemminga *et al* 1996; Bouillon *et al*, 2007).

Figure 2: Biodiversity in subtidal seagrass meadows of Gazi bay (left) *Protoreaster linckii* also known as the red knob sea star (right) a school of fish and soft coral.(by *Derrick Omollo*)

Seagrasses regulate the climate, nutrients and maintain water clarity. They mitigate global warming and climate change by reducing the amount of CO_2 in the atmosphere and storing it in plant tissues and sediments inform of carbon (Oreska *et al*, 2017). Beside storing of photosynthetically derived carbon, they also facilitate storage of carbon derived from terrestrial and the adjacent ecosystems constituting about 50% of the total carbon stored in seagrass meadows (Kennedy, 2010). About 97% of the carbon in seagrass ecosystem is stored in the sediment for millennial timescales (Romero *et al.*, 1994; Mateo *et al.*, 2006). The value of carbon sequestration service provided by seagrass ecosystem is estimated at U.S. $ 394/ha/yr (Pendleton *et al.*, 2012). Seagrass also improves water quality by filtering particles and other wastes from the water column. They are acknowledged as good biological indicators because of their measured and fast reaction to changes in water quality, extensive distribution, and sessile nature. Seagrass meadows also produce oxygen which helps to aerate the water column and rhizosphere (Olsen *et al.*, 2018).

The contribution of seagrasses in supporting life and life processes in the marine environment is remarkable. Seagrasses are able to take up nutrients (mainly inorganic carbon, nitrates and phosphates) not only though the roots but also through the leaves. Thus, seagrasses are able to take up nutrients in the water column as well as in pore water of sediments (Short and McRoy, 1984; Pedersen *et al*, 1997). The value of this ecosystem service to the global economy is valued at $ 3.8 trillion/year (Dewsbury *et al*, 2016). Seagrass meadows also alter the physical and chemical parameters of the water column and sediments mainly though the metabolic processes and structure of seagrass beds (Fonseca *et al*, 2000). Seagrass metabolism affects the dynamics of carbon, nutrients and oxygen dynamics in the water column and sediments while seagrass canopy structure enhances water clarity and facilitate a depositional environment by reducing the velocity of water currents (Ondiviela *et al.*, 2014; Potouroglou *et al.*, 2017). Furthermore, the extensive network of rhizomes and roots effectively preserves the sediments produced and deposited in them besides preventing erosion (Ondiviela *et al.*, 2014).

Seagrass meadows are a valuable resource in many parts of the world, with indigenous lifestyles closely linked to them (Cullen-Unsworth *et al.*, 2014; Nordlund *et al.*, 2018). They sustain a diverse range of species, with great genetic diversity among them. This helps to provide food security and better nutrition for human population (Cullen-Unsworth *et al.*, 2014). Seagrass is estimated to have a supporting function in food security of US$ 3500 ha/yr (Nordlund *et al.*, 2018). Shellfish gleaning and invertebrate collecting for commercial purposes have improved rural lifestyles in Africa, with income ranging from US $ 8.51 to US $ 17.01 per catch (Nordlund *et al.*, 2018; Musembi *et al*, 2019). Seagrasses also provide cultural livelihood services such as bio-fertilizers, medication, baits, and a substrate for seaweed aquaculture (Tuya *et al*, 2014). Posidonia litter has been used to fill beddings since the 16th century (Vasarri *et al.*, 2021). Seagrass was also exploited by Cottars in Orkney, Scotland, in the 18th century to thatch flagstone roofs as a substitute for straws in Orcadian buildings (Cullen-Unsworth *et al.*, 2014). Seagrass has been used for aesthetic and religious purposes in coastal Kenya, resulting in improved lifestyles (de la Torre-Castro and Rönnbäck, 2004)

2.1.2: Threats to Seagrass Ecosystem

Seagrass meadows are declining at a rate of 1.5 % per year due to natural and anthropogenic influences (Orth, 2006). Anthropogenic activities such as boat anchoring and mooring, bad artisanal fishing practices, aquaculture, unsustainable development along the coastline, introduction of invasive species, reclamation of coastline and dredging, all put pressure on seagrass ecosystems (Freeman *et al.*, 2008; Grech *et al.*, 2012). Additionally, sedimentation and nutrient over-enrichment in marine waterways are caused by agricultural operations and wastewater discharge upstream, raising turbidity, algal blooms and diminishing water clarity (Freeman *et al.*, 2008). This results in lower seagrass productivity and, in certain cases, the loss of seagrass meadows due to burial (Freeman *et al.*, 2008; Coles *et al.*, 2011). Furthermore, these anthropogenic activities not only cause altered species diversity within faunal communities in seagrass meadows (i.e., alpha-diversity), but also lead to increased similarity in species composition among these communities (i.e., beta-diversity) (Iacarella *et al.*, 2018). This biotic homogenization may occur when generalized species thrive at the expense of specialized species due to habitat fragmentation and loss. Seagrass cover and ecosystem health is also reduced by natural factors such as herbivory, strong waves, diseases and sedimentation (Orth, 2006; Waycott *et al.*, 2007).

Anthropogenic and natural disruptions affecting seagrass ecosystems can undermine their role as climate regulators. Physical disturbance such as removal of seagrass, shading or grazing inhibits direct carbon fixation through photosynthesis (Ruiz and Romero, 2001). It also leads to loss of organic carbon stored in the shoots and roots inform of biomass. Additionally, due to the reduced canopy cover and reduced canopy complexity, input of allochthonous carbon into the sedimentary carbon pool is reduced (Dahl *et al*, 2016; Trevathan-Tackett *et al.*, 2018). Furthermore, the organic carbon stored in sediments of seagrass meadows risk being released into the atmosphere through erosion, oxidation, microbial mineralization and leaching (Dahl *et al.*, 2016).

Seagrass ecosystems are becoming less resilient as a result of global climate change and major environmental shifts (Fraser *et al.*, 2014; Unsworth *et al.*, 2015), and therefore putting them at risk of failing to provide habitat for fish and invertebrates that provide food and better nutrition to the human population. (Nordlund *et al.*, 2018). Clearly, keeping this ecosystem healthy is critical to ensuring food security (Cullen-Unsworth *et al.*, 2014).

2.2: Global Seagrass Biogeography

Except for Antarctica, seagrasses can be found along the coasts of every continent. (Hartog and Kuo, 2001). Among the twelve genera, seven are distributed in the tropics while five are distributed along the temperate waters (Figure 3). The genera present in the tropical waters include *Thalassia, Halophila, Syringodium, Halodule, Cymodocea, Thalassodendron and Enhalus* (Hartog and Kuo, 2001).*Thalassia, Halophila, Syringodium and Halodule* have species in both tropical Atlantic and Indo-Pacific bioregions, while *Cymodocea, Thalassodendron* and *Enhalus* are confined in the indo-west pacific bioregion (Short *et al.*, 2007). However, it has been observed that species of the genera *Cymodoceacea*, *Thalassodendron and Halophila* are expanding their distribution from tropical into warm temperate waters due to the effect of warm currents (Short *et al.*, 2007).

Temperate seagrass species belong to the genus *Zostera*, *Heterozostera*, *Posidonia*, and *Amphibolis.* Amongst the temperate seagrasses, *Zostera* and *Posidonia* are distributed in both the North and South poles while *Heterozostera* and *Amphibolis* are restricted in temperate Australia. Southern distribution of species belonging to *genus Zostera sub genus zosterella* exists around Australia and New Zealand as well as in Southern Africa. In the northern hemisphere, species of this subgenus are distributed around Eastern Asia, Atlantic and Mediterranean coasts of Europe and North Africa (Hartog and Kuo, 2001; Short *et al.*, 2007). Another species, *Zostera noltii*, is only found in West Asia, whereas the subgenus *zostera* is only found in the Northern Pacific, Northern Atlantic, Mediterranean, and Black Sea. *Zostera marina* is distributed across the arctic circle in Europe and Northern Pacific. Finally, among the temperate seagrasses, on *Zostera*, sub genus *zosterella* can be found extending their distribution to tropical areas (Hartog and Kuo, 2001).

Although many changes in abundance of seagrass have been observed due to human activities such as fishing, aquaculture, shipping and pollution (Waycott *et al.*, 2009), seagrass distribution has been relatively intact (Grech *et al.*, 2012). However, few cases of invasion due to human interference have been reported including Zostera japonica's unintentional introduction into North America (Harrison and Bigley, 1982; Shafer *et al*, 2014), expansion of *Halophila stipulacea* into the Mediterranean through Suez Canal (Georgiou *et al.*, 2016) and the expansion of the temperate species *Zostera capensis* into Kenya believed to be as a result of shipping (Wakibya, 1995; Gullström *et al.*, 2002). Furthermore, climate change is projected to alter species distribution and abundance (Short and Neckles, 1999).

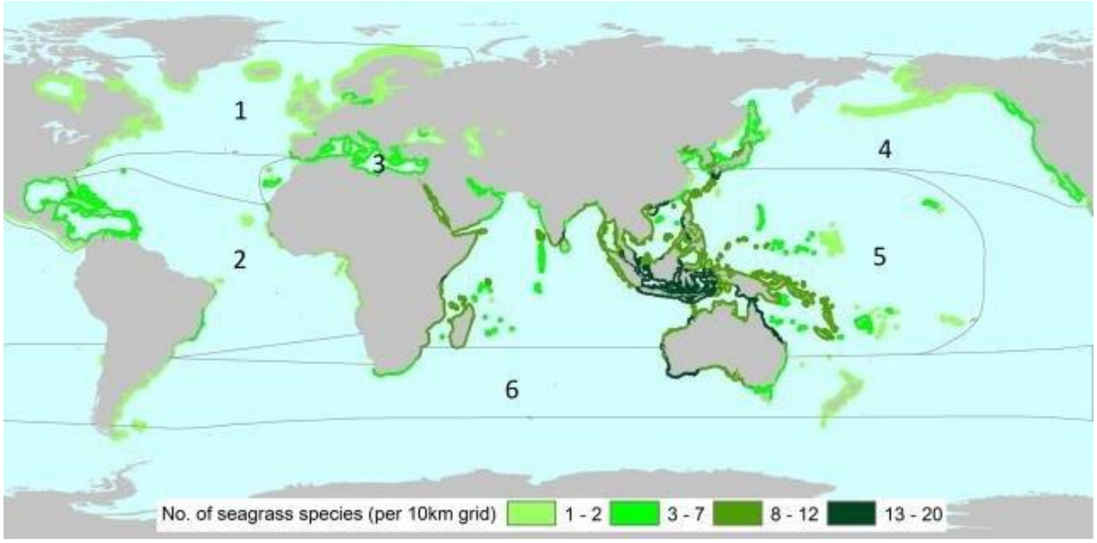


Figure 3: Global distribution of seagrass species richness. Numbers 1-6 indicate geographic bioregions: 1. Temperate North Atlantic, 2. Tropical Atlantic, 3. Mediterranean, 4. Temperate North Pacific, 5. Tropical Indo-Pacific, 6. Temperate Southern Oceans; (Source: Short *et al*., 2011).

2.2.1: Seagrass Distribution in Western Indian Ocean (WIO) Region

The WIO region extends from the coast of Somalia to South Africa and includes the Indian Ocean Island states of Madagascar, Comoros, Mauritius and Seychelles (Figure 4). This region is characterized by twelve species of seagrass belonging to three families and 8 genera (Gullström *et al.*, 2002). *These include Thalassodendron ciliatum* (Forssk.) den Hartog, *Thalassia hemprichii* (Ehrenb.) Ashch, *Enhalus accoroides* (L.f.) Royle, Syringodium *isoetifolium (Asch.) Dandy, Cymodocea rotundata Asch. &Schweig, Cymodocea serrulata (Braun) Asch. & Magnus, Halodule uninervis (Forssk.) Asch,* Halodule *wrightii*, *Halophila minor* (Zollinger) den Hartog , *Halophila ovalis (Braun) Hooker, Halophila stipulacea* (Forssk.) Asch., and *Zostera capensis* (Ochieng and Erftemeijer, 2016). Kenya, Tanzania and Mozambique have the highest diversity (10 species each), followed by Seychelles and Comoros (8 each), Somalia and Madagascar (7 each), Mauritius (6), South Africa (5), and reunion having only one species. *S isoetifolium* (Gullström *et al.*, 2002).

Seagrasses can be found in creeks, estuaries, lagoons and reef crests (Gullström *et al.*, 2002; Ochieng and Erftemeijer, 2016).

Seagrass cover is yet to be estimated for most countries of the WIO region except Kenya and Mozambique with 131, 712 ha and 43,900 ha respectively (Bandeira and Björk, 2001; Harcourt *et al*, 2018). The Major areas with seagrass cover in the WIO region include but not limited to ; Somalia from Adale to Ras Chiamboni ; Tanga coast in deltas of rivers Ruvu, Wami and Rufiji, Mafia island and around Kilwa and Chwaka bay in Tanzania; Moheli marine park ,Mitsamiouli ,male and Ouroveni in Grande Comoro and Bitombini and Ouani in Anjouan in Comoros; Lamu archipelago, Malindi, Mombasa, Diani-Chale, Gazi bay and Mida creek in Kenya (Ochieng and Erftemeijer, 2016); Inhassoro and Bazaruto island , merufi Pemba and in the southern Quirimbas archipelago as well as in Inhaca island in Mozambique (Bandeira and Björk, 2001; Gullström *et al.*, 2002)

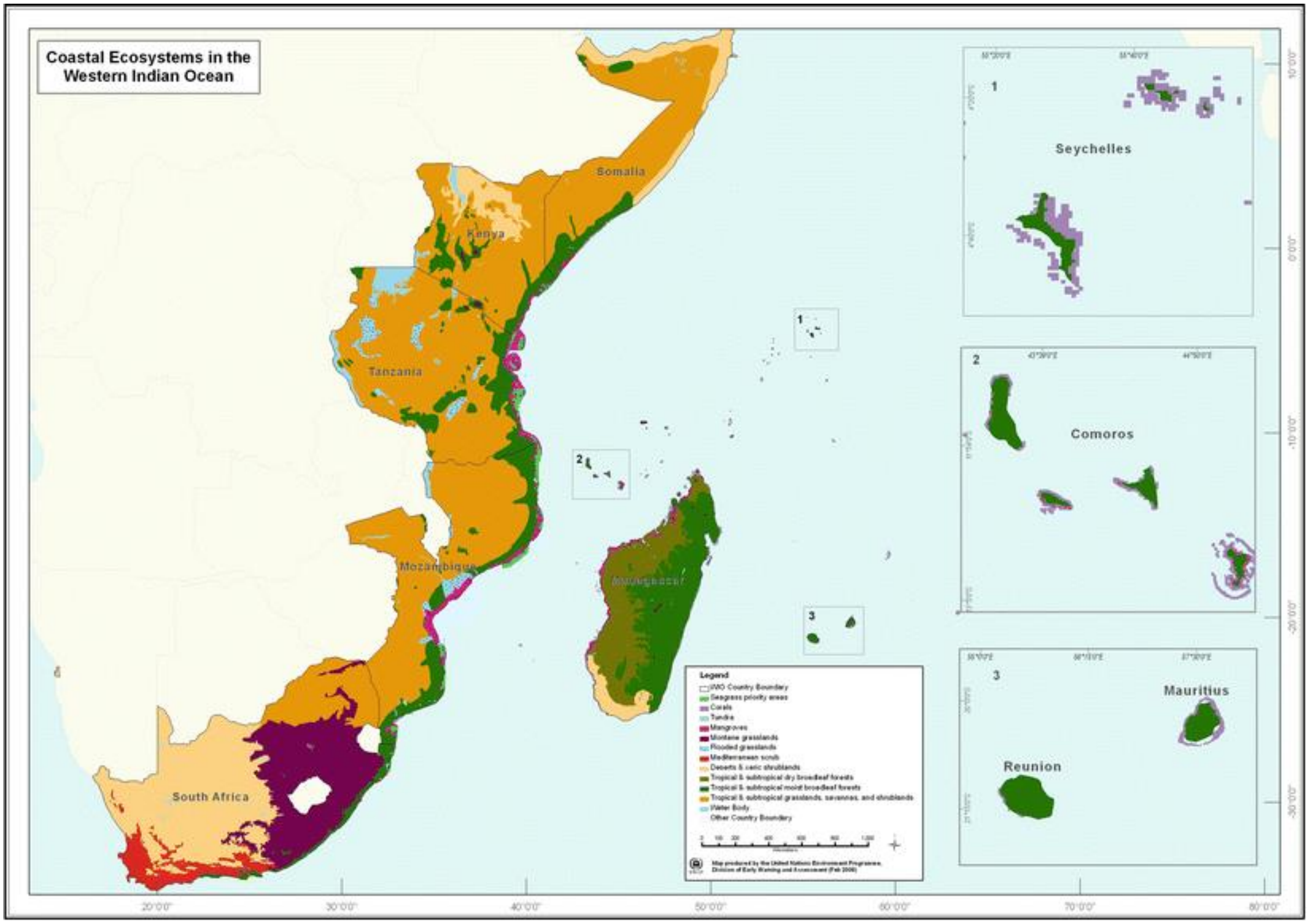


Figure 4: Distribution of seagrass and other coastal ecosystems in the Western Indian Ocean region; (Source: Diop and Scheren, 2016)

2.2.2: Species Composition and Distribution in Gazi Bay, Kenya

Twelve species of seagrasses are found in Gazi Bay (Figures 5-13). The seagrass community is composed of four dominant species: *T. ciliatum*, *T. hemprichii*., *E. acoroides* and *S. isoetifolium* (Coppejans *et al*, 1992; Githaiga *et al.*, 2017). These species either form monospecific meadows or mixed stands. Other species present in the bay are: *C. rotundata*, *Cymodocea serrulata*, *H. uninervis, H. ovalis, and H. stipulacea* (Coppejans *et al*, 1992; Juma *et al*., 2020). *H. wrightii* , *H.*

minor and *Z. capensis* are less abundant although they have been sighted and reported in previous studies in the bay (Coppejans *et al*, 1992).

Figure 5: *Thalassodendron ciliatum (Tc) "sickle leaved cymodocea"*; (Source: Richmond, 2003)

Figure 6: *Thalassia hemprichii (Th) “Sickle seagrass”*; (Source: Richmond, 2003)

Figure 7: *Enhalus acoroides* (Ea) “Tape seagrass”; (Source: *Richmond, 2003)*

Figure 8: *Syringodium isoetifolium* (Si) “Noodle seagrass”; (Source: *Richmond, 2003)*

Figure 9: Cymodocea rotundata (Cr) “Ribbon seagrass; (Source: Richmond, 2003)

Figure 10: *Cymodocea serrulata (Cs) “Serrated ribbon seagrass”*; (Source: Richmond, 2003)

Figure 11: *Halodule uninervis* (Hu) “Needle seagrass”; (Source: Richmond, 2003)

Figure 12: *Halophila ovalis (Ho)* “spoon seagrass";(Source: Richmond, 2003)

Figure 13: *Halophila stipulacea (Hs) “Broadleaf seagrass”*; (Source: Richmond, 2003)

These seagrass species exhibit different growth forms and are classified into six categories based on morphological classification by Denhartog (2001) namely: The parvozosterids (e.g., *Halodule*), magnozosterids (e.g., *Cymodocea* and *Thalassia*), syringodiids (e.g., *Syringodium*), enhalids (e.g., *Enhalus*), halophilids (e.g., *Halophila*) and the amphibolids (e.g., *Thalassodendron*). These Seagrasses exhibit a general zonation along a depth profile from the intertidal to the sub-tidal area (Coppejans *et al*, 1992). Occupying the shore and the whole intertidal area is a mixture of *H. uninervis and H. ovalis* (Figure 14). These two species are the pioneers in this zone, occasionally interspersed with *T. hemprichii*. In the intertidal zone, *T. hemprichii* is the climax vegetation, and it may establish mixed associations with *C. rotundata* and *C. serrulata*. There are mixed meadows of *T. hemprichii, C. serrulata, C. rotundata, H. uninervis, S. isoetifolium,* and *H. stipulacea* from the mean low water down to 1 m. From 1 m down, there are monospecific *T. ciliatum* meadows that are locally replaced by *E. acoroides* (Coppejans *et al*, 1992).

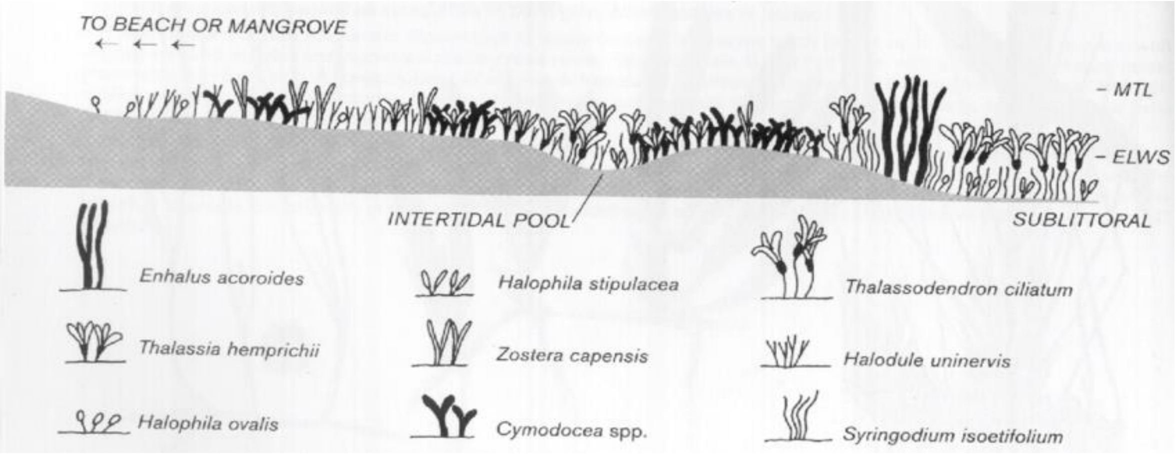


Figure 14: Seagrass species zonation along the east African coastline. Mean Tide Level *(MTL*), Extreme Low Water Springs (ELWS*);* (Source: Richmond, 2003)

2.3: Carbon Storage by Seagrasses

Despite constituting only 1% of the world's ocean, seagrasses are predicted to sequester and store 27.4% Tg C yr-1(Fourqurean *et al.*, 2012) accounting for almost 10% of marine carbon sequestration (Figure 15). Seagrass meadows, in addition to burying autochthonous carbon, provide a depositional habitat for imported carbon through particle trapping in the water column and sediment stabilization (Kennedy, 2010). Additionally, the deoxygenated anaerobic soils of the seagrass meadows and fine mud contents prevent remineralization of stored carbon therefore promoting long term sequestration up to millennial timescales (Mateo *et al.*, 1997). Carbon stored in seagrass sediments is estimated to be between 4.2 to 8.4 Pg C on a conservative basis. (Fourqurean *et al.*, 2012). However, human activities such as habitat conversion and water pollution have increased the rate of seagrass loss leading to increased emissions from sediments. This therefore calls for the implementation of efficient protection measures that seek to protect carbon stocks and other ecosystem services provided by seagrass ecosystems. Hence, a thorough understanding of seagrass carbon storage capacity is critical for developing effective management strategies for these ecosystems as well as forming the foundation for appropriate conservation policies.

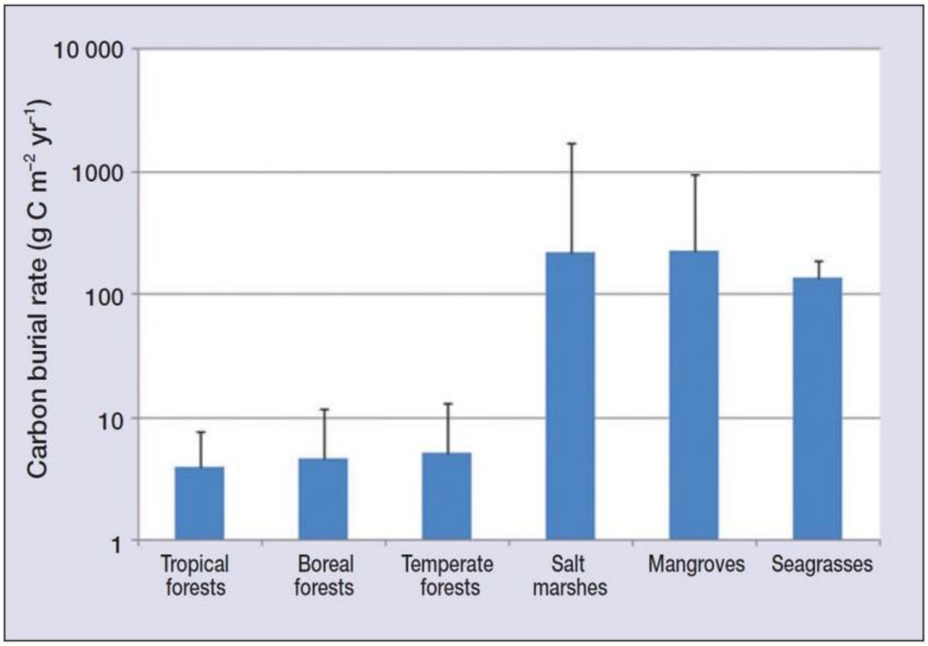


Figure 15*:* Carbon burial in marine ecosystems; (Source: Fourqurean *et al*., 2012)

2.3.1: Habitat Characteristics Influencing Carbon Storage and Preservation

Seagrasses have different abilities to store carbon owing to their differences in primary production, biomass accumulation, nature of resistant compounds in their organs and different canopy structures which facilitates input of allochthonous carbon in the meadows (Duarte and Chiscano, 1999). They also live in a wide range of environments with varying hydrodynamic energy which have different capacities of preserving and accumulating organic carbon (Lavery, 2013). Globally, difference in soil stocks is upto 18 fold (Lavery, 2013). Jointly, biotic factors (species composition, primary production, biomass and density) and abiotic factors (depth, sediment grain size, sediment accumulation rate (SAR), and hydrodynamic factors) interact and affect the rate of organic matter accumulation and preservation across seagrass meadows globally (Figure 16).

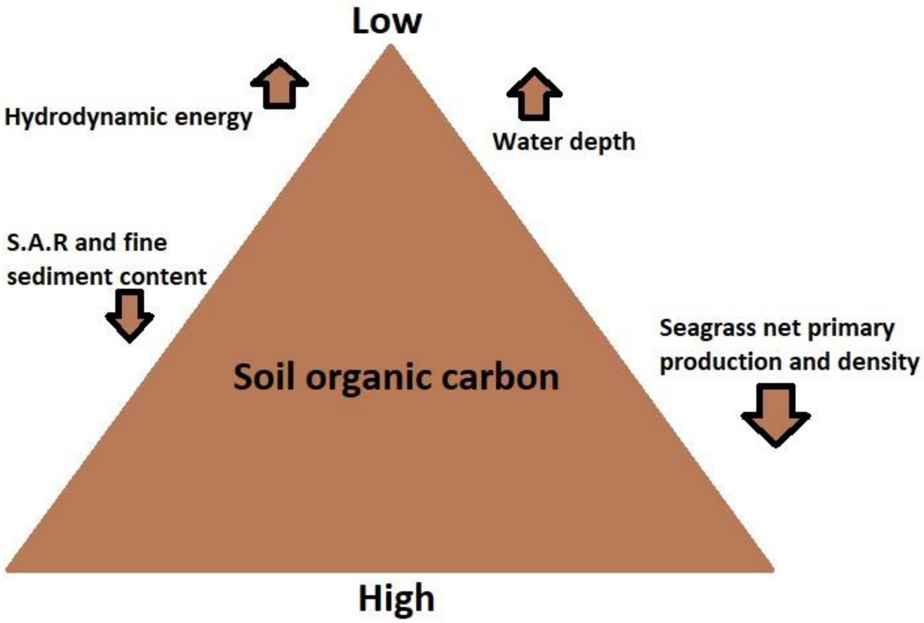


Figure 16: Factors impacting the storage of organic carbon in seagrass soils; (Source: Serrano *et al.*, 2016)

Variations in seagrass biomass, productivity and amount of nutrients in their tissues directly affect carbon storage (Miyajima *et al.*, 2015; Serrano *et al.*, 2016). Meadows with large species have more organic carbon compared with smaller sized ones due to higher belowground biomass, higher lignin content, high productivity and enhanced capacity of their canopies to facilitate settling of particles suspended in the water column (Mazarrasa *et al.*, 2018). Furthermore, meadows where seagrass material is the main source of detritus have more stable carbon stocks because seagrass materials are resistant to decay due high content of structural compounds such as lignin and cellulose. However, because shoot density, biomass and productivity of seagrasses correlate with irradiance, seagrass carbon storage capacity varies with depth (Serrano *et al.*, 2014, 2016). As a result, organic carbon reserves in shallow meadows are anticipated to be higher than in deeper meadows.

The rate of soil accumulation, the proportion of fine particles in the sediment, and the biogeochemical composition of the organic matter are all important factors in the preservation and storage of carbon that has been integrated into the soil of seagrass meadows. (Burdige, 2007). High soil accumulation rate enhances high organic carbon accumulation and is associated with high canopy complexity, biomass and density as well as high availability of fine-grained particles in the water column (Kennedy, 2010; Mazarrasa *et al.*, 2015). Sediment accumulation rate is also determined by the ability of the seagrass meadow to produce biogenic carbonates (De Falco *et al.*, 2008). Fine sediments enhance organic carbon preservation through reduced oxygen exchange and redox potentials, thus sediments with fine sediments have low remineralization rates and retain more organic carbon (Burdige, 2007). Additionally, it has been shown that hydrodynamic energy is correlated with sediment grain size thus fine sediments are associated with low hydrodynamic energy favouring deposition (Serrano *et al.*, 2016; Burdige, 2021). Finally, although seagrass sediments are composed of both allochthonous and autochthonous material, the proportion of autochthonous material largely determines the carbon storage capacity. Meadows with high autochthonous carbon are more resistant to degradation compared to allochthonous sources made up labile end members such as seston and algae (Mazarrasa *et al.*, 2018).

2.3.2: Habitat Characteristics that Threaten Carbon Storage Capacity

While the factors discussed above have favorable effects on carbon storage abilities, nutrient availability, altered trophic food webs, anthropogenic disturbance and climate change have detrimental consequences on seagrass carbon stocks (Mazarrasa *et al.*, 2018). Increased eutrophication and sedimentation in seagrass areas due to human activities along the coast is detrimental to seagrass survival. This favour the input of allochthonous carbon as the capacity of meadows to generate autochthonous carbon is inhibited. Thus, the stability of the carbon stock is compromised given the labile nature of non-seagrass derived material. Additionally, high nutrient inputs in the sea water may accelerate remineralization rates due to increased soil microbial activities (Lovelock *et al.*, 2017; Kelleway *et al.*, 2020). Furthermore, increased human activities will increase fragmentation which affects the ability of seagrass meadows to accumulate and store carbon in soils.

Habitats with altered food webs and consequently lack of predators due to overfishing or invasion are likely to have low carbon stocks. Lack of predation results in increased abundance of grazers which not only reduce standing biomass but also alter the efficiency of leaves to trap allochthonous carbon (Atwood *et al.*, 2015; Dahl *et al.*, 2016). Increased population of burrowers leads to increased bioturbation thus favouring oxygenation and remineralization of organic matter (Kristensen, 2000).

Finally, the potential of seagrass meadows to sequester carbon is anticipated to be affected by climate change (Short and Neckles, 1999; Arias-Ortiz *et al.*, 2018). Sea level rise is projected to negatively affect seagrass primary production and carbon sequestration due to reduced irradiance and increased turbidity due to erosion. However, this might be compensated by landward migration of seagrass. On the contrary, sea level rise may enhance organic carbon sequestration in intertidal zones by reducing desiccation time and increasing emersion periods (Short and Neckles, 1999).

Higher sea temperatures will lead to reduced biomass and productivity rates and increased turnover of temperate meadows, thus reducing autochthonous carbon production (Duarte and Chiscano, 1999; Duarte *et al.*, 2018). However, ocean warming could lead to expansion of seagrass meadows to Polar regions thereby increasing the areal carbon stocks (Krause-Jensen and Duarte, 2014). High temperatures could also lead to mass mortality of temperate or sub-tropical seagrass meadows as well as affect seed survival rates, however, it might favour flowering. Besides, high temperature is likely to increase remineralization rates thus reducing carbon storage efficiency in soils (Mateo *et al.*, 2006). Although there have been few studies on the impact of ocean acidification on carbon storage, it is anticipated to have a favorable impact on both above and belowground biomass (Mazarrasa *et al.*, 2018).

2.3.3: Habitat Characteristics with Unclear Effects on Carbon Storage Capacity

While there has been significant improvement in terms of quantifying capacity of seagrass ecosystems as carbon sinks and understanding factors that affect carbon storage, there is a consensus among scientific community to address certain limitations that hinder application of seagrass conservation strategies. Such bottlenecks include inadequate information on sediment accumulation rates (SAR) from different meadows as S.A.R gives status of carbon stocks (Mazarrasa *et al.*, 2018).

Another concern is the need to resolve factors that have not been investigated and thus their effect on carbon storage is not clearly understood like intertidal vs subtidal meadows, Ocean acidification and climatic regions (Mazarrasa *et al.*, 2018). Whereas it is expected that meadows of the same species in the inter-tidal area have low organic carbon stocks than sub-tidal meadows, possible interaction between biotic and abiotic variables might also interact disapproving this hypothesis. This is corroborated by the findings of Lavery et al (2013), who reported no substantial differences in carbon stocks between intertidal and subtidal *Posidonia Sinuosa* meadows. Intertidal meadows are subjected to periods of sunlight exposure which could either increase or decrease primary production depending on species and severity of exposure. Conversely, intertidal meadows are generally more exposed to adverse hydrodynamic conditions such as waves and tides. This reduces the capacity of the canopy to facilitate settlement of suspended particles as well as reduce erosion. Consequently, these meadows have less fine-grained sediments that favour carbon preservation than deep meadows. Intertidal meadows are also at risk of high remineralization of carbon in soils than sub-tidal meadows (Mazarrasa *et al.*, 2018).

2.3.4: Seagrass Carbon Dynamics in Gazi Bay

Seagrass meadows and mangrove forests in Gazi Bay exist in close proximity. This enhances exchange of organic matter between these two ecosystems (Hemminga *et al.*, 1994). Previous investigations have indicated that particle organic matter from the mangrove forest is removed from the water column and is predominantly deposited in seagrass beds during ebb tide (Hemminga *et al.*, 1994). However, the gradient of POM in sediment reduces with increasing distance from the mangroves. Consequently, the reverse is observed during flood tides, where seagrass derived, organic matter is transported to the nearby mangrove forest where they get deposited. Some of the mangrove derived organic matter deposited in the seagrass zone undergoes through a phase of intensive decomposition and mineralization (Hemminga *et al.*, 1994; Hemminga and Mateo, 1996). Mangrove particulate organic matter trapped in the seagrass zone mineralizes, releasing dissolved CO_2 that *Thalassodendron cilliatum* uses, thereby making mangroves a direct supply of carbon for the seagrasses.

Organic carbon in the water column is mainly derived from mangrove and seagrass materials (Bouillon *et al.*, 2007) and also exhibits a distinct spatial distribution from the mangrove creeks towards the open ocean. The water column in the creeks and adjacent seagrass meadows is more enriched with POC whose main source is mangrove material illustrating the efficiency of sea grasses in accumulating and stripping particles off the water column (Hemminga *et al.*, 1994; Bouillon *et al.*, 2007). This contributes to the sedimentary organic carbon reservoir while also providing a significant input for benthic mineralization in the seagrass zone. Organic matter of terrestrial origin flows into the bay through the River Mkurumuji estuary where the vegetation is composed of less mangrove and more terrestrial C_4 plants (Signa *et al.*, 2017). Thus generally, the dense seagrass beds in Gazi bay greatly affect the aquatic biogeochemistry through trapping and mineralization of particulate organic carbon, high oxygen production and CO_2 uptake (Bouillon *et al.*, 2007).

(Githaiga *et al.*, 2016) reveals a paucity of studies on seagrass biomass and sediment carbon in Africa with available studies mainly concentrated around East Africa. This makes it hard to make any conclusions or implement blue carbon conservation strategies on seagrass ecosystems given the uncertainties in carbon stocks and sequestration rates. Pioneer assessment of carbon stocks in meadows of the dominant seagrass species of Gazi bay (Githaiga *et al.*, 2017), reveal that there is considerable organic carbon in biomass and sediment of the four dominant seagrass species. Seagrass sediments store 236 ± 24 Mg C ha^{-1} whereas total biomass C_{org} for the four seagrass species is 5.9 ± 0.9 Mg C ha-1. This demonstrates that the sediment compartment is the greatest carbon pool in the seagrass ecosystem in Gazi Bay, accounting for 97 % of total carbon stocks. Both biomass and sediment carbon stock varied significantly among the four species. Total biomass was highest in *Syringodium isoetifolium* and lowest in *Thalassodendron ciliatum* while Sediment Corg was highest in *Enhalus acoroides* meadows and the lowest in *Syringodium* *isoetifolium* meadows. Significant variation in allocation of biomass also exists among the species with BGB being significantly higher than the AGB accounting for over 80% of the total biomass. Highest BGB was recorded in *Syringodium isoetifolium* despite being relatively small sized. This is attributed to its high shoot density and percentage cover. Both sediment and biomass carbon values in seagrass meadows of Gazi bay are above the global means of 166 Mg C ha-1 and 2.51 ± 0.49 Mg C ha- respectively. Githaiga *et al.*, (2017) also established that biomass does not correlate with sediment organic carbon and therefore cannot be used as a predictor for belowground carbon. This might give an indication that the source of the sediment organic carbon is likely of allochthonous origin and is highly susceptible to remineralization if this ecosystem is degraded, given the unstable nature of allochthonous carbon (Mazarrasa *et al.,* 2018). Juma *et al* (2020) reported a variation in carbon stocks between seagrass meadows found in two creeks with differing salinity levels in Gazi bay. This was attributed to the variation in species composition as well as the environmental conditions in the two creeks. However, neither the contribution of other seagrass species in Gazi nor the carbon stores in the subtidal area were included in these studies. There is therefore the need to conduct comprehensive stock assessment on other species and depth limits in order to have a robust estimate of carbon stored by the seagrasses in Gazi bay. This investigation will further assess variation in carbon storage between monospecific and mixed species meadows in subtidal zone. This will give researchers more information about the dynamics of carbon storage in seagrass meadows.

2.4: Policy Gaps and Implications

This study will fill the following gaps in conservation and management of seagrasses in Kenya.

1. The data and information generated from this study will be used in revising Kenya's NDC to accommodate seagrasses ecosystems in Kenya.
2. Continued understanding of composition, distribution and abundance of seagrasses will necessitate implementation of appropriate blue carbon conservation strategies in both local and national level
3. Incorporation of seagrass ecosystem into PES schemes and therefore achieving the triple win for communities, biodiversity and climate regulation.

2.5: Conceptual Framework

This study considers structural attributes (canopy height, %cover and species composition), soil depth interval and meadow type (monospecific or mixed species) as independent variables. These variables can be affected by natural or anthropogenic factors. Dependent variables include aboveground and belowground carbon, soil dry bulk density, soil carbon concentration and sediment organic carbon (Mg C ha^{-1}). These are in turn affected by variability in structural attributes and meadow complexity. The intervening variables include natural factors such as herbivory, sedimentation, wave action, and unsustainable anthropogenic activities. Through these factors, the independent variables are able to exert an influence on dependent variables. Moderating variables include environmental factors such as turbidity, temperature, salinity, depth and pH. These modify the relationship between independent and dependent variables (Figure 17).

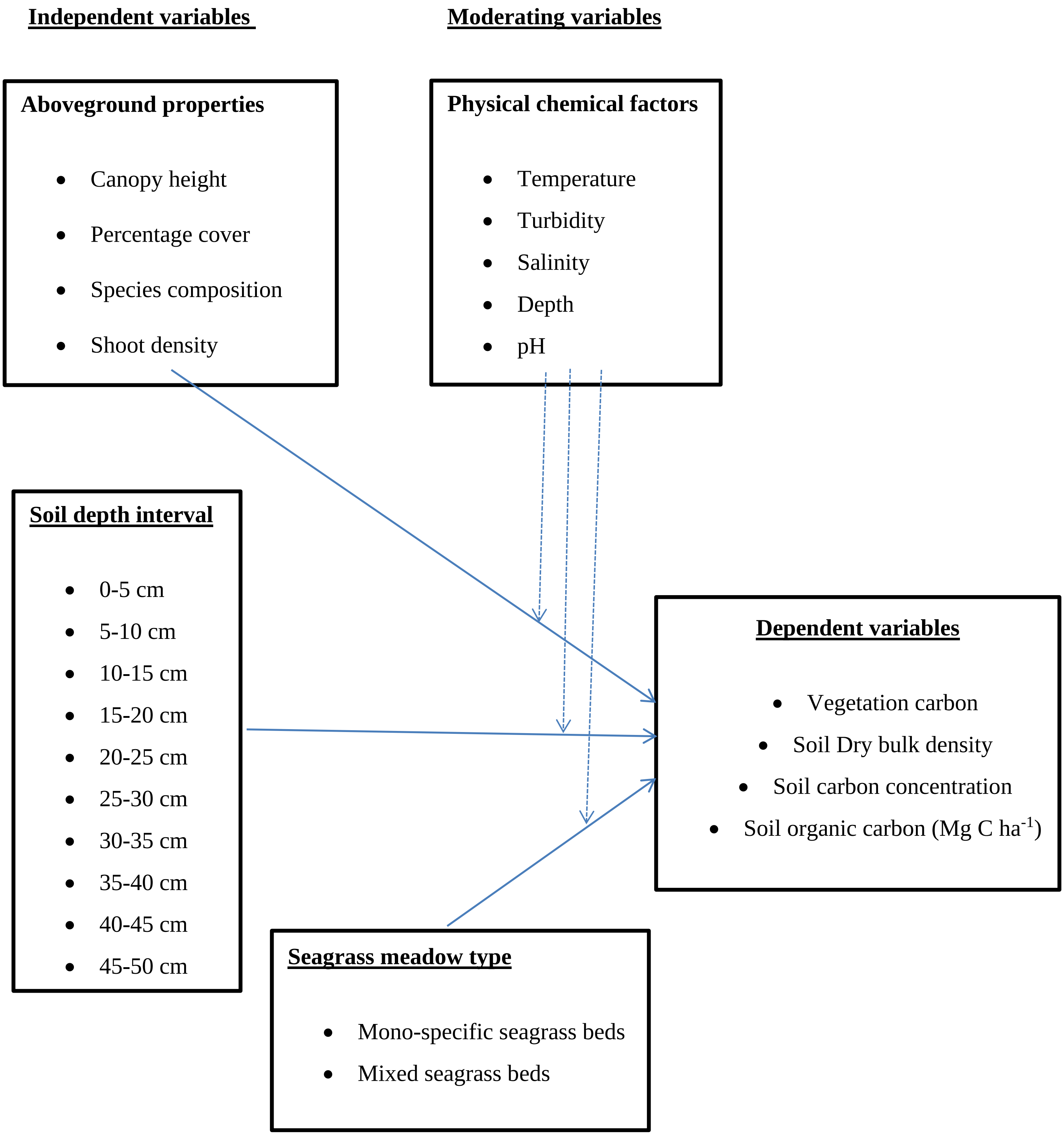


Figure 17: Conceptual framework of the study

CHAPTER THREE

MATERIALS AND METHODS

3.1: Description of the Study Area

This study was conducted at Gazi Bay (4^{o}25’S, 39^{o}31’E) located along the Kenyan south coast in Kwale County 50 km south of Mombasa (Figure 18). The bay is a tropical semi-enclosed shallow coastal water system (Kitheka, 1996), with a total surface area of approximately 17 km^{2} (Coppejans *et al*, 1992).

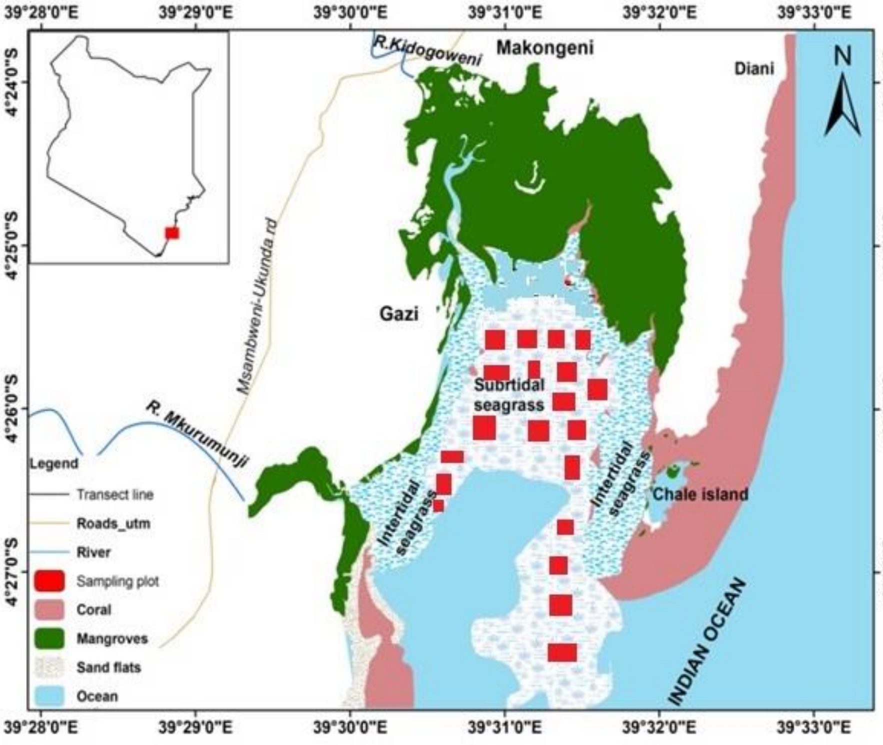


Figure 18: Map of Gazi bay indicating the sampling points in subtidal seagrass area; (Source: Bouillon *et al*., 2007)

The embayment is protected from strong waves by the Chale peninsular from the East and a fringing reef from the South and has a shallow, wide opening to the open ocean (Kitheka, 1996). Freshwater is supplied to the area by River Kidogoweni in the north west and R. Mkurumuji in the south west of the bay (Kitheka, 1996). Kinondo creek located in the North eastern side of the bay is the only channel that lacks fresh water supply and is regulated by tidal movements.

The climate of Gazi Bay can be classified as tropical wet/dry according to the Koppen climate classification (Peel *et al*, 2007). The South East monsoon period (Kuzi), is a wet season associated with heavy rains and rough seas usually from March to August. This is followed by the North East monsoons (Kazkazi), which is a dry period characterized with calm seas from November to March (Mc Clanahan, 1988). Gazi's annual total rainfall ranges from 1000 mm to 1600 mm. Temperatures range from 22 to 34 °C during the North East Monsoon season, and from 19 to 29 °C during the South East Monsoon season. Humidity is high, and averages 80% all year round (Schott et al., 2009). The tidal cycle at Gazi Bay is semi diurnal with an amplitude varying between 0.7 m at neap tide and 2.90 m at spring tide (Hemminga *et al.*, 1994).

Gazi Bay is characterized by mangroves, seagrasses, macroalgae and coral reefs with seagrasses covering about 70% of the total bay area (Coppejans *et al*, 1992). The geomorphological characteristic of Gazi Bay facilitates the exchange and circulation of organic matter across the continuum (Signa *et al.*, 2017). There is a noticeable gradient in the distribution of organic matter across the ecosystems, which is mainly affected by riverine export and tidal influence. Organic material from the mangrove forest is retained in the adjacent seagrass beds along Kinondo creek whereas in Kidogoweni creek, mangrove material is widely spread into the bay particularly in the wet season. In the southern part of the bay, terrestrial organic matter flows into the bay through

River Mkurumudzi (Signa *et al.*, 2017). Other less dominant sources of organic matter in Gazi Bay include brown macroalgae and bacteria which are also the main mineralizers of organic detritus in the Bay (Bouillon *et al.*, 2003).

Seagrass in Gazi face pressure from fishing activities especially the use of seine and drag nets (Githaiga *et al.*, 2017; Musembi *et al*, 2019) as well as sedimentation (Harcourt *et al*, 2018). In the last two decades, these are thought to have accelerated the loss of seagrass cover at a pace of 1.68 percent per year (Harcourt *et al*, 2018).

3.2: Sampling Design

The revised Intergovernmental Panel on Climate Change (IPCC, 2014) carbon accounting standards for coastal wetlands and the sampling methodologies recommended by the Coastal Blue Carbon manual were applied (Githaiga *et al*.,2017; Howard *et al*.,2014, IPCC, 2014). The area of subtidal seagrass in Gazi Bay was estimated after classifying the seagrass area in the bay using shapefiles from (Harcourt *et al*., 2018) as well as field in-situ validation. Seagrass areas less than 3m deep during high tides in the bay area were classified as inter-tidal, while seagrass areas deeper than 3m deep were classified as sub-tidal and hence based on this classification, the subtidal seagrass area was estimated to be 470 ha. A systematic random sampling approach was used to identify sampling sites within the subtidal zone of the bay. Four zones in the subtidal area were identified based on tidal gradient and distance from shore starting from the mean low water of springs (mlws) heading into the lagoon (Figure 19 A). In each of these zones, two parallel transects measuring 300m long and 50 m apart were established, and five sampling points marked along each transect (Figure 19 B).

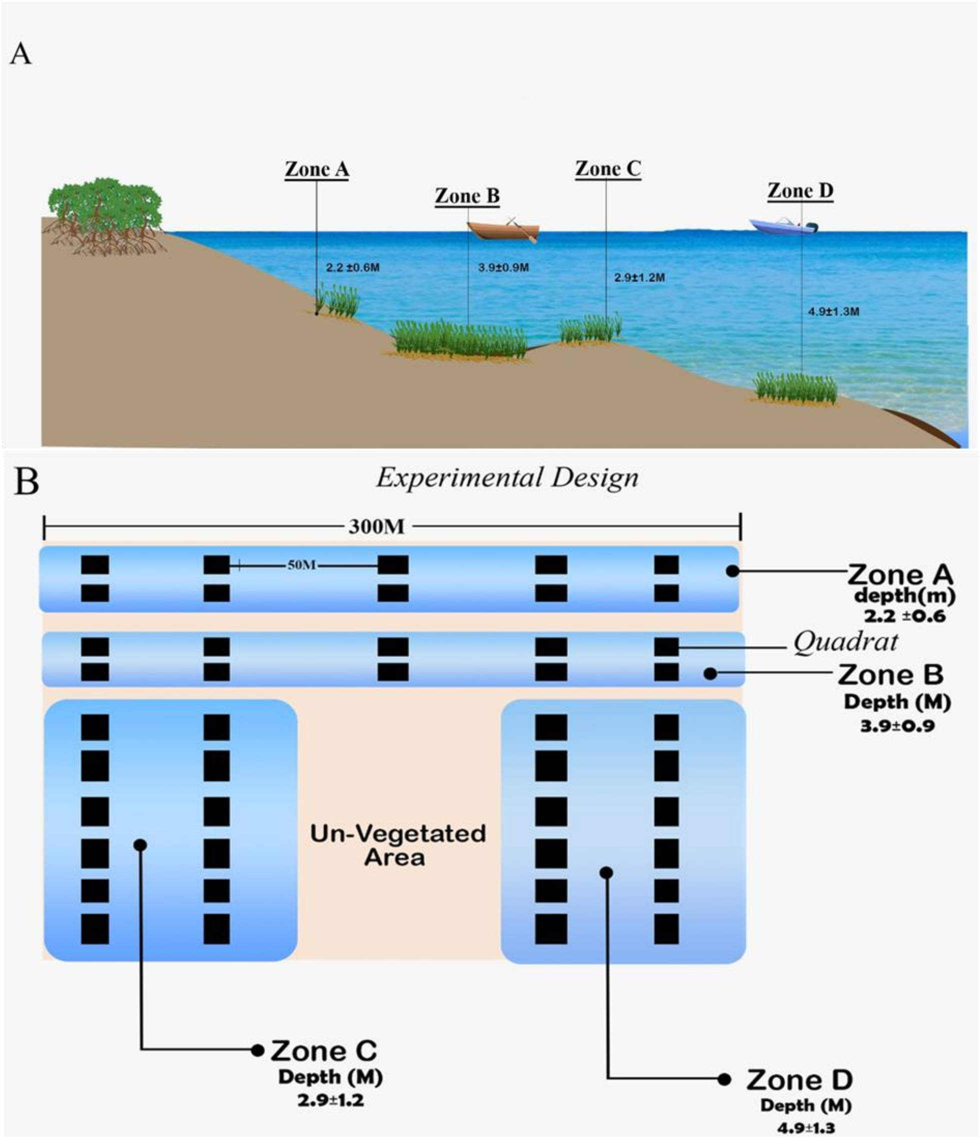


Figure 19: Diagrammatic representations of sampling design within the subtidal zone of Gazi Bay: A) generalized north-to-south transect showing mean depth, and B) aerial view showing the spatial arrangement of replicate sampling sites within each zone.

Samples were collected from 40 quadrats each measuring 0.25m^2 placed 60m apart along each transect. We worked as a team of three divers to collect seagrass and sediment samples, with two field assistants staying on the boat to assist with sorting, labeling, and packaging the samples after they were collected.

3.2.1: Measurement of Physicochemical Parameters

Measurement of physicochemical parameters of water was done *in situ*, in every quadrat, during low tides. Total dissolved solids (mg/L), water temperature (˚C), salinity and pH were measured using the YSI Professional Plus handheld multiparameter meter W14-05. Depth was measured using a dive computer. In each plot, these measurements were taken three times.

3.2.2: Determination of Seagrass Meadow Structure

In each sampling point, a quadrat measuring $0.25m^2$ was placed on the vegetation and photograph of the vegetation taken using OLYMPUS Tough TG-6 Waterproof Camera. Percentage cover was determined through visual estimation with an aid from seagrass net percentage cover guide (Short *et al.*, 2006). All the shoots in the quadrat were harvested, packed in pre-labeled zip lock bags and taken to the laboratory. Species identification was done in the laboratory using a field identification guide (Figure 20), shoots counted, and heights of 10 % of the shoots measured. Following this, the shoots and leaves were scrapped gently with a scalpel to remove epiphytes.

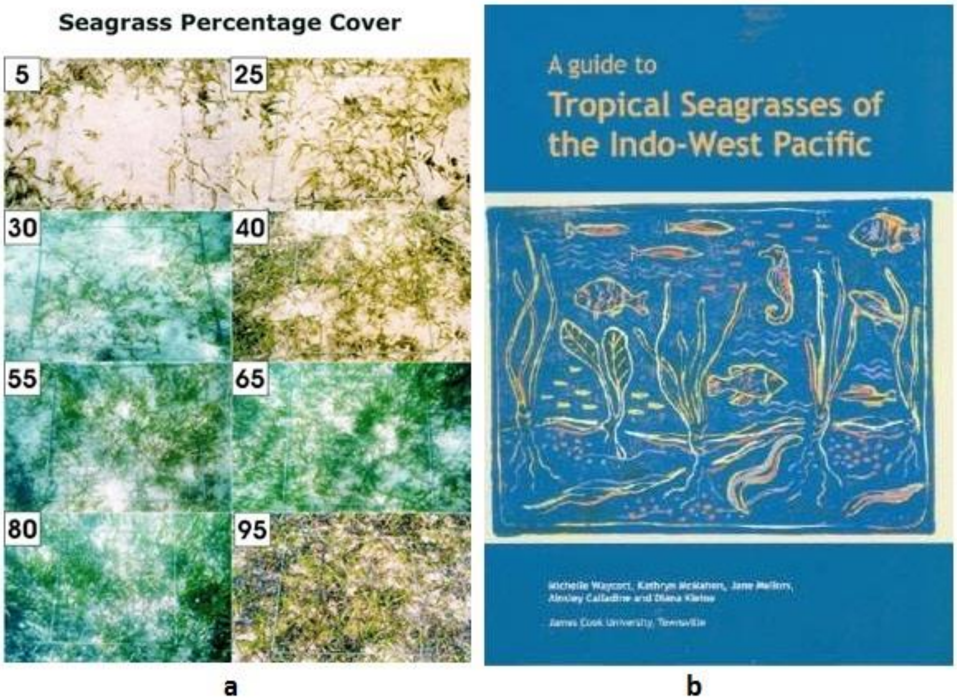


Figure 20: **(a)** seagrass net's guide to seagrass percentage cover estimation; (Source: Short, 2006), **(b)** species identification guide used in species identification; (Source: Waycott *et al*, 2004).

3.2.3: Determination of Aboveground Carbon

The harvested aboveground material (shoots and leaves) from each quadrat were sorted into species and weighed using an electronic Micro weighing digital scale. These were then oven dried at 60°C for 72 hours to achieve a constant weight (Howard *et al*, 2014; Githaiga *et al*,2017), after which a record was taken.

3.2.4: Determination of Belowground Carbon

Within the same quadrats where above ground samples were taken, two cores were taken (totaling 20 cores per sampling zone and 80 cores across the entire sub tidal area) using a PVC corer (6 "internal diameter, 50cm long). The corers were 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 washed and later sieved to separate from the sediment matrix and put into labeled zip loc bags for transport to the laboratory. The roots, rhizomes and necromass were further rinsed with distilled water without separation into species and oven dried for 72 hours at 60^0C to constant weight. They were then weighed and the dry weights recorded.

Standing stock (both above and belowground biomass) was converted to carbon as described by (Duarte, 1991) where;

AGC/BGC (kg C/m^2) = (plant biomass *(0.34)) / 0.25(m^2)

Where: 0.34 is carbon conversion factor

0.25m^2 is the area of the quadrat

The general carbon conversion factor of 0.34 was used due to a lack of site-specific organic carbon values for seagrass in Gazi bay measured directly using an elemental analyzer. This is recommended in both the coastal blue carbon manual and the IPCC 2014 (Howard *et al.*,2014, IPCC, 2014).

3.2.5: Determination of Sediment Organic Carbon

Two additional PVC cores (3 internal diameters, 50cm long) were used to obtain sediment samples. These corers were pushed 50cm into the sediments, retrieved, covered with a stopper and taken to the boat for extraction, in which the corer was placed on a clean cutting board and a wooden plunger inserted at the bottom end of the corer after which, the corer was carefully pulled over the plunger. The samples were sliced into 5cm subsamples and stored in pre-labeled zip lock bags and taken to the laboratory (Figure 21). Samples were then oven dried for 72 hours at 60°C to constant weight. The dry sediment samples were then weighed using a weighing balance and their dry weights recorded.

After that, the Dry Bulk Density (DBD) of each sediment sample was computed, and all the sections in the core were pooled together.

Dry Bulk Density (DBD) (g/cm^3) = dry weight of sample (g)/ volume of dry soil sample (cm^3) Where:

Volume of dry soil sample = [π * (radius of corer) ^{2}] * (height of the sample)

The dry samples were homogenized using mortar and pestle and sieved to remove shell and roots. These were then divided into duplicate sub samples of 5g each for determination of organic carbon content using the Loss on Ignition (LOI) technique (Howard *et al.*, 2014). Soil samples were ashed in a furnace at 450^o for 6 hrs and organic matter loss used as proxy for organic carbon. percentage LOI was calculated as follows:

% LOI = (weight before ashing - weight after ashing) / weight before ashing * 100 %.........(i)

Carbon content in the ashed samples was obtained by using the carbon conversion factors for seagrass soils (Fourqurean *et al.*, 2012).

(% C_{org}= 0.43*%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 soil samples in each core and summed. This study reports Carbon estimates to a maximum depth of 50 centimeters, or when this was not achieved (due to meeting substrate resistance) to the maximum depth achieved (e.g., the minimum was 30cm). While some studies and sampling guides recommend extrapolating data to 1 meter (to permit global comparison), this is not warranted in Gazi Bay due to its unique and relatively shallow geological features. Thus, the values presented here are a robust and true assessment of the carbon stocks in study area. Because of the core used, compression was found to be 15%. This was assessed by measuring and recording the difference in length from the upper part of the core to the sediment surface, inside and outside the corer, when the corer was in the sediment. This was applied to corrections in core lengths. Total amount of carbon in the subtidal area was determined by summing up the average carbon stocks from each pool (to a maximum depth of 50cm) and multiplying this with the area of the subtidal area. The variabilities and errors associated with the measurements were determined by calculating the standard deviation for each pool and multiplying by the area the subtidal area.

Figure 21: from **top left**; Sediment coring in subtidal seagrass meadows; **top right** extraction and sectioning of sediment core. **Bottom left**; harvesting seagrass samples underwater. **Bottom right**; Sorting, packing and labeling of collected biomass and sediment samples.

3.3: Data Analysis

Statistical analysis was done in SPSS (Version 25.0. Armonk, NY: IBM Corp). Assumptions of normality and homogeneity of response variables (AGB, BGB and sediment carbon) were tested using Kolmogorov Smirnov test for normality. Where this was not met, the data was log transformed, and if it failed to conform, a non-parametric equivalent was used. A student t-test was used to determine the variation in above and below ground carbon stocks within the sub-tidal seagrass meadows of the bay. Two-way ANOVA was used to test for significant differences in above, belowground biomass as well as sediment carbon among the dominant species as well as among the zones in subtidal zone. T-test was used to test for variation in Sediment carbon stocks between mono-specific and mixed specific seagrass meadows. Relationship between above ground parameters and biomass were tested using spearman correlation. In all these tests, the level of significance was set at α .05.

CHAPTER FOUR

RESULTS

4.1: Physico-Chemical Properties in the Sub Tidal Area

Mean depth in the sub tidal area was 3.4±0.2 m, range (1.2-7.4 m) during low spring tide. Mean temperature was 28.6±0.1 °C; range (27.9-29.3 °C). Salinity ranged between 35-36.6 ‰ in the sub tidal area with a mean value of 35.3±0.2 ‰, while mean pH was 7.8±0.1 with a range of 7.5-8.1 Turbidity ranged between 34580-35815mg/l with a mean value of 35003±47.3 mg/l.

All the physical parameters significantly varied among the four zones in subtidal area, (Table1). Depth varied significantly among the four zones in subtidal area ($F_{(3,40)}$ =12.601, p <.05). Zone A was significantly shallower than Zone B (p= .001) and Zone D (p=.000) while Zone D was significantly deeper than zone A (p=.00) and zone C(p=.00).

Temperature varied significantly among the four zones ($F_{(3,40)}$ =5.852, p <.05). Temperature was statistically significantly higher in Zone A compared to Zone D (p=.002). Temperature was also significantly higher in Zone B compared to Zone D (p=.013).

Salinity varied significantly among the four zones in subtidal area (F (3,40) =11.381, p <.05). Salinity was significantly higher in Zone A than Zone C (p=.002) and Zone D (p= .00). Zone B had significantly higher salinity levels that Zone D (p=.001).

pH also varied significantly among the four zones in subtidal area (F (3,40) =5.304, p <.05) Zone A was significantly higher in pH concentration than Zone D(p=.019). Zone B was also significantly higher than Zone D (p=.01), and Zone C was also higher than Zone D (p=.004).

TDS varied significantly among the four zones in subtidal area (F (3,40) =15.654, p <.05). Zone A was significantly more turbid than Zone B(p=0.022), Zone C(p<.00) and Zone D (p=0.00). Zone B was Significantly more turbid than Zone D (.001) while zone D was significantly less turbid than Zone A (p=.000) and B(p=.001); (Table 1).

Table 1: Environmental factors in the four zones in the subtidal area of Gazi Bay (Mean ±SD)

Area	**depth(m)**	**temp(°C)**	**Salinity(ppt)**	**pH**	**TDS (mg/l)**
Zone A	2.2 ±0.6	28.9 ±0.4	35.8±0.5	7.8 ±0.1	35340.5 ±370
Zone B	3.9±0.9	28.7±0.3	35.6±0.2	7.8±0.1	35062.9±163
Zone C	2.9±1.2	28.5±0.3	35.3±0.2	7.8±0.1	34877.9±185
Zone D	4.9±1.3	28.2±0.4	35.1±0.1	7.7±0.1	34661.3±46

4.2: Seagrass Species Composition, Distribution and Abundance in Subtidal Zone of Gazi Bay

4.2.1: Seagrass Species Composition

Nine seagrass species belonging to three families namely *Zosteracea*, *Hydrocharetacea* and Cymodoceaceae were identified in the subtidal area of Gazi bay. These include: *Cymodocea rotundata* Asch. & Schweig, *Cymodocea serrulata* (Braun) Asch. & Magnus, *Enhalus accoroides* (L.f.) Royle, *Halodule uninervis* (Forssk.) Asch, *Halophila. ovalis* (Braun) Hooker, *Halophila* *stipulacea* (Forssk.) Asch., *Syringodium isoetifolium* (Asch.) Dandy, *Thalassia hemprichii* (Ehrenb.) Asch., and *Thalassodendron ciliatum* (Forssk.) den Hartog. (Figure. 22)

Enhalus acoroides

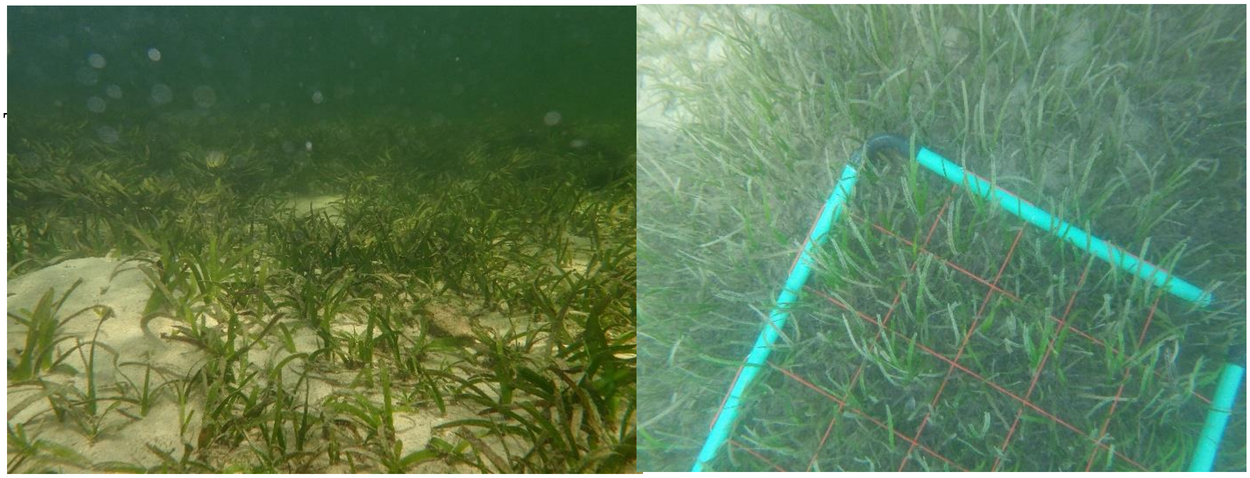
Halophila stipulacea

Thalassodendron ciliatum

Syringodium isoetifolium

Thalassia hemprichii

Halophila ovalis



Cymodocea serrulata *Cymodocea rotundata*

Halodule uninervis

Figure 22: Seagrass species found in subtidal area; (Source: Derrick Omollo, 2020)

4.2.2: Seagrass Species Distribution

C. serrulata was found in three zones, whereas *E. acoroides* and *C rotundata* were only found in zone B. *T. Ciliatum* was found in deeper zones C and D (Table 2) ;(Figure 23).

Table 2: Distribution of seagrass species in the subtidal zone, + = presence, - = absence

Species	Zone A	Zone B	Zone C	Zone D
C. serrulata	+	-	+	+
T. hemprichii	+	+	-	-
C. rotundata	-	+	-	-
H. uninervis	-	+	+	-
E. acoroides	-	+	-	-
S. isoetifolium	-	+	+	-
H. stipulacea	-	-	+	+
H. ovalis	-	-	+	-
T. ciliatum	-	-	+	+

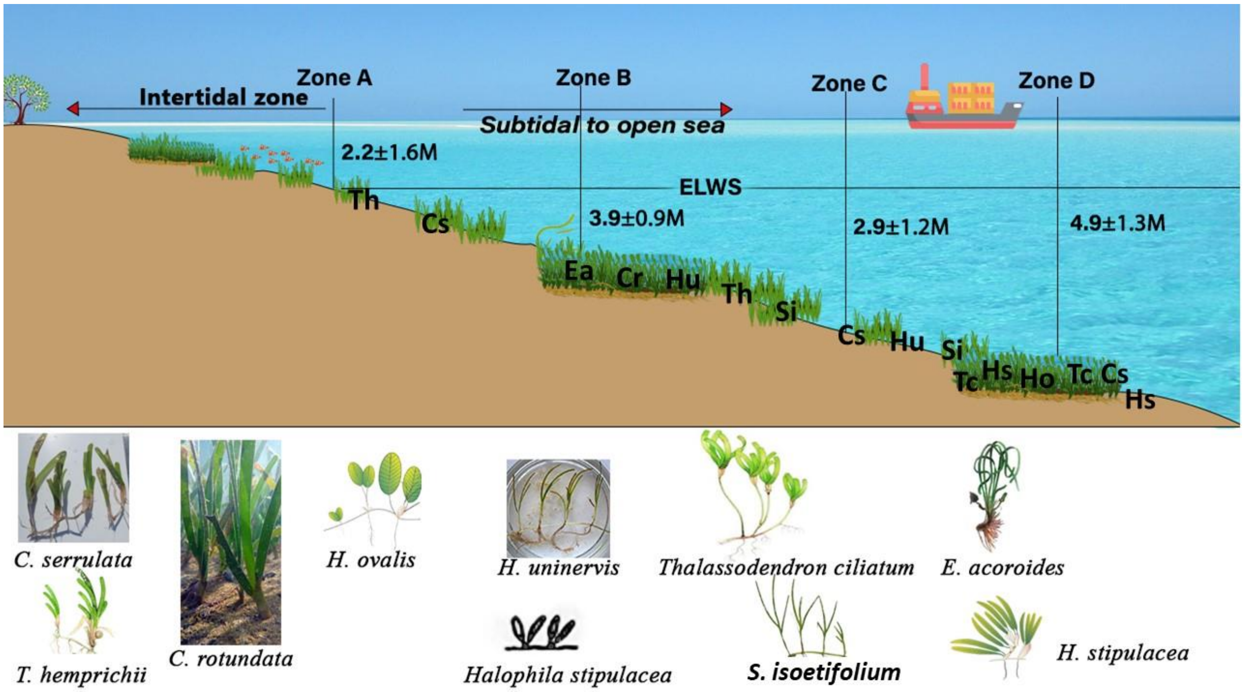


Figure 23: Diagrammatic illustration of species zonation in the subtidal zone of Gazi Bay below the extreme low water springs (ELWS); (Source @Derrick Omollo 2022)

T. hemprichii, *T. ciliatum and C. serrulata* had the highest frequency while *E. acoroides* and *H. ovalis* had the lowest frequency in the subtidal zone; (Table 3).

Table 3: Frequency of occurrence of seagrass species in sub tidal area of Gazi Bay

Species	Frequency	% Frequency
C. rotundata	5	6.3
C. serrulate	12	15
E. acoroides	2	2.5
H. uninervis	8	10
H. ovalis	1	1.3
H. stipulacea	7	8.8
S. isoetifolium	8	10
T. hemprichii	23	28.7
T. ciliatum	14	17.4

4.2.3: Seagrass Species Abundance

Cymodocea rotundata and *Halodule uninervis* had highest abundance followed by *Cymodocea serrulata*, *Syringodium isoetifoilum* and *Thalassia hemprichii* while *Enhalus acoroides*, *Halophila stipulacea* and *Halophila ovalis* were the least abundant species (Figure24).

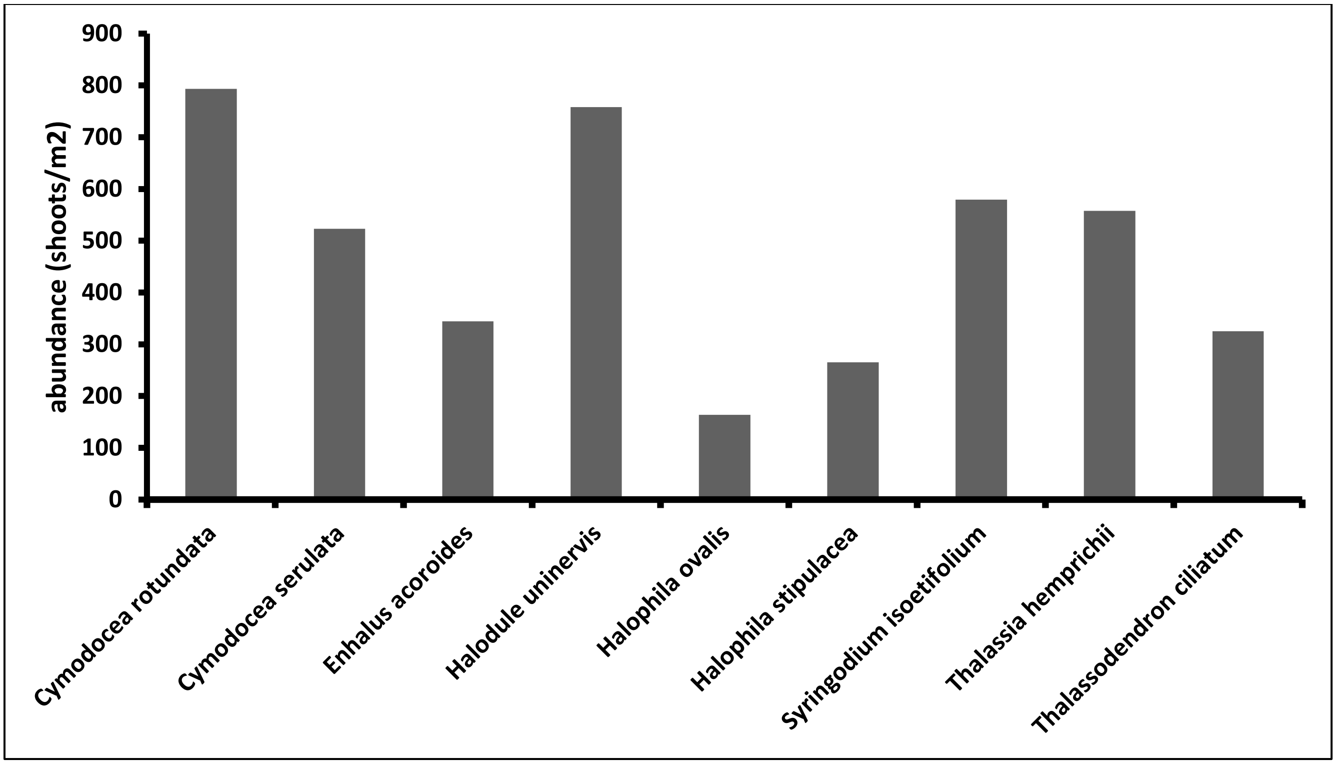


Figure 24: No. of shoots m^{-2} for the different seagrass species in sub tidal zone

4.2.4: Seagrass Meadow Structure

Average percentage canopy cover in subtidal area was 57.2 ±2.2 %, range 40%-90% while the mean canopy height was 20.4 ±1.9 cm, ranging between 5.0 cm and 61.4cm. Additionally, seagrass density was 666±61 shoots per m^2 with a range of 68-179 shoots per m^2. *E. acoroides* had the highest canopy height (49.2±0.4 cm) followed by *T. ciliatum* (41.8±0.8 cm). *Halophila ovalis and H. stipulacea* had the lowest canopy height with 5.0±0.1 cm and 4.8±0.1 cm respectively (Table 4).

C. rotundata had the highest %cover (66.3%) followed by *H. uninervis* (65%) while *T. ciliatum* had the lowest (53.5%). *C. rotundata* (793.6±42.9m^2) and *H. uninervis* (758±19.7 m^2) recorded the highest densities while *H. ovalis* recorded the lowest density (164±0.3).

Table 4: Mean shoot density, canopy height and canopy cover for seagrass species in subtidal zone (± SE)

Species	**Density/m^2**	**Canopy height(cm)**	**% Cover**
C. rotundata	794±42.9	16.5±0.2	66.3
C. serrulata	523±14.3	19.4±0.1	55.4
E. acoroides	344±19	49.2±0.4	55.0
H. uninervis	758±19.7	11.3±0.1	65.0
H. ovalis	164± 31	5.0±0.1	60.0
H. stipulacea	464±30.9	4.7±0.1	48.4
S. isoetifolium	580±26.4	20.6±0.1	64.3
T. hemprichii	611±10.1	15.6±0.1	53.8
T. ciliatum	350±11	41.8±0.8	53.5

In comparing shoot density among the four dominant species in subtidal area, *S. isoetifolium* recorded the highest shoot density at 1021±69 shoots/m^2 while *T. ciliatum* recorded the lowest shoot density at 286±72 shoots/m^2. Variation in Shoot density among the dominant species was statistically significant (F (3,16) = 24.708, p<.05). Shoot height also varied among dominant species in subtidal area (F $_{(3,16)}$ =13.592, p<.05) with *T. ciliatum* recording 41.8±1 cm while *T. hemprichii* recorded the lowest height at 15.6±0.1cm. Canopy cover was highest in *S. isoetifolium* at 64.3% and lowest in *T. hemprichii* at 53.8%. There was no statistically significant difference in canopy cover among the four dominant species in subtidal area (F (3,16) =2.13, p<.05).

4.3: Vegetation carbon stocks of the seagrasses

4.3.1: Above Ground carbon of the Seagrasses

Mean above ground vegetation carbon stock in sub tidal seagrass meadows was 0.5±0.1 MgCha^{-1} and ranged between 0.2 - 2.1 MgCha^{-1}.

There was no significant variation in above ground biomass among the zones (f $_{(3,38)}$ = 1.685, p >.05), while there was significant difference among species (*S. isoetifolium*, *C. serrulata*, *T. hemprichii* and *T. ciliatum*) (F (3,16) = 4.967, p <.05); (Table 5). Tukey HSD test showed that AGB in *T. ciliatum* meadows was significantly higher than that of *T. hemprichii* meadows (p=.013).

Table 5: Above ground carbon of dominant seagrass species in subtidal zone

Species	**AGC MgCha^{-1} (mean ±SE)**	**AGCMgCha^{-1} (range)**
C. serrulata	0.48±0.2	0.19-0.7
S. isoetifolium	0.42±0.3	0.25-0.7
T. hemprichii	0.35±0.2	0.22-0.7
T. ciliatum	1.04±0.4	0.63-2.1

4.3.2: Belowground Carbon of the Seagrasses

Mean below ground vegetation carbon concentration in sub tidal seagrass meadows was 5.1±0.7MgCha^{-1} with a range of (0.51 - 23.16 MgCha^{-1}).

Belowground biomass among the zones in subtidal area was not significantly different (f (3,38) = 1.952, p >.05). Similarly, the belowground carbon among the four dominant species in subtidal area showed no significant difference (F (3,16) = 1.108, p >.05).

Belowground carbon stocks were significantly higher than aboveground carbon stocks in the sub-tidal seagrass meadows of the Bay. (t (43) =-6.817, p<.05); (Figure 25). The mean total vegetation carbon in subtidal area was 5.6±0.7 MgCha^{-1}; (range: 0.8-23.9 MgCha^{-1}); giving a total vegetation carbon of seagrasses in the bay of 2631 Mg C.

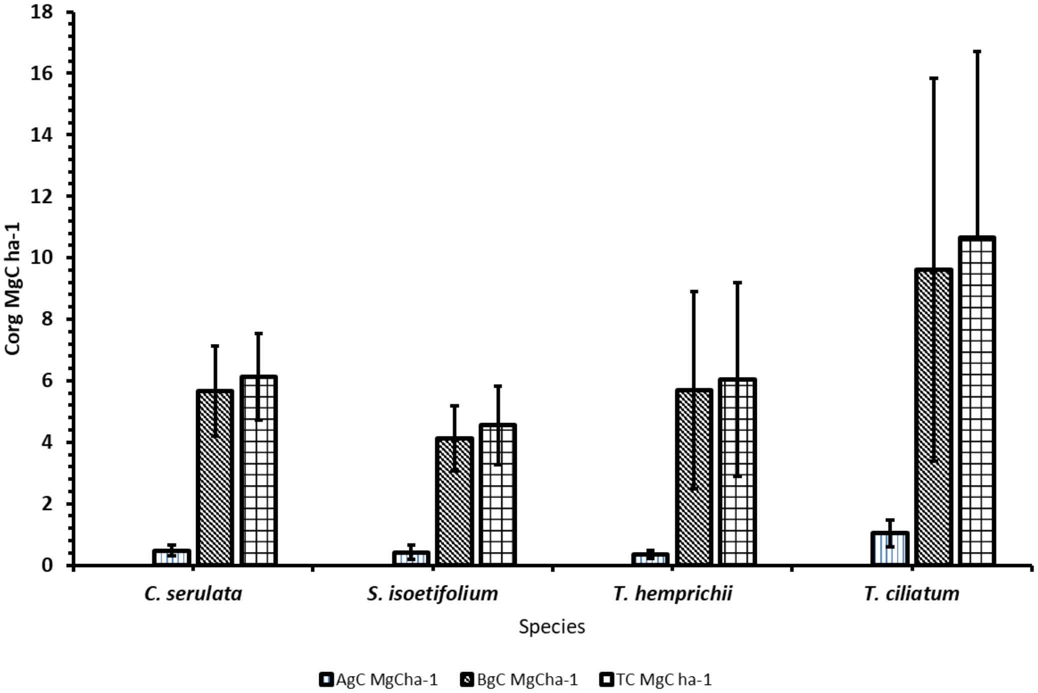


Figure 25: Vegetation aboveground (Agc), belowground (Bgc), and total biomass carbon (Tc) stocks of dominant species reported to a maximum depth of 50cm. Below ground carbon (Bgc) does not include sediment carbon.

4.4: Sediment Carbon of Seagrass Species

The mean sediment carbon stock across subtidal seagrass areas was 113±8Mg C ha^{-1}. Carbon values ranged between 20.1 and 193.1MgCha^{-1}, with no significant differences (t = -8.73; p = .237) between monospecific (S. *isoetifolium*, *C. serrulata*, *T. hemprichii*, *H. uninervis*, *T. ciliatum*, *H. ovalis*) and mixed (*S. isoetifolium* and *T. hemprichii*; *H. uninervis* and *T. hemprichii; C. serrulata* and *T. hemprichii; E. acoroides, T. hemprichii* and *S. isoetifolium; T. hemprichii, S. isoetifolium* and *C. rotundata*) seagrass meadows.

There was no significant difference in sediment carbon among the zones in subtidal area (F (3,39) = 0.35, p= 7.90). Sediment carbon stocks in *S. isoetifolium* meadows were the highest at 134±63.2 Mg C ha$^{-1,}$ range (28.3-188.8) and lowest in *T. ciliatum* meadows with a value of 98.2±43.7 Mg C ha$^{-1,}$ range (36.4-152.3 Mg C ha^{-1}); (Figure 26). However, variation in sediment carbon stocks among the four dominant seagrass species in the subtidal area was not statistically significant (F (3,16) = 0.958, p= .437).

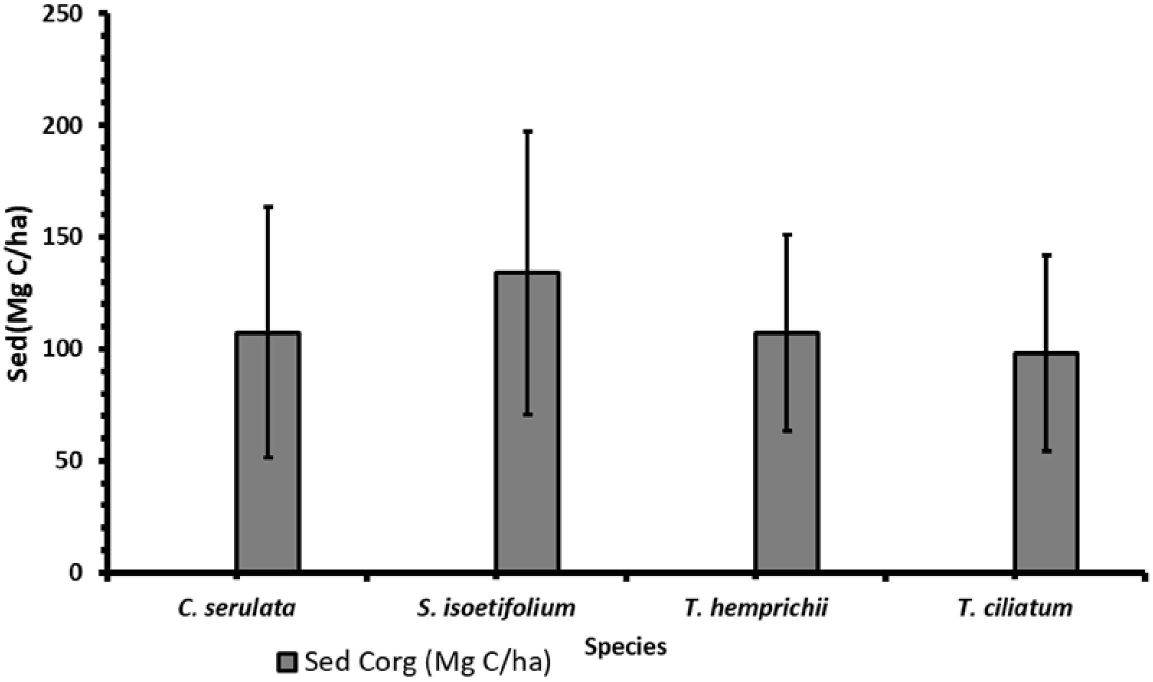


Figure 26: Corg stock in top 50cm in sediments of dominant seagrass species in subtidal area

Depth profile showed that on average, carbon concentrations in sediment were relatively higher in the first 10 cm and then decrease significantly with depth (Figure 27). Total sediment carbon stored in the subtidal areas of Gazi bay is estimated at 53,100 Mg C.

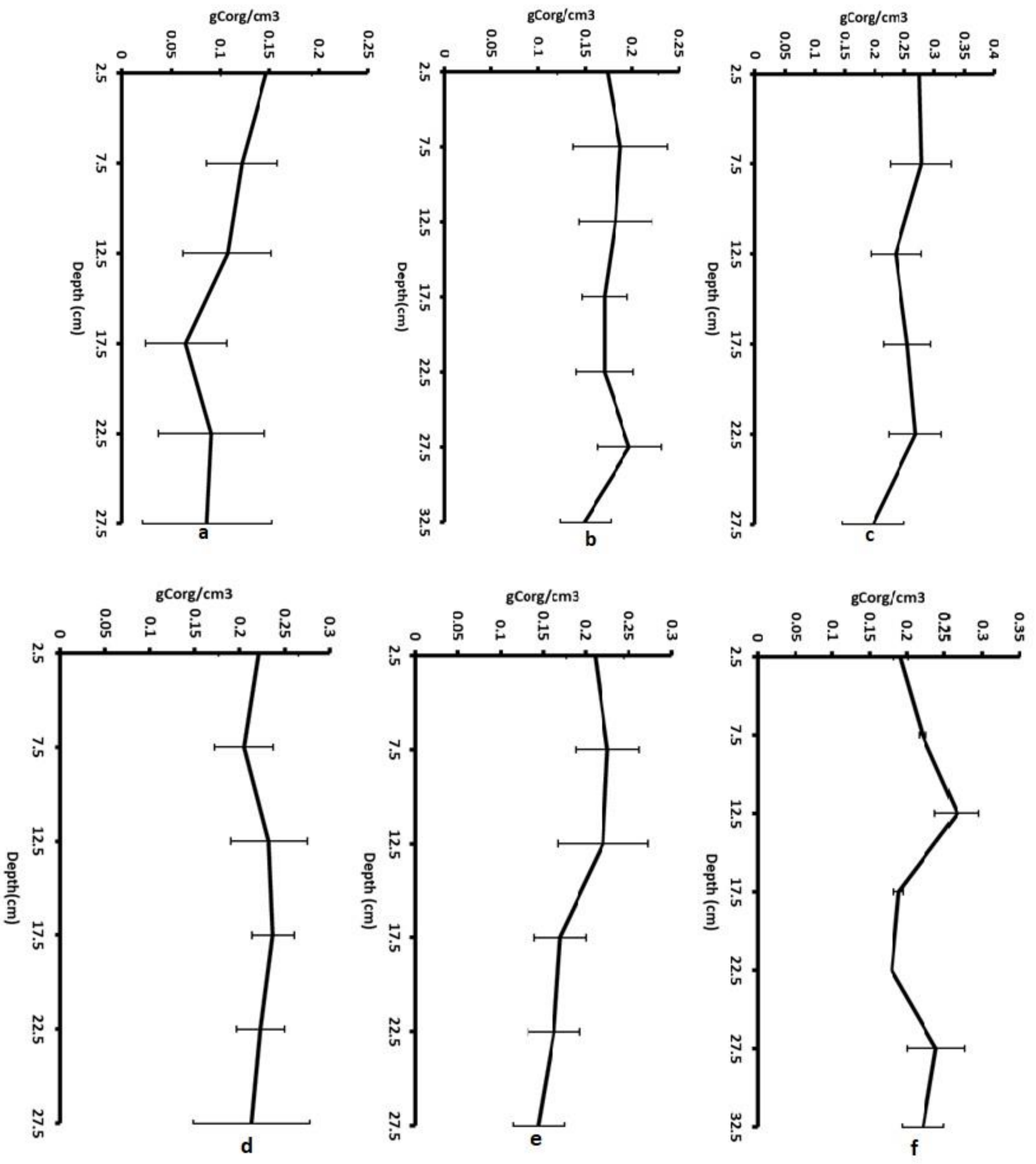


Figure 27: Depth profile in meadows of. a). *Syringodium isoetifolium* b) *Cymodocea serrulata* c) *Thalassia hemprichii* d) *Halodule uninervis* e) *Thalassodendron ciliatum* f) *Halophila ovalis*

4.5: Total Carbon Stocks in Subtidal Seagrass Meadows of Gazi Bay, Kenya

The total carbon stock from subtidal seagrass meadows which covers approximately 470 ha of the bay is estimated at about 55,742 Mg C. Sediment carbon contributes 97% of the total ecosystem carbon pool. This is followed by belowground car-bon (2%) and lastly the aboveground carbon component which comprises only 1% of the total ecosystem carbon (Table 6).

Table 6: Total carbon stocks in Subtidal seagrass meadows of Gazi Bay, Kenya

Habitat	**Area(ha)**	**Aboveground carbon* (Mg C ha-^{1})**	**Belowground carbon * (Mg C ha-^{1})**	**Sediment Carbon* (Mg C ha^{-1})**	**Total ecosystem carbon Mg C**
Subtidal	470	0.54±0.1(1)	5.06±0.7(2)	113±8(97)	55,742

*Number in parenthesis represent %

4.6: Relationship between biomass and meadow structure parameters

There was a significant positive relationship between canopy height and aboveground biomass ($r_{(38)} = .71$, $p< .001$), as well as between belowground biomass and total biomass ($r_{(38)} = .98$, $p<.001$). Conversely, shoot density and canopy height were negatively correlated ($r_{(38)} = -.34$, $p=.036$); (Table.7).

Table 7: Correlational Analysis to Test for Relationship between carbon and meadow structure parameters)

			Cover	Density	Height	Agc	Bgc	Tc
Spearman's rho	Cover	Correlation Coefficient	1.000	.310	-.004	.254	-.079	-.099
		Sig. (2-tailed)	.	.058	.979	.124	.639	.555
	Density	Correlation Coefficient	.310	1.000	-.341*	-.080	-.249	-.282
		Sig. (2-tailed)	.058	.	.036	.633	.131	.086
	Height	Correlation Coefficient	-.004	-.341*	1.000	.714**	.039	.147
		Sig. (2-tailed)	.979	.036	.	.000	.816	.377
	Agc	Correlation Coefficient	.254	-.080	.714**	1.000	-.006	.132
		Sig. (2-tailed)	.124	.633	.000	.	.973	.428
	Bgc	Correlation Coefficient	-.079	-.249	.039	-.006	1.000	.978**
		Sig. (2-tailed)	.639	.131	.816	.973	.	.000
	Tc	Correlation Coefficient	-.099	-.282	.147	.132	.978**	1.000
		Sig. (2-tailed)	.555	.086	.377	.428	.000	.

*. Correlation is significant at the .05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Agc – above ground carbon, Bgc – below ground carbon, Tc – total carbon

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1: Physico-Chemical Properties in the Sub Tidal Area

Gazi is a shallow bay, with subtidal depths ranging from 1.2 to 7.4 meters at low spring tide. Differences in zones are caused by the gradient associated with the continental shelf. Zone A is the shallowest within the littoral zone, whereas Zone D is the deepest and closest to the open ocean. However, Gazi Bay is shallow in comparison to Ungwana Bay in Northern Kenya (range 12m-100m at 1.5 nm and 7 nm respectively) (Marine *et al*.,2002). The decreasing gradient in temperature with depth across the zones is due to differences in irradiation and evaporation. Higher temperatures in Zone A can be attributed to greater heat absorption in shallow depths versus deeper areas (Serrano *et al*., 2014; Mazarrasa *et al*.,2018; Serrano *et al*.,2018) Gazi Bay's average water temperature is typical of tropical bays and comparable to the Bay of Bengal in Bangladesh, 28.02±2.49 (Pai and Govekar,2016). Salinity was also high in shallow zones of the bay compared to deep zones. This is due to the influx of fresh water from R. Mkurumudzi into the southern part of the bay (Kitheka ,1996). The salinity in Gazi Bay is higher than in the Bay of Bengal, at 28.18 ± 3.72. This could be due to differences in hydrology and fresh water sources. Unlike Gazi, which has only two seasonal sources of fresh water, the Bay of Bengal has many rivers flowing into it (Pai & Govekar, 2016). Gazi bay's PH levels are suitable for supporting life because they are more alkaline. These measurements were obtained once during the entire sampling period and due to seasonal variability presents only a snapshot.

5.2: Species Composition Distribution and Abundance of Seagrasses

This study confirmed the presence of nine seagrass species within the subtidal zone of Gazi Bay. These were found occurring either as single or mixed species stands. Previous studies (Githaiga *et al*., 2017; Juma *et al*., 2020; Coppejans *et al* 1992) reported 12 species of seagrass species in the intertidal areas of the bay. *Halodule wrightii*, *Halophila minor* and *Zostera capensis* were not encountered in our study though their presence was recorded in the intertidal area of the bay in previous studies (Githaiga *et al*., 2017; Juma *et al*., 2020). The distribution of seagrasses in the bay follows the typical distribution observed along the East African coast (Gullstrom *et al*., 2018) which is mainly attributed to the variation in substrate type, water quality parameters mainly salinity and water depth (Gullstrom *et al*., 2018). Additionally, the presence of multi-species formations in the subtidal area is also a common occurrence in tropical seagrass meadows (Aller *et al*., 2019). Seagrass communities in the bay are dominated by *T. ciliatum, T. hemprichi, E. acoroides and S. isoetifolium* (Githaiga *et al*., 2017). These species are slow growing, have high above ground to belowground biomass ratios and possess large roots and rhizomes. This makes them efficient in accumulating allochthonous material, stabilizing sediments and minimizing resuspension by reducing water motion thus inhibiting erosion and promoting deposition (Githaiga *et al*., 2017; Mateo *et al*.,2016; Mazarrasa *et al*.,2018; Dahl, 2016). 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 (Duarte and Chiscano ,1999). Human or biological disturbance to aquatic communities is known to cause dominance of pioneering species. This shift in species composition is beneficial as it allows for succession and meadow re-establishment for large and perennial species. However, shifts can sometimes lead to permanent loss of seagrass and subsequently, the loss of seagrass ecosystem services and functions that enhance the biophysical functioning of sediments (Bourque *et al.*, 2015). 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 (Bourque *et al.*, 2015. Effects of disturbance in tropical seagrass meadows have been reported by (Githaiga *et al*.,2019), and (Dahl *et al*.,2016) who highlighted that seagrass loss due to grazing and shading lead to the loss of associated fauna and carbon stocks respectively.

5.3: Seagrass Above Ground Carbon

The mean vegetation carbon for subtidal seagrasses within Gazi Bay estimated from this study was (5.60±0.66 Mg C ha^{-1}) which is above the global value (2.51 ± 0.49 Mg C ha^{-1}) as reported by (Fourqurean *et al.*, 2012). The difference in aboveground biomass observed among species is likely due to differences in species traits which affects photosynthesis, productivity and biomass accumulation rates (Lavery,2013; Mateo et al., 2006; Githaiga *et al*.,2017;2016) Therefore, large sized species such as *E. acoroides* and *T. hemprichii* tend to have higher biomass when compared to smaller species (Duarte and Chiscano 1999). Similarly, species that form high canopy and or dense canopies can accumulate more biomass and organic matter (Mazarrasa *et al*.,2018). This was confirmed by the positive correlation between above-ground biomass and canopy height as found in this study. *Thallasondedron ciliatum* had the highest above-ground biomass and also the greatest canopy height. On the other hand, there was no significant difference in aboveground carbon among the four zones in the subtidal area, this possibly indicates a relatively homogenous environment owing to the relatively small spatial extent of the subtidal area. Differences in aboveground carbon among species observed in our study is comparable to previous studies in WIO region where the large sized species *T. ciliatum* had the highest AGC stocks, 1.06 ±0.09 Mg C ha-1 followed by *S. isoetifolium*, 0.84 ± 0.30 Mg C ha^{-1} (Palacios *et al.*,2021). Smaller sized species on the other hand recorded the lowest mean ABG stocks i.e., *H. ovalis*, 0.16 ± 0.02 Mg C ha-^{1}, *Z. capensis* 0.08 ± 0.01 Mg C ha-^{1}, and *H. wrightii*, 0.03 ± 0.01 Mg C ha-^{1} (Palacios *et al.*,2021). Our values however, are lower than previous studies in Kenya, 0.89 ± 0.13 Mg C ha-^{1}(Githaiga *et al.*,2017) and Seychelles, 0.76 ± 0.04 Mg C ha-^{1} (Palacios *et al.*,2021), but higher than Madagascar, 0.06 Mg C ha-1(Palacios *et al.*,2021). The observed differences in aboveground carbon could be attributed to sample size and species composition.

5.4: Belowground Carbon of Subtidal Seagrasses

Belowground organic carbon of seagrasses in the subtidal zone of the bay did not show significant differences among species and zones. Variation among habitats is often attributed to differences in environmental conditions that influence seagrass growth such as light, temperature and nutrient supply (Lavery,2013; Mateo *et al*.,2006; Thom *et al*.,2003; Miyajima *et al*.,2015). The lack of significant variation observed in this study could be an indicator that the biophysical setting in the subtidal area is homogenous and that the species in the subtidal zone do not exhibit huge differences in productivity and accumulation of belowground biomass. On the other hand, this could indicate the general absence of herbivory of belowground biomass.

Belowground organic carbon was significantly higher than aboveground carbon and is consistent with observations from previous studies in the region (Dahl *et al*., 2016;Githaiga *et al*.,2017; Juma *et al*.,2020;Dahl *et al.*, 2020) and globally (Rohr et al.,2018; Palacios *et al*.,2021; Duarte and

Chiscano ,1999; Aller *et al*.,2019; York *et al.*,2018). Large difference in AGB and BGB is often observed in the literature and attributed to greater disturbance of above ground biomass and pressure such as grazing, higher turnover rates in AGB and higher content of refractory matter in belowground biomass (Duarte and Chiscano,1999; Govindasamy *et al*.,2013). Gullstrom *et al* (2018) and Dahl *et al* (2016) reported high relationship between belowground biomass and sediment carbon in seagrass meadows of Zanzibar, mainland Tanzania and Mozambique. This suggests that belowground biomass often dominates total biomass and ensures inflow of decay resistant organic matter, rich in lignin, into the sedimentary carbon pool (Serrano *et al*., 2014; Harcourt *et al*.,2018). These BGC stocks are higher than those reported from other studies in Tanzania; 1.92 ± 0.20 Mg C ha-^{1}, Mozambique, 1.58 ± 0.24 Mg C ha-^{1} and Mauritius; 0.78 ± 0.02 Mg C ha-^{1}(Gullstrom *et al*.,2018; Palacios *et al*.,2021).

5.5: Sediment Organic Carbon Stocks in Subtidal Area of Gazi Bay

Sediment C_{org} from subtidal seagrasses in the bay yielded a mean of 113±8 Mg C ha^{-1}. This is just below the global range of 115.5 - 829.2 Mg C ha^{-1} (Fourqurean *et al*., 2012). Available information from a global database (Fourqurean *et al*., 2012)., revealed that the carbon storage capacity within one meter depth of sediment of seagrasses was 19.9 Pg with an average of 137.7 Mg C·ha^{-1} though with large variation globally (Fourqurean *et al*., 2012). The Mediterranean bioregion had the highest C stock at 372±74.5 2Mg C·ha^{-1} while the lowest was in the Indo-pacific bioregion at 23.6±8.3 2 Mg C·ha^{-1} (Fourqurean *et al*., 2012). Similar variability has also been observed on regional, meadow, landscape scale and across species around the world; where there was an 18-fold difference in C stocks (Lavery, 2013). 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; Hemminga *et al*.,1994; Bouillon 2005).

Seagrasses in the subtidal zone are mostly submerged, and with reduced photosynthetic activities (Serrano et al 2014) culminating to low biomass increment. However, through allochthonous process, the sedimentary carbon pool in subtidal seagrass meadows can be enriched by organic carbon from the nearby mangroves and other terrestrial ecosystems (Palacios *et al*.,2012; Signa *et al* 2017; Bouillon et al 2007). Typically, the transport of organic matter and fine sediment from mangrove forest reduces with increased distance from the mangrove fringed creeks (Huxham *et al* 2., 2018). This is supported by relatively higher turbidity in Zone A closer to the intertidal areas and relatively low turbidity observed in meadows in zone D. This might have an implication in the subtidal area as gradient is already reduced. The absence of significant differences in sedimentary organic carbon stocks across the four subtidal zones supports this hypothesis. It also further indicates a fairly homogenous sedimentary substrate and almost equal capacity of seagrass meadows to filter and facilitate the deposition of organic matter regardless of the meadow type. This is also supported by the lack of significant differences in sedimentary carbon among species and between meadow type (mixed or monospecific). Similar results were reported by (Lavery, 2013) who did not find significant differences between the soil C_{org} stocks in seagrass meadows occurring in shallow and deep subtidal habitats in Australia. This was also the case for (York, 2018), who found no evidence of a decreasing gradient in carbon stock with depth in Lizard Island within the Great Barrier Reef. However, small scale spatial variation has been shown to exist in seagrass meadows by (Serrano *et al*., 2016; Kennedy, 2010). Their studies showed a fourfold decrease in C_{org} stocks from shallow to deep meadows of *Posidonia sinuosa* in Australia (averaging 7.0 and 1.8 kg m ^{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 in Spain (200 and 19 kg m^{2} average, respectively; top 2.7m of sediment). Additionally, Dahl *et al* (2016), in a study conducted in four distinct areas of Europe i.e., Gullmar Fjord on the Swedish Skagerrak coast, Askö in the Baltic Sea, Sozopol in the Black Sea and Ria Formosa in southern Portugal; also reported that sediment characteristics (dry bulk density, grain size, porosity) and water depth affect *C*org storage.

The OC stocks in the top 50cm of sediment in the subtidal area of Gazi Bay is lower than those in the Mediterranean bioregion, 372 ± 74.5 2Mg C ha^{-1} (Fourqurean *et al*.,2012), temperate Northern hemisphere region (Rohr et al 2018), and the global average for all seagrass species (Fourqurean *et al*.,2012). This value, is also lower than those of the United Kingdom (140 ±73.32 Mg C h-1(Rohr *et al*., 2018). However, it is higher than the Arabian Peninsula, 49.1 ± 7.0 Mg C ha^{-1} (Campbell *et al*., 2015), and the Pacific Northwest region (71.68 Mg C h-1) (Prentice *et al*., 2020). This value is also lower than the average sediment organic carbon stock in WIO, which is 116 24.1 Mg C ha^{-1}(Palacios *et al*., 2021); (However these values represent stocks in 1m depth). Our estimates of carbon stocks are low compared to those in Kenya 236 ± 24 Mg C ha^{-1} (Githaiga.,2017) but higher than stock estimates from Zanzibar 33.9±7.7 Mg C ha^{-1} (Belshe et al.,2018), Mozambique, 28.99 ± 13.70 tonnes C ha^{-1} and Tanzania 40.14 ± 3.45 tonnes C ha^{-1} (York 2018; Palacios et al.,2012). Our values are also higher than most studies reporting shallow cores (25cm) e.g Denmark, Baltic Sea, North Sea 43.25 ± 11.88 MgCha-^{1}(Rohr *et al* .,2018); UK, English Channel, 33.71 ± 16.26 MgCha-^{1} (Green *et al* 2018); Sweden, Baltic Sea 20 ± 21.21

MgCha-^{1} (Jankowska *et al* .,2016);; Portugal, North Atlantic 10 ± 1.20 MgCha-^{1} (Jankowska *et al* .,2016); Finland, Baltic Sea 627.00 ± 25.00 MgCha-^{1}(Rohr *et al*., 2018); Bulgaria, Black Sea 500.00 ± 50.00 MgCha-^{1} (Garcias *et al* .,2019).Organic matter content in the sediment was higher in the top layer representing the accumulation of organic matter in the surface sediments. The subsequent decrease in organic carbon content with depth is attributed to remineralization or breakdown of organic matter by anaerobes (Kennedy *et al*.,2010; Bouillon *et al*.,2005; Campbell *et al.*,2015; Serrano *et al*.,2018). While we acknowledge that the scaling-up approach recommended in the Blue Carbon Manual (Howard et al.,2014) can under some circumstances, overestimate carbon stocks (Gorman 2020; Asplund *et al*.,2021) the absence of data on environmental covariates in Gazi Bay means that modelling is not currently a viable alternative approach but one to consider for future studies. Conversely, while uncertainties caused by extrapolation of sediment to 1m depth have been avoided, there is a possibility that this estimate has been underestimated. Due to the shallow cores obtained in most areas during sampling, this study only considered the top 50cm depth in the subtidal area. Other areas may have deeper sediment and are thus more likely to harbor larger stocks. Future research at Gazi Bay should aim to identify areas with deeper subtidal soils, and also quantify the sediment accumulation rate and the inorganic carbon within the subtidal area.

5.6: Total Carbon Stocks of the Seagrass Meadows in Gazi Bay

The mean carbon density for the 470 ha of subtidal seagrass meadows in Gazi Bay was 118.6 ±6 Mg C·ha^{-1}, giving a total stock of 55,742 Mg C, with the sediment organic carbon pool contributing 97% of the total ecosystem carbon stocks. Similar carbon allocations have been obtained in previous research conducted within the intertidal meadows as well as seagrasses in creeks, where the sediment carbon pool was larger than biomass at (97%) and (3%) respectively (Githaiga *et al*.,2017; Juma *et al*.,2020). This highlights the significance of the sediment carbon pool in seagrass ecosystems, as the organic carbon in sediment is more stable and can be stored for millennia in contrast to that stored in living biomass (Howard et al.,2014; Fourqurean et al.,2021). The proximity of mangrove forest and seagrass meadows, combined with hydrodynamic and geomorphologic forcing, necessitates the inclusion of allochthonous material in sediment of seagrass ecosystem (Bouillon et al.,2005; Huxham et al.,2018). However, this study did not assess the sources of carbon within the subtidal area, which can be an important influencing factor determining carbon stocks (Green *et al*.,2018; Macreadie et al.,2014).

Previous estimates of the total carbon stored by seagrass meadows within the bay by (Githaiga *et al*.,2017) was 168,642 Mg C. However, this study arrived at the estimate by using values obtained from the intertidal seagrass meadows only, excluding sub-tidal and creek seagrasses, and thus is certain to have underestimated the total carbon stored by seagrasses across the entire bay. Combining the subtidal carbon stocks with the open intertidal (Githaiga *et al*., 2017) and mangrove fringed creeks (Juma *et al*.,2020), provides a better and more robust estimate of the total carbon stocks in seagrass ecosystems within the bay. Pooling stocks from the three zones, the total carbon stored in seagrass meadows of the bay is now estimated to be 196,721 Mg C (Table 8). Intergovernmental Panel on Climate Change (IPCC) and other studies provide a range of possible fates for ‘near-surface carbon’ upon conversion from 25% to 100% emissions to the atmosphere depending on land use types (IPCC, 2014). Using the low-end figure of 25% emissions, the potential carbon loss from seagrasses in Gazi Bay is estimated at 9,216 Mg C ha^{-1}, equivalent to 33,822.72Mg CO$_2$e yr^{-1}.

Table 8: total ecosystem carbon in seagrass meadows of Gazi bay

Habitat	**Area(ha)**	**Vegetation carbon (Mg C ha-^{1})**	**Sediment Carbon (Mg C ha^{-1})**	**Total ecosystem carbon* Mg C**	**Source**
Eastern Creek	50	10.2 ± 0.6	258 ±90	13,420 (7)	*Juma et al (2020*)
Western creek	70	4.3 ± 0.3	107 ±21	7,769± (4)	*Juma et al (2020)*
Intertidal	495	5.9 ± 0.9	236 ± 24	119,790(61)	*Githaiga et al (2017)*
Subtidal	470	5.6±0.7	113 ±8	55,742(28)	This study
Total				**196,721**	This study

*Number in parenthesis represent %

5.6: Conclusion

This study observed the existence of nine species of seagrass in the subtidal zone of Gazi Bay. It further shows that subtidal seagrass meadows store a substantial proportion of the carbon stocks and contribute significantly to the total seagrass ecosystem carbon stocks in Gazi Bay. This should strongly encourage targeted evaluations of subtidal seagrass meadows when estimating total carbon stocks in any carbon accounting frameworks, especially in regions where this information is limited (e.g., those in which resources and water quality have historically restricted subtidal sampling). Sediment carbon was the largest carbon pool (97%), followed by belowground biomass at (2%) and above ground biomass making up the remaining (1%). Even though different species have different capacities to sequester carbon evidenced by differences in their biomass, sediment carbon appears relatively homogenous. It is likely that species composition is not a major factor influencing the accumulation and storage of carbon in the subtidal sediments of Gazi bay.

This study builds on previous regional and global studies (Gullstrom *et al*., 2018; Githaiga *et al* 2017; Juma et al 2020; Dahl *et al*., 2016) and provides information crucial to facilitate expansion of carbon offset projects that include seagrass meadows. Furthermore, these findings add to the growing database of carbon inventories demonstrating the significance of subtidal and deep-water seagrasses as Blue Carbon sinks (Jankowska *et al*., 2016). These trends emphasize the importance of obtaining local values for carbon sequestration and storage in coastal habitats, particularly in the context of carbon credits and offset schemes. Finally, these findings highlight the risks of basing total ecosystem carbon on intertidal meadows only, as this is likely to underestimate total stocks. Seagrass ecosystems provide numerous goods and services, and their role as active carbon sinks presents a nature-based solution to mitigate climate change. As a result, improving and maintaining the integrity of seagrass ecosystems is critical for improving livelihoods, conserving biodiversity, and regulating climate. This study builds on previous studies in the area and provides information crucial to facilitate expansion of carbon offset to include seagrass beds. Additionally, these findings contribute to the growing database of carbon inventories that’s useful for implementing the country’s efforts to incorporate blue carbon ecosystems into nationally determined contributions (NDCs). This further advocate the need to adopt better conservation strategies for seagrass ecosystem. Seagrass ecosystems provide several goods and services, and their role as active carbon sinks is a natural solution to mitigate climate change. As a result, improving and maintaining the integrity of the seagrass ecosystem is critical for improving livelihoods, conserving biodiversity, and regulating climate.

5.7: Limitation of the Study

The sub tidal areas remain inundated even during low spring tides, therefore; sampling had to be done through SCUBA diving. With high expenses involved in the planning, purchasing and hiring of dive equipment, the sampling time had to be short. Additionally, the sampling period during South East Monsoon period (March -October) is characterized by rough seas, strong waves and reduced water clarity. This limited the data collection process to times of the day when water was clear and the sea was calm.

5.8: Recommendations

According to the findings of the current study, the following recommendations are made:

i. To improve management and implementation of carbon conservation strategies, assessments of seagrass species distribution, abundance, and carbon stocks should be conducted in other parts of Kenya's coastline.
ii. Setting carbon monitoring plots in intertidal area will help reduce pressure on seagrass ecosystems, prevent potential emission of stored carbon and further enhance accumulation of carbon stocks and other environmental benefits. Furthermore, the intertidal area is ideal due to ease of access and thus activities such as monitoring and surveillance will be conducted easily at minimal expenses.
iii. Since this study only accounted for organic carbon stocks, future research, should seek to assess the sequestration rates as well as determine the sources of organic matter in the sediments of seagrass meadows in the bay. Understanding the age and stability of carbon stocks will help in developing predictive models that will inform future conservation efforts in the bay.

REFERENCES

Ackerman, J.D., 2007. Sexual reproduction of seagrasses: pollination in the marine context. In Seagrasses: Biology, Ecology and Conservation (pp. 89-109). Springer, Dordrecht.

Aller, E.A., Eklöf, J.S., Gullström, M., Kloiber, U., Linderholm, H.W. and Nordlund, L.M., 2019. Temporal variability of a protected multispecific tropical seagrass meadow in response to environmental change. Environmental monitoring and assessment, 191(12), pp.1-15.

Arias-Ortiz, A., Serrano, O., Masqué, P., Lavery, P.S., Mueller, U., Kendrick, G.A., Rozaimi, M., Esteban, A., Fourqurean, J.W., Marbà, N.J.N.C.C. and Mateo, M.A., 2018. A marine heatwave drives massive losses from the world's largest seagrass carbon stocks. Nature Climate Change, 8(4), pp.338-344.

Asplund, M.E.; Dahl, M.; Ismail, R.O.; Arias-Ortiz, A.; Deyanova, D.; Franco, J.N.; Hammar, L.; Hoamby, A.I.; Linderholm,H.W.; Lyimo, L.D.; et al. Dynamics and fate of blue carbon in a mangrove–seagrass seascape: Influence of landscape configuration and land-use change. Landsc. Ecol. 2021, 36, 1489–1509.

Atwood, T.B., Connolly, R.M., Ritchie, E.G., Lovelock, C.E., Heithaus, M.R., Hays, G.C., Fourqurean, J.W. and Macreadie, P.I., 2015. Predators help protect carbon stocks in blue carbon ecosystems. Nature Climate Change, 5(12), pp.1038-1045.

Bandeira, S.O. and Björk, M., 2001. Seagrass research in the eastern Africa region: Emphasis on diversity, ecology and ecophysiology. South African Journal of Botany, 67(3), pp.420-425.

Behringer, D.C., Butler IV, M.J., Herrnkind, W.F., Hunt, J.H., Acosta, C.A. and Sharp, W.C., 2009. Is seagrass an important nursery habitat for the Caribbean spiny lobster, Panulirus argus, in Florida?. New Zealand Journal of Marine and Freshwater Research, 43(1), pp.327-337.

Belshe, E.F.; Hoeijmakers, D.; Herran, N.; Mtolera, M.; Teichberg, M. Seagrass community-level controls over organic carbon storage are constrained by geophysical attributes within meadows of Zanzibar, Tanzania. Biogeosciences 2018, 15, 4609–4626.

Blandon, A. and Zu Ermgassen, P.S., 2014. Quantitative estimate of commercial fish enhancement by seagrass habitat in southern Australia. Estuarine, Coastal and Shelf Science, 141, pp.1-8.

Bouillon, S., Dehairs, F., Abril, G. and Borges, A., 2005. Distribution and sources of organic carbon in a mangrove seagrass ecosystem (Gazi Bay, Kenya).

Bouillon, S., Dehairs, F., Velimirov, B., Abril, G. and Borges, A.V., 2007. Dynamics of organic and inorganic carbon across contiguous mangrove and seagrass systems (Gazi Bay, Kenya). Journal of Geophysical Research: Biogeosciences, 112(G2).

Bourque, A.S., Kenworthy, W.J. and Fourqurean, J.W., 2015. Impacts of physical disturbance on ecosystem structure in subtropical seagrass meadows. Marine Ecology Progress Series, 540, pp.27-41.

Burdige, D.J., 2007. Preservation of organic matter in marine sediments: controls, mechanisms, and an imbalance in sediment organic carbon budgets? Chemical reviews, 107(2), pp.467-485.

Burdige, D.J., 2021. Geochemistry of marine sediments. Princeton university press.

Campbell, J.E.; Lacey, E.A.; Decker, R.A.; Crooks, S.; Fourqurean, J.W. Carbon storage in seagrass beds of Abu Dhabi, United Arab Emirates. Estuaries Coasts 2015, 38, 242–251.

Christianen, M.J., van Belzen, J., Herman, P.M., van Katwijk, M.M., Lamers, L.P., van Leent, P.J. and Bouma, T.J., 2013. Low-canopy seagrass beds still provide important coastal protection services. PloS one, 8(5), p.e62413.

Coles, R., Grech, A., Rasheed, M., McKenzie, L., Unsworth, R. and Short, F., 2011. Seagrass ecology and threats in the tropical Indo-Pacific bioregion. Seagrass: Ecology, Uses and Threats. Hauppauge: Nova Science Publishers, pp.225-240.

Coles, R.G., Long, W.L., Watson, R.A. and Derbyshire, K.J., 1993. Distribution of seagrasses, and their fish and penaeid prawn communities, in Cairns Harbour, a tropical estuary, northern Queensland, Australia. Marine and Freshwater Research, 44(1), pp.193-210.

Coppejans, E., Beeckman, H. and De Wit, M., 1992. The seagrass and associated macroalgal vegetation of Gazi Bay (Kenya). In The Ecology of Mangrove and Related Ecosystems (pp. 59-75). Springer, Dordrecht.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'neill, R.V., Paruelo, J. and Raskin, R.G., 1997. The value of the world's ecosystem services and natural capital. nature, 387(6630), pp.253-260.

Cullen-Unsworth, L.C., Nordlund, L.M., Paddock, J., Baker, S., McKenzie, L.J. and Unsworth, R.K., 2014. Seagrass meadows globally as a coupled social–ecological system: Implications for human wellbeing. Marine Pollution Bulletin, 83(2), pp.387-397.

Dahl, M., Deyanova, D., Lyimo, L.D., Näslund, J., Samuelsson, G.S., Mtolera, M.S., Björk, M. and Gullström, M., 2016. Effects of shading and simulated grazing on carbon sequestration in a tropical seagrass meadow. Journal of Ecology, 104(3), pp.654-664.

Dahl, M., Deyanova, D., Gütschow, S., Asplund, M.E., Lyimo, L.D., Karamfilov, V., Santos, R., Björk, M. and Gullström, M., 2016. Sediment properties as important predictors of carbon storage in Zostera marina meadows: a comparison of four European areas. PLoS One, 11(12), p.e0167493.

De Falco, G., Baroli, M., Cucco, A. and Simeone, S., 2008. Intrabasinal conditions promoting the development of a biogenic carbonate sedimentary facies associated with the seagrass Posidonia oceanica. Continental Shelf Research, 28(6), pp.797-812.

Den Hartog, C. and Kuo, J., 2007. Taxonomy and biogeography of seagrasses. In Seagrasses: biology, ecologyand conservation (pp. 1-23). Springer, Dordrecht.

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

Dewsbury, B.M., Bhat, M. and Fourqurean, J.W., 2016. A review of seagrass economic valuations: gaps and progress in valuation approaches. Ecosystem Services, 18, pp.68-77.

Diop, S. and Scheren, P.A., 2016. Sustainable oceans and coasts: Lessons learnt from Eastern and Western Africa. Estuarine, Coastal and Shelf Science, 183, pp.327-339.

Duarte, B., Martins, I., Rosa, R., Matos, A.R., Roleda, M.Y., Reusch, T.B., Engelen, A.H., Serrão, E.A., Pearson, G.A., Marques, J.C. and Caçador, I., 2018. Climate change impacts on seagrass meadows and macroalgal forests: an integrative perspective on acclimation and adaptation potential. Frontiers in Marine Science, 5, p.190.

Duarte, C.M. Seagrass nutrient content. Mar. Ecol. Prog. Ser. 1990, 6, 201–207.

Duarte, C.M., 2002. The future of seagrass meadows. Environmental conservation, 29(2), pp.192-206.

Duarte, C.M., 2013. The role of seagrass in climate change mitigation and adaptation. The University of Western Australia and Spanish National Research Council, Bonn.

Duarte, C.M. and Chiscano, C.L., 1999. Seagrass biomass and production: a reassessment. Aquatic botany, 65(1-4), pp.159-174.

Duffy, J.E., 2006. Biodiversity and the functioning of seagrass ecosystems. Marine Ecology Progress Series, 311, pp.233-250.

Fonseca, M.S., Kenworthy, W.J. and Whitfield, P.E., 2000. Temporal dynamics of seagrass landscapes: a preliminary comparison of chronic and extreme disturbance events. Biologia Marina Mediterranea, 7(2), pp.373-376.

Fourqurean, J.W., Duarte, C.M., Kennedy, H., Marbà, N., Holmer, M., Mateo, M.A., Apostolaki, E.T., Kendrick, G.A., Krause-Jensen, D., McGlathery, K.J. and Serrano, O., 2012. Seagrass ecosystems as a globally significant carbon stock. Nature geoscience, 5(7), pp.505-509.

Fraser, M.W., Kendrick, G.A., Statton, J., Hovey, R.K., Zavala-Perez, A. and Walker, D.I., 2014. Extreme climate events lower resilience of foundation seagrass at edge of biogeographical range. Journal of Ecology, 102(6), pp.1528-1536.

Freeman, A.S., Short, F.T., Isnain, I., Razak, F.A. and Coles, R.G., 2008. Seagrass on the edge: land-use practices threaten coastal seagrass communities in Sabah, Malaysia. Biological Conservation, 141(12), pp.2993-3005.

Garcias-Bonet, N.; Delgado-Huertas, A.; Carrillo-de-Albornoz, P.; Anton, A.; Almahasheer, H.; Marbà, N.; Hendriks, I.E.;Krause-Jensen, D.; Duarte, C.M. Carbon and nitrogen concentrations, stocks, and isotopic compositions in Red Sea seagrass and mangrove sediments. Front. Mar. Sci. 2019, 6, 267.

Georgiou, D., Alexandre, A., Luis, J. and Santos, R., 2016. Temperature is not a limiting factor for the expansion of Halophila stipulacea throughout the Mediterranean Sea. Marine Ecology Progress Series, 544, pp.159-167.

Githaiga, M.N., Gilpin, L., Kairo, J.G. and Huxham, M., 2016. Biomass and productivity of seagrasses in Africa. Botanica marina, 59(2-3), pp.173-186.

Githaiga, M.N., Kairo, J.G., Gilpin, L. and Huxham, M., 2017. Carbon storage in the seagrass meadows of Gazi Bay, Kenya. Plos one, 12(5), p.e0177001.

Gorman, D.; Sumida, P.Y.; Figueira, R.C.; Turra, A. Improving soil carbon estimates of mudflats in Araçá Bay using spatial models that consider riverine input, wave exposure and biogeochemistry. Estuar. Coast. Shelf Sci. 2020, 238, 106734.

Govindasamy, C., Arulpriya, M., Anantharaj, K., Ruban, P. and Srinivasan, R., 2013. Seasonal variations in seagrass biomass and productivity in Palk Bay, Bay of Bengal, India. International Journal of Biodiversity and Conservation, 5(7), pp.408-417.

Grech, A., Chartrand-Miller, K., Erftemeijer, P., Fonseca, M., McKenzie, L., Rasheed, M., Taylor, H. and Coles, R., 2012. A comparison of threats, vulnerabilities and management approaches in global seagrass bioregions. Environmental Research Letters, 7(2), p.024006.

Green, A.; Chadwick, M.A.; Jones, P.J. Variability of UK seagrass sediment carbon: Implications for blue carbon estimates and marine conservation management. PLoS ONE 2018, 13, e0204431.

Gullström, M., de la Torre Castro, M., Bandeira, S.O., Björk, M., Dahlberg, M., Kautsky, N., Rönnbäck, P. and Öhman, M.C., 2002. Seagrass ecosystems in the western Indian Ocean. Ambio, pp.588-596.

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

Harrison, P.G. and Bigley, R.E., 1982. The recent introduction of the seagrass Zostera japonica Aschers. and Graebn. to the Pacific coast of North America. Canadian Journal of Fisheries and Aquatic Sciences, 39(12), pp.1642-1648.

Hemminga, M.A., Slim, F., Kazungu, J., Ganssen, G.M., Nieuwenhuize, J. and Kruyt, N.M., 1994. Carbon outwelling from a mangrove forest with adjacent seagrass beds and coral reefs (Gazi Bay, Kenya). Marine Ecology Progress Series, 106.

Hemminga, M.A. and Mateo, M.A., 1996. Stable carbon isotopes in seagrasses: variability in ratios and use in ecological studies. Marine Ecology Progress Series, 140, pp.285-298.

Howard, J., Hoyt, S., Isensee, K., Telszewski, M. and Pidgeon, E., 2014. Coastal blue carbon: methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrasses.

Huxham, M., Whitlock, D., Githaiga, M. and Dencer-Brown, A., 2018. Carbon in the coastal seascape: how interactions between mangrove forests, seagrass meadows and tidal marshes influence carbon storage. Current forestry reports, 4(2), pp.101-110.

Iacarella, J.C., Adamczyk, E., Bowen, D., Chalifour, L., Eger, A., Heath, W., Helms, S., Hessing-Lewis, M., Hunt, B.P., MacInnis, A. and O'Connor, M.I., 2018. Anthropogenic disturbance homogenizes seagrass fish communities. Global change biology, 24(5), pp.1904-1918.

Intergovernmental Panel on Climate Change. Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories:Wetlands; IPCC: Geneva, Switzerland, 2014.

Jackson, E.L., Rowden, A.A., Attrill, M.J., Bossey, S.J. and Jones, M.B., 2001. The importance of seagrass beds as a habitat for fishery species. Oceanography and marine biology, 39, pp.269-304.

Jankowska, E.; Michel, L.N.; Zaborska, A.; Włodarska-Kowalczuk, M. Sediment carbon sink in low-density temperate eelgrass meadows (Baltic Sea). Journal of Geophysical Research: Biogeosciences 2016, 121, 2918–2934.

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

Kelleway, J.J., Serrano, O., Baldock, J.A., Burgess, R., Cannard, T., Lavery, P.S., Lovelock, C.E., Macreadie, P.I., Masqué, P., Newnham, M. and Saintilan, N., 2020. A national approach to greenhouse gas abatement through blue carbon management. Global Environmental Change, 63, p.102083.

Kennedy, H., Beggins, J., Duarte, C.M., Fourqurean, J.W., Holmer, M., Marbà, N. and Middelburg, J.J., 2010. Seagrass sediments as a global carbon sink: Isotopic constraints. Global biogeochemical cycles, 24(4).

Kitheka, J.U., 1996. Water circulation and coastal trapping of brackish water in a tropical mangrove-dominated bay in Kenya. Limnology and Oceanography, 41(1), pp.169-176.

Koch, E.W.; Sanford, L.P.; Chen, S.N.; Shafer, D.J.; Smith, J.M. Waves in Seagrass Systems: Review and Technical Recommendations. 2006. Available online: https://apps.dtic.mil/sti/pdfs/ADA458760.pdf (accessed on 10.8.2022).

Krause-Jensen, D. and Duarte, C.M., 2014. Expansion of vegetated coastal ecosystems in the future Arctic. Frontiers in Marine Science, 1, p.77.

Kristensen, E., 2000. Organic matter diagenesis at the oxic/anoxic interface in coastal marine sediments, with emphasis on the role of burrowing animals. In Life at interfaces and under extreme conditions (pp. 1-24). Springer, Dordrecht.

Lavery, P.S., Mateo, M.Á., Serrano, O. and Rozaimi, M., 2013. Variability in the carbon storage of seagrass habitats and its implications for global estimates of blue carbon ecosystem service. PloS one, 8(9), p.e73748.

Lovelock, C.E., Atwood, T., Baldock, J., Duarte, C.M., Hickey, S., Lavery, P.S., Masque, P., Macreadie, P.I., Ricart, A.M., Serrano, O. and Steven, A., 2017. Assessing the risk of carbon dioxide emissions from blue carbon ecosystems. Frontiers in Ecology and the Environment, 15(5), pp.257-265.

Macreadie, P.I., Baird, M.E., Trevathan-Tackett, S.M., Larkum, A.W.D. and Ralph, P.J., 2014. Quantifying and modelling the carbon sequestration capacity of seagrass meadows–a critical assessment. Marine pollution bulletin, 83(2), pp.430-439.

Macreadie, P.I., Costa, M.D., Atwood, T.B., Friess, D.A., Kelleway, J.J., Kennedy, H., Lovelock, C.E., Serrano, O. and Duarte, C.M., 2021. Blue carbon as a natural climate solution. Nature Reviews Earth & Environment, 2(12), pp.826-839.

Mateo, M., Cebrián, J., Dunton, K. and Mutchler, T., 2006. Carbon flux in seagrass ecosystems. Seagrasses: biology, ecology and conservation, pp.159-192.

Mateo, M.A., Romero, J., Pérez, M., Littler, M.M. and Littler, D.S., 1997. Dynamics of millenary organic deposits resulting from the growth of the Mediterranean seagrass Posidonia oceanica. Estuarine, Coastal and Shelf Science, 44(1), pp.103-110.

Marine, K. Current Status of Trawl Fishery of Malindi-Ungwana Bay Final Report December 2002; Kenya Marine and Fisheries Research Institute: Mombasa, Kenya, 2002.

Mazarrasa, I., Marbà, N., Lovelock, C.E., Serrano, O., Lavery, P.S., Fourqurean, J.W., Kennedy, H., Mateo, M.A., Krause-Jensen, D., Steven, A.D. and Duarte, C.M., 2015. Seagrass meadows as a globally significant carbonate reservoir. Biogeosciences, 12(16), pp.4993-5003.

Mazarrasa, I., Samper-Villarreal, J., Serrano, O., Lavery, P.S., Lovelock, C.E., Marbà, N., Duarte, C.M. and Cortés, J., 2018. Habitat characteristics provide insights of carbon storage in seagrass meadows. Marine pollution bulletin, 134, pp.106-117.

McClanahan, T.R. Seasonality in East Africa’s Coastal Waters. 1988. Available online: https://www.intres.com/articles/meps/44/m044p191.pdf (accessed on 10.8.2022).

Mcleod, E.; Chmura, G.L.; Bouillon, S.; Salm, R.; Björk, M.; Duarte, C.M.; Lovelock, C.E.; Schlesinger, W.H.; Silliman, B.R. A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. Front. Ecol. Environ. 2011, 9, 552–560.

Miyajima, T., Hori, M., Hamaguchi, M., Shimabukuro, H., Adachi, H., Yamano, H. and Nakaoka, M., 2015. Geographic variability in organic carbon stock and accumulation rate in sediments of East and Southeast Asian seagrass meadows. Global Biogeochemical Cycles, 29(4), pp.397-415.

Musembi, P., Fulanda, B., Kairo, J. and Githaiga, M., 2019. Species composition, abundance and fishing methods of small-scale fisheries in the seagrass meadows of Gazi Bay, Kenya. Journal of the Indian Ocean Region, 15(2), pp.139-156.

Nellemann, C. and Corcoran, E. eds., 2009. Blue carbon: the role of healthy oceans in binding carbon: a rapid response assessment. UNEP/Earthprint.

Nordlund, L.M., Unsworth, R.K., Gullström, M. and Cullen-Unsworth, L.C., 2018. Global significance of seagrass fishery activity. Fish and Fisheries, 19(3), pp.399-412.

Ochieng, C.A. and Erftemeijer, P.L.A., 2003. The seagrasses of Kenya and Tanzania. World Atlas of Seagrasses, 82.

Olsen, Y.S., Fraser, M.W., Martin, B.C., Pomeroy, A., Lowe, R., Pedersen, O. and Kendrick, G.A., 2018. In situ oxygen dynamics in rhizomes of the seagrass Posidonia sinuosa: impact of light, water column oxygen, current speed and wave velocity. Marine Ecology Progress Series, 590, pp.67-77.

Ondiviela, B., Losada, I.J., Lara, J.L., Maza, M., Galván, C., Bouma, T.J. and van Belzen, J., 2014. The role of seagrasses in coastal protection in a changing climate. Coastal Engineering, 87, pp.158-168.

Oreska, M.P., McGlathery, K.J. and Porter, J.H., 2017. Seagrass blue carbon spatial patterns at the meadow-scale. PloS one, 12(4), p.e0176630.

Orth, R.J., Carruthers, T.J., Dennison, W.C., Duarte, C.M., Fourqurean, J.W., Heck, K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Olyarnik, S. and Short, F.T., 2006. A global crisis for seagrass ecosystems. Bioscience, 56(12), pp.987-996.

Pai, I.K.; Govekar, K. An Extensive Study on Physico-Chemical Parameters of Bay of Bengal and Central Indian Ocean Basin. 2016. Available online: http://medcraveonline.com/JAMB/JAMB-04-00097.pdf (accessed on 9.8. 2022).

Palacios, M.M.; Waryszak, P.; de Paula Costa, M.D.; Wartman, M.; Ebrahim, A.; Macreadie, P.I. Literature Review: Blue Carbon Research in the Tropical Western Indian Ocean. 2021. Available online:https://seyccat.org/wpcontent/uploads/2020/01/BlueCarbonLab_LitReport_Seychelles_20210301_final.pdf (accessed on 12.6.2022).

Pedersen, M.F., Paling, E.I. and Walker, D.I., 1997. Nitrogen uptake and allocation in the seagrass Amphibolis antarctica. Aquatic Botany, 56(2), pp.105-117.

Peel, M.C., Finlayson, B.L. and McMahon, T.A., 2007. Updated world map of the Köppen-Geiger climate classification. Hydrology and earth system sciences, 11(5), pp.1633-1644.

Pendleton, L., Donato, D.C., Murray, B.C., Crooks, S. and Jenkins, W.A., Si eet S, Craft C, Fourqurean JW, Kauffman JB, Marba N, Megonigal P, Pidgeon E, Herr D, Gordon D, Baldera A (2012) Estimating global" blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems. PloS one, 7, p.e43542.

Potouroglou, M., Bull, J.C., Krauss, K.W., Kennedy, H.A., Fusi, M., Daffonchio, D., Mangora, M.M., Githaiga, M.N., Diele, K. and Huxham, M., 2017. Measuring the role of seagrasses in regulating sediment surface elevation. Scientific reports, 7(1), pp.1-11.

Prentice, C.; Poppe, K.L.; Lutz, M.; Murray, E.; Stephens, T.A.; Spooner, A.; Hessing-Lewis, M.; Sanders-Smith, R.; Rybczyk, J.M.; Apple, J.; et al. A synthesis of blue carbon stocks, sources, and accumulation rates in eelgrass (Zostera marina) meadows in the Northeast Pacific. Glob. Biogeochem. Cycles 2020, 34, e2019GB006345.

Richmond, M.D., 2002. A field guide to the seashores of Eastern Africa and the Western Indian Ocean Islands.

Röhr, M.E.; Holmer, M.; Baum, J.K.; Björk, M.; Boyer, K.; Chin, D.; Chalifour, L.; Cimon, S.; Cusson, M.; Dahl, M.; et al. Blue carbon storage capacity of temperate eelgrass (Zostera marina) meadows. Glob. Biogeochem. Cycles 2018, 32, 1457–1475.

Romero, J., Pérez, M., Mateo, M.A. and Sala, E., 1994. The belowground organs of the Mediterranean seagrass Posidonia oceanica as a biogeochemical sink. Aquatic botany, 47(1), pp.13-19.

Ruiz, J.M. and Romero, J., 2001. Effects of in situ experimental shading on the Mediterranean seagrass Posidonia oceanica. Marine Ecology Progress Series, 215, pp.107-120.

Serrano, O., Lavery, P.S., Rozaimi, M. and Mateo, M.Á., 2014. Influence of water depth on the carbon sequestration capacity of seagrasses. Global Biogeochemical Cycles, 28(9), pp.950-961.

Serrano, O., Lavery, P.S., Duarte, C.M., Kendrick, G.A., Calafat, A., York, P.H., Steven, A. and Macreadie, P.I., 2016. Can mud (silt and clay) concentration be used to predict soil organic carbon content within seagrass ecosystems? Biogeosciences, 13(17), pp.4915-4926.

Serrano, O.; Almahasheer, H.; Duarte, C.M.; Irigoien, X. Carbon stocks and accumulation rates in Red Sea seagrass meadows. Sci. Rep. 2018, 8, 15037.

Shafer, D.J., Kaldy, J.E. and Gaeckle, J.L., 2014. Science and management of the introduced seagrass Zostera japonica in North America. Environmental Management, 53(1), pp.147-162.

Dahl, M. *et al.* (2020) 'The influence of hydrodynamic exposure on carbon storage and nutrient retention in eelgrass (Zostera marina L.) meadows on the Swedish Skagerrak coast', *Scientific Reports*, 10(1), p. 13666. Available at: https://doi.org/10.1038/s41598-020-70403-5.

Lavery, P.S. *et al.* (2013) 'Variability in the Carbon Storage of Seagrass Habitats and Its Implications for Global Estimates of Blue Carbon Ecosystem Service', *PLOS ONE*, 8(9), p. e73748. Available at: https://doi.org/10.1371/journal.pone.0073748.

Schott, F.A., Xie, S.-P. and McCreary Jr, J.P. (2009) 'Indian Ocean circulation and climate variability', *Reviews of Geophysics*, 47(1).

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

Short, F.T., Koch, E.W., Creed, J.C., Magalhaes, K.M., Fernandez, E. and Gaeckle, J.L., 2006. SeagrassNet monitoring across the Americas: case studies of seagrass decline. Marine Ecology, 27(4), pp.277-289.

Short, F.T. and McRoy, C.P., 1984. Nitrogen uptake by leaves and roots of the seagrass Zostera marina L.

Short, F.T. and Neckles, H.A., 1999. The effects of global climate change on seagrasses. Aquatic Botany, 63(3-4), pp.169-196.

Short, F.T. and Wyllie-Echeverria, S., 1996. Natural and human-induced disturbance of seagrasses. Environmental conservation, 23(1), pp.17-27.

Signa, G., Mazzola, A., Kairo, J. and Vizzini, S., 2017. Small-scale variability in geomorphological settings influences mangrove-derived organic matter export in a tropical bay. Biogeosciences, 14(3), pp.617-629.

Thom, R.M., Borde, A.B., Rumrill, S., Woodruff, D.L., Williams, G.D., Southard, J.A. and Sargeant, S.L., 2003. Factors influencing spatial and annual variability in eelgrass (Zostera marina L.) meadows in Willapa Bay, Washington, and Coos Bay, Oregon, estuaries. Estuaries, 26(4), pp.1117-1129.

Trevathan-Tackett, S.M., Wessel, C., Cebrián, J., Ralph, P.J., Masqué, P. and Macreadie, P.I., 2018. Effects of small-scale, shading-induced seagrass loss on blue carbon storage: Implications for management of degraded seagrass ecosystems. Journal of applied ecology, 55(3), pp.1351-1359.

Tuya, F., Haroun, R. and Espino, F., 2014. Economic assessment of ecosystem services: monetary value of seagrass meadows for coastal fisheries. Ocean & Coastal Management, 96, pp.181-187.

Unsworth, R.K., Collier, C.J., Waycott, M., Mckenzie, L.J. and Cullen-Unsworth, L.C., 2015. A framework for the resilience of seagrass ecosystems. Marine pollution bulletin, 100(1), pp.34-46.

Vanderklift, M.A.; Gorman, D.; Steven, A.D. Blue carbon in the Indian Ocean: A review and research agenda. J. Indian Ocean Reg. 2019, 15, 129–138.

Vasarri, M., De Biasi, A.M., Barletta, E., Pretti, C. and Degl'Innocenti, D., 2021. An overview of new insights into the benefits of the seagrass Posidonia oceanica for human health. Marine Drugs, 19(9), p.476.

Wakibya, J.G., 1995. The potential human-induced impacts on the Kenya seagrasses.

Waycott, M.; McMahon, K.; Mellors, J.; Calladine, A.; Kleine, D. A Guide to Tropical Seagrasses of the Indo-West Pacific; James Cook University: Townsville, Australia, 2004.

Waycott, M., Procaccini, G., Les, D.H. and Reusch, T.B., 2007. Seagrass evolution, ecology and conservation: a genetic perspective. In Seagrasses: biology, ecologyand conservation (pp. 25-50). Springer, Dordrecht.

Waycott, M., Duarte, C.M., Carruthers, T.J., Orth, R.J., Dennison, W.C., Olyarnik, S., Calladine, A., Fourqurean, J.W., Heck, K.L., Hughes, A.R. and Kendrick, G.A., 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceedings of the national academy of sciences, 106(30), pp.12377-12381.

York, P.H.; Macreadie, P.I.; Rasheed, M.A. Blue Carbon stocks of Great Barrier Reef deep-water seagrasses. Biol. Lett. 2018, 14, 20180529.

APPENDICES

Appendix 1: Statistics and ANOVA tables

Table 2: Differences in environmental factors among the four zones in the subtidal area of Gazi Bay as revealed by Analysis of Variance (ANOVA).

		Sum of Squares	df	Mean Square	F	Sig.
Depth	Between Groups	37.914	3	12.638	12.601	.000
	Within Groups	40.116	40	1.003		
	Total	78.030	43			
Temperature	Between Groups	2.140	3	.713	5.852	.002
	Within Groups	4.876	40	.122		
	Total	7.016	43			
Salinity	Between Groups	2.725	3	.908	11.381	.000
	Within Groups	3.193	40	.080		
	Total	5.918	43			
PH	Between Groups	.142	3	.047	5.304	.004
	Within Groups	.357	40	.009		
	Total	.499	43			
TDs	Between Groups	2311306.369	3	770435.456	15.654	.000
	Within Groups	1968618.631	40	49215.466		
	Total	4279925.000	43			

Table 3: Test for variations in meadow structure parameters among the dominant seagrass species using analysis of variance (ANOVA).

		Sum of Squares	df	Mean Square	F	Sig.
Density	Between Groups	1379242.150	3	459747.383	24.708	.000
	Within Groups	297718.800	16	18607.425		
	Total	1676960.950	19			
Height	Between Groups	3353.971	3	1117.990	13.592	.000
	Within Groups	1316.027	16	82.252		
	Total	4669.998	19			
cover	Between Groups	1621.567	3	540.522	2.130	.136
	Within Groups	4059.633	16	253.727		
	Total	5681.200	19			

Table 4: Differences in mean Above Ground and Below Ground Biomass among dominant species analyzed by analysis of variance (ANOVA)

		Sum of Squares	df	Mean Square	F	Sig.
AGB	Between Groups	1.716	3	.572	4.967	.013
	Within Groups	1.843	16	.115		
	Total	3.559	19			
BGB	Between Groups	82.385	3	27.462	1.108	.375
	Within Groups	396.642	16	24.790		
	Total	479.027	19			

Table 5: Differences of the mean sediment carbon between the four subtidal zones analysed by Analysis of Variance (ANOVA) Test

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	12137.752	3	4045.917	.350	.790
Within Groups	451402.702	39	11574.428		
Total	463540.454	42			

Appendix II: Conversion Table

Value (grams)	Unit	Name
10^3	Kg	Kilogram
10^6	Mg	Megagram
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

Appendix III: Student's introduction letter

UNIVERSITY OF NAIROBI
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SCHOOL OF BIOLOGICAL SCIENCES

School of Biological Sciences
P.O. Box 30197- 00100,
Nairobi.

15th May, 2020

The Director,
Kenya Marine and Fisheries Research Institute,
P.O.Box-81651-80100,
Mombasa.
Phone: 020-8021560, 020-8021561

Dear Sir/Madam,

RE: Request for authorization to conduct research in Gazi bay for Derrick Omollo

This is to confirm that the above named is a bonafide student at the university of Nairobi, School of Biological Sciences, undertaking a Master of Science degree in Biology of Conservation. He has successfully completed his course work and is currently in his second year where he is supposed to carry out his field research project as per the course requirements.

He has developed a research proposal on *'Assessment of organic carbon stocks in sub tidal seagrass meadows of Gazi Bay'* which is due for submission to Graduate School. I am his university supervisor and will collaborate with Dr. James Kairo and Dr. Michael Njoroge.

We would appreciate any assistance with authorization to undertake the research in the KMFRI Gazi Station. His research will generate information on carbon storage capacity in sub tidal-seagrass meadows, further contributing to blue carbon research. Kindly get back to me if further clarification is needed.

Thank you.

Yours faithfully,

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