American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Abundance, Distribution and Diversity of Seagrass Species in Lagoonal Reefs on the Kenyan Coast

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Abstract

The study described the diversity of Seagrasses, measuring the canopy height and relative abundance in Diani, Nyali, Kanamai and Vipingo seagrass meadows along the Kenyan Coast. Using a 1 m^2 quadrats along a predetermine line transect, the percentage cover and the species density of Seagrasses were measured respectively to compare the diversity of the observed species between the study sites. The canopy height associated was also documented at each study site. The data collected was subjected to Shannon - Weiner Diversity Index to determine the species density and ANOVA for variation. The index provides more information about community composition by taking into account the relative abundances and evenness of different species. Data was collected from December, 2013 to January, 2014. There was a significant difference in seagrass abundance and canopy height between the four study sites. Kanamai had higher abundance while Nyali recorded high species diversity ($p<0.05$). *T. ciliatum* recorded high canopy height and was connected to its higher productivity. It was concluded that Seagrasses species abundance and diversity showed spatial variation within and between the study sites and that levels of protection affect herbivore rates thus higher abundance in unprotected site. The work recommends further research should specifically target the source of changes in seagrass abundance and distribution between the study sites through time, and determine if any other stressors (nutrients, epiphytes, etc.) contributed to the loss of seagrass habitat in these sites.

Keywords: Density; Canopy height; Relative Abundance; Percentage cover; Productivity.

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1. Introduction

Seagrass are marine angiosperm permanently or temporarily submerged in the sea [1]. They are unique flowering plants that are been influenced by physical, chemical and biological characteristics of marine environment [2]. They can live in different aquatic conditions such as freshwater, estuarine, marine or hypersaline [3]. They comprised of four families, 12 genera of angiosperm and about 60 species [4]. They occur in meadows and are distributed in the nearshore, subtidal and intertidal sand in temperate and tropical regions [5]. However, there is a decline of seagrass species caused by habitat destruction and marine pollution [6].

Seagrass survival and growth is being controlled by different parameters that include physical (temperature, salinity, waves, currents, depth, substrate and day length), natural (light, nutrients, epiphytes and diseases), and anthropogenic inputs - nutrient and sediment loading [4]. This had resulted to different spatial distribution. For example, out of 12 genera in the world, only 7 genera are found in tropical and subtropical regions, the remaining genera are found in temperate waters [1,7]. In the East African coast, Twelve seagrass species have been identified [8]. Whilst West Indian ocean recorded 13 species; *Cymodocea rotundata, Cymodocea serrulata, Enhalus acoroides, Halodule uninervis, Halodule wrightii, Halophila decipiens, Halophila minor, Halophila ovalis, Halophila stipulacea, Syringodium isoetifolium, Thalassia hemprichii, Thalassodendron ciliatum*, and *Zostera capensis* [6]. These species are distributed mostly within the lagoon formed between the reef and the mainland, providing habitat for seagrass communities [9]. Their distribution, composition and density may therefore vary over time, place and seasonally [10] hence it is important to consider this ecosystem in monitoring program.

Seagrasses are among the most productive ecosystems on earth [11]. They are also vital and dominant primary producer that support food web [12]. They offer important ecological services to marine environment [2]. They support biodiversity [7,13], providing substrate for organism such as bacteria, microalgae, macroalgae and invertebrates, [1], serves as breeding, nursery and feeding grounds for fish, crustaceans and invertebrates [14], largest carbon sink ecosystem in the ocean [15], and nutrient cycling, hiding places from predation for small and juvenile fish and macro invertebrates [16].

Despite its benefits, seagrasses meadows are threatened worldwide [17]. The trend of its degradation is approximated to be 5% per year [18]. The two-thirds loss of the seagrass meadows was attributed to human activities [19]. The human implications to seagrasses include coastal shore development and dredging [20], illegal fishing practices, poor aquaculture development [17] and uprooting of seagrass by boats [21].

The Kenyan coast has recorded 12 seagrass species; *Halodule uninervis, Halodule wrightii, Syringodium isoetifolium, Cymodocea rotundata, Cymodocea serrutata, Thalassodendron ciliatum, Zostera capensis, Enhalus acoroides, Halophila minor, Halophila ovalis, Halophila stipulacea and Thalassia hempnchii* with *Thalassodendron ciliatum* being the dominant species [22,23].

They are mostly distributed in shallow-water environments within inshore lagoon ecosystem [24] in water less than 10 m deep [4]. However, there distribution along the continental shelf which lies a few kilometer from the shore make them vulnerable from overexploitation and influence from demographic growth [23]. The documented human activities that's cause disturbance to seagrass ecosystem include dredging and filling operations, silt discharge, oil and sewage pollution, fishing activities, motor boat propeller and anchor and Introduction of alien seagrass species which resulted to loss of some seagrass species [22]. Regrettably, the seagrass functioning had been affected by the increase of the human population in East Africa which puts pressure on seagrass meadows [25].

In spite of the benefits and threats accrued to the seagrass meadows in Kenya, research on seagrass ecosystem is still scarce [11]. The management plans in the region also not directly focused on seagrass ecosystem [11]. Also, lack of information on the status of East African seagrass beds prevents forecasts on the future of seagrasses species in this region [8]. It is therefore very important to document seagrass species diversity and distribution to be able to identify areas requiring conservation measures [4].

The focus of this study is therefore to determine the species diversity and patterns of distribution and abundance of seagrass species among lagoons in coastal Kenya. This will provide the community structure of seagrass species at lagoonal reefs of Diani, Vipingo, Kanamai and Nyali on the Kenyan coast. The study is guided by the below specific objectives;

- To determine and compare the distribution and abundance of seagrass species between the four study sites on the Kenyan coast.
- To determine and compare the seagrass species diversity and evenness between the four study sites on the Kenyan coast.
- To determine the variation of canopy height of selected seagrass species between the four study sites on the Kenyan coast.

2. Materials and Methods

2.1 Study Area

The seagrass meadows forms a productive ecosystem along the Kenya coastline that provide livelihoods for coastal fisheries [26]. The study sites (Vipingo, Kanamai, Nyali and Diani; Fig. 1) were selected on the basis of previous research [22,23,22,27] and their accessibility. The site in Vipingo - Kuruwitu (03^{o} 47' S, 39^{o} 51'E) is about 33 Km north of Mombasa. This site is characterized by few residential houses along the beach. The reef is a community conserved area and has a relatively low complexity and is adjacent to a sandy beach [27]. The 2nd study site Nyali is located at 4^{o} 03'S, 39^{o} 43' E. This site is one of the tourist center located 2 Km from Mombasa island. There are numerous hotels and settlement along the beach. Kanamai (3º 55'S, 39º 46' E) on the other hand lies approximately 30 Km away from Mombasa Island on the Kenyan north coast. This area is unprotected and is open to fishing activities. Diani Beach (4^{o} 21'S, 39^{o} 33'E) is situated at approximately 72 Km south of Mombasa on the coast of Kenya. A survey was carried out in Diani - Mvureni lagoon area.

Figure 1: A map of Kenya coastline showing the location of Nyali, Kanamai, Vipingo and Diani beaches of which the study was done

2.2 Sampling Design

Sampling was conducted in the month of December, 2013 and January, 2014. December – January are northeast monsoon (NEM) months, they are characterized by low precipitation, high temperatures, low cloud cover, less turbulence in marine waters and improved transparency [28]. Sampling was carried out during the low spring tides because the seagrass beds were exposed and easily accessible. Three transects were established at each study site at an interval of 400 m between transects. The starting point of the transect was chosen at random from the upper seagrass limit to the lagoon. Along the transect line, 1 m^2 quadrats were laid at intervals of 20 m. At each point on the transect, the quadrat was randomly thrown three times and sampled each time. The percentage cover of each species in the quadrat was estimated visually. Three species were selected randomly in each quadrat and their canopy height measured to the nearest centimeter. Each site was visited once during the study period. Seagrass identification was guided by "*The seagrass of the world*" [29].

2.3 Quantitative sampling method

2.3.1 Systematic sampling along a line transect

A transect line was stretched from the highest to lowest zone of the seagrass meadow (running perpendicular form the beach to the subtidal zone). In measuring the canopy height of the species in each quadrat, the leaf of a species within the quadrat was extended to its maximum length/height without uprooting and measured from the sediments to the leaf tip using 30 cm ruler. The same quadrat was used to estimate the abundance of each species as percentage cover (Fig. 2 & 3). During the study period, seagrass meadows were found to have monospecies such as in Nyali and Diani.

Figure 2: Measuring canopy height

Figure 3: Measuring canopy height and abundance approximation within the quadrat

2.4 Data analysis

Preliminary data exploration was done with a simple spreadsheet program. The data was keyed in an excel sheet, coded and then exported to SPSS. The excel spreadsheet was also useful in answering descriptive statistical questions such as; what are the dominant species and what is the distribution of the dominant species.

2.4.1 Calculation of species diversity and richness

Biodiversity indices are an overall measure of diversity that usually combines aspects of species richness and evenness. Species richness is the number of species in a given area. Evenness, or equitability, is the uniformity of abundance in an assemblage of species [30]. This study used Shannon - weinner diversity index (H) and index of evenness (E) as given by [31];

$$H = -\sum_{i=1}^{s}(Pi \times Ln\ Pi)$$

Where,

H; species diversity index, **s;** the number of species and **P_i;** the proportion of individuals of each species belonging to the ith species of the total number of individuals and,

$$E = H/\ln S$$

Where,

E; Species evenness, **H;** Shannon-Wiener index and **S;** Species richness

The excel sheet was used in drawing the **Rank – Abundance Curve or the Whittaker plot**. The curve was also used to visualize species richness and species evenness at the site. It overcomes the shortcomings of biodiversity indices that cannot display the relative role different variable played in their calculation [32].

2.4.2 Statistical analysis

The percentage cover data was first arcsine transformed. This is because the percentages from 0 to 100% form a binomial, rather than a normal, distribution, the deviation from normality being great for small or large percentages (0 to 30% and 70 to 100%). If the square root of each proportion, *p*, in a binomial distribution is transformed to its arcsine, then the resultant data will have an underlying distribution that is nearly normal [27]. The data was then coded before being analyzed in SPSS. One – way analysis of variance (ANOVA) was then used to test the difference in species cover between the four sites (Vipingo, Kanamai, Nyali and Diani). Post hoc Duncan test was also used in defining the subsets of variance of species cover that contribute to differences between sites. The difference in diversity of species between sites was analyzed using ANOVA in the PAST program.

3. Results

3.1 Seagrass species distribution and abundance

During the survey, 8 seagrass species in 6 genera were recorded in the four study sites as shown in Table 1. The highest number of species recorded at a site was in Nyali (8), followed by Diani (7), Vipingo (5) with Kanamai recording the lowest number (3) of seagrass species.

Table 1: Distribution of seagrass species in the study areas of Kanamai, Vipingo, Nyali and Diani lagoonal reefs (+ = present, - = absent).

Species	Kanamai	Vipingo	Nyali	Diani
Halophila ovalis	–	+	+	+
Halophila stipulacea	–	–	+	+
Halodule wrightii	+	+	+	+
Syringodium isoetifolium	–	–	+	+
Cymodocea rotundata	+	+	+	+
Cymodocea serrulata	–	–	+	+
Thalassia hemprichii	+	+	+	+
Thallasondendron ciliatum	–	+	+	–
Total Number of Species	**3**	**5**	**8**	**7**

The percentage relative abundance of each species at the site is shown in Figure 4. *Thalassia hemprichii* had the highest cover at Vipingo (52.58%) and Kanamai (43.02%) followed by *Cymodocea rotundata* that have covers ranging from 4.95 – 10.20%. At Nyali, *Thallasondendron ciliatum* showed the highest cover of 52.70%. Other important species at this site were *Cymodocea rotundata* (10.05%), *Thalassia hemprichii* (6.11%) and *Halodule wrightii* (4.74%). Diani site was dominated by *Syringodium isoetifolium* (56.11%). The species *Thalassia hemprichii, Cymodocea rotundata* and *Halodule wrightii* were recorded at all the study sites while, *Syringodium isoetifolium* and *Halophila stipulacea* were recorded at Nyali and Diani sites only (Fig. 4).

Overall the seagrass cover variation shows that *Syringodium isoetifolium* had the highest overall cover at 29.78 % in all sites combined (Fig. 5) followed closely by *Thalassia hemprichii* (27.32 %) and *Thallasondendron ciliatum* (27.01 %). *Halophila ovalis* and *Halophila stipulacea* recorded the lowest cover of 0.59 % and 0.64 %, respectively in all sites. The remaining species had a cover of 7 % or less (Fig. 5). ANOVA analysis showed significant differences in mean seagrass cover between sites ($p<0.05$, Table 2). Among sites, Post – hoc Duncan range test showed cover in Kanamai was significantly ($p<0.05$) higher than all the other sites, Vipingo (b) site also differed with Kanamai (c) and Nyali (a) mean seagrass cover, while Diani only differed with Kanamai (Fig.6).

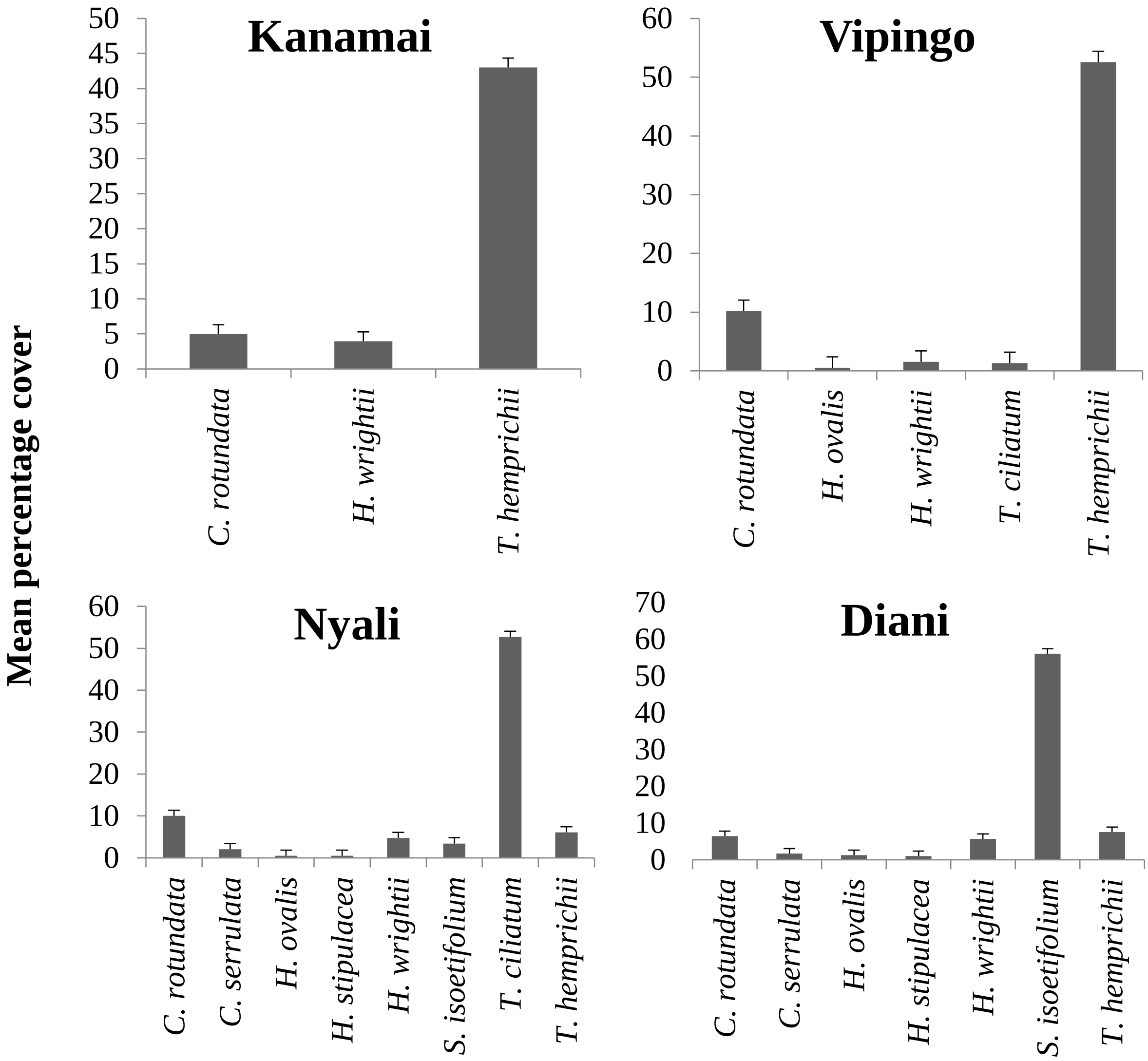

Figure 4: Variation of mean species cover between sites (error bars are standard error)

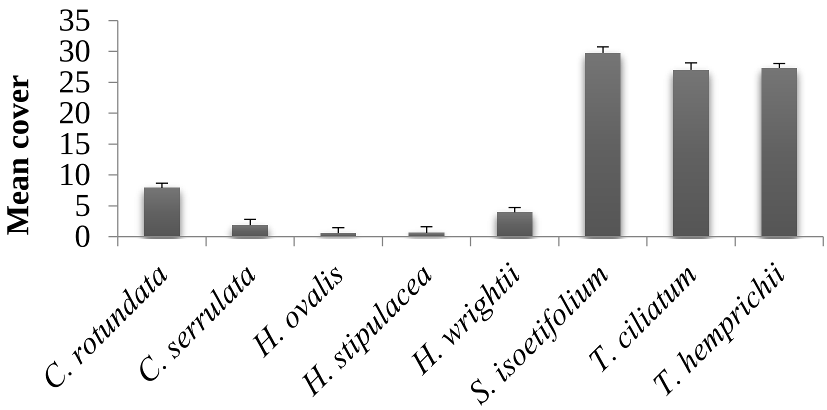

Figure 5: Variation in seagrass species cover for all sites combined (error bars indicate standard error)

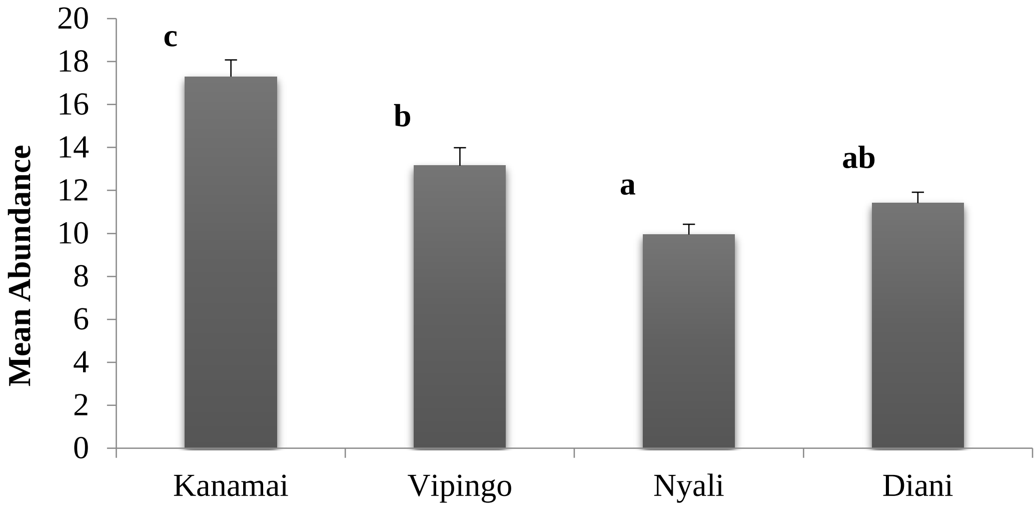

Figure 6: Variation in overall mean seagrass cover at site and Post – hoc Duncan range test showing similarity of sites based on mean seagrass cover (values with the same superscript are not significantly different).

Table 2: Analysis of variance (ANOVA) to test difference in mean seagrass cover between sites (Significant *p*-levels = 0.05)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	215.5344111	3	71.8448037	12.4667	0.000
Within Groups	22435.2	3893	5.762959157		
Total	22650.73441	3896			

3.2 Species diversity and evenness

The diversity of seagrass species (expressed as Shannon - Weiner index, H) was generally higher in Nyali (H = 1.165) followed closely by Diani (H = 1.068) and lowest in Kanamai (H = 0.5753) and Vipingo (0.6508) (Fig. 7). Kanamai site had the highest species evenness. Therefore it is important to note that although Nyali had higher diversity, the site had low evenness while, Kanamai with low diversity had highest evenness (Fig. 7). Evenness between sites had lowest variance compared to the Shannon diversity (Fig. 7).

The Whittaker plot or Rank - Abundance Curves (Fig. 8) showed patterns of diversity (i.e. richness and evenness) varied between sites. The species richness from the rank-abundance curve are in the order Nyali > Diani > Vipingo > Kanamai. However, in terms of species evenness, a steep gradient indicates low evenness while a shallow gradient indicates high evenness. In Figure 8 therefore, high species evenness occured in

Kanamai (gradient = -0.1425) followed by Diani (gradient = -0.047). In terms of abundance, Kanamai had much higher abundances followed by Vipingo as they have high ranking species.

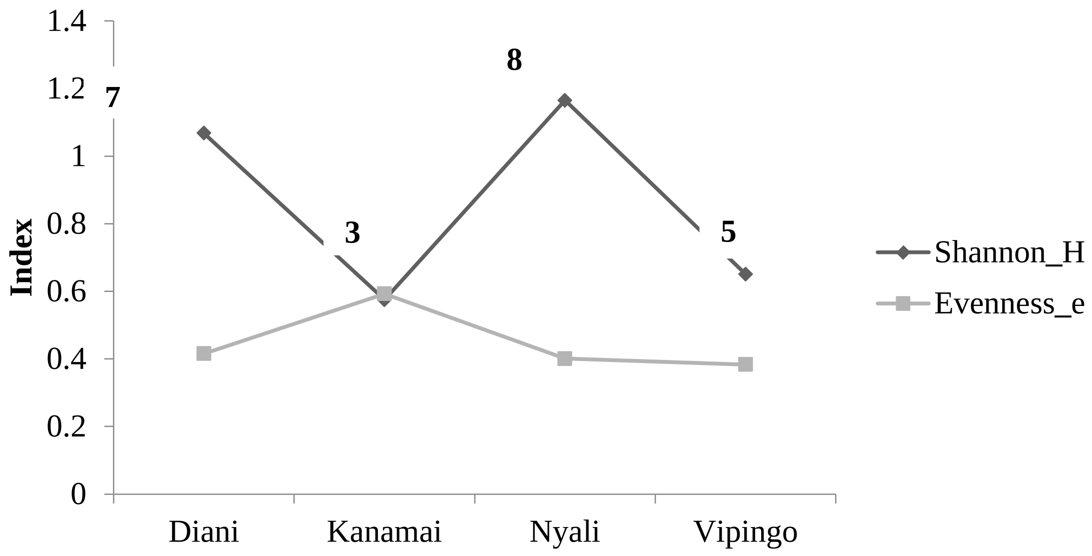

Figure 7: Variation of species diversity and Evenness index between the study sites (superscripts indicates number of species at sites)

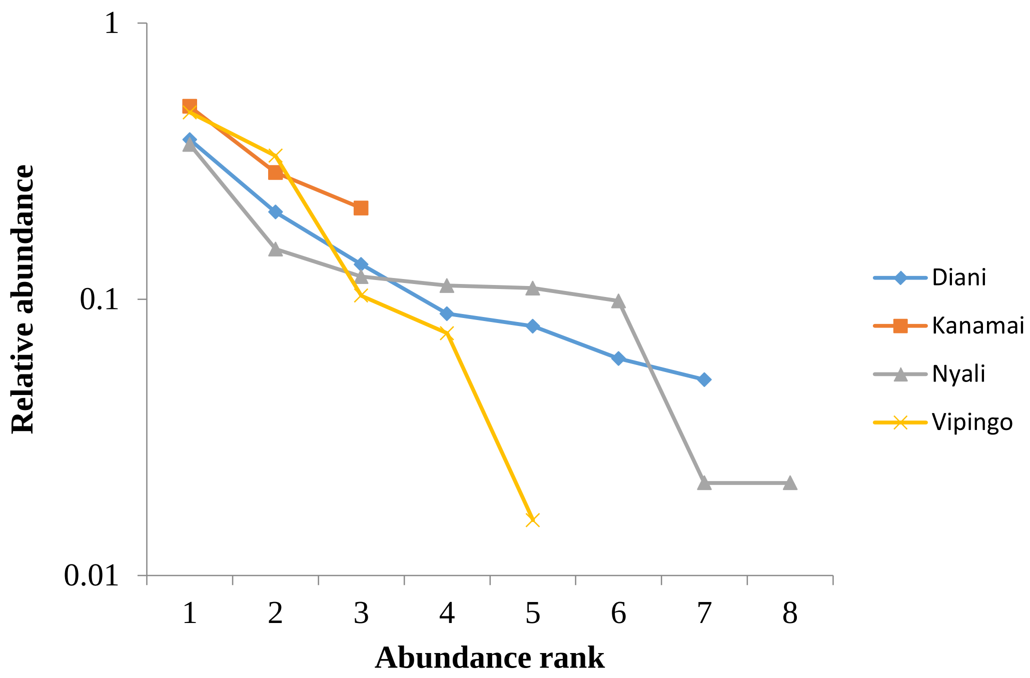

Figure 8: Rank-abundance curves of seagrass species for the four sites. Abundance is in proportional abundance (percentage of each species of total abundance).

3.3 Canopy height

Canopy height of seagrass species as measured from the sediment to the leaf tip, showed different seagrass species had different heights in the same site and between sites (Fig. 9). For example in Kanamai and Vipingo, *Thalassia hemprichii* was the tallest in canopy height (at 9.98 ± 4.07 cm and 15.2 ± 4.67 cm, respectively) followed by *Cymodocea rotundata* (Fig. 9 and Table 4). Some species recorded different heights at different site; for example, *Thalassia hemprichii* differed in height between Kanamai (9.98 ± 4.07 cm), Vipingo (15.2 ± 4.67 cm) and in Diani (17.17 ± 0.56 cm). At different sites, canopy height of all the species studied showed significance difference between the sites. Among species variability being much greater than that within species, canopy height of *Thallasondendron ciliatum* was significantly ($p<0.05$) higher than other species.

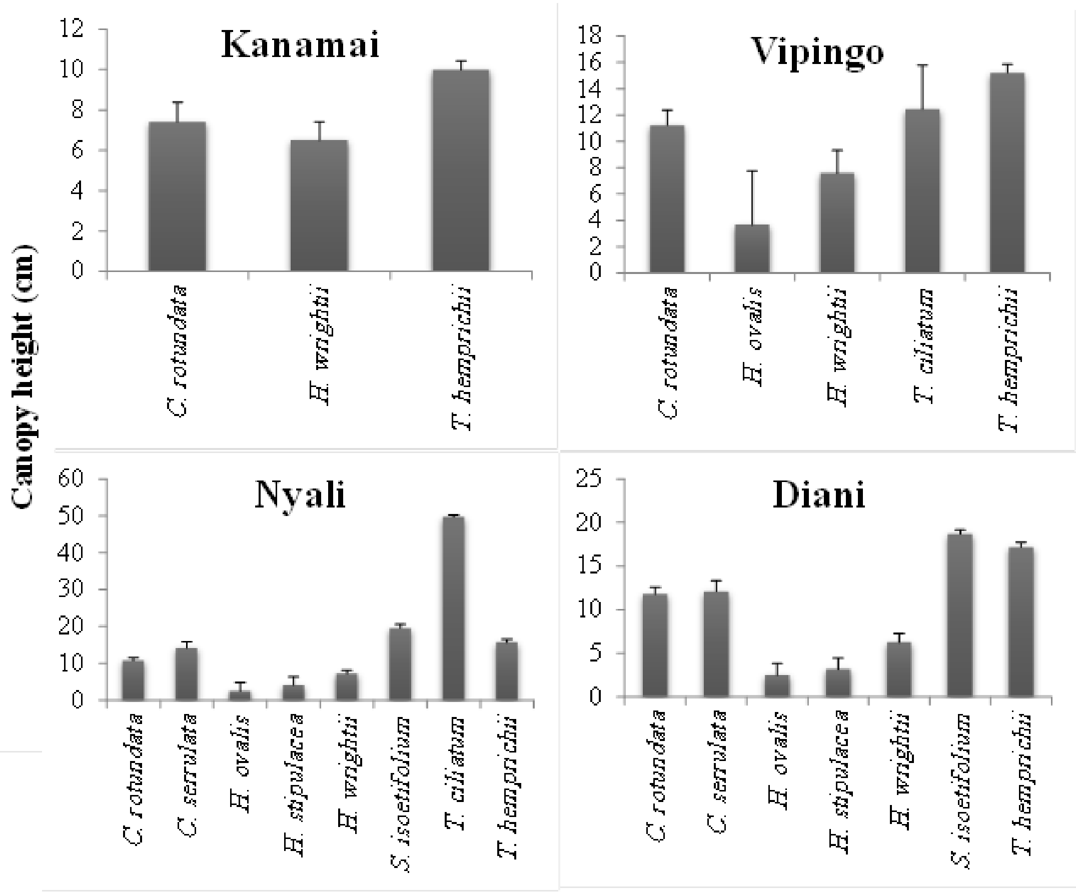

Figure 9: Variation in canopy height of seagrass species at different site

The table 4 shows statistical analysis presenting significant differences in seagrass canopy height ($p<0.05$) between the study sites. Only three species (*Cymodocea rotundata*, *Thelassodendron ciliatum* and *Thalassia hemprichii*) showed the significant different between the four study sites. The highest range in canopy height was recorded for *T. ciliatum* (12.43 ± 5.58 - 49.66 ± 13.13 cm) and *T. hemprichii* **(**9.98 ± 4.07 - 17.17 ± 0.56 cm). The highest mean canopy height value (±SD) recorded was 49.66 ± 13.13 (*T. ciliatum)* cm and the lowest was 2.47 ± 1.50 cm (*H. ovalis*). Among the sites, Nyali recorded highest canopy height in many of the species, these are *C. serrulata* (14.18 ± 4.35 cm), *H. stipulacea* (4.05 ± 1.05 cm), *S. isoetifolium* (19.48 ± 3.78 cm) and

T. ciliatum (49.66 ± 13.13 cm). Post hoc Duncan test between the species showed some species to have no significant different in their canopy height while others showed to be significant different with all the other sites (values with the same superscript are not significantly different). Among species, *C. rotundata* (c), *S. isoetifolium* (e) and *T. ciliatum* (f) differed with all species in their canopy height, while *C. serrulata* and *T. hemprichii* did not show significant differences.

Table 3: variation in canopy height between the study sites. Superscript represent post-hoc Duncan subsets for the species (mean ± Sd, p = 0.05, values are in cm)

	Kanamai	Vipingo	Nyali	Diani	F	P
C. rotundata	7.4 ± 1.84 ^{c}	11.23 ± 2.41 ^{c}	10.73 ± 3.68 ^{c}	11.78 ± 0.80 ^{c}	16.602	0.000
C. serrulata			14.18 ± 4.35 ^{d}	12.07 ± 1.26 ^{d}	2.861	0.101
H. ovalis		3.65 ± 0.92 ^{a}	2.47 ± 1.50 ^{a}	2.48 ± 1.33 ^{a}	1.574	0.229
H. stipulacea			4.05 ± 1.05 ^{a}	3.16 ± 1.29 ^{a}	3.848	0.062
H. wrightii	6.51 ± 1.06 ^{b}	7.57 ± 2.43 ^{b}	7.18 ± 2.49 ^{b}	6.21 ± 1.08 ^{b}	0.98	0.405
S. isoetifolium			19.48 ± 3.78 ^{e}	18.68 ± 0.46 ^{e}	0.728	0.395
T. ciliatum		12.43 ± 5.58 ^{f}	49.66 ± 13.13 ^{f}		23.859	0.000
T. hemprichii	9.98 ± 4.07 ^{d}	15.2 ± 4.67 ^{d}	15.62 ± 4.51 ^{d}	17.17 ± 0.56 ^{d}	66.513	0.000

4. Discussion

During the present study, the spatial variation of seagrass species along the Kenyan coast was observed. Eight species were distributed along the study sites (*H. ovalis, H. stipulacea, H. wrightii, S. isoetifolium, C. rotundata, C. serrulata, T. hemprichii* and *T. ciliatum*). Vipingo beach had been shown to have 8 seagrass species [22] while this study recorded five species. During the study by Wakibya [22], Gazi, Mombasa and Vanga sites were the only stations found to have all the 12 species while others recorded only some of the species as in this study. This shows that other species are site restricted, for example *Zostera capensis* which is a temperate species, has a restricted distribution among studied sites. It has been collected in stations which used to be harbors or calling ports by early traders [22]. This could be due to the seasonal variations in the physico- chemical parameters, affecting the occurrence and distribution of seagrass species.

Abundance of seagrass cover was significantly higher in Kanamai than in the other three sites. Kanamai is different from Nyali, Vipingo – Kuruwitu and Diani - Mvureni in that it is an open access area. Nyali is marine reserves, with limited protection by the Kenya Wildlife Service while Vipingo – Kuruwitu and Diani – Mvureni are protected through community management areas. The ‘Protection and Seagrass’ analysis showed that predation rates in protected areas were 3 times higher than in fished [33]. The results in this work therefore suggest that the open access effect in Kanamai has led to overfishing of certain fish which predate on other species such as sea urchins that feed on seagrass, thus resulting to the high abundance of seagrass species.

Reports indicate *T. ciliatum* as the dominant seagrass species in the Kenyan waters followed by *S. isoetifolium* [22] whereas, the present study found *S. isoetifolium* as being the dominant species and occupy larger area of the lagoon followed by *T. ciliatum*.

Seagrasses in the study sites were found distributed in the lagoon areas near the coast, and some patches of seagrass beds were also encountered in the reef flats and slopes. Nobi and his colleagues [34] reported the same distribution in Lakshadweep islands. Nyali and Diani support extensive seagrass growth, with the former having higher species diversity (8 species), supporting large number of associated organism and the latter with 7 seagrass species, having larger seagrass spatial cover. *Syringodium isoetifolium* were distributed widely in the deeper parts of the lagoon. The lower seagrass diversity in Kanamai was attribute to the shallow lagoon hence exposing the seagrass bed thus causing desiccation stress to the seagrass species. Vipingo on the other hand has a short lagoon (~ 200 m) and was highly covered by coral reefs.

Differences in plant canopy height may help to explain productivity differences among seagrass species. Results for seagrass canopy height provide interesting insight into the relative health of the seagrass beds assessed [35]. They showed clear variation within the species and between the species at different sites, this indicates that the local ecology plays a distinct role in determining the productivity of Seagrasses species. In addition, productivity of seagrasses depends largely on the environmental factors prevailing in the surrounding areas [34]. *T. ciliatum* and *S. isoetifolium* which formed the Monospecies meadows were found distributed in the deeper tides in the lagoon and are the species that recorded the highest canopy height. These suggest their contribution to the higher productivity in Nyali and Diani (e.g [34]). Daytime tides at the study sites were substantially higher in Nyali (0.9 m) and Diani thus they recorded high canopy height and hence productivity.

Canopy height was also directly comparable among species. *C. rotundata*, *T. ciliatum* and *T. hemprich*ii shows the variation between the sites and this was attributed to its habitat in the deeper water. This study therefore concludes the same as that Meadows that were dominated by *Thalassodendron ciliatum* had the greatest productivity compared to other dominated species [36]. These can be closely linked to the higher production rates of associated fisheries [9] and thus the seagrass communities make significant contributions to the coastal productivity.

The seagrass community structure along the study sites occurs in patches. As a result there was no uniform pattern in distribution among the transects along the lagoons. This patchy distribution is either due to deterioration of a once - continuous meadow, or to an environmental limitation. Physical removal of seagrass by researchers and/or local fishermen in search of baits (as observed) may lead to substantial damage. The lower daytime tides expose the seagrass hence lower their productivity. Kanamai for example had very low tides at the day time (0.2 m). This exposed the lagoon hence influence rising in temperatures and exposure related desiccation that resulted in dieback of seagrass canopy height and a decrease in photosynthetic rate. This is caused by water temperatures that reach levels that inhibit photosynthesis and lead to tissue death [37] hence affects its structure.

This study concludes that seagrass species abundance and diversity showed spatial variation within and between the study sites. A total of eight seagrass species were identified during the field sampling effort. *T. ciliatum* was the most dominant species encountered during the survey, and dominated the percent coverage in all the study sites. Seagrass percent coverage was greater in unprotected lagoons (Kanamai) followed by community conserved areas (Vipingo and Diani) and lowest in partially protected area (Nyali). There was a notable decrease in mean canopy height from the protected sites to unprotected one. Therefore, seagrass bed as one of the important coastal ecosystems requires greater attention for its conservation, monitoring and management.

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