Original Article

The viability of seagrass ecosystems for supporting dugong recovery in Kenya

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Abstract
Seagrasses are the primary source of food for dugongs and a good indicator of marine ecosystem health. The East African dugong (*Dugong dugon*) population is listed as critically endangered under the IUCN Red List. This study aimed to document the status of seagrass beds and evaluate their potential for supporting dugong recovery in Kenya. A cross-sectional survey was conducted in December 2016 to March 2017, with data gathered through desktop reviews, interviews, beach surveys and aerial surveys. Seven seagrass species were found at sampled sites, namely *Syringodium isoetifolium*, *Thalassodendron ciliatum*, *Halophila ovalis, Zostera capensis*, *Thalassia hemprichii*, *Cymodocea serrulata*, and *Halodule uninervis*. *Halodule* and *Halophila* seagrass species are important in the diet of dugongs. Two dugongs were sighted during the aerial survey. The spread of sea urchins, unplanned infrastructure development, Illegal, Unreported and Unregulated fishing, and boat anchors negatively affected seagrass ecosystems and hence dugong distribution in Kenya.

Keywords: seagrass, dugong, *Dugong dugon*, conservation, Kenya

Introduction
Dugongs (*Dugong dugon*) are the only herbivorous marine mammals in the world and the only extant member of the family Dugongidae (Grech and Marsh, 2008; Marsh and Saalfeld, 1990; Tol *et al.*, 2016). Over the years, there has been a sharp decline in the population of dugongs globally, leading to their listing as 'vulnerable to extinction' under the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Zedan, 2004) and critically endangered in East Africa (IUCN, 2022) necessitating their protection and conservation. The diet of dugongs is predominantly seagrass, whose ecosystems are located between mangrove ecosystems and coral reefs (Meidina *et al.*, 2023). Seagrass are marine flowering plants found in shallow coastal water where they flower, pollinate, seed, and germinate into new plants forming meadows (Akbar *et al.*, 2021; de la Torre-Castro and Rönnbäck, 2004; Tol *et al.*, 2016; Valentine and Duffy, 2007). They are habitats and foraging areas for many marine organisms including dugongs (Meidina *et al.*, 2023). The IUCN Red List attributes approximately 27 % of threatened marine species, including dugongs, to loss of seagrass and degradation of seagrass beds (Akbar *et al.*, 2021; Zedan, 2004).

Seagrass species are grouped into two major groups based on their life forms. The first group comprises short-lived, 'pioneering' species which include *Halophila ovalis*, *Halophila minor*, *Cymodocea rotundata*, *Halodule uninervis*, *Halodule wrightii*, *Halophila stipulacea*, *Syringodium isoetifolium* and *Zostera capensis*. The second group consists of long-lived, 'climax' species which include *Enhalus acoroides*, *Thalassia* *hemprichii*, and *Thalassodendron ciliatum*. Species in both groups exhibit typical zonation that is dependent on the water's depth, exposure to air and sunlight during low tide, and soil structure (Meidina *et al.*, 2023). None of the species is widespread, with all limited to the tropics except for *Zostera* spp. (Awadh *et al.*, 2021). Twelve species of seagrass occur in Kenya (Eklöf *et al.*, 2008) and cover approximately 75 % of the reef surface of Kenyan coastal waters, with pioneer species occurring closer to the coastal areas (Abuodha, 1998; Ochieng and Erftemeijer, 2003) while climax species occur in the deeper areas (Awadh, 2021).

Dugongs forage different genera of seagrasses in different locations with preferences varying due to extremes of weather conditions (Marsh and Saalfeld, 1990). Adulyanukosol *et al.* (2010) ranked dugong's preference for seagrasses based on the regularity of feeding, the relative abundance of different seagrasses, and signs of previous feeding. *Halophila ovalis* has been reported to be the most preferred species of seagrass by dugongs followed by *Halodule uninervis* thin-leaf morph, *Syringodium isoetifolium*, *Halodule uninervis* broad-leaf morph, and finally *Zostera muelleri* (Adulyanukosol and Poovachiranon, 2006; Adulyanukosol *et al.*, 2010; Marsh and Saalfeld, 1990; Tol *et al.*, 2016). The preferred order of seagrasses by dugongs varies across ranges and times (Anderson, 1998).

The absence of dugongs in seagrass meadows is increasingly being associated by scientists with a decline in dugong populations partly attributed to the loss and destruction of meadows (Hays *et al.*, 2018; Valentine and Duffy, 2007). Various human factors such as netting, hunting, trawling, vessel traffic, poor-quality terrestrial runoff, and biological factors such as sea urchin outbreaks have been noted to have the potential of adversely affecting the well-being of dugongs and their seagrass habitat (Grech and Marsh, 2008). Understanding dugong feeding behaviour and threats to the health of seagrasses in Kenya will assist in conservation strategies to conserve and even recover the population of dugongs. This analysis aimed to document the status of seagrass and evaluate its potential for supporting dugong recovery in Kenya.

Materials and methods

Study Design

This cross-sectional analysis of the status of seagrasses on the Kenyan coast was carried out using data from a main study that assessed the distribution, status, threats, and strategies for dugong conservation in Kenya since the 1960s (Awadh, 2021). The triangulation method using desktop reviews, interviews, beach surveys, and aerial surveys was used in the main study. For the current analysis, data was collected between December 2016 and March 2017. Approval to conduct the study was granted by the Kenya Wildlife Service (KWS).

Study procedure

Data for this analysis was collected through aerial surveys and beach seagrass meadow surveys. Additional information on dugong sightings was gathered through interviews with fishers.

Seagrass meadow surveys

Rapid ecological surveys were used to sample dugong habitats along the coast of Kenya. The location for the sampling of seagrass meadows was selected following a review of literature, a beach cast survey, and in consultation with local conservationists and fishers on locations of dugong sightings. Six fishing villages adjacent to the beach with a history of anecdotal, scientific or documented information on dugong sightings and seagrass meadows were selected as sites for the survey. Three of the selected villages were in the south of Kenya's coast; specifically Vanga, Shimoni, and Msambweni, while three were in the north; Matondoni, Kizingitini, and Kiunga. Systematic beach surveys were used to track seagrass species and beach-cast incidence to identify the availability of suitable seagrass habitat for dugongs. These surveys were carried out during low tide through snorkelling. Sampled sites were about 1-2m below sea level during low tide. For every sampled site, three random 50 m^2 (5 m width by 10 m length) plots divided into nine quadrants of 1 m^2 were sampled at an interval of 10 m along the beach. In total, 18 plots were sampled in this study. The total number of seagrass stems and species in each quadrant was counted and recorded following recorded procedures (McKenzie, 2003)(Fig. 1). Whole samples of seagrass were collected for species identification (FishCORAL Project, 2015). Underwater photographs were taken to show the density or level of degradation of seagrass meadows in study sites.

Aerial surveys

Aerial surveys were used to complement data on the distribution of seagrass along the Kenya coast, and for locating dugongs. The procedure used in the aerial surveillance was as described by Findlay *et al.* (2011). An aircraft was flown at a series of East to West or West to East 12-mile transects during the day in a progressive North to South direction at an altitude of 137m and speed of approximately 80 knots. A total of 37 transects were established in the north, extending from the Somali border at Kipini while sixteen transects were established in the south, from Diani Beach to Jimbo on the Tanzanian border. The aerial surveys were conducted for 3 days in December 2016 and another three days in March 2017. A total of 847 aerial sightings of the ocean were made. The survey was done at a time when the ocean was calm, with less turbulence and good visibility.

The Arc GIS 9.3 software was used to plot and map data from the aerial survey to indicate the location of dugong sightings and the distribution of seagrass in the study area.

Seagrass data analysis

The normality, distribution, and skewness of collected data were determined using the Kolmogorov – Smirnov test. The ability of different seagrass species to predict the presence of dugongs was determined using linear regression. For this analysis, species of seagrasses were the predictor variable while the presence of dugong was the dependent variable. Species with statistically significant correlation to dugong were included in a multivariate regression analysis model (Alexopoulos, 2010). Seagrass species with a low correlation coefficient that was not statistically significant were not included in the predictive model. The statistical level of significance was set at p=0.05.

Results

Seagrass ecosystem

The results of the seagrass species and densities in each of the study sites and the estimated dugong population are presented in Table 1. The stem counts and densities of seagrass per site are indicated. Seven species of seagrass were found occurring in Kenyan coastal waters, namely. *Syringodium isoetifolium*, *Thalassodendron ciliatum*, *Halophila ovalis*, *Zostera capensis*, *Thalassia hemprichii*, *Cymodocea serrulata*, and *Halodule uninervis*.

S. isoetifolium was the most ubiquitous seagrass species in the study sites. Vanga had the highest densities of S. *isoetifolium* at 67.9 stems/m^2 while Kiunga had the lowest densities at 12.0 stems/m^2. *Halophila ovalis* and *T. ciliatum* species occurred across all sites. Kiunga had a fair coverage of *H. ovalis* at 69.9 stems/m^2 and *H. uninervis* at 72.1 stems/m^2 as well as having the highest density of seagrass. *Cymodocea serrulat*a was only recorded in Shimoni while *Z. capensis* species was recorded in four sites with densities of less than 11.3 stems/m^2 in each site.

Thalassia hemprichii spp. only occurred in study sites located on the northern part of the Kenyan coast. Five (5) seagrass species were recorded in five out of the six study sites. The existence of *C. serrulate*, *Halodule* spp. and *S. isoetifolium* seagrasses varied slightly in their stem count densities. Overall, *S. isoetifolium*, *H. ovalis* and *T. ciliatum* occurred across all study sties while *C. serrulata* and *T. hemprichii* were the least common species in all study sites.

Correlation between seagrass species and dugong presence

From the linear regression, only *Halodule* and *Halophila* spp. showed statistically significant association to dugong and were included in the multivariate analysis. These two seagrass species were found to predict the presence of dugong with *Halodule* spp. being stronger predictors of dugong presence compared to *Halophila*

Table 1. Densities of seagrass per site and current dugong estimates.

Landing site	Seagrass Specie cover (stem count (density/m2))								Estimates of dugong population
	SI	HO	ZC	TC	TH	HU	CS	Total count	
Kiunga	180(12.0)	620(68.9)	53(5.9)	359(39.9)	482(53.6)	649(72.1)	0	**2343**	10
Kizingitini	268(29.7)	543(60.3)	102(11.3)	473(52.6)	104(11.5)	0	0	**1490**	1
Matondoni	400(44.4)	74(8.2)	77(8.6)	238(26.4)	282(31.3)	0	0	**1069**	1
Msambweni	333(37.0)	29(3.2)	0	263(29.2)	0	83(9.2)	0	**708**	1
Shimoni	459(51)	187(20.8)	0	398(44.2)	0	71(1.42)	332(6.64)	**1447**	1
Vanga	611(67.9)	39(4.3)	20(2.2)	449(54.4)	0	46(5.1)	0	**1165**	0

KEY: SI- *Syringodium isoetifolium;* HO- *Halophila ovalis;* ZC- *Zostera capensis;* TC- *Thalassodendron ciliatum;* TH- *Thalassia hemprichii;* HU- *Halodule uninervis;* CS- *Cymodocea serrulate*

Table 2. Regression analysis results of predicting dugong by seagrass species.

Regression Statistics	Halophila ovalis	*Halodule uninervis*
Correlation coefficient.	0.832783	0.905105
R Square	0.693528	0.819214
Adjusted R Square	0.61691	0.774018
Standard Error	2.337823	1.795553
Observations	6	6

ANOVA		df	SS	MS	F	Significance F
Halophila ovalis	Regression	1	49.47166	49.47166	9.051761	0.039604
	Residual	4	21.86167	5.465418		
Halodule uninervis	Regression	1	58.43729	58.43729	18.12564	0.01308
	Residual	4	12.89605	3.224012		

		Coefficients	Standard Error	t Stat	P-value
Halophila ovalis	Intercept	-1.80931	1.67536	-1.07995	0.340932
		0.35132	0.116771	3.008614	0.039604
Halodule uninervis	Intercept	-0.292	0.95791	-0.30483	0.775697
		0.323782	0.076051	4.257422	0.01308

spp. Statistically significant regression equations were generated for the two seagrass species with that of *H. ovalis* being significant at (F (1,4) = 9.052, p = 0.039) with an R^2 of 0.69 while the equation for *H. uninervis* was (F (1,4) = 18.126, p = 0.013) with an R^2 of 0.82.

The equation to predict dugong presence using *Halodule* spp. of seagrass was calculated as y= -0.292+0.324 + 1 while the predictive equation for *Halophila* spp. was calculated as y= -1.81+0.351 + 1. This model can be explained by 69.4 % of *Halophila* spp. and 81.9 % of *Halodule* spp. Thus, if things remain constant, the dugong population will increase 0.35 times for every increase in *Halophila* spp. per square meter of seagrass while it increases 0.32 times for every increase in *Halodule* spp. (Table 2).

Dugong's sighting

Two dugongs were sighted during the aerial survey. The first one was sighted in Kiunga at latitude (-4.541705°S 39.473034°E) while the second was sighted between Shimoni and Msambweni at latitude (-1.986209°S 41.142696°E) (Fig. 1). From the interviews with fishers, an estimated 14 dugongs were thought to occur in the study area with the majority occurring in Kiunga. Locations where fishers reported to have sighted dugongs included Doa, Sii island, Mwarembo, Mbayai, and Funzi creeks in the south and from the Siyu channel through Kiwayuu to Kiunga at Pezali, Konani, Ndia-mbili, Mlango-wa-huseni and Kui on the north coast. The estimated number of dugongs per site as given by fishers is indicated in Table 1.

Threats to seagrass

Observed threats to seagrass health and thus dugong survival were categorized into two; anthropogenic and natural threats.

Habitat loss and degradation caused by human activities (Anthropogenic threats)

A combination of frequent seine nets, gill nets, ring nets fishing, and the use of boat anchors in fishing zones, were noted to lead to the uprooting of seagrasses; moreover, these activities did not give time for the meadows to recover. These activities contributed to patchy, shorter, and degraded seagrass beds in studied areas. Figure 2 (A and B) shows two photos from the underwater ecological survey. Figure 2 (A) is a healthy seagrass bed photo taken in Kiunga which hosts a conserved marine national reserve; Figure 2 (B) is a degraded seagrass bed taken from Kizingitini. The healthy seagrass bed is dense, with at least three species of seagrasses visible while the degraded seagrass bed is patchy with sand visible.

These human activities have negatively affected seagrass meadows thus threatening the survival of dugongs. The threats were highest in Vanga, while they were average in Kizingitini, Matondoni, and Msambweni. Vanga is a fishing village at the Kenya-Tanzania border characterized by migrant fishers who use illegal and harmful methods in fishing that could be contributing to seagrass degradation. Kiunga and Shimoni reported slightly less habitat loss and degradation; this is likely because fishers' access to these areas is restricted by the presence of the conservation area.

Discussion

Status of seagrass

This analysis aimed to document the status of seagrass and evaluate its potential for supporting dugong recovery in Kenya. Seven species of seagrass were found to occur in the study areas. The distribution and densities of the seagrass varied between the study sites. Two dugongs were sighted in the study area during the aerial survey. Kiunga which was reported to have higher numbers of dugong than other sites had higher densities of seagrass compared to other sites. This area also had high densities of *Halodule* spp., and *Halophila* spp. that are reported as the preferred species of seagrass by dugongs. *Halodule* spp., and *Halophila* spp. were found to predict the presence of dugongs indicating that their restoration could result in the recovery of dugongs. On the other hand, areas with low densities of seagrass were also noted to have corresponding low numbers of dugongs as reported by fishers.

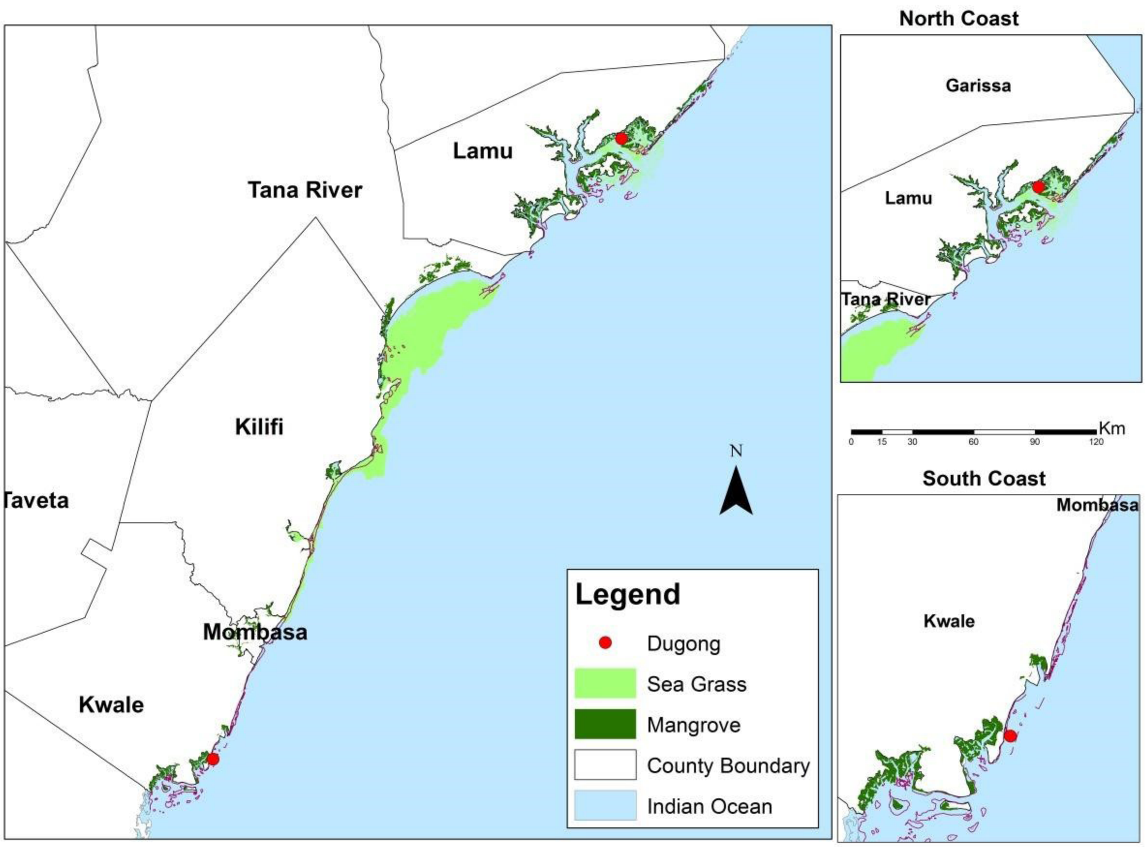
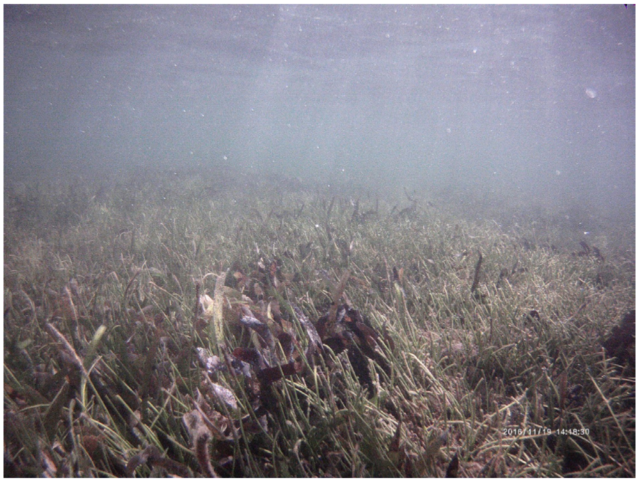


Figure 1. Map of Kenya coastline indicating the locations of dugong sightings during the aerial survey conducted between December 2016 and March 2017.

Natural threats to seagrass

During the seagrass surveys, seagrass beds were regularly found to have high densities of sea urchins, across study sites. However, some sites, e.g., one out of three sample plots in Kiunga and one out of three in Shimoni, did not record any sea urchins. Kiunga and Shimoni had the lowest (2) and second-lowest (4) mean sea urchin occurrence per square meter. The number of sea urchins per meter square was highest in Vanga with a mean of 22 urchins per m^2 followed by Msambweni, Matondoni, and Kizingitini as indicated in Table 3.

Seagrass decline and loss have been reported worldwide (Nadiarti *et al.*, 2021). Species of seagrass preferred by dugong are scarce in Kenyan waters. Seven



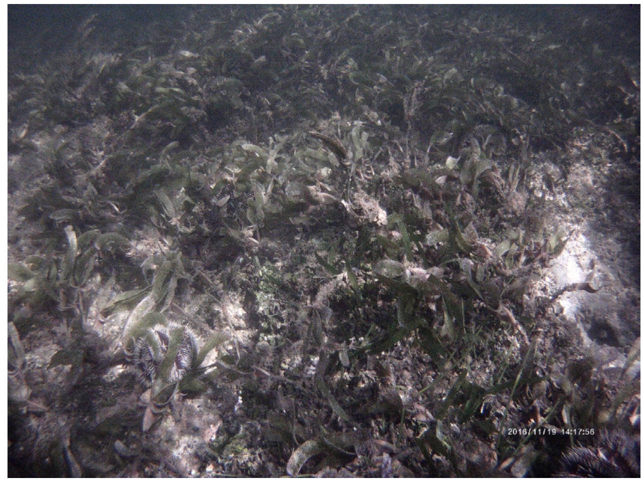


Figure 2. Photograph of a dense and healthy seagrass bed (A), versus a weak and a degraded seagrass bed (B).

of the twelve species of seagrass recorded along the Kenyan intertidal were identified in the six sample sites. Preen and Marsh (1995) and Adulyanukosol *et al.* (2010) reported dugongs to prefer *Halodule* spp., *Halophila* spp., *Thalassia* spp., and *Syringodium* spp. of seagrass. The findings from the present agree with this observation as the locations of dugong sighting were found to have high densities of these species. In this study, the coverage for *Halodule* and *Halophila* was low in five sites and fair in Kiunga. This correlates with dugong sightings in this area during aerial surveys and reports of higher dugong populations from fishers when compared to other studied areas. *Thalassia* coverage was fair in Matondoni and poor in five sites, while *Syringodium* was fair in Matondoni Shimoni Msambweni and Vanga and poor in Kizingitini and Kiunga. Hence, the study area has the potential to host dugongs and may offer ideal conditions for their population to thrive and recover.

Halophila spp. and *Halodule* spp. of seagrass were associated with dugongs as well as being predictors of dugong presence. These two species were fairly common in Kiunga and low in the rest of the study area. Kiunga is thought to host the highest populations of dugongs in Kenyan waters. Even so, the densities of these seagrasses are not high enough to support large populations of dugongs due to their heavy foraging. These findings agree with Meidina *et al.* (2023) and Preen (1995) that dugongs target *H. uninervis* and *H. ovalis* species of seagrass. Preen (1995) and Preen and Marsh (1995) suggested that dugongs target *H. uninervis* and *H. ovalis* for food, likely due to these species' low fibre and high nitrogen content. The finding from the present study also agree with Ochieng and Erftemeijer (2003) who found vast meadows of *H. uninervis* and *H. ovalis* to be uncommon on Kenya's south coast, explaining the apparent scarcity of dugongs in the south of Kenya. The relationship between *Halodule* spp. coverage and presence of dugongs calls for its restoration for success in dugong conservation. Dugong sites in Kenya have decreased from at least 28 sites to about ten areas. The diminishing number of dugongs and the low coverage of dugong's preferred seagrass species in the study area present the risk of dugong habitat shrinking further.

Threats to the health seagrass meadows

Anthropogenic and natural threats were identified that result in the degradation of seagrass meadows and thus affect dugong distribution and recovery. Human activities related to fishing practices were observed to

Table 3. Count of sea urchins per m^2 per study site.

	Kiunga	Kizingitini	Matondoni	Msambweni	Shimoni	Vanga
Plot 1	0	163	216	124	102	112
Plot 2	22	40	190	305	0	297
Plot 3	34	102	34	87	7	191
Site total	56	305	440	516	109	600
Plot mean	18.67	101.67	146.67	172.00	36.33	200.00
#Urchins per m^2	2.07	11.30	16.30	19.11	4.04	22.22

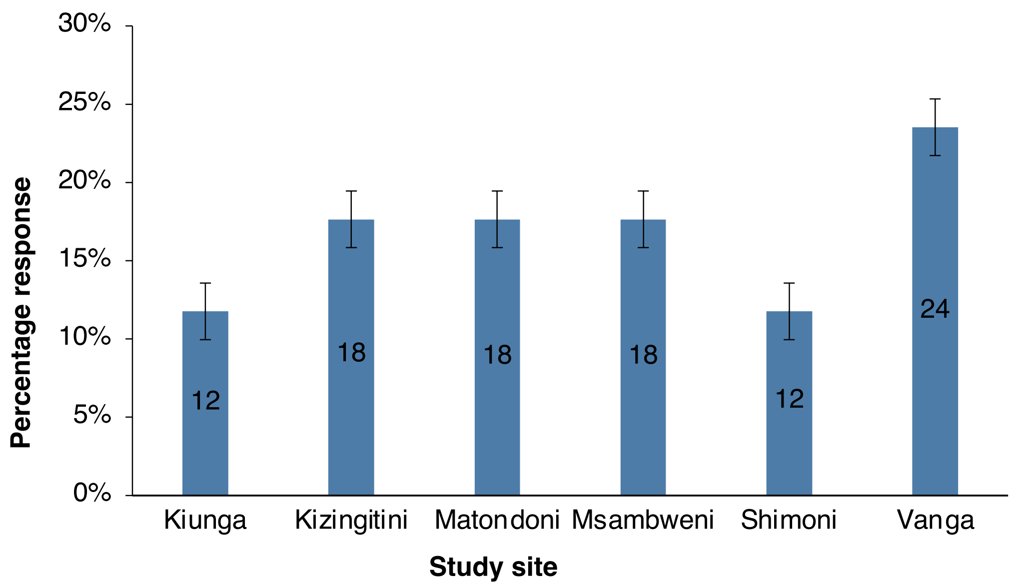


Figure 3. Densities of sea urchins by study site along the Kenya coast.

cause the degradation of seagrass beds. This being an activity that is repeated very frequently, it was noted to also affect the recovery of degraded meadows. A contrast was observed in the densities and health of seagrass when comparing sites that were protected from fishing within marine parks and unprotected sites. Protected sites had more as healthy seagrass beds compared to unprotected areas. Moreover, protected areas were thought to have higher numbers of dugongs compared to unprotected areas with high fishing activities. Urchins were a major natural threat observed to affect seagrass in the study area. The presence of urchins corresponded with high human actives with areas having high human activity such as Vanga which has a port having higher urchin densities per meter square compared to other sites. Besides urchin infestation destroying seagrass meadows, they are also known to affect dugong feeding as dugongs avoid foraging in areas with high densities of urchins.

Seagrass plays a vital role in the coastal ecosystem as is an indicator of the overall health of the ecosystem. The well-being of seagrass meadows can reveal changes in the surrounding environment, which may be due to natural causes and other anthropogenic activities (Hemminga and Duarte, 2000). While seagrass beds are in fair condition in the surveyed locations, threats leading to their decline still exist. Sea urchins, unplanned infrastructure development, IUU fishing and boat anchors were some of the factors found to destroy seagrasses in the study site. The government of Kenya has enacted legislation to protect dugongs as well as adopting articles 61, 63, and 64 of the United Nations Convention on the Law of the Sea (UNCLOS) that takes into consideration the protection and management of marine mammals inclusive of dugongs (Awadh *et al.*, 2021; Samoilys *et al.*, 2017). Protected areas had higher densities of seagrasses with greater diversity compared to unrestricted areas. This reinforces the need for conservationists and stakeholders to meet COP 15 biodiversity targets. More effort needs to be put in place to conserve dugong feeding grounds and seagrass if dugong populations are to be restored.

Conclusion

Seven species of seagrass were found occurring in Kenyan coastal waters. The densities of these seagrass species varied across the coast. The densities of seagrass can support dugongs but are not enough to support dugong recovery. *Halodule* spp., and *Halophila* spp. of seagrass were highly associated with dugongs and can be used to predict their presence. Both human activities such as harmful fishing practices, and natural threats such as urchin inundation, were found to negatively affect seagrass meadows. Reducing human activities in areas known to host dugongs could lead to an increase in the densities of seagrasses and recovery of dugongs.

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