Spatial-Temporal Occurrence of Sea Urchins and their Grazing along Diani-Chale Lagoonal Reefs, Mombasa

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Abstract

Seagrass plays a key role in coastal ecosystems influencing environmental abiotic parameters and supporting a great abundance and diversity of species belonging to many phyla. Overgrazing by herbivores has been postulated as a potential threat to seagrass in Kenya. Indirectly, fishing may result in sea urchin outbreaks caused by removal of sea urchin predators. Therefore the purpose of this study was to determine the spatial and temporal occurrence of sea urchins and grazing on seagrass along Diani lagoonal reefs, in Kwale. Three sites, namely, Mvuleni, Chale, and Mwaepe, were selected and quadrats randomly used in sampling sea urchins and seagrass. Moreover, 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). Descriptive statistics and inferential statistics were applied in determining abundance, density, and diversity of sea urchins and their seasonal and temporal influence 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 the northeast monsoon and more degraded habitats when compared to healthy ones. Regression 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. Therefore, the study concludes that sea urchins are major macro-grazers that contribute to overgrazing and degradation of the seabed. This study recommends further studies to identify specific biotic and abiotic factors that affect their distributions, employ longitudinal design to demonstrate trends of sea urchin migration, overgrazing, and degradation of seabed along the Kenyan coastline.

Keywords: Sea urchins, Seagrass, Abundance, Density, Diversity, Overgrazing

INTRODUCTION

Sea urchins are one of the herbivores in marine ecosystem who graze on seagrass and algae, and they belong to an ancient group of marine invertebrates, the Echinoderms (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 (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 (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. 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 as angiosperms, which contribute significantly in the productive marine systems (Uku *et al.*, 2021). 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 (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). They also create 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). 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 (Crump *et al*., 2018; 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 coupled with biotic factors in coastal areas (Iacarella *et al*., 2018; Dahl *et al*., 2022). In Kenyan coast sea urchins have exhibited dominance and population explosions owing to the reduction in predation by carnivorous invertebrates (lobsters) and fishes (triggerfish, wrasse, and puffer fish) due to overfishing in Diani-Chale reefs (Githaiga *et al*., 2019; Uku *et al*., 2021). In their study, Alcoverro and Mariani, (2002), established that sea urchin grazed on seagrass (*Thalassodendron ciliatum*) beds of a Kenyan lagoon with *Tripneustes gratilla* accounting for 39% and over 70% of seagrass left as dead shoots. 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, in Mombasa city.

MATERIALS AND METHODS

Research Design

Cross-sectional research design was employed to determine spatial and temporal occurrence of sea urchins and seagrass in Diani beach. The cross-sectional design was used to capture trends and pattern of sea urchins and seagrass in Diani beach 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). Moreover, the data was collected from three study sites in the Diani beach, namely Mvuleni, Mwaepe, and Chale lagoons. 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 was collected in a cross-sectional design in each season formed the basis of determining the influence of seasons and sites on seagrass and sea urchins.

Study Sites

The study was conducted in Diani-Chale area, located at latitude 04º22'S to 04º44'S and 39º54'E to 39º61E in the south coast region, Msambweni division, Kwale County (Figure 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), Chale (04˚22'07.6"S and 39˚33'90.2"E).

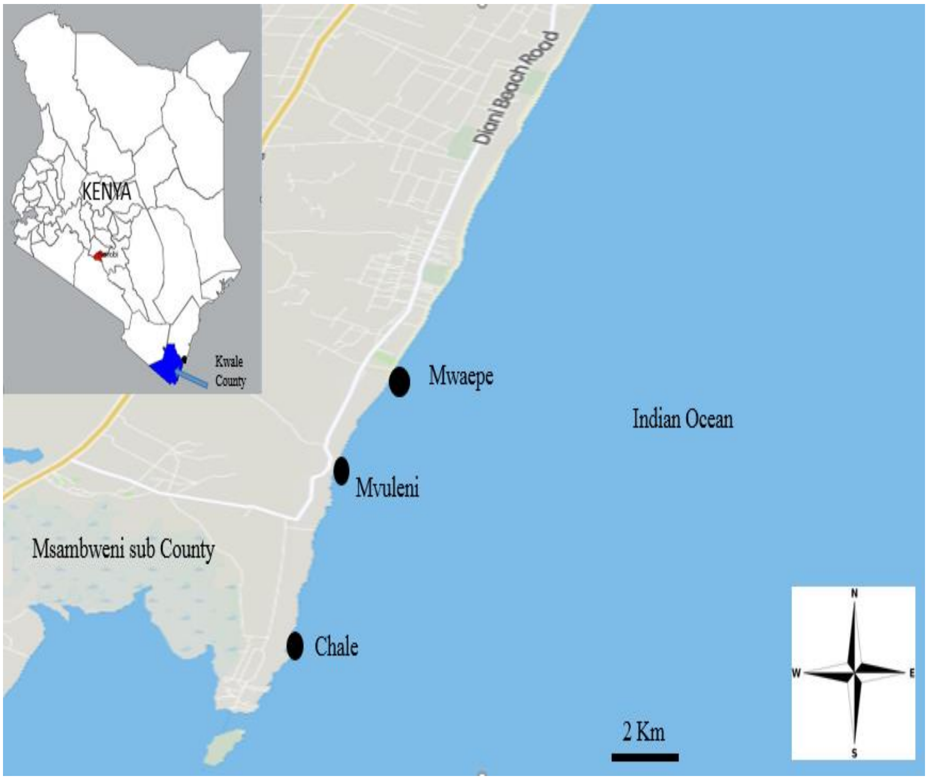

Figure 1: Map of the Diani beach with study sites, Mwaepe, Mvuleni, and Chale

Climatic Conditions

The study sites of Chale, Mvuleni, and Mwaepe (Figure 1) experience variable climatic conditions and weather patterns. Inter-Tropical Convergence Zone (ITCZ) and the seasonal monsoon cycle are drives of weather patterns and climatic conditions of the study site. The southeast and northeast are 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; Dzeha *et al*., 2022). During the northeastern monsoon season (October through April), the currents migrate southwards and drive water to offshore sites (Kebacho, 2022). These conditions are favorable to high levels of radiation, low level of cloud cover, 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.

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) between January 2016-December 2017. Quadrats were thrown randomly 20 times in each of the two months in every season. This was done in each of the study sites of Mwaepe, Mvuleni, and Chale. The sampling frequency was 40 quadrats per site per season (N=360). The sampling was done in each of the three seasons as follows: South-east Monsoon (SEM) on July and August, intermonsoon (IM) on March and April, and the North-East Monsoon (NEM) on December and January. The months were representatives of dry, wet and transition seasons, respectively. The data collected from each quadrat were the number of each sea urchin's species and percentage cover of each of the seagrass species. Sampling sites were spatially located along the coastal region in the range of 30 m to 80 m from the coastline.

Sea Urchins Sampling

In sampling sea urchins, diversity, relative abundance, and density were determined from all the quadrats obtained. The diversity of sea urchins was determined by classifying and identifying different species by following an established classification guide (Richmod, 2011; Ziegler *et al*., 2008). The Simpson's diversity index (D-1) was used to calculate the degree of diversity of sea urchins in different study sites.

Simpson's diversity index (D-1) = $1 - \frac{\sum n(n-1)}{\sum N(N-1)}$

Where D is diversity index, n is number sea urchins of species, and N is the total number of sea urchins

Relative abundance of sea urchins was determined by calculating the average number of species in each quadrat and determining their percent proportions.

Relative abundance (%) = Number of species/Total number of sea urchins × 100%

The density of sea urchins was calculated by counting the number of sea urchins collected in each season divided by the number of quadrats.

Density (m^{-1}) = Number of sea urchins counted/Total number of quadrats (40)

Seagrass sampling

Sea grass sampling was done at each of sampling locations through SCUBA diving and diversity and relative abundance were determined. At each sampling station, 20 quadrats of 1 m^2 were randomly placed on selected sampling sites as those of sea urchin sampling in each of the two months in every season (Nakanishi *et al.*, 2006). The diversity of sea grass was estimated by identifying species using Field guide to Western Indian Ocean seashores by Richmond.

Simpson's diversity index (1-D) = $1 - \frac{\sum n(n-1)}{\sum N(N-1)}$

The seagrass percentage cover (abundance) of each species in each quadrat was determined visually. Each quadrat was divided into four equal square measurements of 0.5m by 0.5m, therefore each square equal 25%. The square's containing seagrass was added up to give percentage cover for sea grass and each species.

Seagrass cover (%) = Area covered by seagrass/Total area of quadrat

The determination of the condition of seabed was done in consultation with people from the area who have information on areas with degraded and healthy seagrass. Reference was also made to adopted criteria (Ame & Ayson (2009). This criterion classified seagrass cover as poor (0-25%), fair (26-50%), good (51-75%), and excellent (76-100%). This study classified areas with poor and fair seagrass covers as having degraded seabed, while those with good and excellent seagrass covers as healthy seabed.

Data Analysis

The study employed both descriptive and inferential statistics to evaluate spatial-temporal distribution of sea urchins and seagrass along Diani-Chale Lagoonal reefs, Mombasa. To determine seasonal abundance and diversity of sea urchins and seagrass in Diani beach, descriptive statistics of means and standard deviations were used and one-way analysis of variance as inferential statistics with Tukey test for post-hoc analysis was applied (Oliveira, *et al*., 1997; Camps-Castella *et al*., 2020). To determine the spatial variation of density of sea urchins in healthy and degraded seabed in Diani beach, means and standard deviations of the density of sea urchins was calculated and the independent-samples t-test was used to compare their differences in healthy and degraded seabed. To evaluate the influence of sea urchin abundance on benthic seagrass cover in Diani beach, Pearson's correlation and linear regression analysis were used to calculate the nature of relationship and the influence of sea urchin abundance on benthic seagrass cover. All analyses of inferential statistics were performed at significance level of 0.05.

RESULTS

Abundance and Diversity of Sea Urchins

Figure 1 shows relative abundances of sea urchins in study sites in Diani beach during northeast monsoon. The most abundant species of sea urchins in Mwaepe were *Echinometra mathaei* (34.7%) and *Tripneustes gratilla* (28.8%), whereas *Salmacis bicolor* (2.5%), and *Toxopneustes pileolus* (2.5%) were the least dominant species in Mwaepe beach. In Mvuleni, *Tripneustes gratilla* (48.7%) was the most dominant species followed by *Diadema savignyi* (22.4%), while *Salmacis bicolor* (1.9%) and *Toxopneustes pileolus* (1.3%) showed the lowest dominance. Comparatively, *Tripneustes gratilla* (38.4%) and *Echinometra mathaei* (23.9%) were the dominant species in Chale, while *Salmacis bicolor* (0.6%), and *Toxopneustes pileolus* (1.9%) were the least common.

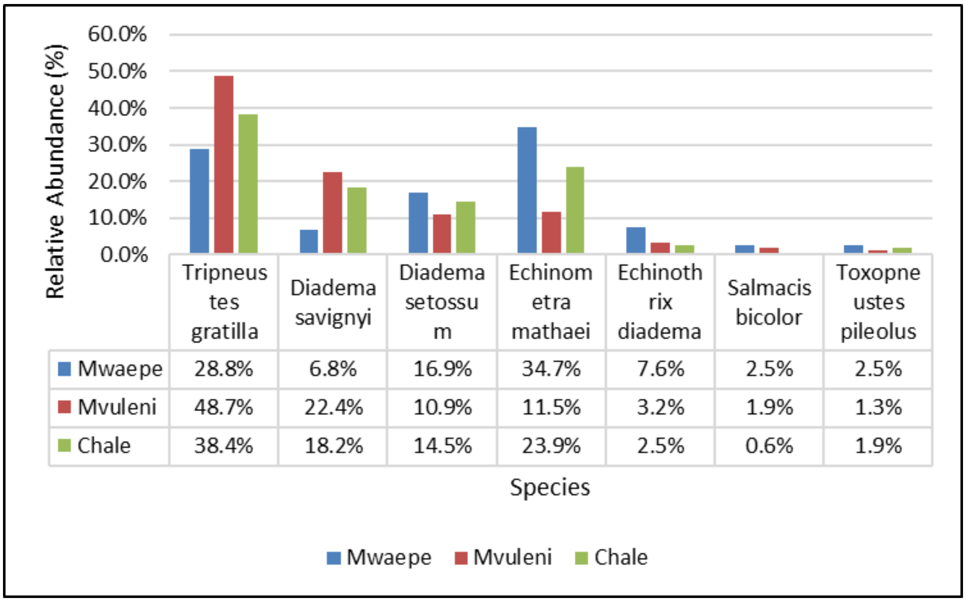

Figure 4. Relative abundance of sea urchins in the northeast monsoon

Figure 2 depicts the abundances of sea urchin's species in Diani beach during southeast monsoon. The abundant species in Mwaepe are *Echinometra mathaei* (31.7%), *Diadema setossum* (28.8%), *Tripneustes gratilla* (20.1%), and *Diadema savignyi* (16.5%). In contrast, the abundant species in Mvuleni are *Echinothrix diadema* (44.8%), *Tripneustes gratilla* (21%), and *Diadema setossum* (17.5%). In Chale, *Echinometra mathaei* (71.8%), *Diadema setossum* (11.5%), and *Tripneustes gratilla* (20.1%) are the main species.

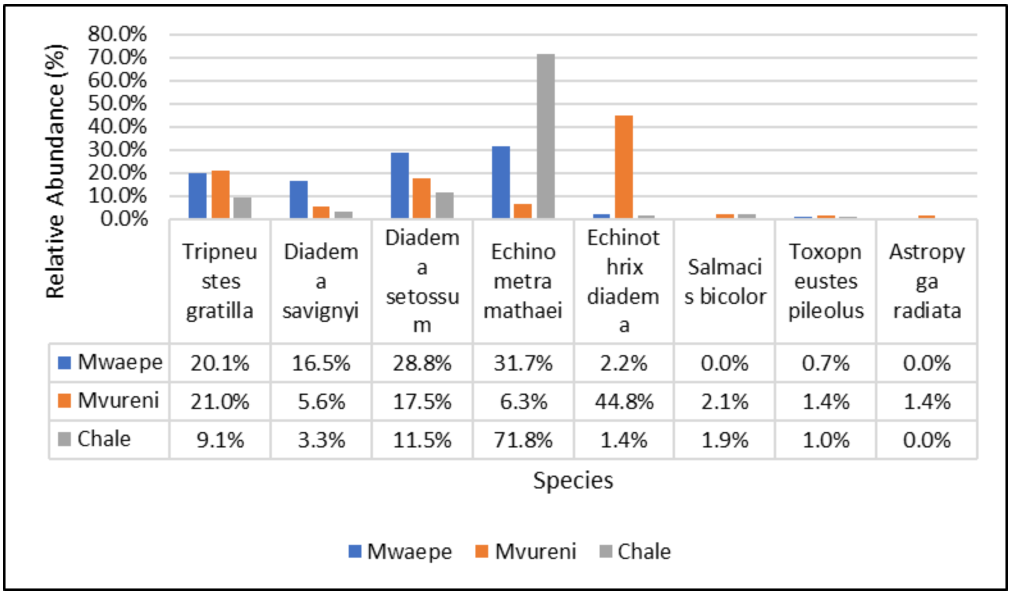

Figure 5: Relative abundances of sea urchins in the southeast monsoon

Figure 3 indicates the relative abundances of sea urchins in intermonsoon season. When compared to northeast monsoon and southeast monsoon, intermonsoon had moderate number of species. The major species present in Mwaepe were *Echinometra mathaei* (59.2%) and *Tripneustes gratilla* (37.9%), while those in Mvuleni were *Diadema setossum* (40.5%) and *Tripneustes gratilla* (36%). Chale had *Echinometra mathaei* (97.1%) as the dominant species.

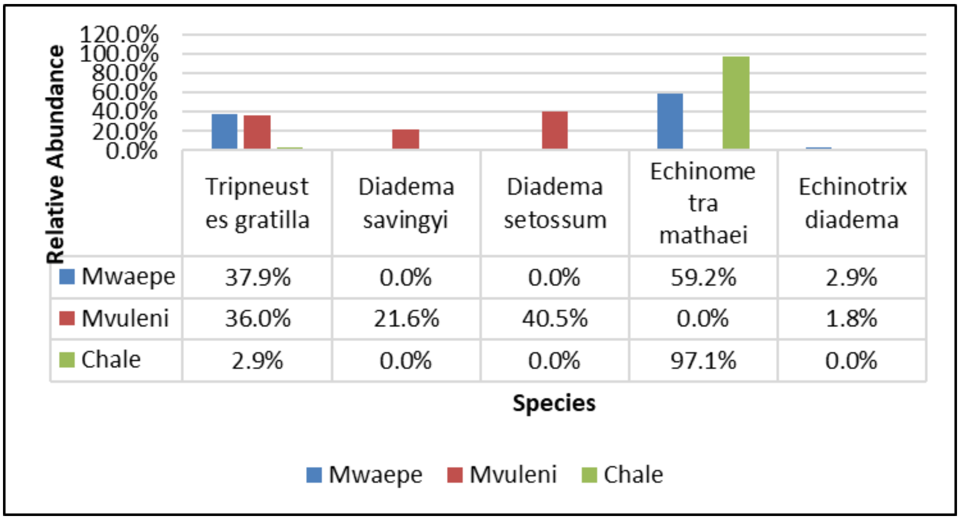

Figure 6: Relative abundances of sea urchins in intermonsoon season

Table 1 shows Simpson's diversity indices of sea urchins in Mwaepe, Mvuleni, and Chale. The most diverse study site is Mwaepe (0.67) followed by Mvuleni (0.66) and Chale (0.61). Seasonal changes in diversity index show that Mwaepe (0.74), Chale (0.74), and Mvuleni (0.74) are most diverse during the northeastern monsoon. Two-way ANOVA indicated that study sites and seasons have significant effects on sea urchin diversity ($p = 0.000$), while the interaction effects of study sites and season were also statistically significant ($p = 0.000$). There was a significant difference in diversity of sea urchins in the North East Monsoon in all the study sites compared to the other seasons. The means of diversity depicts that Chale significant difference in diversity of sea urchins compared to other sites (Table 1).

Table 3: Simpson's diversity indices for sea urchins in different seasons and study sites

		Study Sites		
		Mwaepe	**Mvuleni**	**Chale**
Seasons	Southeast monsoon	0.61±1.38[a]	0.65±1.29[a]	0.51±1.21[a]
	Intermonsoon	0.67±1.37[a]	0.62±1.93[a]	0.58±1.34[a]
	Northeast monsoon	0.74±1.43[b]	0.71±1.26[b]	0.74±1.55[b]
	Mean	0.67±1.63[a]	0.66±1.85[a]	0.61±1.56[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

Abundance and Diversity of Seagrass Cover

The percentage seagrass cover (Figure 4) varies from one study site to another, depending on conditions of seabed. In healthy seabed, seagrass cover was 92%, 88%, and 68% in Mvuleni, Chale, and Mwaepe, respectively. In degraded seabed, the seagrass cover was 41%, 35%, and 37% in Mvuleni, Chale, and Mwaepe, correspondingly.

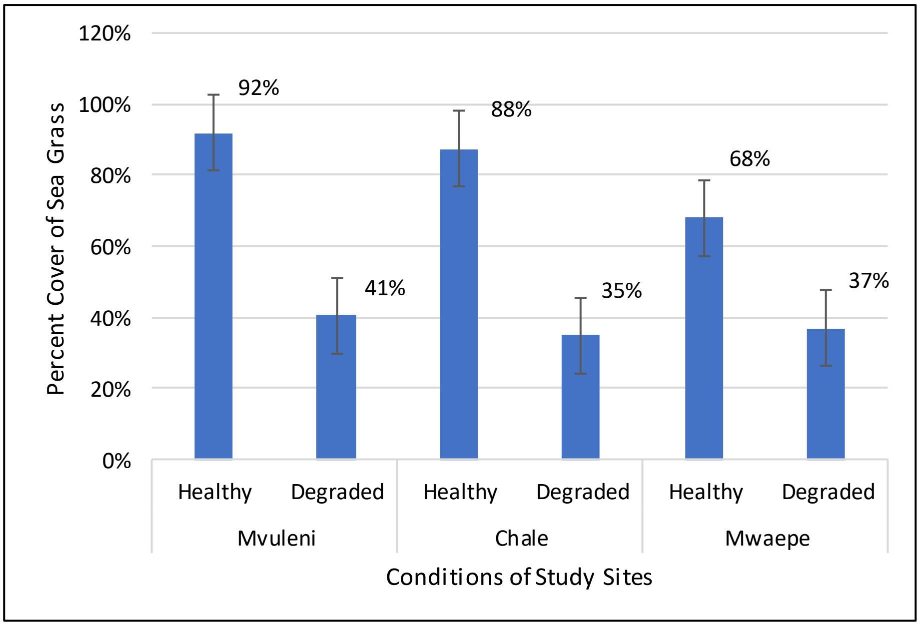

Figure 7: Distribution of seagrass cover in study sites

Table 2 indicates that *Syringodium isoetifolium* (58%) and *Thalassia hempnchii* (27.5%) are dominant species in healthy seabed, whereas *Syringodium isoetifolium* (20%) are dominant in degraded seabed in Mvuleni. In Chale, *Syringodium isoetifolium* (79%) and *Halophila ovalis* (25%) are dominant in healthy and degraded seabed, respectively. *Thalassodendron ciliatum* (24%), *Cymodocea rotundata* (14%), and *Halodule wrightii (*16%) are dominant in healthy seabed, whereas *Halophila ovalis* (25%), *Halophila stipulacea* (12%), and *Halodule wrightii* (11%) are predominant in degraded seabed in Mwaepe.

Table 4: Percent cover of seagrass species

	Mvuleni		Chale		Mwaepe	
Seagrass Species	**Healthy**	**Degraded**	**Healthy**	**Degraded**	**Healthy**	**Degraded**
Thalassodendron ciliatum	1%	0%	0%	0%	24%	0%
Syringodium isoetifolium	58%	20%	79%	0%	8%	0%
Halophila stipulacea	4%	7%	3%	10%	6%	12%
Halophila ovalis	0%	0.5%	0%	25%	9%	25%
Cymodocea serrutata	0%	7%	0%	0%	7%	0%
Thalassia hempnchii	27.5%	0%	5.5%	0%	0%	0%
Cymodocea rotundata	1.5%	6%	0%	0%	14%	0%
Halodule wrightii	0%	0%	0%	4%	16%	11%
Total	92%	40.5%	87.5%	35%	68%	37%

Comparison of diversity of seagrass (Figure 5) shows that healthy and degraded seabed of Mvuleni has 0.51 and 0.67, respectively. Chale had the lowest diversity indices of 0.18 and 0.40 in healthy and degraded study sites, correspondingly. Mwaepe has the highest diversity index in healthy seabed (0.73) and average diversity index in degraded (0.35).

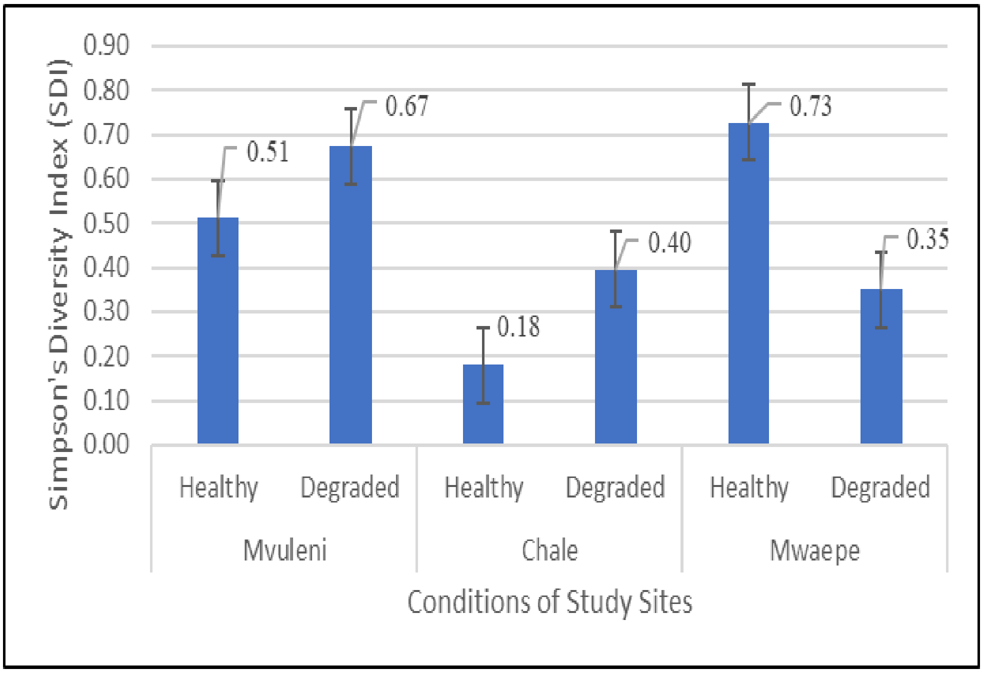

Figure 8: Species diversity of seagrass in each study site and conditions

Density of Sea Urchin in Healthy and Degraded Seabed

Descriptive statistics (Table 3) shows that the mean density of sea urchins in degraded seabed (7.88±1.507) is higher than that of healthy seabed (5.94±1.586). In healthy seabed, the density of sea urchins ranged from 2 to 14, while the density of sea urchins in degraded seabed ranged from 5 to 22. The analysis of variance (ANOVA) reveals that the apparent difference in mean densities of sea urchins in healthy seabed and degraded seabed is statistically significant, $F(1,358) = 142.167$ $p = 0.000$.

Table 5: Statistically significance difference in means of the density of sea urchins

State of seabed	M±SD		F
Healthy Seabed	5.94±	1.586[a]	F(1,358) = 142.167
Degraded Seabed	7.88±	1.507[b]	p = 0.000
Total	6.91±	1.826	

Ab, significance at 0.05 alpha level

Seasonal Variation in Seagrass Cover

Descriptive statistics (Table 4) shows that there were seasonal variations in the density of sea urchins in Diani beach. The density of sea urchins increased from southeast monsoon (6.10±3.32), intermonsoon (11.20±4.08), and northeast monsoon (14.95±3.41). The ANOVA (Table 4) indicates that differences in means of the density of sea urchins are statistically significant, F(2,357) = 30.076, p = 0.000.

Table 6: Significant differences in the density of sea urchins

State of seabed	M±SD		F
Southeast monsoon	6.10±	3.32[a]	F(2,357) = 30.076
Intermonsoon	11.20±	4.08[b]	p = 0.000
Northeast monsoon	14.95±	3.41[c]	
Total	10.75±	5.104	

Influence of Sea urchin on Seagrass Cover

The regression model (Table 5) indicates that there is a strong relationship between the density of sea urchins and the proportions of 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 ANOVA (Table 5) 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. Regression coefficients (Table 5) 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). The proportion of seagrass cover = -1.713 (Density of Sea Urchins) + 84.886

Table 7: Effect of sea urchins of seagrass cover

Model	R	R Square	F	Sig.
Regression	.699[a]	.488	55.275	0.000
Coefficients	Beta	Std Error	t	
Constant	84.866	2.738	30.998	0.000
Density of sea urchins	-1.713	0.230	-7.435	0.000

DISCUSSION

Abundance of Sea Urchins

The analysis of the abundance of sea urchins shows the existence of variation between different habitats in Diani Beach. The abundant species in Mwaepe were *Echinometra mathaei*, *Tripneustes gratilla*, and *Diadema setossum*, whereas *Tripneustes gratilla* and *Diadema savignyi* were abundant species in Mvuleni. Comparatively, *Tripneustes gratilla* and *Echinometra mathaei* are abundant species in Chale. Researchers have shown that *Tripneustes gratilla* and *Echinometra 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 explains why their distributions remained relatively constant in northeast monsoon, southeast monsoon, and intermonsoon seasons. The abundance of *Diadema* species is variable because they are sensitive to changes in environmental conditions and seasons (Muthiga & McClanahan, 2007; Ditzel *et al*., 2022). Temporal analysis of sea urchins revealed that their abundance varies across the year due to ecological changes that influence their growth and development. In southeast monsoon, intermonsoon, and northeast monsoon, the most dominant species in Mwaepe are *Echinometra mathaei* and *Tripneustes gratilla*, *Tripneustes gratilla* and *Diadema savignyi* are the most dominant species in Mvuleni, *Tripneustes gratilla*, and *Echinometra mathaei* are dominant species in Chale. Temporal analysis shows that *Tripneustes gratilla* is common in all seasons, while *Echinometra mathaei and Diadema setossum* exhibited seasonal variations as demonstrated by Ditzel *et al*. (2022). Additional findings indicated that *Echinometra mathaei and Diadema setossum* are sensitive to changes in weather conditions as reflected by monsoon trends (Nadiarti *et al*., 2021). *Tripneustes gratilla* is a dominant grazer in coastal areas that has adapted different niches and seasons (Okuku *et al.*, 2022; Ditzel *et al.*, 2022). Hence, the temporal variation of sea urchins exhibits their adaptive features and seasonal effects of weather on their growth and development.

Diversity of Sea Urchins

Based on Simpson's diversity index (Roff, 2013), the diversity of sea urchins was moderate on average but indices ranged from average low to high. The assessment of diversity using Simpson's index indicates that the most diverse study site was Mwaepe, followed by Mvuleni, and Chale. Seasonal changes in diversity index show that Mwaepe, Chale, and Mvuleni had the most diverse sea urchins during northeast monsoon. The trend of diversity index follows the weather patterns because southeast monsoon provides favorable environment for the growth of seagrass and sea urchins from the months of October through May (Msuya *et al*., 2022; Tarimo *et al*., 2022). These findings show that diversity varies from one site to another and season influences variation in diversity.

Seagrass Cover

Comparison of seagrass cover shows that healthy and degraded seabed had significant differences. 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. The distribution of seagrass shows that *Syringodium isoetifolium* and *Halodule wrightii* were dominant in both healthy and degraded seabed, while *Halophila ovalis* and are common in degraded seabed. Comparison of diversity of seagrass indicates that the diversity of healthy and degraded seabed exhibited not apparent differences. In the 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. These findings suggest that Mvuleni and Mwaepe are relatively protected when compared to Chale because they exhibited a higher level of diversity.

Density of Sea Urchin in Healthy and Degraded Seabed

Comparison of the density of sea urchins in degraded and healthy seabed shows differences. Descriptive statistics indicates that the mean density of sea urchins in degraded seabed (M = 13.77, SD = 4.25) was higher than that of healthy seabed (M = 7.73, SD = 4.02). These findings suggest 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 density of sea urchins in degraded seabed than healthy seabed reflects the degree of overgrazing. The analysis of variance outcomes demonstrates that the apparent difference in mean density of sea urchins in degraded seabed was statistically significant higher when compared to those of sea urchins in healthy seabed ($p = 0.000$). The significance confirms that sea urchins overgraze on seagrass and cause 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.

Seasonal Variation in of Seagrass Cover

Seasons have some influence on the variation of the proportion of seagrass cover. According to descriptive statistics, the proportion of seagrass cover was lowest in southeast monsoon, moderate in intermonsoon, and highest in northeast monsoon. Low salinity, optimum temperature, right pH, and enough nutrients are available during the monsoon season (Govindasamy *et al.*, 2013; Byrne *et al.*, 2013; Koch *et al*., 2022). Inference from one-way analysis of variance showed that the differences in the proportions of seagrass cover were statistically significant ($p = 0.000$). Moreover, multiple comparison using post hoc analysis demonstrated that the difference in the proportions of seagrass cover between the three seasons were statistically significant. These findings indicated that southeast monsoon had unfavorable biotic and biotic conditions, while northeast monsoon and intermonsoon had favorable conditions for the growth of seagrass.

Seasonal Variation in Sea Urchins

In the analysis of the variation of densities of sea urchins, descriptive statistics showed that there were seasonal variations in the density of sea urchins in Diani beach. The density of sea urchins increases from southeast monsoon, intermonsoon, and northeast monsoon. These descriptive statistics imply that densities of sea urchins follow the seasonal distribution pattern of the seagrass cover. The analysis of variance indicated that differences in means of the density of sea urchins were statistically significant. Post hoc analysis indicated that variations in densities of sea urchins among the three seasons were statistically significant. 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; Harianto *et al.*, 2021). These findings demonstrated that Diani Beach has optimum conditions for the growth of both sea urchins and seagrass in northeast monsoon.

Influence of Sea urchin on Seagrass Cover

Regression 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 ($r = -0.699$). In their study, which was done in Tanzanian beaches, revealed that seagrass biomass and sea urchin abundance have statistically significant negative relationship ($r = -0.666$) (Mamboya *et al.*, 2009). 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 ($R^2 = 0.488$) with statistical significance ($p = 0.000$). 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*., 2021). Regression coefficients confirmed that the density of sea urchins is a statistically significant negative predictor of the proportion of seagrass cover ($t = -7.435$, $p = 0.000$). The coefficient implies that the abundance, density, and diversity of sea urchins in Diani beach causes overgrazing and the decline of seagrass cover.

CONCLUSION AND RECOMMEDATION

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 assessment of diversity indicated that the most diverse study site was Mwaepe, followed by Mvuleni, and Chale, with most diversity occurring in northeast monsoon. The analysis of sea urchins shows that their densities in degraded and healthy seabed showed differences.

The mean density of sea urchins in degraded seabed was statistically significantly higher than that of healthy seabed. The abundance of sea urchins is a statistically significant predictor of seagrass cover in Diani beach, suggesting they are major macro-grazers that contribute to overgrazing and degradation of seabed. Therefore, the study recommends further studies to identify specific biotic and abiotic factors that affect their distributions, apply longitudinal research design to demonstrate trends of sea urchin migration, overgrazing, and degradation of seabed. In addition, use of extensive study sites that cover Kenyan coastline are needed to enhance the external validity of the study.

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