SPATIAL-TEMPORAL DISTRIBUTION OF SEA URCHINS AND SEAGRASS ALONG DIANI-CHALE LAGOONAL REEFS, MOMBASA

BY

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DECLARATION

Declaration by the Student

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DEDICATION

I dedicate this thesis to my supportive family for they have enabled me to accomplish this work despite many challenges.

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ABSTRACT

Overgrazing by herbivores has been postulated as a potential threat to seagrass in Kenya. Indirectly, fishing may result in increase in sea urchin population caused by removal of sea urchin predators. This study determined the spatial and temporal distribution of sea urchins and seagrass along Diani lagoonal reefs.The objectives of this study were (i) To determine seasonal abundance and diversity of sea urchins and seagrass in Diani Beach (ii) To determine spatial variation of density of sea urchins in healthy and degraded seabeds in Diani Beach (iii) To evaluate the influence of sea urchin abundance on benthic seagrass cover in Diani beach. Three sites of Mvuleni, Chale, and Mwaepe, and three seasons of northeast monsoon, intermonsoon, and southeast monsoon were selected.Healthy and degraded sections were identified in each of the selected sites and 40 samples were obtained from each study site and for each season using one-meter square quadrats (N = 360). Seagrass cover was computed using percentages, density of sea urchins was calculated using frequencies, and the diversities of both were determined using Simpson's diversity index. In the analysis of data, the study used t-test, two-way analysis of variance and post hoc test in comparing differences among sites and seasons. Ultimately, Pearson's correlation and regression analysis were used to establish the nature of relationships and the influence of sea urchins on seagrass cover. Research findings indicated that the abundance and diversity of sea urchins and seagrass varied according to seasons. The density of sea urchins was highest during northeast monsoon and lowest during southeast monsoon.Correlation outcome demonstrated that the density of sea urchins was statistically significant negative predictor (r = -0.699) of the proportion of seagrass cover and accounted for 48.8% of variation. Canonical Correspondence Analysis suggests that seasons, study sites, and sea urchins influence distribution of seagrass species and nature of seabed because they account for 7.87% in the first dimension and 86.9% in the second dimension. However, other studies are necessary to establish the role of other biotic factors and abiotic factors in the growth of seagrass in seabed. This study recommends sustainable use of ocean resources for economic growth,improved livelihoods and jobs while preserving the health of ocean ecosystem.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA – Analysis of Variance

IOD – Indian Ocean Dipole

ITCZ – Inter-Tropical Convergence Zone

NEM – Northeast Monsoon

SCUBA – Self Contained Underwater Breathing Apparatus

SD – Standard Deviation

SEM – Southeast Monsoon

SPSS – Statistical Program for Social Scientists

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Plant-herbivore interactions comprise an important biotic factor that determines composition, distribution, functioning, and ecological processes in the marine ecosystem (Wallner-Hahn *et al.*, 2022). Sea urchins are one of the herbivores in marine ecosystem which graze on seagrass and algae, and they belong to an ancient group of marine invertebrates, the Echinoderms (Rivers & Short, 2007; Hamad *et al.*, 2022). They are globular and spiny animals belonging to the class of Echinoidea in the sub-Phylum Echinozoa, the Phylum of Echinodermata and the Kingdom of Animalia (Maina *et al.*, 2008; Dennis-Cornelius *et al.*, 2022). Sea urchins are dominant grazers in a wide range of intertidal and sub-tidal habitats worldwide within coral reefs, seagrass beds, and kelp forests (Short et al, 2007; Miller *et al.*, 2021). Despite the fact that sea urchins mainly feed on algae, they also feed on seagrass in coastal regions where they are dominant.

Sean urchins have adaptive features that enable them feed on seagrass and other vegetation on seabed. They have specialized jaws with strong calcified teeth that they use in grazing (Ruppert *et al.*, 2004; Klaoudatos *et al.*, 2022). Sea urchins use their mouths and teeth in scavenging, scuffing, and eroding sea surfaces such as coral reef substrate (Macinnis-Ng & Ralph, 2004; Yaguchi & Yaguchi, 2022). There are about 1000 species of accepted sea urchins worldwide, and 64 are described from the Philippines (Appeltans *et al.,* 2012). The distribution of sea urchins shows that they are common in temperate and tropical regions (Ohgaki *et al.*, 2019; Zhang *et al.*, 2022). As the density of sea urchins influences the distribution of seagrass, the understanding of their seasonal and spatial distribution is necessary in modelling their interactions in the marine ecosystem.

As producers in the marine ecosystem, seagrasses are categorized angiosperms, which contribute significantly in the productive marine systems (Island, 2009; Uku *et al.*, 2021a). Seagrasses grow in coastal regions of marine environments of various continents except the cold regions of Antarctica (Short *et al.*, 2007). Seagrass grow in costal beds where they are the major primary produces of energy in the tropical marine ecosystems (Philips & Milchakova, 2003; Bastos *et al.*, 2022). Seagrass beds are important because they act as habitats for sea urchins where they shelter, feed, and breed (Jeyabaskaran *et al.*, 2018; Yahya *et al.*, 2020). It also creates habitats for fish breeding and endangered marine species such as green turtle, dudong, sea horses, and manatee (Harris, 2020). Seagrass photosynthetic activity releases oxygen (Lee *et al.*, 2020) and stabilizes sediments that prevent coastal erosion (James *et al.*, 2019; Twomey *et al.*, 2021). Seagrass meadows also provide food for a range of organisms (Jinks *et al.*, 2019). In addition, seagrasses can filter toxic compounds from the water column (Crump *et al.*, 2018; Harris, 2020; Bastos *et al.*, 2022) and absorb nutrients, which potentially reduces eutrophication and phytoplankton blooms (Burkholder *et al.*, 2007; Crump *et al.*, 2018; Hasegawa & Nakaoka, 2021; Bastos *et al.*, 2022). Essentially, seagrass has immense benefits to marine ecosystem as primary producer and mediator of pollution effects.

Despite their economic importance worldwide, populations of seagrasses have been declining consistently due to increasing anthropogenic activities for example overfishing and release of harmful substances to the ocean coupled with biotic factors like overgrazing by aquatic fauna in coastal areas (Waycott *et al.*, 2009; Iacarella *et al.*, 2018; Dunic *et al.*, 2021; Dahl *et al.*, 2022). In developed coastal areas, surface runoff carries and deposits sediment particles, nutrients, and pesticides into estuaries, leading to the pollution of marine environment (Freeman *et al.* 2019). The accumulation of pollutants in the coastal areas affects the growth of seagrass or limitation of available food for herbivores (Bonanno & Orlando-Bonaca, 2020). Increasing population and human activities threaten the existence of seagrass and herbivores that rely on them.

Seagrass have an important role in the environment because they act as carbon sinks in the marine ecosystem. Globally, seagrass accounts for 10 percent of the ocean's carbon storage capacity despite only covering 0.2% of the sea floor (Duarte, 2017). These findings suggest that the seagrass cover should have a cover of over 10% for them to contribute significantly in reversing trends of global warming by reducing the amount of carbon dioxide in the sea. Additionally, seagrass play a significant role in marine ecosystem because they form a symbiotic relationship with microbes called holobiont (Conte et al., 2021). The formation of holobiont enables seagrass to interact with microbes and respond to changing environmental units. Conte et al. (2021) explain that seagrass provides substrates for microbes to attach, grow, and fix nitrogen, while microbes supply nutrients after degrading debris material for the growth of seagrass. Hence, by acting as carbon sink and creating holobiont, seagrass are integral in the marine ecosystem.

In Kenyan coast sea urchins have exhibited dominance and population explosions owing to the reduction in predation by triggerfish, wrasse, and puffer fish due to overfishing in

Diani-Chale reefs (Githaiga *et al.*, 2019; Juma, 2019; Steneck, 2020; Uku *et al.*, 2021a). In their study, Alcoverro and Mariani, (2002), established that sea urchin grazed on seagrass (*Thallasodendron ciliatum*) beds of a Kenyan lagoon with *T. gratilla* accounting for 39% and over 70% of seagrass left as dead shoots. Seasonal changes in weather patterns are also significant factors that influence the distribution of sea uchins and the growth of seagrass (Rahman *et al.*, 2009). Juma (2019 found out that the diversity of seagrass in western and eastern creeks of Gazi bay accounts for role in maintaining ecosystems and stabilizing seagrass meadows. Therefore this study was undertaken to evaluate the spatial and temporal distributions of sea urchins and their effect of grazing on seagrass along Diani-Chale lagoonal reefs in the Indian Ocean basin, for sustainable development in Kenya.

1.2 Statement of the Problem

Seagrass plays a major role in coastal ecosystems as one of the producers that determines energy flow in the marine ecosystems and exists as a biotic factor that influences the abundance and diversity of other species (Juma, 2019; Nadiarti *et al.*, 2021). However, in the 21^{st} Century, the decline in seagrass has occurred worldwide due to anthropogenic activities, as well as biotic and abiotic factors (Eklof *et al.,* 2008; Uku *et al.*, 2021b). Overgrazing by herbivores has been postulated as a potential threat to seagrass since they disturb the structure of the seagrass habitat by removing a large amount of plant biomass (Juma 2019; Carnell *et al.*, 2020). Fishing may result in sea urchin population increase, caused by removal of sea urchin predators (Juma, 2019; Norderhaug *et al.*, 2021). Sea urchins are voracious feeders and large urchin density is known to bring about significant changes in benthic community structure through grazing of seagrass, algae and bioerosion of calcified substrate (Glynn & Manzello, 2015; Carnell *et al.*, 2020; Miller *et al.*, 2021). These significant changes threaten to destabilize the benthic ecosystems and cause extinction of important fauna and flora in the marine environment.

Although most studies center on fishing as an indirect factor that influence seagrass (Hughes *et al.*, 2009; Heck *et al.,* 2021; Valentine & Heck, 2021), increasing findings indicate that sea urchins and fish are major seagrass grazers (Uku *et al.*, 2021) ,(Yaguchi & Yaguchi, 2022). A specific case of the decline in seagrass is evident in the persistent overgrazing at the Kenyan coastal areas by *T. gratilla* (Uku *et al.*, 2021a). A mediating factor is the predators of sea urchins such as the triggerfish, *Balistapus undulate*, influence the abundance and distribution of seagrass in the coastal regions of Kenya (Ditzel *et al.*, 2021; Sevillano-González *et al.*, 2022). Owing to the influence of sea urchin predators, researchers have proposed that their removal in coastal regions would lead to overgrazing of seagrass. In their study, Amus *et al.* (2022) indicated that the abundance of *T. gratilla* in fished areas tripled those of protected areas with intact seagrass beds. Even though the absence of predators offers an explanation of overgrazing, new findings shows that none-fishing zones in Mombasa with sea urchin predators experience overgrazing in Watamu and Chumbe Marine Parks (Uku *et al.*, 2021a). These findings suggest that sea urchins are also significant contributors of overgrazing even in the presence of predators to control their abundance in marine environment.

Adult sea urchins have a critical role in reef ecology due to their grazing behavior (Williams, 2022); they reduce the reefs biomass, especially that of seagrass.

Consequently, the abundance of sea urchins rise on a reef, the reef and seagrass community decrease due to their grazing habits. Certainly, additional studies are necessary to confirm the influence of predators on sea urchins and their cascading effects on seagrasses in various coastal environments. Therefore, there is need for a study to evaluate the abundance of sea urchin and seagrass in Diani-Chale lagoonal reefs. Studies have been done on the diversity of sea urchins in Watamu and none has been done in Diani-Chale lagoons. This study is necessary to determine spatial-temporal occurrence of sea urchins and their grazing along diani-chale lagoonal reefs as it contributes to our understanding of Kenya's important marine resources.

1.3 Justification

There is declining population of seagrass in coastal areas due to anthropogenic activities and imbalances in marine ecosystems. Previous studies performed in coastal reefs in Kenya has shown that overfishing has led to the removal of sea urchin predators, resulting in negative effects of overgrazing on seagrass in unprotected regions (Uku *et al.*, 2021a; Ditzel *et al.*, 2022). Current studies have identified triggerfish as a major predator of sea urchins with high abundance of seagrass on coastal areas. Excessive fishing cause decline of fish populations and, as fish are the main predators of sea urchins, can in turn cause problems like overpopulation of sea urchins (Lapointe *et al.*, 2004; Uku *et al.*, 2021a; Whitfield *et al.*, 2022). Therefore, overpopulation of sea urchins in coastal regions has led to the emergence of the problem of overgrazing and diminishing abundance of seagrass.

Much marine research and management in the tropics target coral reefs, whereas other habitats in the seascape may be equally or even more important for delivering ecosystem services (Kadagi *et al.*, 2020; Wilson *et al.*, 2022). The ecosystem of seagrass in marine environment has obtained limited attention (Gerstenbacher *et al.*, 2022), in spite of producing economically important finfish and shellfish, sequester carbon, stabilize sediment and protect coast-lines worldwide (Kadagi *et al.*, 2020; Uku *et al.*, 2021a). Together, their importance emphasize the significance of research and management. Therefore, this research is important in obtaining baseline information on the abundance and distribution of both seagrass and sea urchins for conservation purposes by the government via the Ministry of Environment, Water, and Natural Resource.

The absence of documentation regarding the effectiveness and efficiency of various conservation measures complicates the addressing of the problem of overgrazing of seagrass by sea urchins. Hence, there is need to understand relationship between sea urchins and seagrass in relation to the evaluation of major interventions that are appropriate in the conservation of environment for sustainable marine ecosystems. For example, conservationists need to understand how to apply short and long-term removal of urchins or addition of their predators and undertake accurate monitoring and evaluation of any interventions deployed. No fishing has been a common strategy employed in the conservation of marine ecosystem, but it has led to increased overgrazing of seagrass on coral reefs (Schuster *et al.*, 2022). The overgrazing of seagrass is also common in marine parks where there are significant predations of sea urchins (Carnell *et al.*, 2020). Moreover, the demarcation of marine protected areas without public support is not effective because it creates resource-user conflicts by limiting fishing activities of the local communities (Kadagi *et al.*, 2020). In this view, it is critical to assess societal costs that marine protected areas have on the extent of seagrass overgrazing.

The intrinsic complexity of marine ecosystems in the aspects of seasons, time, and interactions indicates that overgrazing management requires the use of adaptive framework premised on the precautionary principle (McKenzie, 2008; Narvaez, 2018). As diverse mechanisms and factors account for overgrazing, customization of intervention is necessary for effective and efficient management of diverse habitats in the marine ecosystem that contributes to the blue economy.

1.4 Objectives

1.4.1 Main Objective

The main focus of this study is to determine spatial and temporal distribution of sea urchins and seagrass along Diani-Chale lagoonal reefs in Mombasa.

1.4.2 Specific Objectives

The following are the specific objectives of the study:

i) To determine seasonal abundance and diversity of sea urchins and seagrass in Diani beach

ii) Determine spatial temporal variation of density of sea urchins in healthy and degraded seabed in Diani beach

iii) To evaluate the influence of sea urchin abundance on benthic seagrass cover in Diani beach

1.5 Hypothesis

i. The seasonal abundance and diversity of sea urchins along Diani-Chale lagoons are low in Diani beach

ii. The difference in the density of sea urchins in healthy and degraded seagrass is significant.

iii. The influence of sea urchin abundance on benthic seagrass cover is significant.

CHAPTER TWO

LITERATURE REVIEW

2.1 Sea Urchins:

2.1.1 Evolution and Adaptive Radiation.

The need for fish and aquatic materials for nutrition has gone up all over the world. So often, natural fisheries are overwhelmed by human activities failing to satisfy the very expanding market. Many countries have supported high value product establishment by coming up with plans to expand the marine aquaculture. Sea urchins find their way into this plan as they are found in all latitudes and oceans (Lessios *et al.,* 2012). The value of sea urchins increased tremendously in Japan as this was the country ready to embrace them. However, the sea urchin supply did not meet the ever-rising demand of the domestic needs. Therefore, Japan had to rely on North America where sea urchins were already eradicated to protect other ecosystems like the kelp beds and lobster fisheries. In that capacity, sea urchin production increased in the southern part of America. In Europe, fish stocks are reducing but aquaculture systems are coming up (Tegner & Dayton, 2000).

Since the 19th century, sea urchins have been very outstandingly important for the development of research and high capacity laboratory systems. This is particularly in preservation of broodstock found in majority of universities (Matranga, 2005). Sea urchins present very unusual aquaculture candidature as they are usually harvested for their gonads. The gonads for both genders are a delicacy, when uncooked while others get salted, pickled and converted into consumable paste. Upon processing, the sea urchins are the key valuable sea food product rated at over US $100 per kg at the wholesale avenue. The major market demands come from Asia, Europe, and North and South America continents. Factors of consideration during the valuation of the sea urchins include, the appropriate color, size, texture and taste (Raposo *et al.*, 2019). One of the reasons people breed sea urchins is to expand the aquaculture family that is the primary significance among many. It is also a source of new product into the existing market. Additionally, it is an opportunity of employment to people (McBride, 2005).

To develop a well-structured sea urchin environment, it needs proper enhancement of wildlife population with keen research on the organisms. Likewise, nutrition, reproduction and appropriate culture systems must be of great consideration (Briefing, 2022). In 1968, Japan began the initial sea urchin production and is part of the bigger market for the national food program for sea foods. Japan's water systems are well protected with a clear framework of support from the Japan government (McBride, 2005). However,focusing on the Eastern part of Africa, a well-structured way of protecting water bodies has not been developed.

In Japan,Sea urchin aquaculture kicked off with management of fishery resources that had bigger animals evacuated to the other fisheries that were more favorable. This method made sea urchin development plan to flourish. The activities were seen in, Kyushu, Tohoku, and Hokkaido (Agatsuma, 2020b). The stated regions are grounds for sea urchin production. The major aim was to improve gonad productions that are very nutritious supplying high nutrients to human. It was believed that the gonads were able to increase the living age of a normal human. However, around 1967, the fisheries began to show signs of exhaustion due to uncontrolled harvesting activities. Thus, efforts were put up to culture sea urchins to supplement the populations running into extinction (Baião *et al.*, 2019). So, the Japanese government provided extra support for basic and applied research on the sea urchins, more specifically in the investigations of the feeding habits, reproductive phases, and environmental conditions (Dvoretsky & Dvoretsky, 2020). Thus, research expanded into culture systems. At least, 55 prefectural hatches have given out small sea urchins for cooperative units. The production laboratories have taken up the role of supplying sea urchins to cooperative societies. The cooperative associations have teamed up to control land based nursery units together with the restocking programs in essential coastal habitats (McBride, 2005). The coastal areas are managed via predator removal, algal addition and habitat improvement up to the point of harvesting. Some cultured sea urchins are raised in cage systems at high populations and fed on cultured sea weed till they attain the market demand size (Agatsuma, 2020b). However, in japan, large scale harvest of cultured sea urchins is not common; usually cultured juveniles are released into water bodies. In 1980s, Japan saw the biggest sea urchin demand and the domestic production was able to supply at least one-1/2 of the demand by consumer population (Ohgaki *et al.*, 2019). This had led to development and expansion of sea urchin fisheries into the North and South of America continents. Aquaculture research was elevated upon early warning of fish depletions or decline from expert fisher men and aquaculture managers. Therefore, aquaculture research became the target in many other countries. This led to development of diets and methods to increase gonad production. It included holding sea urchins in cages or sea food and transplanting urchins to habitats with more natural food in form of algae (Agatsuma, 2020b). To date, sea urchin research utilizes urchins collected from the ocean to be elaborately used in the standard scientific laboratory. Notably, sea urchin history takes the same shape as that of Japan (Agatsuma, 2020b).). Some of the sea urchin species reported in Watamu are: *D.setossum, D. savingyi, E. diadema, T. gratilla, E. calamaris, Echinometre mathaei*, and *Echinostrephus molaris* (Cowburn *et al.*, 2018).

2.1.2 Sea Urchin Morphology

Commercially significant sea urchins are spherical with a slight modification having flattened and movable spines. Each spine is well fitting into socket joint which aids in the horizontal and vertical movement of the urchin. Tubular feet or podia are seen in rows, parallel with the spines with well-structured suckers for positional attachment (Smith *et al.*, 2019). Podia are also very sensitive to chemicals and any form of touch. They take in oxygen, prey on drifting algae and keeping the body clean. Spines are controlled by muscles and are a reason for self-protection. Equally, spines capture, hold food and aid movement. They also possess, Pedicellarias, small, stalked, appendages for defense, preying and cleaning the body surface. Generally, in close examination of the body of a sea urchin body is radically symmetrical (Andilala *et al.*, 2020). Externally, sea urchins are noticeably colorful due to skin pigmentation. At points, they can be seen to be pale-yellow, green, pink, purple, red, or black. Internally, there exist colorful gonads. This is due to the carotenoid pigments (Fox, 2020). The desirable gonad colors are yellow and orange while the undesirable gonads are white, tan, brown, black, or green. The body of sea urchin has an oral at the bottom while aboral at the top surface. The aboral consist of the anus where excretory wastes are eliminated, gametes are released from this part and the control of the water vascular done. The spherical body surface is well covered with flexible spines comprising of 50% of the sea urchin body weight. The oral surface is; the mouth having membranes that allow movement, short spines and podia. The mouth tears algae or seagrass into manageable digestible pieces. The mouth is connected to tubular digestive system. It has also been noted to contain teeth and five calcareous plates controlled by muscles (Brewster *et al.*, 2018; Tappero, 2021). Therefore, the connection leads to five gonads, by mesenteries and heme strands. Structures of the water vascular system come in between the five gonads. The gonads must present 10-14% of the sea urchin body weight for significant processing and marketing (Tappero, 2021). In a nutshell, reproduction in sea urchins is generally very complex process. It involves nutrient accumulation, the gonads, transfer of the nutrients to gametogenic cells, keeping of the gametes and spawning via release of dribs of massive spawns at a given time (Tappero, 2021).

2.1.3:Ecology of sea urchins

Sea urchins belong to the Phylum *Echinodermata*.Most of them are consumed and are well adapted on hard, benthic surfaces. They greatly live in areas having high concentration of algae, which is their source of food. Shallow waters are their preferred living habitat. Parameters include, about 50m water depth (Andilala *et al.*, 2020).

The maritime organisms and consequent pelagic propagules have been indicated to experience oceans presenting elevated temperatures and decrease in PH due to anthropogenic carbon IV oxide (CO_2) productions. The existing atmospheric carbon IV. Oxide amounts read approximately thirty (30) percent, which is higher than the past two

(2) million years. Ocean acidification is illustrious with the obtainable carbonate minerals. So, as a result, there will occur the adverse consequences on skeletogenesis and altered metabolism. The degree of acidification and warming keeps on changing every time of the year both locally and regionally as a result of the rotational nature of the ocean, Geo-spatial heat variation, pH, carbonate environments and many more. The rise in ambient temperatures will intensify updraft stress against the coastal shallow water biota, with straight worries that temperature rise may surpass the bearable limits. Some areas such as Australia and the Antarctic Peninsula receive quicker warming air heats than the global normal (Karelitz *et al.*, 2017).

The sea urchin larvae towards acidification is affected by the locale type, and sometimes, species specific suggesting that portions of spp. are more strong towards ocean alteration stressors than others. For instance, most sea urchin spp. like *T. gratilla*, consist of extensive tropical–temperate spreading, while some at the temperate level, like the *Centrostephanus rodgersii*, have their northern limit in the subtropical locations. Insights will be made by analysis of the responses of the larvae of wide-range species in regard to their tropical–temperate distribution. In spite of the inescapable consequence of temperature on development, ocean warming is seldom considered for climate change studies in relation to marine larvae. Both warming and acidification possess negative impressions on sea urchin advancement. Increased temperatures kill the initial developmental (pre-larval) phase of the larvae. Additionally, it is a bigger stressor for majority of echinoderms like *T. gratilla*, larvae for the coral and Crustacea and subsequent algae food (Birkeland, 1989; Pagano *et al.*, 2001; Przeslawski *et al.*, 2008).

Notwithstanding, there exists very few information pertaining responses of species throughout the entire life cycle of marine invertebrates.

2.1.4:Reproductive ecology

Sea urchins reproduce by means of gonads.At a growing stage, the gonads have got majorly non-germinal nutritive cells with glycogen, lipid and protein. They are preferable with desirable color and larger unlike at the matured level when the gonads tend to fall apart (Brink, 2020). The maturity of the sea urchins goes up to 6 months depending on marine temperature, available food, light and the density distribution of the urchins. So, gonad production is usually measured by gonad index (Mos & Dworjanyn, 2019).

More innovative formulae have been put up for mass reproduction of sea urchins. For instance, intermediate stages of the urchins are transplanted in Japan. Whereby adults and juveniles get transplanted. With this method, sea urchins were harvested at least every three months. The main species that went through this process include; *Pseudocentrotus depressus* and *Strongylocentrotus pulcherrimus* in southern Japan and *S. intermedius* and *S. nudus* towards the North (Murata *et al.*, 2020). At least 1-2% mortality rate was witnessed which can be categorized as low, with a 20 metric tons of transplant. So, transplanting has been an exceptional method of sea urchin management.

Diet largely affects sea urchin establishment in such a manner that, it influences reproduction. So, it affects the size of gonads rather than gametogenesis. Sea urchins improve the size of gonads with the availability of food. This results in more food ingestion. High feeding rates leads to extended gametogenesis and spawning in laboratory and wild populations. Somatic growth in wild and laboratory populations is inversely proportional to reproductive development. In the event of lack of food or scarcity of food, natural populations appear to allocate less resources to somatic growth than reproduction (Brink-Hull *et al.*, 2022). Rationing of food on laboratory sea urchins, has resulted in lower gonadal indices, notwithstanding same productive development. Sea urchins have been noted to shrink or reduce in size when starved. Their gonads decrease in size too. So, as long as diet seems to not influence gametogenesis, it has been shown to extend the mature stage. So, the realignment in size of the gonadal apparatus leads to reshuffle of nutrient supplies in the body wall and gonad (Brink-Hull *et al.*, 2022).

Seasonal variation of sea water temperatures influence annual reproductive cycles. Nonetheless, there is always little or no relationship between temperature and spawning among many spp.In areas such as Antarctic or deep-sea, where there appears to be little or no changes in temperatures, annual reproductive cycles are presented in sea urchins. Studies conducted both in the field and laboratory illustrates that, seawater temperature has had little effect on gametogenesis of *S. purpuratus*. At sometimes, sea water temperature may cause gametogenesis out of season like in the laboratory systems and in areas where there is a strong variation in sea water temperatures (Schuh *et al.*, 2020). Importantly, gametogenesis has succeeded under certain temperatures using, *Hemicentrotus pulcherrimus*, *Pseudocentrotus depressus* and *Anthocidaris crassispina* (Agatsuma, 2020a). In 1958, Giese et al mentioned photoperiodic control of annual reproductive cycles. Illustratively, *S. purpuratus* was used to demonstrate the effect within 18 months of laboratory assays. Practically, the species were kept in a photoperiodic regime six months out of the stage with laboratory and field samples at the most ambient photoperiod (Giese, 1959). Ideally, *S. purpuratus* developed a gametogenic cycle, 6 months out of phase. Individual *S. purpuratus* showed continuous gametogenesis upon exposure to light less than 12h per day for a year.

2.1.5 Diseases and Parasites

Sea urchins accommodate a number of pathogens, roughly 100. Bacteria and fungi are the main causers of diseases in the sea urchin. Protozoans, mostly cause protozoan diseases. Reports have demonstrated lesions and mass mortalities against the sea urchins. Injury of the body of the urchin is enough reason to cause body lesions. In the gut, facultative symbionts, turbellarians, of the gut may be found. Sea urchins are vectors carrying trematodes which affect fish (Wang *et al.*, 2013).

Larva contamination may take place during culture work. Sometimes the larva may get to be less robust and arms lets regress. Bacterial diseases also infect infantile sea urchins in Japanese culture systems. At temperatures above 20°c, mass mortalities of sea urchins are seen (Wang *et al.*, 2013).

2.1.6 Economic Importance of Sea Urchins

Sea urchins are globular and spiny animals that live in the sea and belong to the class of Echinoidea. Across the world, there are about 950 species of sea urchins inhabiting oceans, especially on the seabed (De Ridder & Saucède, 2020). Sea urchins are important animals to biology because researchers have used their embryos in studying developmental biology and ecosystems. Sea urchins influence seagrass ecosystems as they feed on them when they forage for algae and macrophytes. In essence, the distribution, density, and abundance of seagrass are dependent on the population of sea urchins in various ecosystems in benthic ecosystems (Chen *et al.*, 2021). Globally, sea Urchins have been considered a source of food, especially in Japan. For instance, the gonads are edible. They are also used as experimental model organism and for toxicological studies (Sato *et al.*, 2019).

The family is made up of uneven Echinoids having no effect on reef corrossion. Additionally, regular urchins can be seen on coral reefs and they are significant bioeroders. The mandibular formula of sea urchins is well established which is commonly known as, ‘highly evolved jaw apparatus’ involving 5 calcium carbonate teeth that are considered to have a self-sharpening capacity. So, they use their dental formula to scrap, and erode hard substrate from the reef; bak (Stock, 2014). Therefore, this is the concrete reason for the over-grazing momentum of the sea urchins against the coral reefs. However, the sea urchins can erode coral reefs circuitously using spines, destroying the strength of the reef that leads to expansion of cracks. Sea urchins nourish themselves with pieces of algal turf, scrapped material sourced from the coral surface and the rubble. Specifically, it has been evident that, few types of urchins dig dipper crevices to allow them hide from predators and subsequent traps thereof. The grazing of these creatures is paramount and of essence as it controls macro algae establishment in terms of population density. Notably, accumulation of macro algae results into death of corals (Cohen-Rengifo *et al.*, 2018). Therefore, from the discussed significant effects of sea urchins, i.e. via bio erosion, there is need to understand the distribution of urchins and economic impact on coral reefs.

2.2 Seagrass

2.2.1 Seagrass Characteristics

Seagrasses are of the order *Alismatale* in *Magnoliophyta* division, made up of almost sixty species. There exists five families of seagrass in the world, namely; Ruppiaceae, Cymodocea, Hydrocharitaceae, Posidoniaceae, and Zosteraceae (Kuo & Den Hartog, 2001). They are monocotyledonous highly specialized aquatic flowering plants inhabiting the coastline and estuarine parts of the globe. As all other flowering plants, seagrass have above and below ground parts. Above ground tissues are organized as shoots, in which several leaves surround (and protect) the apical meristem. The leaves are the site of primary production through photosynthesis (Kuo & Den Hartog, 2001). All seagrass have prostrate stems buried in sand or mud. The below-ground tissues are composed of rhizomes and roots. They provide anchoring for mechanical support, are responsible for (part of) the nutrient uptake, and constitute reserve tissues, especially in annual species in temperate climates which survive winter, based on these reserves (Beerling, 2019). Seagrass reproduce sexually by pollination and complete entire life cycle underwater, pollination is hydrophilic, and pollen grains are elongated into filamentous shape (Tongkok *et al.*, 2020).

Evolutionary studies are a phenomenon that cannot be ignored in regards to the study of the seagrass. Going forward, the seagrass has reestablished itself within a specific time, increased in numbers, affecting the levels of the sea water and subsequent modification of the coastlines for over 100 million years. Hence, the initial *Hydrocharitaceae* occurred about ninety million years ago, *Cymodoceae* occurred 80 million years ago, and

Zosteraceae occurred thirty million years ago. This evolutionary process is reflected in different morphological adaptations to the environment, e.g. in leaves and roots, but also in reproductive organs (Kuo & Den Hartog, 2001). The high diversity of the latter suggests that seagrass did not evolve from a common ancestor and that parallel evolution lines have taken place in different geological periods. Seagrasses have been well known to be found all over the planet Earth. However, they possess much less diversity that is, sixty species globally (Waycott *et al.*, 2018). This data is incomparable with the rough estimate of 250,000 terrestrial angiosperms that have been evidence in the world.

2.2.2 Seagrass Distribution in East Africa

Seagrasses are well distributed in East Africa, forming a rich and productive marine and coastal ecosystems. The coastlines, i.e Tanzanian (800 km) and Kenyan (600 km) have relatively narrow and shallow continental shelf that neighbors Indian Ocean (Nordlund *et al.*, 2010). They are well characterized by comprehensive fringing coral reefs, many shelter creeks and bays, forests of the mangroves, beaches and sand dunes. The tidal amplitude runs up to 4m near Mombasa. Therefore, there exists a fairly distributed intertidal zone in between the coastal lining and the coral reefs. The substrate in the zone has sands coming about from carbonate material from the eroding reef. On that note, the seagrasses and microalgae determine the productivity of the intertidal areas. The seagrasses do well where there are low tides with shallow depressions. Back-reef lagoons house the most extensive seagrass meadows. This is usually amidst, beaches or cliffs and fringing reefs that are adjacent. During low tides, narrow channels connect the lagoons with the sea but high-tide water pass over the reef crest into the lagoon. Some fish live there while others feed from the lagoon (McKenzie *et al.*, 2020). During high tides they swim deeper to run away from the strong tides. These lagoons are very common in the following places in the East African coast; at Mida, Kilifi, Mtwapa, Tudor, Gazi and Funzi in Kenya, while in Tanzania, at Tanga, Bagamoyo, Mohoro, Kilwa and Mtwara in Tanzania. These are regions where mangroves strive very well. Seagrass meadow and coral reefs additionally do well. See grasses are also common in creeks, and channels housing mangroves. They likely function as traps and reduce the extent of the fluxes of particulate matter and nutrients between the mangroves and the ocean. In Gazi Bay, one is likely to see that the water is very clear at the top but covered by healthy grown seagrasses in a luxurious rest. However, at the delta points like Tana River, Kenya and Rufiji River in Tanzania, showcase very minimal seagrass growth (Painter, 2020).

2.2.3 Biogeography of Seagrass

Several studies in Kenya and Tanzania have revealed the existence of the following twelve seagrasses,: *Halodule uninervis, Zostera capensis, T. hemprichii , H. wrightii, C. rotundata, C. serrulata, T.ciliatum, Enhalus acoroides, S. isoetifolium , S. isoetifolium , Halophila minor, H. ovalis* (Erftemeijer, 2003). Both countries have been discovered to have a fairly equal distribution of the mentioned species. However, some species like *Zostera capensis, S. isoetifolium* and *Halophila minor* have received limited observation. The seagrass do not purely exist as individual breeds, they live in a community having two or more species, forming a mixed society. Surprisingly, one species outstands this odd, *T.ciliatum* is a sole “stander” forming big biomass with a pure breed. Additionally, 3 more species of seagrass have been noted, that is, *Halodule pinifolia, Halophila beccarii* and *Halophila ovata*. Some researchers have classified *H. wrightii* in East Africa based on leaf and tip morphology but the species appear to be very controversial (Short *et al.*, 2007). However, a study carried out in Florida show that the leaf tips in *Halodule* spp. contrast widely with bicuspidate and tridentate on the respective shoots.

Cultures of the species indicate that the leaf tips of *Halodule* are environmentally inconstant, in regard to nutrient variability or tidal zone. Additionally, analysis of isozyme of various collections all over the tropical western Atlantic and indo pacific show genetic diversity between the dual ocean systems with clear genetic uniformity within each of the two ocean systems. Regarding this findings, all plants from indo pacific having this kind of morphology will be named as *Halodule uninervis* while *H. wrightii* for those in the tropical western Atlantic (Ochieng & Erftemeijer, 2003). All the same, *H. wrightii* continues to be mentioned in literature despite all the reports from field, culture and isozyme analysis. Suggestively, there must be deeper analysis for the chromosomal differences and physiological studies to distinctively isolate the *Halodule* species. The seagrass beds in East Africa, anchor a diverse array of associated plant and animal species; above fifty species of microalgae and eighteen species of algal epiphytes, approximately 75 species of benthic invertebrates specifically bivalves and gastropods, many species of cucumbers, precisely 7 species of sea urchin, countless shrimp, crab and lobster species, and finally at least 100 species of fish depend on the seagrass (Otero *et al.*, 2013). Thus, the study may not conclude that seagrass is consumed by only sea urchin but significantly, seagrass is the stable food for the urchins. The assumption of the study is that the sea urchins are the major seagrass grazers in the coastline lagoon and this is consistent with the many research aspects that have been carried out before elsewhere in the world. This clearly puts the seagrass meadows on the forefront that it is indeed an important source of biodiversity.

The seagrass population has also supported two forms of endangered species, such as the green turtle Chelonia mydas (30-33) and the dugong dugong (Ochieng & Erftemeijer, 2003). In 1994, a total of four hundred and forty three sea turtles was documented along the Kenyan coast, with the green turtle predominantly appearing.

2.2.4 Impact of Climatic Conditions and Seasons on Distribution and Diversity

The growth of seagrass and sea urchins are subject to climatic conditions and seasons because they exist in the marine ecosystem and exhibit holobiont coexistence. According to Conte *et al*. (2021), seagrass provides substrates for microbes to attach, grow, and fix nitrogen, while microbes supply nutrients after degrading debris material for the growth of seagrass. In tropical regions such as Kenya coastline, the optimal temperatures for the growth of seagrass range from 23 °C to 32 °C (Lee *et al.,* 2007). Seagrass growth show seasonal trends in which there are high growth rates in summer and spring, but low growth rates in winter and fall. Moreover, monsoon patterns also influence seasonal growth of seagrass by affecting temperatures and availability of nutrients. Seagrass are sensitive to climatic changes as global warming causes more than 7% decline in seagrass cover (Brodie & N'Yeurt, 2018). Due to the coexistence of sea urchins and seagrass as holobiont, their distribution follows seasonal and climatic conditions of tropical regions, as well as trends of monsoon winds.

2.2.5 Seagrass Ecosystem Services and Functions

Seagrass meadows are one of a number of valuable natural habitat types that occur in our coastal waters. It provides important ecosystem services in the marine environment, such as: provision of physical structure enhancing and sustaining the biodiversity for other marine species, as well as the provision of nursery functions for fish establishment and aftermath support to coastal fortification that will accumulate nutrients and sequestration of carbon (Unsworth & Butterworth, 2021). Seagrass are edible, providing incredible amount of organic carbon, that way, are a source of considerable number of herbivores like dugongs (*Dugong dugong)*, manatees (Trichecus manatus) and green turtles (*Chelonia mydas*) (Marsh *et al.*, 2018). These plants need oxygen to be tapped to their roots and rhizomes, thus, the sole source is via catchment of increased levels of light. This can also help in supporting big amounts of non-photosynthetic tissue. Oxygen is required as the seagrass inhabits sediments containing toxic sulfide potential. These high light requirements imply that seagrasses mainly occur in very clear water and at places with high solar fluxes; further away from the equator they must live in more shallow water, thus exposing them more to frost, which is a source of stress. On the other hand, despite the less diversification, seagrass has been shown to distribute widely at the evolution point and physiological avenue in many polar seas. Some seagrass thrive in temperate climates and survive severe winters by shedding their leaves in autumn and surviving as below-ground tissue or by annual regeneration from seeds (Van Dam *et al.*, 2021).

Seagrass add up as most fertile germinating and foraging grounds that provide environment for fish-hiding from obvious predators. Other invertebrates have also benefited from this aspect. Additionally, there pops up the benefit of subsistence, commercial and recreational fisheries. The seagrass creates a strong leaf canopy as it contains very firm root network that stabilizes sediments serving as hydrodynamic barriers. The hydrodynamic from the complex architecture of the leaf canopy in combination with the dense network of roots and rhizomes seagrass meadows may stabilize bottom sediments and serve as effective hydrodynamiathe coastline (Asmus *et al.*, 2022). Further, seagrass fields are a reason for accumulation of big portions of nutrients and organic matter at the lowest points of the sediment. Seagrass biomass find their way into the food web via marine microbial decomposition as detritus, supporting productivity through carbon and nutrient recycles (Unsworth & Butterworth, 2021).

In Kenya, seagrasses find shallow water to be the most comfortable environment to survive. Majorly, they do well at the inshore ecosystems of lagoons. Most of the lagoons are arranged parallel to an endless fringing coral reef platform. The fringing reef stand is well-known to halt strong waves, in that way, soothing seawaters at the back of the reef lagoons, which support seagrass establishment and development (Harcourt *et al.*, 2018; Musembi *et al.*, 2019). All over the world, more specifically in East Africa, seagrass fields provide keen preservation status in the coastline and oceanic environments. They anchor ecological resources around the coastal environments. They produce gradual carbon in the waters (sequesters of carbon iv. oxide); elevation of biological connections (for instance, effect of grazing, detritus creation and epiphyte assembly) and accordingly backing up much biodiversity, as well as supporting dual rare species in Eastern Africa, i.e. the green turtle, the dugong. Seagrass beds similarly offer protection of the coastal environs from storm flows (vertical stems are breakwaters), so, offering normal coast line shield/calming (Himes-Cornell *et al.*, 2018).

A better understanding has been reached on the significance of seagrass of ecosystems in Tanzania and Kenya. However, there are effects that have been considered to be limiting factors to seagrass. The leaf productivity of *T.ciliatum* ranges right from 4.9 to 9.5 g/m2 each day (Ochieng & Erftemeijer, 2003). The growth of the named species vertically is standing at forty two internodes, in that 42 leaves per day. These are among the fastest growing species of seagrass within the population that is thriving well in Kenya. Its horizontal growth capability runs up to 16cm each year, now this makes it fall among the slowest growing species. The rejuvenation of shoots in the meadows of seagrass along the coastal regions of Kenya and Zanzibar have always been either similar or slightly varying from the mortality rates. This suggests that the environmental parameters for this region support the growth of the seagrass. Herein, we re-report factors that have already been discussed elsewhere; i.e. that temperature and light are the biggest motivators of growth. The conditions are genuinely constant all-through the year. Notwithstanding, the composition of the oceanic water and the amount of freshwater which enters the coastal areas are influenced by varying factors. Sometimes, the coastal lining receives differential levels of water seepage, which results to brackish water on the seagrass (Ochieng & Erftemeijer, 2003).

Importantly, the stable isotope nitrogen signatures have determined that the abundance and diversity of *T.ciliatum* is influenced largely than in areas having *T. hemprichii* that sees little effect on the seagrass. Studies that have been carried out in Zanzibar, of carbon IV. Oxide; this is because of the change of the global climate. The following species, *H. ovalis* and *C. rotundata* have been demonstrated to possess high carbon dioxide intake due to overexposure in the intertidal zones. This must have been due to the maximum intake of carbonate quantities directly. Additionally, these seagrass were determined to be very sensitive in desiccation when compared to subtidal seagrass. However, in this case, *S. isoetifolium* stands out. In this matter, the tolerance level of desiccation may not surreal become an equatorial determinant of vertical growth among seagrass but still plays an important role in the tropics (Ochieng & Erftemeijer, 2003). The capability to stand high capacities of irradiances, high nutrient inputs right at the shore, means that shallow species will occupy the topmost intertidal zone. The cast materials against the seagrass can contribute significantly to the stability of the beach, as indicated by a study done in the coastal part of Kenya. There has been shown that the Gazi region of Kenya, has received constant carbon out welling via the mangroves to the neighboring seagrass meadows, plus, a reverse flux of the organic materials at the zone of the seagrass into the mangroves. The surrounding coral reefs exist in a state of isolation in relation to existence of particulate matter (Ochieng & Erftemeijer, 2003).

The carbon isotope and the 15N Delta studies have discovered the relationship existing in seagrass beds and the fish life. So, the fish in Gazi Bay live ideally dependent on the growth of the seagrass (Dromard *et al.*, 2017). Illustratively, *Calotomus carolinus*

(Scaridae), amongst the most appearing fish in Watamu Marine National Park, like the seagrass species that are short-lived to the long-lived seagrass. The study also demonstrated the role of fish on seagrass overgrazing. Taking note that at this point, the sea urchins are amongst the subjects of the study. Interestingly, the sea urchins bring in the completive progress of the diverse seagrass and fish species both abundance and distribution-wise. According to their study, sea urchins are able to decrease the grazing rates of some fish whereas, increase of sea urchins will lead to high fishing pressure on the herbivorous fish (Erftemeijer, 2003). *T. gratilla*, for instance, can graze up to 1.8 shoots of seagrass within a day per metres square and this occurs at the fronts that support the growth of the sea urchins, at growth rate of 10.4 individual per day per meters square. It appears that the composition of the seagrass in reef environment is partly affected by predation of the dominant grazers. Parrotfishes and the sea urchin *E. diadema* seem to support seagrass beds subjugated by *T.ciliatum*, whereas some sea urchin species like *D. setosum*, *E. mathaei* and *D. savignyi* support regions having *T. hemprichii* (Johannsen, 2019).

A previous research carrying out survey on the human utilization of seagrass, has shown very anecdotal report that may not be conclusive. There is little or no direct utilization of the seagrasses in East Africa except for the seagrass leaves from Enhalus acoroides that have been used for mat-weaving and thatching of huts. Additionally, though minimally, the residents of Lamu use seagrass to harvest rhizomes, that is later on dried and ground for consumption. However, no matter how little the information comes in, there is still pain in losing the seagrass due to overgrazing as it is used by the people of the specific localities in Kenya and elsewhere in East Africa (Ochieng & Erftemeijer, 2003). Seagrass seems to be endangered species so as the sea urchin in the lagoon reefs.

2.2.6 Natural and Anthropogenic Impacts on Seagrass Populations

Seagrasses are threatened by both anthropogenic and natural factors. The biggest losses of the seagrass have been noted due to prevalence of storms, deadly plant diseases and herbivores. Additionally, human activities have been a reason for the influence of loss of seagrasses. The activities encompass eutrophication and land reclamation. The activities have led to stoppage of penetration of light into the column of water; which turns out to be the biggest threat to ever exist upon seagrass survival (Joseph *et al.*, 2019). However, the human activities mostly affecting seagrass equally mess up the water quality and/or clarity. Likewise, affect sedimentation and nutrient development from runoff. Sewage dumping, dredging and filling, contamination, high ground growth, and negative fishing practices add up the list (Newton *et al.*, 2020).

2.2.6.1 Natural Impact

Natural disturbance of habitats is one of the factors that threaten the growth and establishment of seagrass in marine environment. The most common macro grazers of seagrass are the sea urchins in the system. Sometimes their grazing frequencies surpass seagrass growth rates, an occurrence occasionally known as overgrazing. Seagrass hyper-grazing is irrefutably the toughest outcome of the interface between seagrasses and grazers. Factors influencing grazing include, intensity of grazing, population and species-specific sensitivity to grazing, the existence of additional conflicts such as shading, and seasonal variations in light and temperature. It has been established that, overgrazing is a threat to tropical and subtropical seagrasses by majority of authors. This is due to concurrent loss of seagrass (Eklöf *et al.*, 2008; Ling *et al.*, 2015). Sixteen identified cases of overgrazing on urchin at the tropical cost showcase that it is indeed a global problem that is yet to be solved. In the phenomenon, eleven seagrass and seven urchin species are encompassed, that is; in East Africa; *T.ciliatum*, in the Americas; *Thalassia testudinum* and *Syringodium filiforme*, in the Mediterranean; *Posidonia oceanica*, and in Australia; *Posidonia sinuosa* (Eklöf *et al.*, 2008; Hartog & Kuo, 2007; Short *et al.*, 2007). This is because, the zones stated above are the major subtidal and meadow forming spp. of all time respectively. Therefore, they are impacted averagely by increased levels of generalist grazers like the sea urchins.

It has been evaluated that in a case of *T. ciliatum* in East Africa, the most sensitive grazing activity emanates from it. This exists among all the meadow forming species in the area. This can explain the reason why it is affected by grazing. Overgrazing has a much far reaching indirect effects e.g. the loss of the linked fauna and reduced stabilization of the sediment (Eklöf *et al.*, 2008). However, majority of the overgrazing occasions appear to affect areas of less than 0.5 km2 with a recovery of few years. The key suggestion for the overgrazing ordeal encompass, bottom-up (enrichment of nutrient), top-down (control of predation events such as overfishing), "side-in" mechanisms (variation of water temperature) and natural inhabitants variations (Bernal-Ibáñez *et al.*, 2021).

2.2.6.2 Anthropogenic Impact

The existence of seagrass communities in marine ecosystem is also dependent on frequent disturbances caused by anthropogenic activities. According to Mutisia (2009), eutrophication, mechanical damage, shoreline construction, and over fishing are major anthropogenic activities that threaten the existence of seagrass in Kenyan coastline and across the world. Economic activities in the agricultural and industrial sector are harmful to environment because they release poisonous chemical and pollute ecosystems (Uku *et al.*, 2021a). Eutrophication of marine water by chemicals from farms and industries causes overgrowth of algae and other aquatic flora, resulting in excessive competition, increased turbidity of water, low oxygen levels, and decreased growth of seagrass (Mutisia, 2009; Bastos *et al.*, 2022). Since some fishes feed on sea urchins, overfishing causes the removal of important predators of sea urchins, making their numbers grow exponentially and hasten the process of seagrass overgrazing.

As per the previous researches, there is a very tight support for the top-down and bottom-up hypotheses. However, many potential factors often co-exist and interrelate, particularly in areas with high anthropogenic pressure, meaning, multiple disturbances concurrently reduce predation control, improve urchin conscription and reduce the resistance of seagrasses which could make way for overgrazing. The main control for overgrazing is to remove urchins. However, there is less or no knowledge of direct and indirect effects this method may portray especially in terms of applicability and sustainability. There is a knowledge gap, which severely limits seagrass management (Bernal-Ibáñez *et al.*, 2021). Based on the wide knowledge gaps, which sternly limits management, we suggest that keen future research should be carried out. Some authors have suggested that over-fishing, nutrient enrichment and abiotic factors such as changes in water temperature resulting from El Niño Southern Oscillation (ENSO) events are among the lead causes. Grounded on the overall food-web method in the community ecology, the major causes are top-down (predation loss), bottom-up (nutrient enrichment), and temperature changeability due to human activities (Eklöf *et al.*, 2008).

2.2.7 Effects of Overgrazing

The straightforward consequence of sea-grass-overgrazing is complete loss of the biomass of seagrass. There are many latest and wide-ranging reviews on circumstance of seagrass grazing. However, the seagrasses are known as "founder" and or "engineering" spp. among the ecosystem (Björk *et al.*, 2008). Overgrazing, has affected processes but not limited to seagrass. Originally, overgrazing was as a result of loss of habitat and a source of food i.e. leaves of seagrass and organisms of epiphytic nature. Ideally, all the species depending on seagrass for survival, are expected to experience the biggest aftermath as a result of overgrazing on the seagrass (Björk *et al.*, 2008).

Importantly, elsewhere, it has been realized that Florida Bay experienced profound nature of overgrazing which translated into 84% decrease of invertebrate; epifauna. The invertebrate; epifauna, has the biggest economic implications that influence food availability for commercially significant predacious crustaceans (Rose, 2004). However, lack of well dedicated studies limit the exact hypothesis of evaluation. Additionally, sketchy findings of overgrazing result in the decrease of viable land used for subsistence fish catchment in Tanzania and Kenya, which are yet to be supported by the ecological studies.

It is dire probable that overgrazing may affect the stabilization of sedimentation and attenuation of water. This usually occurs as a result of loss of the seagrass due to in-seagrass cover threshold. Getting back to Florida Bay incidence, overgrazing has eroded the seabed, improving the cases of turbidity (Rose, 2004). Consequently, a process called "feedback loop" that is considered to be self-escalating will pop up with the continuous loss of the seagrass due to reduction of light penetration. Nonetheless, there is no explanation for the mechanism of loss of seagrass as pertained to overgrazing (Eklöf *et al.*, 2008). In an event of seabed establishment, structures of the underground, for instance, rhizomes and roots get exposed to natural disturbances like the effect of grazing and wave action. Anthropogenic disturbances like crushing, boat quays, and propeller scoring are major contributors too (Roberts *et al.*, 2010). Species with rhizomes growing into shallow depths such as *T.ciliatum* are more vulnerable to such ancillary effects than those with deeper developing rhizomes (Belshe *et al.*, 2018). Rhizomes and roots have a significant part to play on the seagrass existence whereby they support the plant in regards to the substrate, securing fine sediments towards the bottom-line, and have great section of seagrass energy reserves that appear to be conceivable. Notwithstanding, they have not yet been confirmed which could be a reason to the loss of biomass leading to long term aftermaths (Belshe *et al.*, 2018).

2.2.8 Local Ecosystem

The people in the locality carry out fishing, tourism and agriculture as a method of survival, to run their families, both extended and nuclear. All these activities are dependent on rainfall to coexist. Waters that are not deeper than 20m inshore to the external portions of the reef, support maximum fishing activities (Yokota & Lessa, 2006). Two registered Beach units of management exist at Mwaepe and Kinondo-Chale. Importantly, Diani-Chale coral reefs are categorized under low coral cover, smaller fish abundance and great abundance of the sea urchins (Mbaru, 2012).

This study site showed a rich ground for the Kenyan seagrass species-wide, having eight species reported in the previous studies. This is quite a good number in consideration with the already existing twelve species at the regional level. *T.ciliatum* is the most prevailing seagrass species that gets affiliated to both soft and hard substrates (Eggertsen *et al.*, 2019). Elaborately, the structure of seagrass mentioned above offers home for trivial and juvenile fish and invertebrates. Thus, this way, seagrass beds are significant environment for majority of species of the coral reef. Investigations done in the lagoon area; Diani-Chale, have previously shown that there is a fifty (50) percentage loss of seagrass with a multiplication of fractions of sand at the specific lagoon (Maina *et al.*, 2008).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Research Design

Cross-sectional research design was employed to determine spatial and temporal occurrence of sea urchins and seagrass in Diani beach. The design was used to capture trends and pattern of sea urchins and seagrass at one point in time but at different seasons, specifically northeast monsoon (December and January), intermonsoon (March and

April), and southeast monsoon (July and August). The data was collected from three study sites in Diani beach. This research design is appropriate because it allows determination of causal-effects and generates valid preliminary data for case control studies (Kothari & Garg, 2019). The data collected in each season formed the basis of determining the influence of seasons and sites on seagrass and sea urchins.

3.2 Study Area

The study was conducted in Kwale County, which borders Kilifi County to the North, Taita Taveta to the West, Tanzanian border to the South, the Indian Ocean to the East and Mombasa County to the North East. The area experiences variable climatic conditions and weather patterns. Inter-Tropical Convergence Zone (ITCZ) and the seasonal monsoon cycle are drivers of weather patterns and climatic conditions of the study site. Long-term Indian Ocean Dipole (IOD) is a new phenomenon influencing the weather and climatic conditions of coastal regions. The effect of the IOD monsoons have an inverse relationship with El Nino, which has a direct relationship with Monsoon rainfall.

The southeast and northeast are the two forms of Monsoons on Kenya reefs that are predictable and emenate from the movement of the Inter-Tropical Convergence Zone, but are not subject to the occurrence of tropical or hurricanes cyclones (Jacobs *et al.*, 2021). These two forms of monsoons account for local differences in chemical, biological, and physical conditions of coastal waters. During the northeastern monsoon (NEM) season (October through April), the currents migrate southwards and drive water to offshore sites (Kebacho, 2022). This season is characterized by high levels of radiation, low level of cloud cover, low degree of wind energy, leading to high productivity.

During southeast monsoon (SEM), the movement of coastal currents directs water to onshore sites as they move northwards along the coastline, leading to high sedimentation rate from surface run-offs, decreased water temperatures, and enhanced river discharge. Consequently, southeast monsoon affect coastal waters by decreasing productivity in coastal area and enhancing abundance of benthic algae (Tarimo *et al.*, 2022). Seasonal variation happen in water circulation patterns and tidal cycles, which exist between monsoon events, and have major effects on fauna (Swaleh *et al.*, 2022).

3.3 Human activities

The main human activities within the study area include farming, fishing, mining, and other commercial businesses.

3.4 Study sites

The study was done in Diani-Chale area, located at latitude 04º22'S to 04º44'S and 39º54'E to 39º61E in the south coast region, Msambweni constituency, Kwale County (Figure 3.1). Three sites were sampled, Mvuleni (04˚21´24.3″S and 39˚43´97.8″E), Mwaepe (04˚36´32.9″S and 39˚56'68.5"E) and Chale (04˚22'07.6"S and 39˚33'90.2"E). The distance between Mwaepe to Mvuleni is about 8 km, while that from Mvuleni to Chale is approximately 10 km. The three sampling sites are spatially located along the coastal region in the range of 30 m to 80 m from the coastline. The study site comprises semi-diurnal variations with two high tides and two low tides with asymmetric changes in current cycles and sea levels (Kosore *et al.*, 2022). The lowest tides are common in northeast monsoon because the dominant wind pattern drive coastal waters to offshore sites. Moreover, the lowest tides are common during daytime in the northeast monsoon and at night in southeast monsoon, implying that desiccation stress varies according to times and seasons (Kosore *et al.*, 2022; Swaleh *et al.*, 2022). Other studies have also demonstrated that spring and neap tides, which drive the circulation of water in coastal area, are two forms of tides that exhibit monsoon variations (Okuku *et al.*, 2022; Dzeha *et al.*, 2022). The seasonal changes and effects of monsoon winds and tides are determinants of seagrass growth and development.

The study sites host diverse species of seagrass, namely *S. isoetifolium ,* *C. rotundata, T.ciliatum, Zostera capensis, Enhalus acoroides, T. hemprichii , H. ovalis , C. serrulata, Halodule uninervis, S. isoetifolium , H. wrightii,* and *Halophila minor* (Githaiga *et al.*, 2019). The most common sea urchins are *E. mathaei* , *T. gratilla*, *D.setossum*, *E. diadema* , *Salmacis bicolor*, and *T. pileolus* , *D. savignyi* and *T. pileolus* (Eklof *et al.,* 2008, Uku *et al.,* 2021a).

Figure 3.1: Map of Kwale County showing the study sites Inset: Map of Kenya

3.5 Sampling Procedure

The sampling of sea urchins and seagrass was performed simultaneously using 1 m^2 quadrat by SCUBA diver (Nakanishi *et al.*, 2006; Bularz *et al.*, 2022). This was done in three different seasons: Southeast Monsoon (wet season), inter-monsoon (transitional season) and North-East Monsoon (dry season), between December 2016 and August 2017. Two months were selected in each season for sampling, that is, December and January (NE monsoon), March and April (inter-monsoon), July and August (SE monsoon). Quadrats were placed in both healthy and degraded sea-beds in consultation with locals and SCUBA divers who have knowledge on condition of seagrass beds in the study sites.

Sea urchins were sampled twice a month for two months in each season. In each sampling occasion, ten quadrats were placed randomly, giving a total of forty quadrats per season per study site (N=360). In each quadrat, sea urchin species were identified, number of individuals per species counted and recorded. Identification of the species was done using established criteria (Richmond, 2011).

The Simpson's Diversity Index was used to calculate the diversity of sea urchins in the different study sites in each season as follows (Roff, 2013)

Simpson's Diversity Index (1-D) = $1-\frac{\sum n(n-1)}{\sum N(N-1)}$……………………………… (**Equation 1)**

Where:

D = Simpson's index

n = total number of organisms of a particular species

N = the total number of organisms of all species

The species relative abundance was determined by dividing total number of individual species (Isi) by total number of species population ($\sum$ Nsi) multiply by one hundred. .

Relative Abundance (%) = $Isi/\sum Nsi \times 100$………………………………… **(Equation 2)**

Where:

Isi = total number of individuals of one species;

$\sum Nsi$ = total number of individuals of all species.

The density of sea urchins was calculated as follows:

$$\text{Density } (m^2) = \frac{\text{Total number of individuals of each sea urchin species}}{\text{Total area sampled}} \quad \textbf{(Equation 3)}$$

Seagrass sampling was done simultaneously with that of sea urchins in healthy and degraded seabed in the study sites. Seagrass cover was assessed subjectively using a $1m^2$ quadrat. In each quadrat,sea grass species were identified,number of individuals per species counted and recorded. Identification of the species was done using established criteria (Richmond, 2011).

The density of seagrass was calculated as follows:

$$\text{Density } (m^2) = \frac{\text{Total number of individuals of each seagrass species}}{\text{Total area sampled}} \quad \textbf{(Equation 4)}$$

The Simpson's Diversity Index was used to calculate the diversity of seagrass in the different study sites in each season as shown in Equation 1 (Roff, 2013).

3.6 Data Analysis

Data analysis was performed using Microsoft Excel 2016, Statistical Package for Social Sciences (SPSS version 26) and Statistical Analysis System Version. Data on seasonal abundance and diversity of sea urchins and seagrass in Diani beach was analyzed using two-way ANOVA with Tukey test for post-hoc analysis for multiple comparison (Oliveira, *et al*., 1997; Camps-Castella *et al*., 2020). The nature of relationships in Diani beach was examined using Pearson's correlation (Field, 2018). Data on density of sea urchins was also analyzed using independent t-test to compare their differences in healthy and degraded seabed.Correlation and Linear regression analysis was used to calculate the influence of sea urchin abundance on benthic seagrass cover by examining coefficient of determination and linear equation (Field, 2018). Canonical Correspondence Analysis (CCA) was used to analyze how seasons, study sites and sea urchins influence distribution of seagrass species and nature of seabed. All analyses were performed at significance level of $P \leq 0.05$.

CHAPTER FOUR

RESULTS

4.1 Seasonal Abundance and Diversity of Sea Urchins and Seagrass Cover

4.1.1 Relative Abundance of Sea Urchins in Northeast Monsoon

There was a significant difference ($P < 0.05$) in the relative abundance of sea urchins among the three study sites (Table 4.1). The most abundant species in Mwaepe was *Echinometra mathaei* (34.7%) which was significantly different ($P < 0.05$) from that obtained for most of the other species. This was followed by *Tripneustes gratilla* (28.8%), whereas *Salmacis bicolor* (2.5%), and *T. pileolus* (2.5%) were the least abundant species. In Mvuleni, the relative abundance of *T. gratilla,* (48.7%), was significantly higher ($P < 0.05$) than that of all the other species. *Diadema savignyi* had the second highest relative abundance of 22.4% while *S. bicolor* and *Toxopneustes. pileolus* had the lowest, 1.9% and 1.3% respectively. Comparatively, the relative abundance of sea urchins was significantly different ($P < 0.05$) for all species in Chale. *T. gratilla* had the highest value of 38.4% followed by *E. mathaei* (23.9%), while *S. bicolor* (0.6%), and *T. pileolus* (1.9%) had the lowest.

Table 4.1: Relative abundance of sea urchins in the season of northeast monsoon

	Study Sites		
Species	**Mwaepe**	**Mvuleni**	**Chale**
Tripneustes gratilla	28.8%^{a}	48.7%^{b}	38.4%^{c}
Diadema savignyi	6.8%^{a}	22.4%^{b}	18.2%^{b}
Diadema setossum	16.9%^{a}	10.9%^{b}	14.5%^{a}
Echinometra mathaei	34.7%^{a}	11.5%^{b}	23.9%^{c}
Echinothrix diadema	7.6%^{a}	3.2%^{b}	2.5%^{b}
Salmacis bicolor	2.5%^{a}	1.9%^{a}	0.6%^{b}
Toxopneustes pileolus	2.5%^{a}	1.3%^{b}	1.9%^{a}

4.1.2 Relative Abundance of Sea Urchins in Intermonsoon Season.

There was a significant difference ($P < 0.05$) in the relative abundance of sea urchins in the three study sites (Table 4.2). The most abundant species in Mwaepe was *E. mathaei* (31.7%) which was significantly different ($P < 0.05$) from that obtained for all the other species. This was followed by *D. setossum* (28.8%), whereas *S. bicolor* (0.0%) and *A. radiata* (0.0%) were the least abundant species. In Mvuleni, the relative abundance of *E. diadema* (44.8%), was significantly higher ($P < 0.05$) than that of all the other species. *T. gratilla* had the second highest relative abundance of 21.0% while *A. radiata* and *T. pileolus* had the lowest, 1.4% and 1.4% respectively. Comparatively, the relative abundance of sea urchins was significantly different ($P < 0.05$) for all species in Chale. *E. mathaei* had the highest value of 71.8% followed by *D. setossum* (11.5%), while *A. radiata* (0.0%) and *T. pileolus* (1.0%) had the lowest.

Table 4.2: Relative abundances of sea urchins in the intermonsoon season

	Study Sites		
Species	**Mwaepe**	**Mvuleni**	**Chale**
Tripneustes gratilla	20.1%^{a}	21.0%^{a}	9.1%^{b}
Diadema savignyi	16.5%^{a}	5.6%^{b}	3.3%^{b}
Diadema setossum	28.8%^{a}	17.5%^{b}	11.5%^{c}
Echinometra mathaei	31.7%^{a}	6.3%^{b}	71.8%^{c}
Echinothrix diadema	2.2%^{a}	44.8%^{b}	1.4%^{a}
Salmacis bicolor	0.0%^{a}	2.1%^{a}	1.9%^{a}
Toxopneustes pileolus	0.7%^{a}	1.4%^{a}	1.0%^{a}
Astropyga radiata	0.0%^{a}	1.4%^{a}	0.0%^{a}

4.1.3 Abundance of Sea Urchins in Southeast monsoon season.

The most abundant species in Mwaepe was *E. mathaei* (59.2%) and it was significantly different ($P < 0.05$) from that obtained for all the other species (Table 4.3). This was followed by *T. gratilla* (37.9%), and *E. diadema* (2.9%) was the least abundant species. In Mvuleni, the relative abundance of *D. setossum* (40.5%), was significantly higher ($P < 0.05$) than that of all the other species. *T. gratilla* had the second highest relative abundance of 36.0% followed by *D. savigyni* (21.6%). *E. diadema* had the lowest relative abundance of 1.8%. The relative abundance of sea urchins was significantly different ($P < 0.05$) for all species in Chale. *E. mathaei* had the highest value of 97.1% followed by *D. setossum* (11.5%) (Table 4.3).

Table 4.3: Relative abundance of sea urchins in the southeast monsoon

	Study Sites		
Species	**Mwaepe**	**Mvuleni**	**Chale**
Tripneustes gratilla	37.9%^{a}	36.0%^{a}	2.9%^{b}
Diadema savingyi	0.0%^{a}	21.6%^{b}	0.0%^{a}
Diadema setossum	0.0%^{a}	40.5%^{b}	0.0%^{a}
Echinometra mathaei	59.2%^{a}	0.0%^{b}	97.1%^{c}
Echinotrix diadema	2.9%	1.8%	0.0%

4.1.4 Diversity of sea urchins

The diversity of sea urchins varied according to study sites and seasons (Table 4.4). Mwaepe (0.672±0.077) and Mvuleni (0.657±0.061) had amost the same overall diversity of sea urchins, while Chale (0.612±0.113) had sgniffficanty lower diversity. Moreover, data shows that seasonal changes in sea urchin diversity are statistically significant as shown by SEM (0.588±0.085), IM (0.625±0.070), and NEM (0.727±0.042). Two-way ANOVA indicated that study sites and seasons have significant effects on sea urchin diversity (p = 0.000), while their interaction effects were also statistically significant (p = 0.000) (Figure 4.1). Appendix I displays additional analyses for seasonal and spatial variations of sea urchins.

Table 4.4. Diversity indices for sea urchins in different seasons and study sites.

		Study Sites			
		Mwaepe	**Mvuleni**	**Chale**	**Means of Seasons**
Seasons	Southeast monsoon	0.610±0.056^{a}	0.646±0.028^{a}	0.510±0.028^{a}	**0.855±0.085^{a}**
	Intermonsoon	0.671±0.067^{a}	0.619±0.071^{a}	0.585±0.071^{a}	**0.625±0.070^{b}**
	Northeast monsoon	0.736±0.049^{b}	0.706±0.036^{b}	0.741±0.029^{b}	**0.727±0.090^{c}**
	Means of Sites	**0.672±0.077^{a}**	**0.657±0.061^{a}**	**0.612±0.113^{b}**	
	Study Sites	**Study Sites**	**Seasons**	**Interactions**	
	F Values (2,351)	38.819	204.226	27.892	
	P Values	0.000	0.000	0.000	

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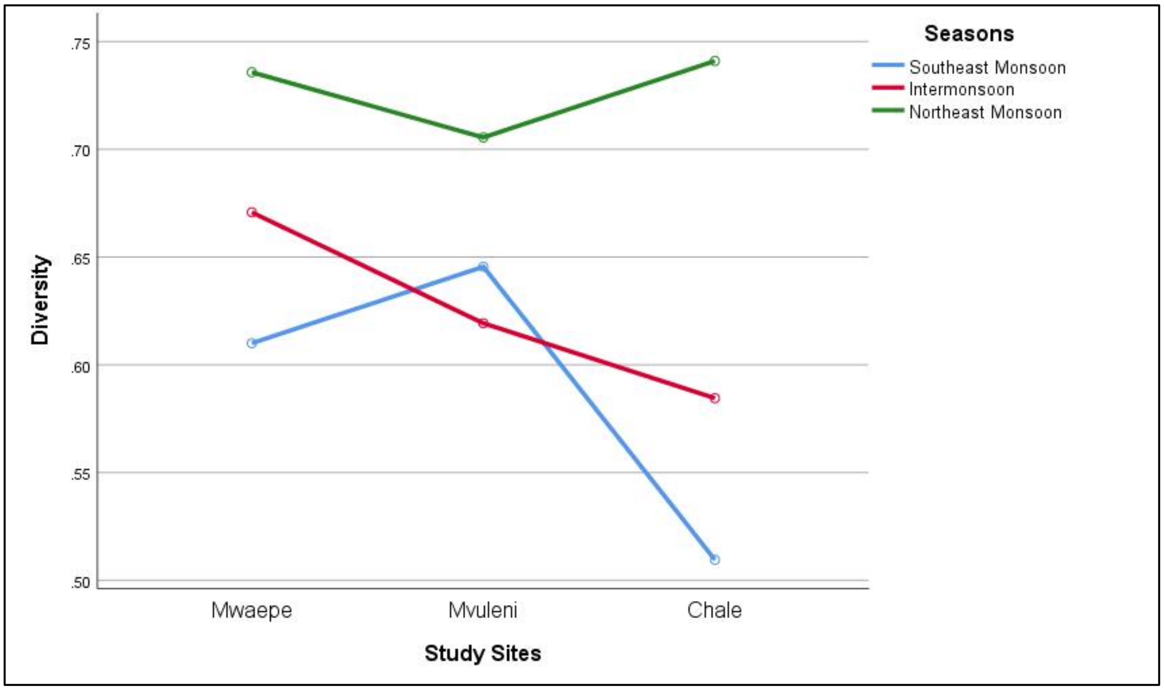

Figure 4.1: Interaction effects of seasons and study sites on diversity of sea urchins

4.1.5 Abundance of seagrass

The overall seagrass cover varied significantly from one study site to another, depending on conditions of seabed. Healthy seabeds recorded (73.41%) significantly higher cover in all study sites as compared to the degraded ones (40.81%), F(1,358) = 1366.101, p = 0.000 (Table 4.5). The abundance of seagrass exhibited significant dfferences in study sites (P = 0.000) and seasons (P = 0.000) (Table 4.6). Two-way ANOVA indicated that the interaction effects of seasons and study sites have statistically significant effects on study sites, F (4,351) = 167.979, p = 0.000. Figure 4.2 depicts the interaction effects of seasons and study sites on influencing the abundance of seagrass cover.

Table 4.5: Differences in Abundance of Seagrass in Seabeds

	Mean	Std. Deviation	df	F	P value
Healthy Seabed	73.41	8.956	(1,358)	1366.101	0.000
Degraded Seabed	40.81	7.734			
Total	57.11	18.337			

The percent cover of specific seagrass species in different sites and seabed conditions shows that *S. isoetifolium* (58%) and *T. hemprichii* (27.5%) were the dominant species in healthy seabed, whereas *S. isoetifolium* (20%) were dominant in degraded seabed in Mvuleni. In Chale, *S. isoetifolium* (79%) and *H. ovalis* (25%) were dominant in healthy and degraded seabed, respectively. *T. ciliatum* (24%), *C. rotundata* (14%), and *H. wrightii (*16%) are dominant in healthy seabed, whereas *H. ovalis* (25%), *S. isoetifolium* (12%), and *H. wrightii* (11%) were predominant in degraded seabed in Mwaepe (Table 4.6).

Table 4.6: Percent cover of seagrass species

	Mvuleni		**Chale**		**Mwaepe**	
Seagrass Species	**Healthy**	**Degraded**	**Healthy**	**Degraded**	**Healthy**	**Degraded**
T. ciliatum	1%	0%	0%	0%	**24%**	0%
S. isoetifolium	**58%**	**20%**	**79%**	0%	8%	0%
S. isoetifolium	4%	7%	3%	10%	6%	**12%**
H. ovalis	0%	0.5%	0%	**25%**	9%	**25%**
C. serrutata	0%	7%	0%	0%	7%	0%
T. hemprichii	**27.5%**	0%	5.5%	0%	0%	0%
C. rotundata	1.5%	6%	0%	0%	**14%**	0%
H. wrightii	0%	0%	0%	4%	**16%**	**11%**

The diversity of seagrass cover varied significantly from one study site to another depending on the state of the seabed. Seagrass diversity for healthy seabeds was significantly higher in Mwaepe (0.73) followed by Mvuleni (0.51) and was least recorded in Chale (0.18). Degraded seabeds recorded significantly higher diversity in Mvuleni (0.67) compared to all other study sites, which are Chale (0.40) and Mwaepe (0.35) (Figure 4.2).

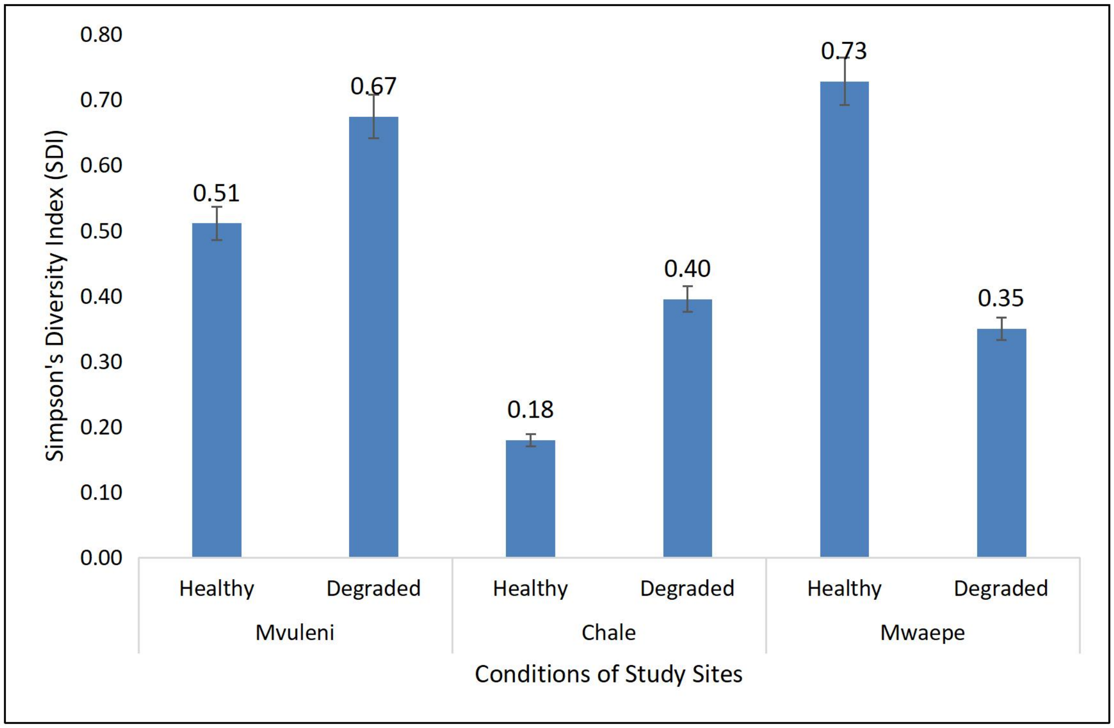

Figure 4.2: Diversity of seagrass in healthy and degraded sites

Northeast monsoon recorded significantly higher overall diversity of seagrass (0.698±0.716) compared to all the other seasons. Analysis of spatial changes in seagrass diversity (Table 4.3) indicates that Mwaepe (0.661±0.118) and Mvuleni (0.662±0.071) had the same level of diversity, while Chale had significantly lower level of diversity level (0.476±0.131). Spatial and seasonal diversity indices of seagrass were statistically significant ($p \leq 0.05$). Moreover, the interaction effects of study sites and seasons is statistically significant ($p = 0.000$) (Table 4.7 and Figure 4.3). Appendix I provides additional analyses for seasonal and spatial variations of sea urchins.

Table 4.7: Simpson's diversity indices for seagrass in different seasons and study sites

		Study Sites			
		Mwaepe	**Mvuleni**	**Chale**	**Means of Seasons**
Seasons	Southeast monsoon	0.543±0.098^{a}	0.630±0.043^{a}	0.357±0.052^{a}	**0.510±0.133^{a}**
	Intermonsoon	0.692±0.077^{b}	0.647±0.090^{a}	0.432±0.049^{a}	**0.590±0.136^{b}**
	Northeast monsoon	0.746±0.066^{c}	0.710±0.044^{b}	0.639±0.058^{b}	**0.698±0.072^{c}**
	Mean of Sites	**0.661±0.118^{a}**	**0.662±0.071^{a}**	**0.476±0.131^{b}**	
	Study Sites	**Study Sites**	**Seasons**	**Interactions**	
	F Values	307.510	239.853	32.925	
	P Values	0.000	0.000	0.000	

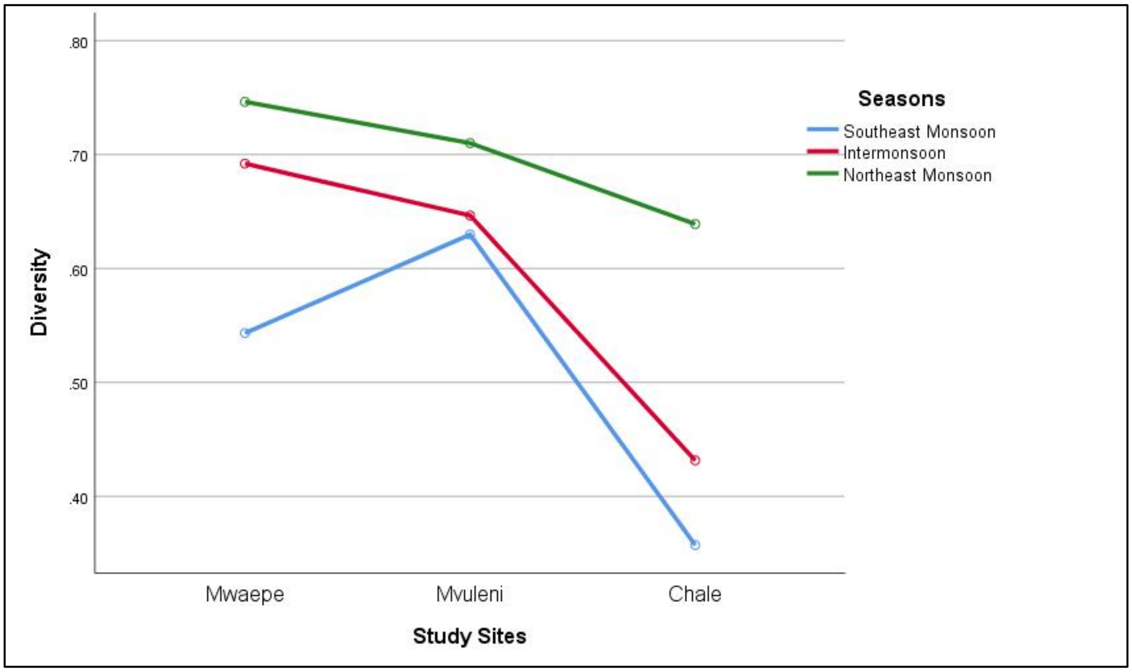

Figure 4.3: Interaction effects seasons and study sites on seagrass diversity

4.2 Overall Density of Sea Urchins in Healthy and Degraded Seabeds

The overall density of sea urchins was significantly higher ($p \leq 0.05$) in degraded seabed (7.88±1.507) as compared to that of healthy seabed (5.94±1.586) (Table 4.8). In healthy seabed, the density of sea urchins ranged from 2 to 14/m^2 while the density of sea urchins in degraded seabed ranged from 5 to 22/m^2.

Table 4.8: Density of sea urchins

State of seabed	Density/m^2	F
Healthy Seabed	5.94± 1.586^a	F(1,358) = 142.167
Degraded Seabed	7.88± 1.507^b	p = 0.000

Table 4.9 shows that the density of sea urchins increases with seasons from SEM, IM, and NEM across the year. In each site, Mwaepe had mean densities of sea urchins in SEM (5.13±1.381), IM(5.90±1.381), and NEM (7.20 ±1.436) with statistically significant differences across seasons. In Mvuleni, the mean densities of sea urchins in SEM (5.35±1.292), IM(7.40±1.932), and NEM (7.75±1.256) had statistically significant differences across seasons ($p<0.05$). In Chale, the mean densities of sea urchins in SEM (8.25±1.214), IM(8.25±1.214), and NEM (8.45±1.552) had statistically significant differences across seasons ($p<0.05$). The interaction effects between seasons and sites had statistically significant differences ($p<0.05$) (Figure 4.4).

Table 4.9: Density of sea urchins in different seasons and study sites

		Study Sites			
		Mwaepe	**Mvuleni**	**Chale**	**Means of Seasons**
Seasons	Southeast monsoon	5.13±1.381^a	5.35±1.292^a	8.25±1.214^a	**6.24±1.923^a**
	Intermonsoon	5.90±1.374^b	7.40±1.932^b	6.77±1.349^b	**6.69±1.679^a**
	Northeast monsoon	7.20 ±1.436^c	7.75±1.256^b	8.45±1.552^c	**7.80±1.498^a**
	Mean	**6.07±1.6230^a**	**6.83±1.849^b**	**7.83±1.559^c**	
	Study Sites	**Study Sites**	**Seasons**	**Interactions**	
	F Values	44.871	37.475	16.385	
	P Values	0.000	0.000	0.000	

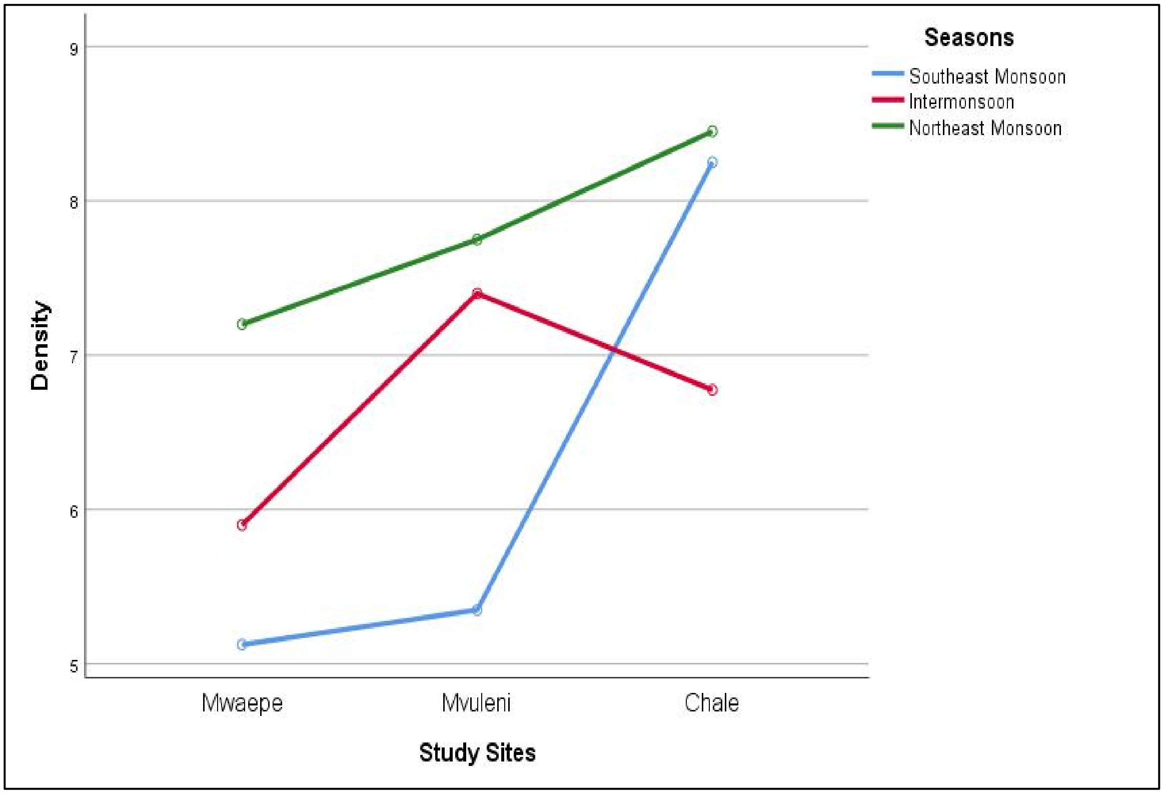

Figure 4.4: Interaction effects of seasons and study sites on density of sea urchins

4.3 Density of Seagrass and Sea Urchins in theThree Seasons

4.3.1 Seasonal Density of Seagrass

The overall density of seagrass cover differed significantly, F (2,537) = 14.165, p = 0.000, in the entire three seasons (Table 4.10), Appendix 1. It was highest in northeast monsoon (73.15±5.528). and lowest in southeast monsoon (61.15±6.115). The trends of sea grass cover increased from southeast monsoon, intermonsoon, and northeast monsoon (Appendices 1 and II).

Table 4.10: Density of seagrass

State of seabed	Density/m^2	F
Southeast monsoon	61.15±6.115^a	F(2,357) = 14.165
Intermonsoon	66.90±8.032^b	p = 0.000
Northeast monsoon	73.15±5.528^c	

4.3.2 Seasonal Density of Sea Urchins

The overall density of sea urchins differed significantly (P≤0.05) in all the three seasons (Table 4.11).The Northeast monsoon recorded the highest overall density of 7.83±1.559 while the Southeast monsoon recorded the least (6.07±1.630) with statistically significant differences, F(2,357) = 32.592, p = 0.000.

Table 4.11: Density of sea urchins

Season	Density/m^2	F
Southeast monsoon	6.07±1.630^a	F(2,357) = 32.592
Intermonsoon	6.83±1.849^b	p = 0.000
Northeast monsoon	7.83±1.559^c	

4.4 Influence of Sea urchin on Seagrass Cover

4.4.1: Relationship between sea urchins density and vegetation cover

Correlation analysis demonstrated that sea urchins and vegetation cover have a negative relationship , which is statistically significant (r = - 0.699, $p < 0.05$). Figure 4.5 shows that there is a linear relationship between seagrass cover and sea urchins density.

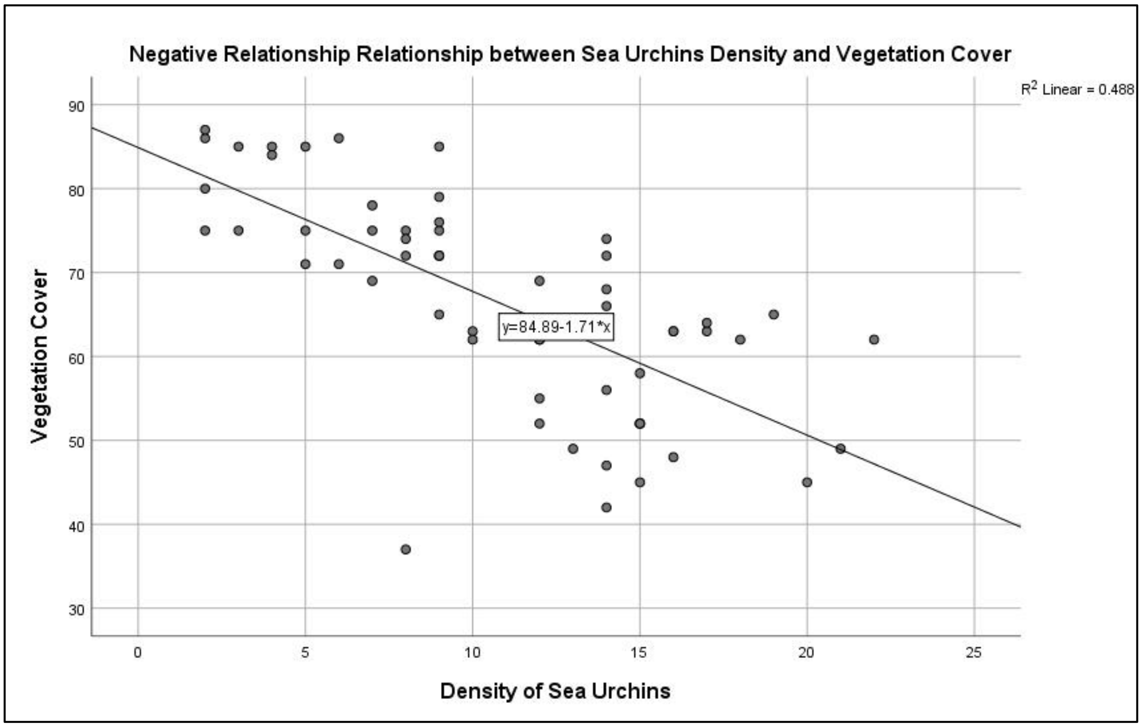

Figure 4.5: Correlation between sea urchins and seagrass cover

The regression model (Table 4.12) indicates that there is a strong relationship between the density of sea urchins on seagrass cover in Diani beach (R = 0.699). In prediction, the regression model indicates that the density of sea urchins accounts for 48.8% of the variation in the proportion of seagrass cover ($R^2 = 0.488$). The adjusted R-square predicts that the density of sea urchins explains 47.9% of the variation in the seagrass cover (Ajusted $R^2 = 0.479$).

Table 4.12: Regression model summary sea urchins predicting seagrass cover

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.699[a]	.488	.479	9.036

a. Predictors: (Constant), Density of Sea Urchins

The ANOVA (Table 4.13) shows that the regression model is statistically significant in predicting the influence of the density of sea urchin on the proportions of seagrass cover, F(1,358) = 55.275, p = 0.000 (Appendix IV). Regression coefficients (Table 4.9) confirms that the density of sea urchins is a statistically significant predictor of the proportion of seagrass cover (β = -1.713, t = -7.435, p = 0.000). Based on 95% confidence interval, the critical values of constant (t = 30.998, CI: 79.405, 90.368) and sea urchins (t = -7.435, CI: -2.175, -1.252) fall on the rejection regions. These findings shows that a unit increase in sea urchin density causes the seagrass cover to decrease by 1.713 in a significant way.

Table 4.13: Regression coefficients of density of sea urchins in predicting seagrass cover

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	84.886	2.738		30.998	.000	79.405	90.368
	Density of Sea Urchins	-1.713	.230	-.699	-7.435	.000	-2.175	-1.252

a. Dependent Variable: Seagrass Cover

Regression equation

The proportion of seagrass cover = -1.71 (Density of Sea Urchins) + 84.89 (Appendix IV)

4.5 Correspondence Analysis

Canonical Correspondence Analysis (CCA) revealed that seasons, study sites, and sea urchins influence distribution of seagrass species and nature of seabed (Figure 4.6). The first dimension of CCA, which are mainly study sites, sea urchins, and seasons, account for 86.9% of variation in the nature of seabed and seagrass species. The second dimension of CCA, which are seasons and study sites, account for 7.87% of variation in the condition of seabed thus sea urchins has a greater effect on seagrass cover. The eigenvalues shows that three factors are significant predictors because they are 0.1 or greater and account for cumulative 83.944% (Appendix V).

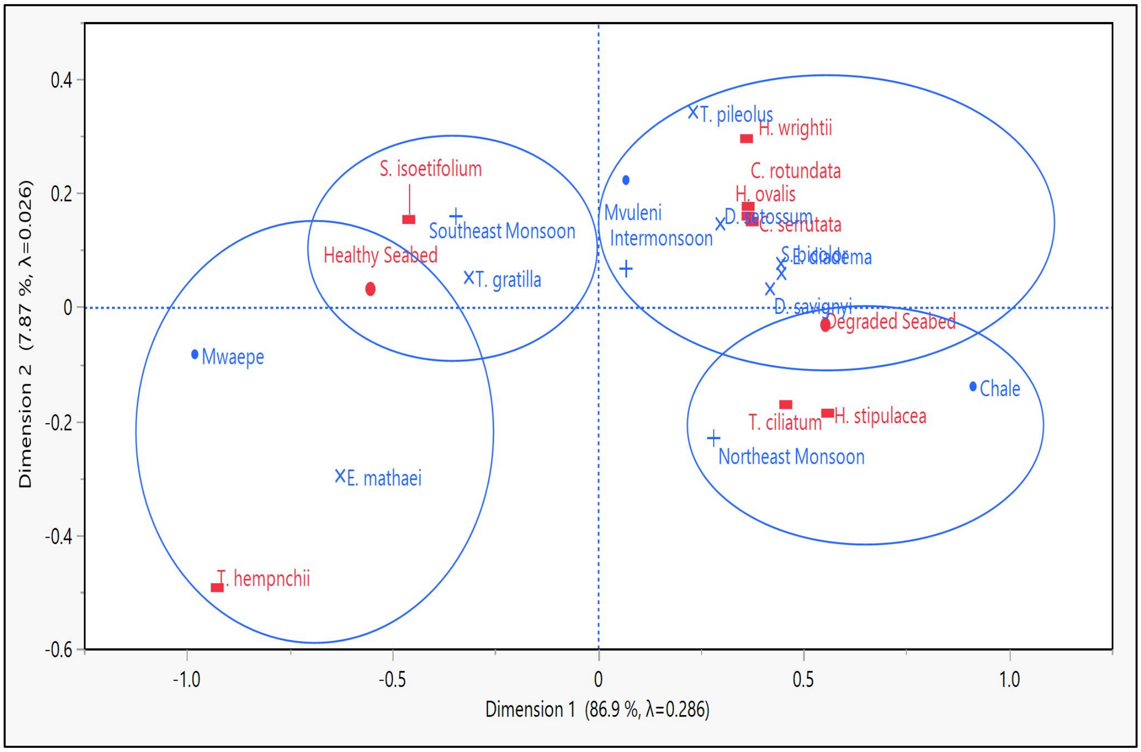

Figure 4.6: Canonical Correspondence Analysis (CCA) shows how study sites, seasons, and sea urchin species contribute to the nature of seabed and seagrass species.

CHAPTER FIVE

DISCUSSION

5.1 Relative Abundance of Sea Urchins

The relative abundance of sea urchins in the marine environment is influenced by several factors. There was a significant variation in sea urchin species relative abundance between different sites in Diani beach. Chale had the highest overall abundance of sea urchins whereas Mwaepe had the least.This is because Chale is relatively less protected compared to Mwaepe and Mvuleni. Interference by human activities like fishing removes sea urchin predators that lead to increase in sea urchins population. Several species were abundant in the three sites during the three seasons. These included *E. mathaei* ,and *T. gratilla.* Researchers have shown that *T. gratilla* and *E. mathaei* are dominant in Indo-Pacific Sea because they are adaptable to various habitats and have the ability to breed all year round (Rahman *et al.*, 2009; Nadiarti *et al.*, 2021). This probably explains why their distributions remained relatively constant during northeast monsoon, intermonsoon, and southeast monsoon seasons and in the three study sites. The abundance of *Diadema* species was variable because they are sensitive to changes in environmental conditions and seasons (Muthiga & McClanahan, 2007; Ditzel *et al.*, 2022). However, *E. diadema* , *Salmacis bicolor*, and *T. pileolus* species were less common in all habitats in Diani Beach. Barret *et al.* (2019) established that the abundance of *T. pileolus* does not relate to the distribution of seagrass but they prefer to thrive where there are large pieces of debris (cover material). The abundance of sea urchins varied significantly across the three seasons.Results show that there was overall higher abundance during the Northeast

Monsoon compared to all other seasons. This variation was probably due to seasonal ecological changes that influence their growth and development. During the northeastern monsoon season (October through April), the currents migrate southwards and drive water to offshore sites (Kebacho, 2022). These conditions are favorable due to high levels of radiation, low level of cloud cover, low degree of wind energy, leading to high productivity of seagrass, which is a source of food for sea urchins. This leads to increase in sea urchin abundance.

During southeast monsoon (SEM), the movement of coastal currents directs water to onshore sites as they move northwards along the coastline, leading to high sedimentation rate from surface run-offs, decreased water temperatures, and enhanced river discharge. Consequently, southeast monsoon affect coastal waters by decreasing productivity in coastal area and enhancing abundance of benthic algae (Tarimo *et al.*, 2022).This decreases the abundance of sea urchins since the seagrass, which is their source of food, is decreased. Additional findings indicated that *E. mathaei and D.setossum* are sensitive to changes in weather conditions as reflected by monsoon trends (Nadiarti *et al.*, 2021). *T, gratilla* is a dominant grazer in coastal areas that has adapted different niches and seasons (Li *et al.*, 2022b).

5.2 Diversity of Sea Urchins

Based on Simpson's diversity index (Roff, 2013), the most diverse study site was Mwaepe,followed by Mvuleni and Chale recorded the least overall diversity. This is because Mwaepe and Mvuleni are protected areas and Chale is least protected.Human activities for instance discharge of harmful substances into the water causes death of some sea urchin species leading to low diversity. The diversity of sea urchins was highest in the three study sites during northeast monsoon. The trend follows the weather patterns because northeast monsoon provides favorable environment for the growth of most seagrass species, and therefore, sea urchins from the months of November through February (Msuya *et al.*, 2022; Tarimo *et al.*, 2022). These findings show that diversity varied from one site to another and season influenced variation in diversity. During intermonsoon, conditions were less favorable for the growth of seagrass thus; less diversity of sea urchins. Southeast monsoon had the least diversity due to unfavorable conditions for example more cloud cover and less transparency in the water.This resulted to lower seagrass cover compared to that in northeast monsoon.

5.3 Seagrass Cover

Healthy and degraded seabed had significant differences in seagrass cover. While healthy seabed had over 68% of seagrass cover, degraded seabed had less than 41% of seagrass cover. The differences in the seagrass cover reflect trends of degradation of habitats in Diani beach. There was a general low seagrass cover in degraded seabed indicating that it was being actively grazed on by the sea urchins. The distribution of seagrass shows that *S. isoetifolium* and *H. wrightii* were dominant in both healthy and degraded seabed, suggesting that sea urchins do not feed on them. *H. ovalis* were common in degraded seabed, and could be an indication that it is less palatable and not preferred by sea urchins. A study by Juma (2019) reported dominance of *S. isoetifolium* species of in Diani beach,and this infers that it is not preferred by sea urchins.

Comparison of diversity of seagrass indicates that the diversity in healthy seabed is higher than that in degraded seabed. There was generally lower diversity of seagrass in Chale compared to Mwaepe and Mvuleni. In a previous study, Aboud, and Kannah (2017) established that the abundance and diversity of seagrass species along the Kenyan coastline is high in protected sites than in unprotected areas where there are extensive disturbance and fishing activities. Govindasamy *et al.* (2013) noted that the abundance of herbivores and predators of fishes and sea urchins determine the growth of seagrass in marine environment. Removal of sea urchin predators through overfishing leads to increase in sea urchin population, which in turn decrease seagrass cover.These studies establish that Mvuleni and Mwaepe are relatively protected when compared to Chale because they exhibited a higher level of diversity. Human activities such as fishing, tourism, agriculture, and mining contribute significantly to degradation of habitats in Diani beach and influence the distribution of seagrass and sea urchins.

5.4 Density of Sea Urchins in Healthy and Degraded Seabed

The mean density of sea urchins in degraded seabed was significantly higher than that in healthy seabed. These findings indicates that the condition of the seabed associates with the density of sea urchins. Eklof *et al.* (2008) assert that sea urchins are macro-grazers that contribute significantly to overgrazing of seagrass systems. The higher densities of sea urchins in degraded seabed than healthy seabed reflect the degree of overgrazing.The significance confirms that sea urchins overgraze on seagrass and therefore is one of the causes of degradation of habitats. In their study, Eklof *et al.* (2008) established that overgrazing is a global phenomenon caused by seven species of sea urchins feeding on 11 species of seagrass.

5.5 Seasonal Variation in of Seagrass Cover

Seasons have some influence on the proportion of seagrass cover. The proportion of seagrass cover was significantly different in the three seasons. It was lowest in southeast monsoon, moderate in inter-monsoon, and highest in northeast monsoon. During the northeastern monsoon season, the currents migrate southwards and drive water to offshore sites (Kebacho, 2022). These conditions are favorable due to high levels of radiation, low salinity, low level of cloud cover and low degree of wind energy, leading to high productivity. During southeast monsoon, the movement of coastal currents directs water to onshore sites as they move northwards along the coastline, leading to high sedimentation rate from surface run-offs, decreased water temperatures, and enhanced river discharge. This leads to lower productivity. The inter-monsoon is a transition season whereby there are changes in conditions thus there was moderate productivity. These findings indicated that northeast monsoon and inter-monsoon had favorable biotic and abiotic conditions, while southeast monsoon had high rainfall and sedimentation that were unfavorable for the growth of seagrass.

5.6 Seasonal Variation in density of Sea Urchins

There were significant seasonal variations in the density of sea urchins in Diani beach. The density decreases from northeast monsoon to inter-monsoon to southeast monsoon. This variation probably indicates that densities of sea urchins follow the seasonal distribution pattern of seagrass cover. Temperature, pH, and availability of food are some of the factors that influence seasonal variation in the distribution of sea urchins (Eklof *et al.*, 2008; Blake & Duffy, 2010; Harianto *et al.*, 2021). The findings from this study indicate that the northeast monsoon had favorable conditions that led to higher density of sea urchins, compared to the southeast monsoon and the inter-monsoon (Harianto *et al.*, 2021.

5.7 Influence of Sea urchin on Seagrass Cover

Correlation analysis indicated that the density of sea urchins influences the proportion of seagrass cover in Diani Beach. The regression model showed that there is a strong negative relationship between the density of sea urchins and the proportions of seagrass cover in Diani beach (r = -0.699). A study by (Mamboya *et al.,* 2009) in Tanzanian beaches, revealed that seagrass biomass and sea urchin abundance have statistically significant negative relationship. In prediction, the regression model indicated that the density of sea urchins accounts for 48.8% of the variation in the proportion of seagrass cover. These findings are in tandem with earlier studies, which demonstrated that sea urchins are major macro-grazers that influence the growth of seagrass (Eklof *et al.,* 2008; Scott *et al.,* 2018; Uku *et al.*, 2021a). In October 1997, Mombasa Marine National Park (MNP) while monitoring seagrass meadows in the Mombasa lagoon, frequently witnessed the incidence of several grazing sea urchins, which were localized with densities of 137 in each area of 10 m^2 within seagrass beds. In a study done by Alcoverro and Mariani (2002), the findings shows that sea urchins heavily grazed on 39% of the seagrass cover and caused over 75% dead shoots, moderately grazed on 23.4% seagrass cover and made 50% dead shoots, and highly grazed on 38.5% seagrass cover and produced 19.8% dead shoots. These findings show that sea urchins caused overgrazing of seagrass beds and hence cause shoreline erosion and decreased sediment stabilization (Rose *et al.* 1999; Peterson *et al.* 2002). Moreover, regression coefficient confirmed that the density of sea urchins is a statistically significant negative predictor of the proportion of seagrass cover. The coefficient implies that a unit increase in density of sea urchins causes the proportions of seagrass cover to decline by 1.713. These findings concur with those of Heck *et al.* (2021) who reported that abundance and distribution of seagrass are subject to herbivory trends in marine environment. Canonical Correspondence Analysis (CCA) proved that season, study sites, and sea urchins influence distribution of seagrass species and nature of seabed because they account for 7.87% in the first dimension and 86.9% in the second dimension.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The study examined spatial-temporal occurrence of sea urchins and their grazing habits along the Diani Beach in Mombasa, Kenya. Results of the study indicated that relative abundance and diversity of sea urchins varied according to seasons and study sites. Moreover, seagrass cover also varied according to the seasons and study sites.

The relative abundance of sea urchins was highest in northeast monsoon due to low rainfall,low sedimentation and increased transparency in the water.There was lower relative abundance in the southeast monsoon due to higher rainfall,high sedimentation and decreased water transparency. Degraded habitats recorded higher relative abundance of sea urchins than in healthy ones.This is because the sea urchins fed on seagrasses causing their depletion. The abundance of sea urchins varies between different habitats in Diani Beach. The study site with highest sea urchin species diversity was Mwaepe, followed by Mvuleni, and Chale, with most diversity. The season that exhibited highest seagrass diversity was northeast monsoon followed by inter-monsoon and southeast monsoon had the least diversity.

The abundance of sea urchins is a statistically significant predictor of seagrass cover in Diani beach. Therefore, the study concludes that sea urchins are major macro-grazers that contribute to overgrazing and degradation of seabed, and that sea grass is a more palatable food preferred by sea urchins.

6.2 Recommendation

- Given that the study indicated that seasons have marked influence on the abundance and diversity of sea urchins and seagrass in Diani beach, further studies are necessary to identify specific biotic and abiotic factors that affect their distributions.
- Since the study demonstrated that sea urchins density associates with degraded seabed, conservation measures to be put in place to secure the integrity of marine resources that contribute to blue economy.
- As the relative abundance of sea urchins have significant influence on seagrass cover in Diani beach, extension of protected areas to be done to reduce the effect of human activities for example overfishing that indirectly leads to high population of sea urchins that degrades seabed.

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APPENDICES

Appendix I: Multivariate Outcomes

Diversity of Sea Urchins

Descriptive Statistics

Dependent Variable: Diversity of Sea Urchins

Study Sites	Seasons	Mean	Std. Deviation	N
Mwaepe	Southeast Monsoon	.6100	.05588	40
	Intermonsoon	.6708	.06746	40
	Northeast Monsoon	.7358	.04914	40
	Total	.6722	.07723	120
Mvuleni	Southeast Monsoon	.6455	.02791	40
	Intermonsoon	.6193	.07105	40
	Northeast Monsoon	.7055	.03637	40
	Total	.6567	.06048	120
Chale	Southeast Monsoon	.5095	.08898	40
	Intermonsoon	.5845	.03863	40
	Northeast Monsoon	.7410	.02916	40
	Total	.6117	.11288	120
Total	Southeast Monsoon	.5883	.08496	120
	Intermonsoon	.6248	.07001	120
	Northeast Monsoon	.7274	.04184	120
	Total	.6469	.08986	360

Tests of Between-Subjects Effects

Dependent Variable: Diversity of Sea Urchins

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.826[a]	8	.228	74.707	.000
Intercept	150.635	1	150.635	49300.762	.000
StudySites	.237	2	.119	38.819	.000
Season	1.248	2	.624	204.226	.000
StudySites * Season	.341	4	.085	27.892	.000
Error	1.072	351	.003		
Total	153.533	360			
Corrected Total	2.899	359			

a. R Squared = .630 (Adjusted R Squared = .622)

Estimated Marginal Means

1. Grand Mean

Dependent Variable: Diversity of Sea Urchins

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
.647	.003	.641	.653

2. Study Sites

Estimates

Dependent Variable: Diversity of Sea Urchins

Study Sites	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Mwaepe	.672	.005	.662	.682
Mvuleni	.657	.005	.647	.667
Chale	.612	.005	.602	.622

Pairwise Comparisons

Dependent Variable: Diversity of Sea Urchins

(I) Study Sites	(J) Study Sites	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
Mwaepe	Mvuleni	.015*	.007	.031	.001	.029
	Chale	.060*	.007	.000	.046	.075
Mvuleni	Mwaepe	-.015*	.007	.031	-.029	-.001
	Chale	.045*	.007	.000	.031	.059
Chale	Mwaepe	-.060*	.007	.000	-.075	-.046
	Mvuleni	-.045*	.007	.000	-.059	-.031

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: Diversity of Sea Urchins

	Sum of Squares	df	Mean Square	F	Sig.
Contrast	.237	2	.119	38.819	.000
Error	1.072	351	.003		

The F tests the effect of Study Sites. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

3. Seasons

Estimates

Dependent Variable: Diversity of Sea Urchins

Seasons	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Southeast Monsoon	.588	.005	.578	.598
Intermonsoon	.625	.005	.615	.635
Northeast Monsoon	.727	.005	.717	.737

Pairwise Comparisons

Dependent Variable: Diversity of Sea Urchins

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	95% Confidence Interval for Difference[b] Upper Bound
Southeast Monsoon	Intermonsoon	-.037*	.007	.000	-.051	-.022
	Northeast Monsoon	-.139*	.007	.000	-.153	-.125
Intermonsoon	Southeast Monsoon	.037*	.007	.000	.022	.051
	Northeast Monsoon	-.103*	.007	.000	-.117	-.089
Northeast Monsoon	Southeast Monsoon	.139*	.007	.000	.125	.153
	Intermonsoon	.103*	.007	.000	.089	.117

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: Diversity of Sea Urchins

	Sum of Squares	df	Mean Square	F	Sig.
Contrast	1.248	2	.624	204.226	.000
Error	1.072	351	.003		

The F tests the effect of Seasons. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

*4. Study Sites * Seasons*

Dependent Variable: Diversity of Sea Urchins

				95% Confidence Interval	
Study Sites	Seasons	Mean	Std. Error	Lower Bound	Upper Bound
Mwaepe	Southeast Monsoon	.610	.009	.593	.627
	Intermonsoon	.671	.009	.654	.688
	Northeast Monsoon	.736	.009	.719	.753
Mvuleni	Southeast Monsoon	.646	.009	.628	.663
	Intermonsoon	.619	.009	.602	.636
	Northeast Monsoon	.706	.009	.688	.723
Chale	Southeast Monsoon	.510	.009	.492	.527
	Intermonsoon	.585	.009	.567	.602
	Northeast Monsoon	.741	.009	.724	.758

Post Hoc Tests

Study Sites

Multiple Comparisons

Dependent Variable: Diversity of Sea Urchins

Tukey HSD

(I) Study Sites	(J) Study Sites	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Mwaepe	Mvuleni	.0154	.00714	.080	-.0014	.0322
	Chale	.0605*	.00714	.000	.0437	.0773
Mvuleni	Mwaepe	-.0154	.00714	.080	-.0322	.0014
	Chale	.0451*	.00714	.000	.0283	.0619
Chale	Mwaepe	-.0605*	.00714	.000	-.0773	-.0437
	Mvuleni	-.0451*	.00714	.000	-.0619	-.0283

Based on observed means.

The error term is Mean Square(Error) = .003.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

Diversity of Sea Urchins

Tukey HSD[a,b]

Study Sites	N	Subset	
		1	2
Chale	120	.6117	
Mvuleni	120		.6567
Mwaepe	120		.6722
Sig.		1.000	.080

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = .003.

a. Uses Harmonic Mean Sample Size = 120.000.

b. Alpha = .05.

Seasons

Multiple Comparisons

Dependent Variable: Diversity of Sea Urchins

Tukey HSD

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Southeast Monsoon	Intermonsoon	-.0365*	.00714	.000	-.0533	-.0197
	Northeast Monsoon	-.1391*	.00714	.000	-.1559	-.1223
Intermonsoon	Southeast Monsoon	.0365*	.00714	.000	.0197	.0533
	Northeast Monsoon	-.1026*	.00714	.000	-.1194	-.0858
Northeast Monsoon	Southeast Monsoon	.1391*	.00714	.000	.1223	.1559
	Intermonsoon	.1026*	.00714	.000	.0858	.1194

Based on observed means.

The error term is Mean Square(Error) = .003.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

Diversity of Sea Urchins

Tukey HSD[a,b]

		Subset		
Seasons	N	1	2	3
Southeast Monsoon	120	.5883		
Intermonsoon	120		.6248	
Northeast Monsoon	120			.7274
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = .003.

a. Uses Harmonic Mean Sample Size = 120.000.

b. Alpha = .05.

Diversity of Seagrass

Descriptive Statistics

Dependent Variable: Diversity of Seagrass

Study Sites	Seasons	Mean	Std. Deviation	N
Mwaepe	Southeast Monsoon	.5433	.09783	40
	Intermonsoon	.6920	.07737	40
	Northeast Monsoon	.7463	.06582	40
	Total	.6605	.11809	120
Mvuleni	Southeast Monsoon	.6298	.04270	40
	Intermonsoon	.6465	.09029	40
	Northeast Monsoon	.7100	.04350	40
	Total	.6621	.07137	120
Chale	Southeast Monsoon	.3572	.05213	40
	Intermonsoon	.4315	.04933	40
	Northeast Monsoon	.6390	.05773	40
	Total	.4759	.13085	120
Total	Southeast Monsoon	.5101	.13291	120
	Intermonsoon	.5900	.13581	120
	Northeast Monsoon	.6984	.07164	120
	Total	.5995	.14016	360

Tests of Between-Subjects Effects

Dependent Variable: Diversity of Seagrass

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5.483[a]	8	.685	153.303	.000
Intercept	129.382	1	129.382	28937.941	.000
StudySites	2.750	2	1.375	307.510	.000
Season	2.145	2	1.072	239.853	.000
StudySites * Season	.589	4	.147	32.925	.000
Error	1.569	351	.004		
Total	136.434	360			
Corrected Total	7.053	359			

a. R Squared = .777 (Adjusted R Squared = .772)

Post Hoc Tests

Study Sites

Multiple Comparisons

Dependent Variable: Diversity of Seagrass

Tukey HSD

(I) Study Sites	(J) Study Sites	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Mwaepe	Mvuleni	-.0016	.00863	.982	-.0219	.0187
	Chale	.1846*	.00863	.000	.1643	.2049
Mvuleni	Mwaepe	.0016	.00863	.982	-.0187	.0219
	Chale	.1862*	.00863	.000	.1659	.2065
Chale	Mwaepe	-.1846*	.00863	.000	-.2049	-.1643
	Mvuleni	-.1862*	.00863	.000	-.2065	-.1659

Based on observed means.

The error term is Mean Square(Error) = .004.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

Diversity of Seagrass

Tukey HSD[a,b]

		Subset	
Study Sites	N	1	2
Chale	120	.4759	
Mwaepe	120		.6605
Mvuleni	120		.6621
Sig.		1.000	.982

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = .004.

a. Uses Harmonic Mean Sample Size = 120.000.

b. Alpha = .05.

Seasons

Multiple Comparisons

Dependent Variable: Diversity of Seagrass

Tukey HSD

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Southeast Monsoon	Intermonsoon	-.0799*	.00863	.000	-.1003	-.0596
	Northeast Monsoon	-.1883*	.00863	.000	-.2087	-.1680
Intermonsoon	Southeast Monsoon	.0799*	.00863	.000	.0596	.1003
	Northeast Monsoon	-.1084*	.00863	.000	-.1287	-.0881
Northeast Monsoon	Southeast Monsoon	.1883*	.00863	.000	.1680	.2087
	Intermonsoon	.1084*	.00863	.000	.0881	.1287

Based on observed means.

The error term is Mean Square(Error) = .004.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

Diversity of Seagrass

Tukey HSD[a,b]

Seasons	N	Subset		
		1	2	3
Southeast Monsoon	120	.5101		
Intermonsoon	120		.5900	
Northeast Monsoon	120			.6984

Sig.	1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = .004.

a. Uses Harmonic Mean Sample Size = 120.000.

b. Alpha = .05.

Density of Sea urchins

Descriptive Statistics

Dependent Variable: Density of Sea Urchins

Study Sites	Seasons	Mean	Std. Deviation	N
Mwaepe	Southeast Monsoon	5.13	1.381	40
	Intermonsoon	5.90	1.374	40
	Northeast Monsoon	7.20	1.436	40
	Total	6.07	1.630	120
Mvuleni	Southeast Monsoon	5.35	1.292	40
	Intermonsoon	7.40	1.932	40
	Northeast Monsoon	7.75	1.256	40
	Total	6.83	1.849	120
Chale	Southeast Monsoon	8.25	1.214	40
	Intermonsoon	6.77	1.349	40
	Northeast Monsoon	8.45	1.552	40
	Total	7.83	1.559	120
Total	Southeast Monsoon	6.24	1.923	120
	Intermonsoon	6.69	1.679	120
	Northeast Monsoon	7.80	1.498	120

Total	6.91	1.826	360

Tests of Between-Subjects Effects

Dependent Variable: Density of Sea Urchins

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	474.206[a]	8	59.276	28.779	.000
Intercept	17194.844	1	17194.844	8348.282	.000
StudySites	184.839	2	92.419	44.871	.000
Season	154.372	2	77.186	37.475	.000
StudySites * Season	134.994	4	33.749	16.385	.000
Error	722.950	351	2.060		
Total	18392.000	360			
Corrected Total	1197.156	359			

a. R Squared = .396 (Adjusted R Squared = .382)

Post Hoc Tests

Study Sites

Multiple Comparisons

Dependent Variable: Density of Sea Urchins

Tukey HSD

(I) Study Sites	(J) Study Sites	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Mwaepe	Mvuleni	-.76*	.185	.000	-1.19	-.32
	Chale	-1.75*	.185	.000	-2.19	-1.31
Mvuleni	Mwaepe	.76*	.185	.000	.32	1.19

	Chale	-.99*	.185	.000	-1.43	-.56
Chale	Mwaepe	1.75*	.185	.000	1.31	2.19
	Mvuleni	.99*	.185	.000	.56	1.43

Based on observed means.

The error term is Mean Square(Error) = 2.060.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

Density of Sea Urchins

Tukey HSD[a,b]

		Subset		
Study Sites	N	1	2	3
Mwaepe	120	6.07		
Mvuleni	120		6.83	
Chale	120			7.83
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = 2.060.

a. Uses Harmonic Mean Sample Size = 120.000.

b. Alpha = .05.

Seasons

Multiple Comparisons

Dependent Variable: Density of Sea Urchins

Tukey HSD

(I) Seasons	(J) Seasons	Mean Difference	Std. Error	Sig.	95% Confidence Interval

		(I-J)			Lower Bound	Upper Bound
Southeast Monsoon	Intermonsoon	-.45*	.185	.041	-.89	-.01
	Northeast Monsoon	-1.56*	.185	.000	-1.99	-1.12
Intermonsoon	Southeast Monsoon	.45*	.185	.041	.01	.89
	Northeast Monsoon	-1.11*	.185	.000	-1.54	-.67
Northeast Monsoon	Southeast Monsoon	1.56*	.185	.000	1.12	1.99
	Intermonsoon	1.11*	.185	.000	.67	1.54

Based on observed means.

The error term is Mean Square(Error) = 2.060.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

Density of Sea Urchins

Tukey HSD[a,b]

		Subset		
Seasons	N	1	2	3
Southeast Monsoon	120	6.24		
Intermonsoon	120		6.69	
Northeast Monsoon	120			7.80
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = 2.060.

a. Uses Harmonic Mean Sample Size = 120.000.

b. Alpha = .05.

Appendix II: ANOVA outcomes of sea urchins density

Descriptives

Density of Sea Urchins

					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Healthy Seabed	180	5.94	1.586	.118	5.71	6.17	2	9
Degraded Seabed	180	7.88	1.507	.112	7.66	8.10	4	12
Total	360	6.91	1.826	.096	6.72	7.10	2	12

ANOVA

Density of Sea Urchins

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	340.278	1	340.278	142.167	.000
Within Groups	856.878	358	2.394		
Total	1197.156	359			

Post hoc analysis of seasonal variation in density of sea urchins

(I) Seasons	(J) Seasons	Mean	Std. Error	Sig.	95% Confidence Interval

		Difference (I-J)			Lower Bound	Upper Bound
Jan	IM	-5.100[*]	1.326	.000	-7.86	-2.34
	SEM	-8.850[*]	1.254	.000	-11.61	-6.09
Intermonsoon	NEM	5.100[*]	1.144	.000	2.34	7.86
	NEM	-3.750[*]	1.188	.005	-6.51	-.99
Northeast monsoon	SEM	8.850[*]	1.254	.000	6.09	11.61
	IM	3.750[*]	1.152	.005	.99	6.51

*. The mean difference is significant at the 0.05 level.

Appendix IV: Significance of regression model

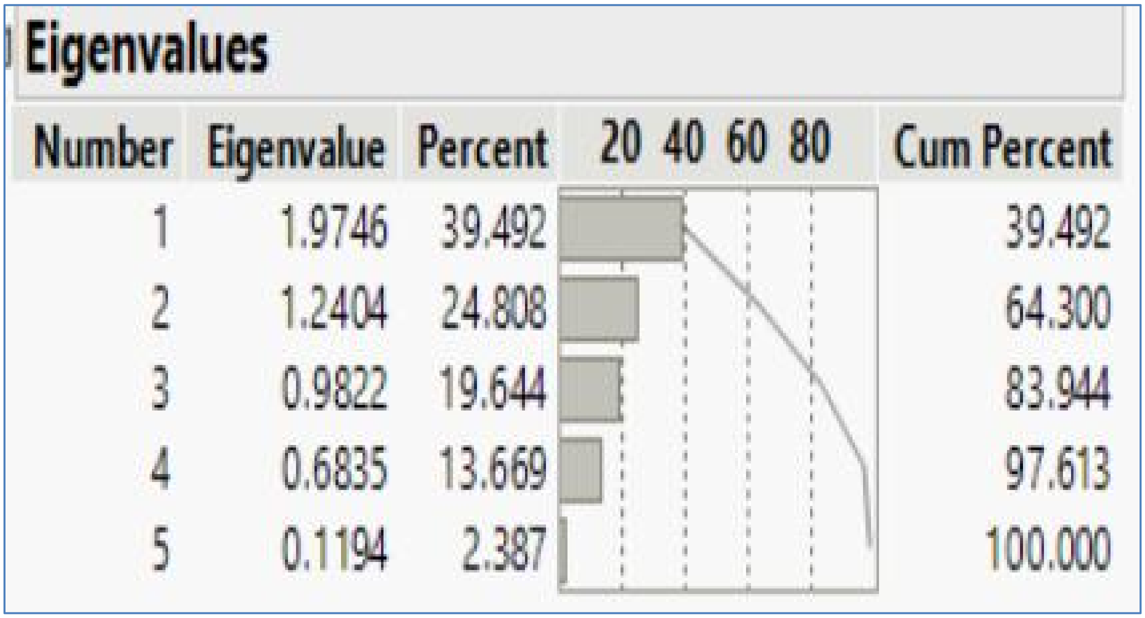
Significance of the regression model of sea urchins predicting seagrass cover

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	4513.226	1	4513.226	55.275	.000[b]
	Residual	4735.708	358	81.650		
	Total	9248.933	359			

a. Dependent Variable: Vegetation Cover

b. Predictors: (Constant), Density of Sea Urchins

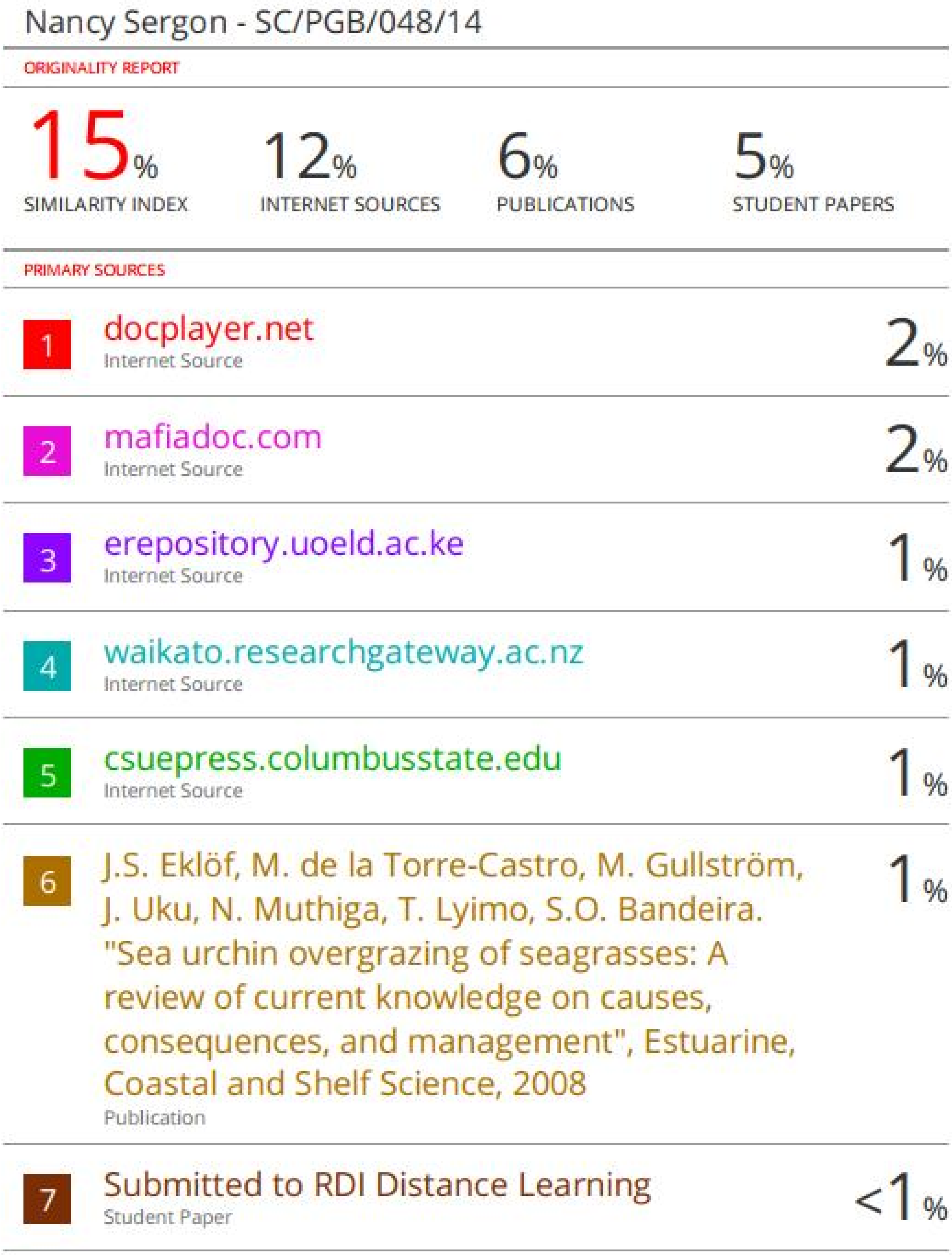
Appendix V: Eigenvalues



Eigenvalues

Number	Eigenvalue	Percent	Cum Percent
1	1.9746	39.492	39.492
2	1.2404	24.808	64.300
3	0.9822	19.644	83.944
4	0.6835	13.669	97.613
5	0.1194	2.387	100.000

Appendix VI: Fieldwork Activities



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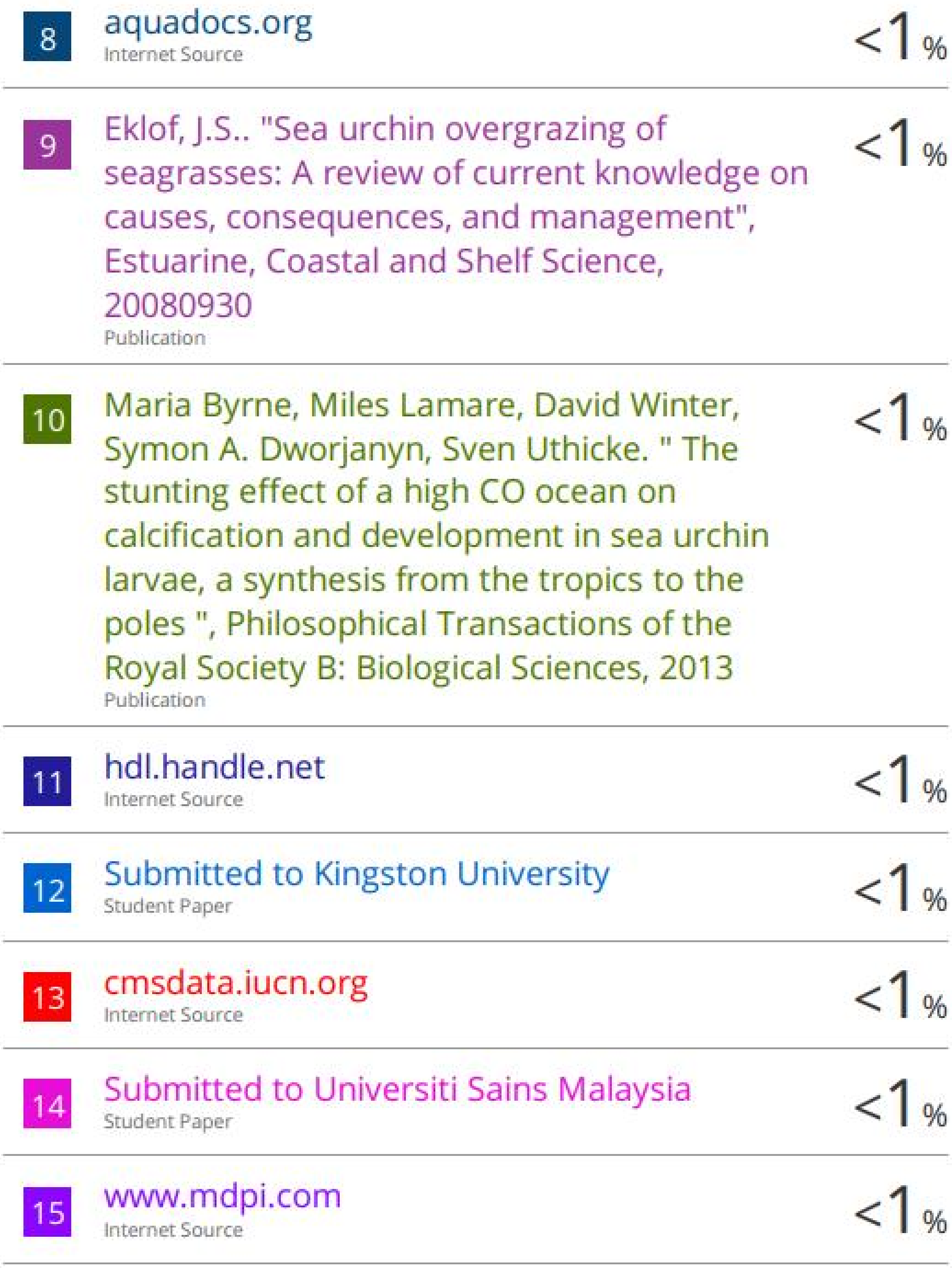

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