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The effect of fishing on the ecology of sea cucumber (Holothuroidea: Echinodermata) *Holothuria scabra and Holothuria nobilis* in Tanzanian sea water

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Abstract

Two species of sea cucumber in the selected sites were studied in 2006-2008 and compared with MPA. The work assesses abundance, density, distribution, size structure of two commercially important species (*Holothuria scabra*, and *Holothuria nobilis*) in 3 different habitats in 4 selected sites from April, 2006 to April 2008. The site selection was based on separate geographical locations Dar Es Salaam and Mafia; different levels of fishing pressure; MPA – (Kitoni), LFA (Buyuni) and IFA (Kunduchi and Magemani) but with similar types of substrata (sand, mud and rock) habitats of sea cucumbers thus providing an important and unique opportunity to envisage effects of exploitation on the sea cucumber ecology. Mean abundance, distribution and modal sizes differ among sites for both *H.scabra* and *H. nobilis* indicating the different levels of fishing distruction among sites. Significant difference in size was on Kunduchi – Buyuni ($p<0.01$), Kunduchi – Kitoni ($p<0.001$), Buyuni – Magemani ($p<0.001$) and Magemani – Kitoni ($p<0.001$,) while that of *H. nobilis* the significant difference was only between Kunduchi – Magemani ($p < 0.05$) and Kunduchi – Kitoni ($p < 0.05$). Temperature, salinity, organic matter and bio-cover correlated variably with density of *H. scabra* and *H. nobilis*. Based on these results the estimated a stock of 11109 individuals for *H. scabra* and 2841 for *H. nobilis*. The study revealed reduced modal sizes, diversity and density of sea cucumbers in the areas outside MPA and inaccessible sites as a result of overfishing and the biological constraints. Other factors e.g. processes affecting the input of planktonic larvae and physical oceanographic features can as well shape local patterns of abundance. The results envisage the need for spatial planning of fisheries management and conservation.

Keywords: Abundance, Distribution, Fishing pressure, Size structure, H. nobilis, H. scabra

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1. Introduction

Sea cucumbers (Holothuroidea) inhabit sheltered shallow water sediment in all tropical and temperate oceans, but their greatest abundance and diversity occur in the tropical Indo-Pacific region (Conand, 2004). They are distributed widely in all depth, and adapted to live in a wide variety of habitats, including rock, mud, and fronds of sea weeds (Hyman, 1955) as cited in Abdel-Razek et al., (2006). They have been fished seasonally from western Indian Ocean (FAO Area 51) (FAO, 2003). The Tanzanian coast is close to the equator and is exposed to monsoonal seasonality with varying oceanographic conditions of temperature, light and productivity (McClanahan, 1998). The Southern Equatorial Current transverses the Indian Ocean, encounter the coast at Tanzania and moves northward forming the East African Coastal Current (McClanahan, 1998). Due to these currents the major down welling area and associated low nutrient waters are along Tanzania and southern Kenya (Bell, 1972) as cited by McClanahan, (1998), the phenomena which ultimately affect physical, chemical and biological oceanographic processes and parameters.

In Tanzania *Holothuria scabra*, *Holothuria nobilis* and others have been fished for a long time to the extent of signs of depletion (Mgaya and Mmbaga, 2007). The impact of fishing in the oceans and coastal areas are a worldwide concern (Pratoni et al., 2012). As pressure on the environment from marine activities increases, marine living resources, and their habitats are being lost or damaged in ways that show diminishing biodiversity. This trend is the same in sea cucumber fishery. The detailed studies on Holothurians are necessary due to their important role in the conservation of the marine environment. There is few substantial autoecological studies concerning population of sea cucumber and other marine animals worldwide, West Indian Ocean (WIO) and Tanzania in particular with respect to habitat and level of exploitation (e.g. Uthicke and Benzie 2001; Hassan, 2005; Odhiambo, 2006; Mgaya and Mmbaga, 2007). Presently, there is a gap in knowledge of population structure, distribution and exploitation levels of sea cucumbers in Tanzania for the purpose of management plan. In this study, I investigated the populations of sea cucumbers focusing on the effects of fishing on the resources in the context of local needs and resource limitations. This was done by targeting selected habitats instead of covering all the areas in a given shore. Abundance, biomass and size structure of target sea cucumber species in Mafia Island Marine Park, adjacent intensively fished areas and other two distant areas were compared. I also collected information on catches and considered how the species may be related to habitat structure.

2. Material and methods

2.1. Research design and sampling

The study sites were chosen to represent two separate geographical locations along the coast and different levels of sea cucumber exploitation but with similar types of substrata, in order to compare the effect of level of fishing on species composition, abundance, distribution, animal size among sites. Species were identified using Desurmont (2003) identification cards, counted and collected on the intertidal by snorkeling and sometimes by SCUBA diving from April 2006 to April 2008. Fisher's information was also sought by interview at landing and processing sites to identify healthy sites due to scarcity, patchy distribution and periodical shifting of sediments and target species.

2.1.1. Ecological data

An area of $600m^2$ was sampled at each station. Specimens were counted and weighed while walking, snorkeling along 4m x 50m in one direction (Lokani et al., 1996). The transect belts located side by side parallel to the beach, were marked using two 50-m yellow measured polyethylene rope laid out on the bottom, 4 m apart and attached at either end. Sampling was done randomly in stakes which were placed at 5m intervals along the belt. Ten random points to be used in sampling were generated with respect to position in each 4m x 50m belt. Animals were identified (using Pacific Island sea cucumber and beche de mer identification cards), counted, length measured and large animals collected for laboratory work. Sea grass and seaweeds were identified and their percentages cover estimated along the belt. Sediment was also taken where sea cucumber was observed for OM and grain size analysis. Temperature and salinity of sea water were also measured.

2.1.2. Species composition

Having no enough *Holothuria nobilis* at the surveyed shallow water (0.3-4m) designated monthly sampling was widened to allow both shallow and deeper water (0.3 -10 m) samples. This is because an interview with sea cucumber fishers at Kitoni and Magemani identified some specific areas including Mange reef as most preferred habitat for *H. nobilis* and *H. scabra* while at Kunduchi the animals were more abundant in deeper water and most available ashore at Buyuni. Sampling was also aided by bought animals from people fishing in wider areas of the same sites. Survey on the density of the two species at 5 random stations with a help of two divers towards Mange reefs revealed the depth dependence for *H. nobilis* but not for *H. scabra.* Population structures were obtained from live weights of animals measured on-site using a digital balance and a pan. Sea cucumbers were divided into size classes based on maximum lengths to assess spatial distribution patterns in size frequency. The belts were surveyed once every month for 2 years. Weight and length frequency distributions then made it possible to compare population characteristics.

2.1.3. Environmental parameters in the selected sites

Environmental variables were recorded at low tide during day-time. Salinity and water temperature were measured at each site; water depth was measured only once using an echo sounder. Salinity was estimated using a hand held refractometer; water temperature was measured using a graduated thermometer. Sediments were sampled by corer triplicate sub-samples of sediment (about 20 g each) using cores from the upper layer of the bottom sediment (to a depth of 20 cm). Macro algae and sea grasses species were identified using a key and the relative percentage frequency of individual taxa and its percentage cover were determined using quadrats.

2.1.4. Organic matter in the selected sites

Sediment samples were collected (10-12cm) using a corer sampler from each site for analysis of granules and organic matter. The sediment samples were frozen until the analysis day. The sediment sub-samples were analyzed for mean grain size by sieve fraction after dried and fractioned on a mechanical shaker with sieves spanning from15 to 0.065mm. The mean grain size was analyzed according to Buchanan (1984). For the case of OM; sub-sample were dried in a 50 ˚C oven to constant weight, pre-weighed, burning in a muffle furnace at 500˚C for 6 hours and then reweighed. The OM was calculated as a percentage weight loss following combustion.

2.1.5. Abundance of H. nobilis and H. scabra in the selected sites

Estimate of absolute abundance of sea cucumber population and catch per unit effort is important in determining the effect of fishing and environmental disturbances. The abundance estimation was done by direct counting method for enumeration of specimens of epifauna (Lokani et al., 1996). At each site 3 transect belts of 4 m x 50 m in three replicated main biotopes were made. To get enough targeted sea cucumber species abundance and population structure, I limited myself to the areas considered being relatively healthy. The boat and swimmers moved along the transect belt, and anchored at regular intervals, for sea cucumbers counting. Total population was estimated for each site using the following formula: $N = (A/a) \times \sum x/n$ (King, 2007), where;

N = total population,

A = the total area occupied by a stock,

a = quadrat area,

x = number of individuals in each quadrat sumpled,

n = number of quadrats sampled

Total area of each site was calculated based on total belts area (4 x 50 m) covered by a boat on all transects of snorkeling or walking. The belts were surveyed once every month for 2 years.

2.1.6. Density of H. nobilis and H. scabra in the selected sites

The density of different sea cucumber species inside each belt was expressed as number of individuals per 100 m^2 at each biotope and type of substrate.

2.1.7. Threat intensity on habitats

Threats to sea grasses and habitat destruction were determined by counting and recording incidences of number of seine netting, trawling, shellfish collectors, anchored boat, number of people found at the habitat, and seaweed farmers as compared to the past records and literature. Important human impacts that each surveyed habitat face were identified. Fishing intensity index was estimated from the catch per unit effort /

area fished surveys for each site. Based on the type of fishing gear, number of boats and methods (SCUBA and skin diving), fishing grounds was assumed to extend from the shoreline to the 10-m depth.

2.2. Statistical analyses

The variations in *H. scabra* and *H. nobilis* densities and environmental variables were analyzed using one-way analysis of variance and the *t*-test. Prior to each analysis, test was applied to check if the assumptions of homogeneity of variances were met. *A posteriori* multiple mean comparisons were performed using Tukey's test for data that showed homogeneity of variances. When the assumptions of homogeneity of variance were not met, even after transformations (square root or log10 (*x*+0.1)), non-parametric tests (Kruskal-Wallis or Mann-Whitney *U*) were applied.

3. Results

3.1. Species composition of sea cucumbers along the coast of Tanzania

Data collected at the landing sites along the studied villages showed several species totaling up to 26 species (Figure 1.1 a).

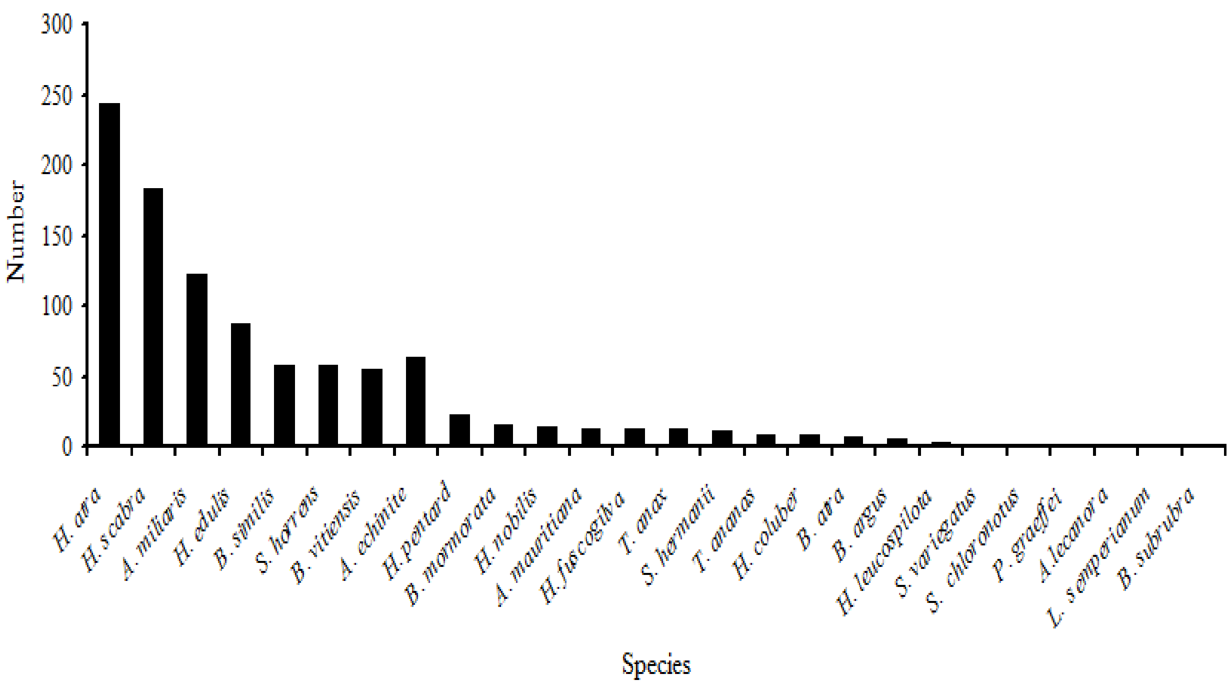

Figure 1.1 a. Species observed at landing sites in all sites during the study period

The survey on the selected substratum in shallow water (0.3-4 m) showed few species of sea cucumbers (Figure 1.1 b). At Buyuni, the average densities of animals differed from species to species depending on the type of substratum. Densities of *Holothuria atra*, (0.002 /m^2), *H. edulis* (0.02/ m^2) and *Bohadschia vitiensis* (0.001/ m^2) were higher in mud substratum followed by *Actinopyga mauritiana* (0.002 / m^2) in rocky and *H. scabra* (0.03/m^2) in the sandy habitats.

At Kunduchi, *Actinopyga milliaris* was more abundant in rocky substratum (0.015/m^2) followed by sandy substratum (0.01/m^2). *Holothuria atra* was at a higher density (0.01/m^2) at the sandy substrata followed by muddy substrate (0.005/m^2) while *Stichopus hermanii* occurred in higher density in rocky substrata.

At Magemani, higher density of 0.05/m^2 was observed for *Bohadschia simillis* in muddy substratum followed by *Holothuria scabra* (0.03/m^2) in sandy, *Stichopus horrens* (0.02/m^2) in rocky areas and *Bohadschia vitiensis* was (0.01/m^2) in the muddy substratum. At Kitoni, the average density of *A. milliaris* was higher in rocky areas (0.03/m^2) followed by *H. fuscogilva* (0.015/m^2), *H. nobilis* (0.01/m^2) and *S. hermanii* (0.005/m^2).

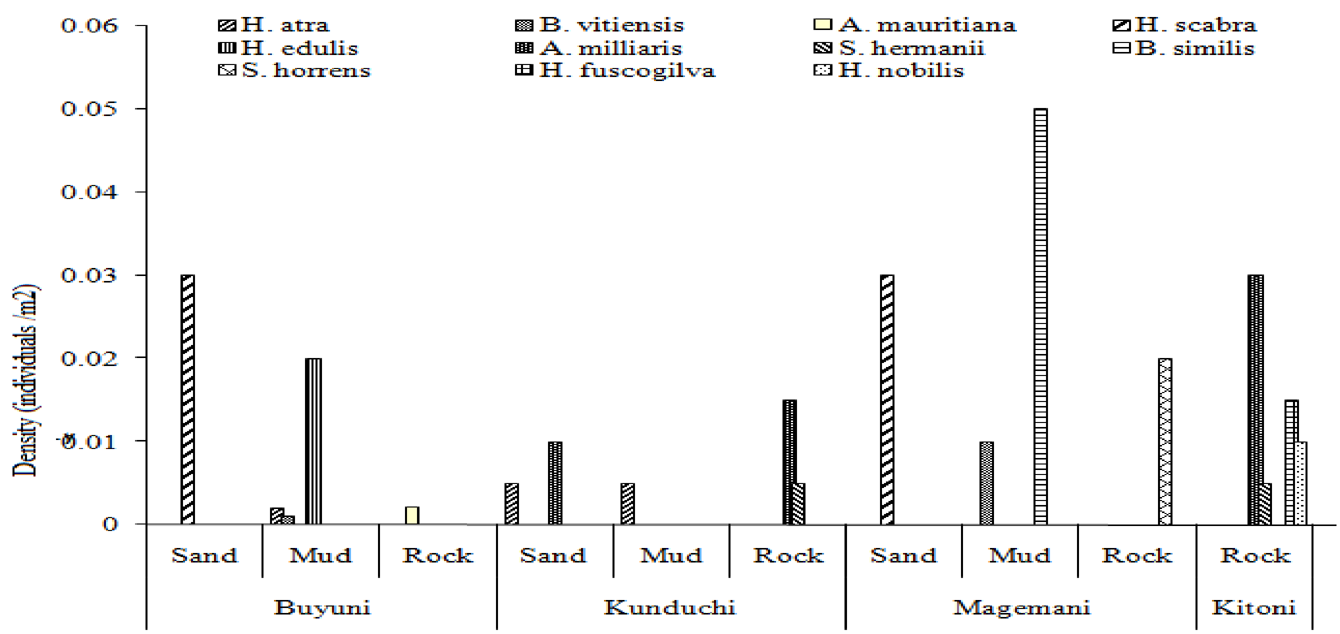

Figure 1.1 b. Species distribution and their density in shallow water 0.3-4m

The survey in deeper water (4-7m) showed more species (by number) and by biomass, but which decreased from the marine park to the more exploited and shallow waters (16/100 m^2 species at Kitoni, 14/100 m^2 at Magemani, 10/100 m^2 at Buyuni and 12/100 m^2 at Kunduchi). *H. nobilis* was more abundant near Mange reef from depth of 6 to12m (Figure 1.2 a) while *H. scabra* was more abundant near the reefs in shallow water (Figure 1.2 b).

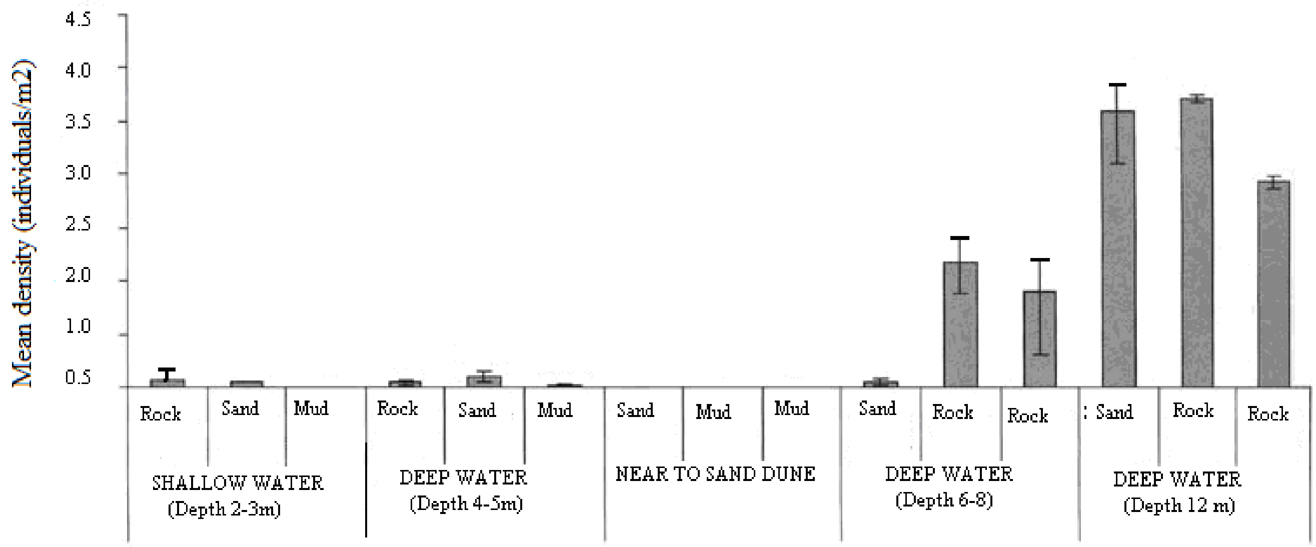

Figure 1.2 a. Distribution of *H. nobilis* and their mean densities (± SE) towards Mange reef from Kitoni in MIMP

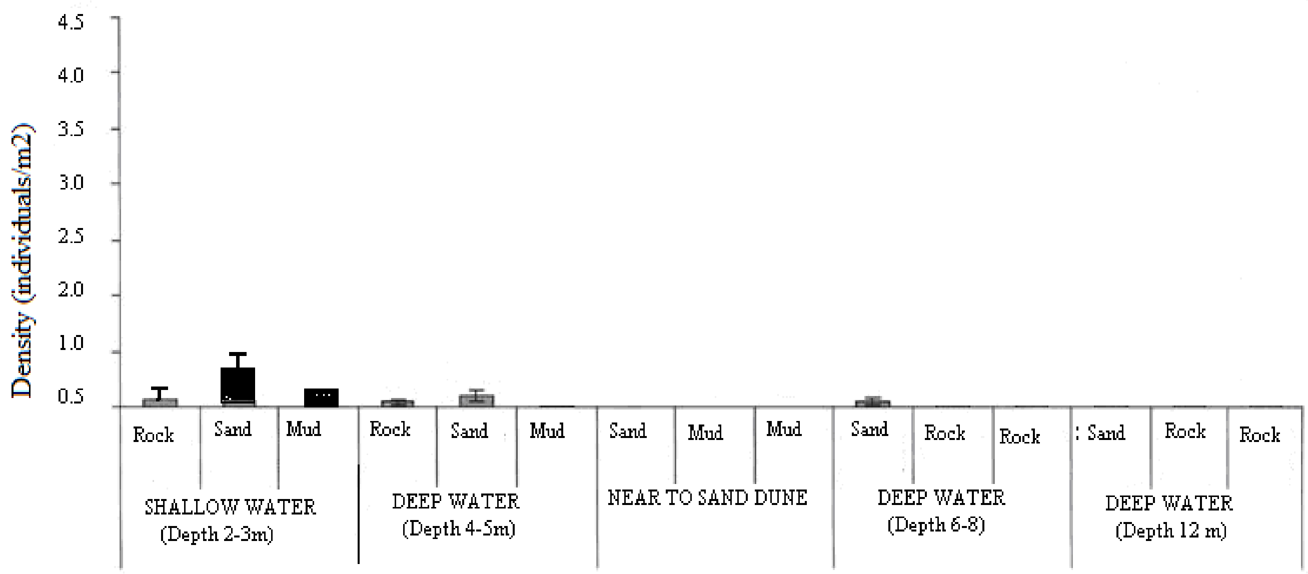

Figure 1.2 b. Distribution of *H. scabra* and their mean densities (± SE) towards Mange reef from Kitoni in MIMP

3.2. Environmental parameters in the selected sites

The mean, minimum and maximum temperature at Kunduchi, Buyuni, Magemani and Kitoni were not much different except for the area identified with juveniles at Buyuni (hotspot) where slightly lower temperatures (mean 28.56°C, median 28.0°C, minimum 23.0°C, and 34.0°C maximum) by comparison were recorded.

Statistically there was a significant difference in water temperature (KW= 41.573; P<0.0001) when including the site of Buyuni with juveniles (Buyuni j or Bj) and when the site of Buyuni with juveniles was excluded (KW = 12.531; P = 0.0058), "Post-hoc" multiple comparison tests conducted in order to identify which pairs of samples are significantly different are shown (Table 1.2 a - 1.2c).

Table 1.2 a. Temperature variations among sites (ANOVA and Dunn's multiple comparisons)

Sites	Kunduchi	Buyuni	Magemani	Kitoni	Buyuni j					
Mean	32.2±2.4	31.7±1.6	32.3±2.3	32.2±0.7	28.5±3.8					
Comparison	Kn vs By	Kn vs Mg	Kn vs Kt	Kn vs Bj	By vs Mg	By vs Kt	By vs Bj	Mg vs Kt	Mg vs Bj	Kt vs Bj
P	> 0.05	> 0.05	> 0.05	< 0.001	> 0.05	> 0.05	< 0.001	> 0.05	< 0.001	< 0.001
Significance				***			***		***	**

** Significant difference; ** very significant difference; *** highly significant difference*

Table 1.2 b. Multiple comparisons on salinity variations and (SD)

Sites	Kunduchi	Buyuni	Magemani	Kitoni	Buyuni j					
Mean	34.2(±8.4)	33.9(±5.6)	34.7(±5.3)	34.6(±8.7)	28.5(±3.6)					
Comparison	Kn vs By	Kn vs Mg	Kn vs Kt	Kn vs Bj	By vs Mg	By vs Kt	By vs Bj	Mg vs Kt	Mg vs Bj	Kt vs Bj
P	> 0.05	< 0.001	> 0.05	< 0.001	< 0.01	> 0.05	< 0.001	> 0.05	< 0.001	< 0.001
Significance		**		**	**		**		**	**

** Significant difference; ** very significant difference*

Table 1.2 c. Multiple comparisons on salinity in substrata of the study sites

Sites	Sand (S)		Mud (M)		Rock (R)		ns /s		
	Mean	SD	Mean	SD	Mean	SD	S vs M	S vs R	M vs R
Kunduchi	34.6	9.3	34.2	8.4	34.4	11.7	ns	ns	ns
Buyuni	34.9	6.5	33.9	5.6	35.7	10.5	ns	*	**
Magemani	34.4	5.5	34.7	5.3	34.5	5.2	ns	ns	ns
Kitoni	34.7	7.7	34.6	8.7	32.9	6.3	ns	*	ns
Buyuni (j)	N/A		32.3	3.6	N/A	N/A	N/A	N/A	N/A

** = p < 0.05; ** = p < 0.001; ns = not significant (p > 0.05).*

Table 1.3. Habitat characteristics of the Sand (S), Mud (M) and Rock (R) substrata within each site (Data are mean values)

Variable	Kunduchi			Buyuni			Magemani			Kitoni			Buyuni j		
	S	M	R	S	M	R	S	M	R	S	M	R	S	M	R
Water depth (m)	2.5	4	1	2	2	3	3	1.5	3	2	1.5	0.8	1	0.6	0.4
Sea grass cover (%)	26	5	2	27	25	40	12	80	40	60	55	60	45	50	50
Macroalgae cover (%)	5	5	2	12	45	5	5	58	60	30	40	35	15	2	5

Dominant species of sea grasses at Buyuni, Magemani and Kitoni were *Syringodium isoetifolium* (15%-50%), *Cymodocea rotundata* (25% -30%) while for sea weeds the dominant species were *Sargassum cristaefolium* (20%-50%) and *Glacilaria salicornia* (25%-50%) respectively. The dominant sea grasses and seaweeds at Kunduchi are *Syringodium isoetifolium* (10%) and *Glacilaria salicornia* (30%) respectively.

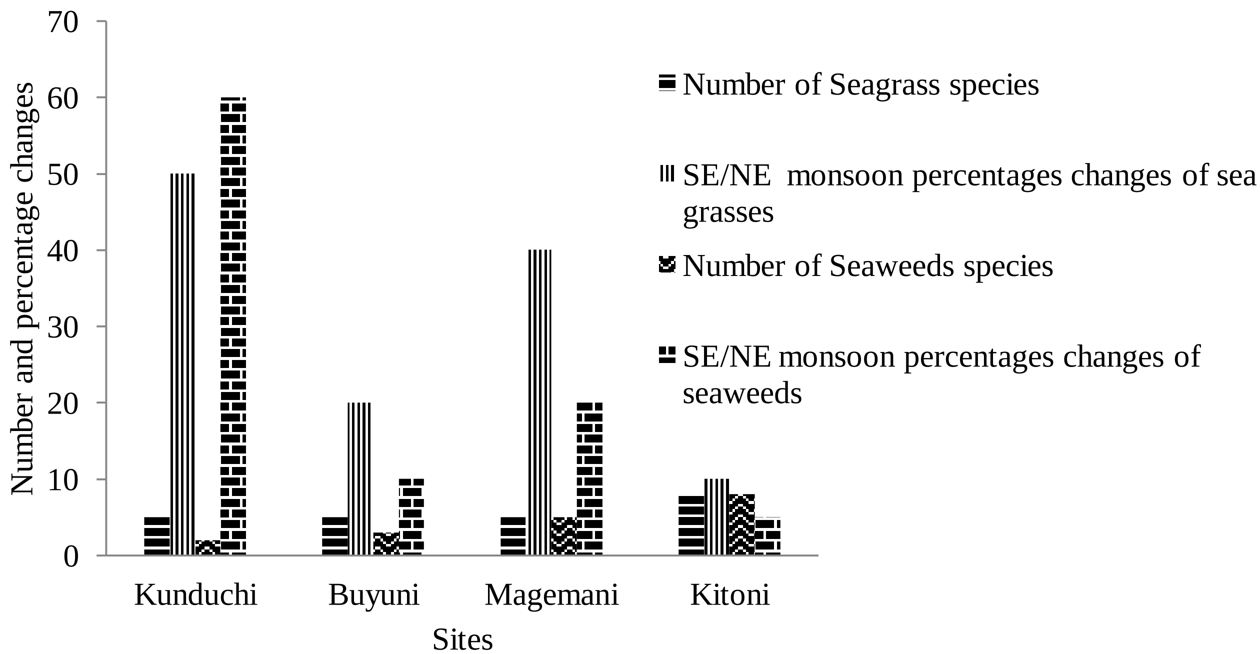

Figure 1.3. Species of sea grasses and sea weeds and mean percentage changes in SE and NE monsoon in the study sites

The bio-cover percentage at Buyuni site of juveniles' was higher and relatively constant throughout the study with minor changes (Figure 1.4).

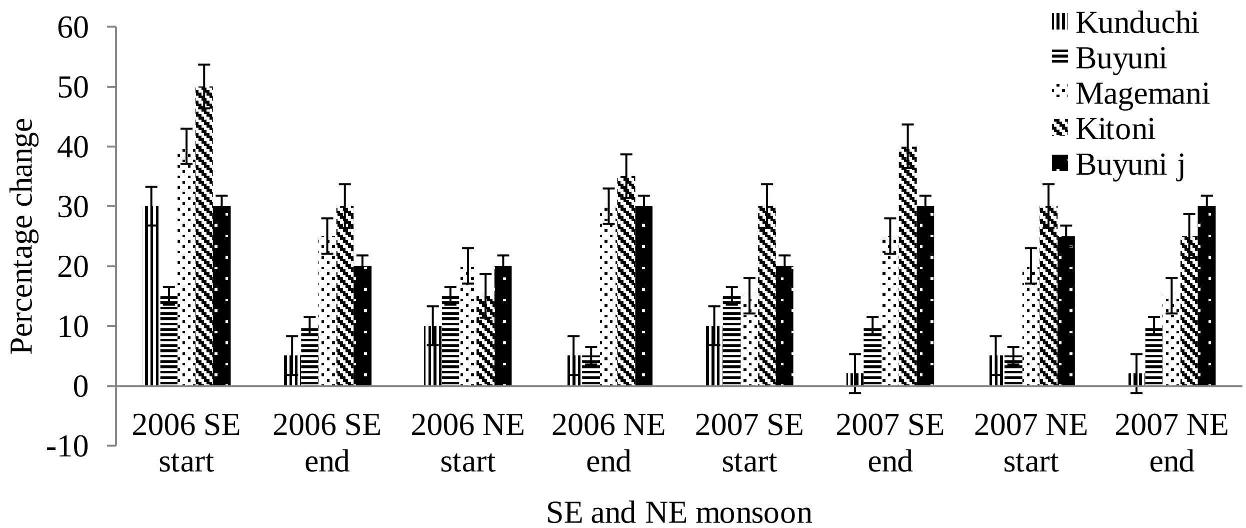

Figure 1.4. Seasonal bio-cover mean percentage changes in NE and SE monsoon among the study sites

Significant differences of bio-cover were found among substrata within sites ($F_{16, 48} = 3.29$, $p < 0.001$).

3.3. Organic matter

Temporal variations of organic matter in the study sites substrata (Sandy, Muddy and Rocky) (mean ± SE) are shown (Figure 1.5 a – 1.6 d) and the ANOVA results (Table 1.4 a- 1.4 e):

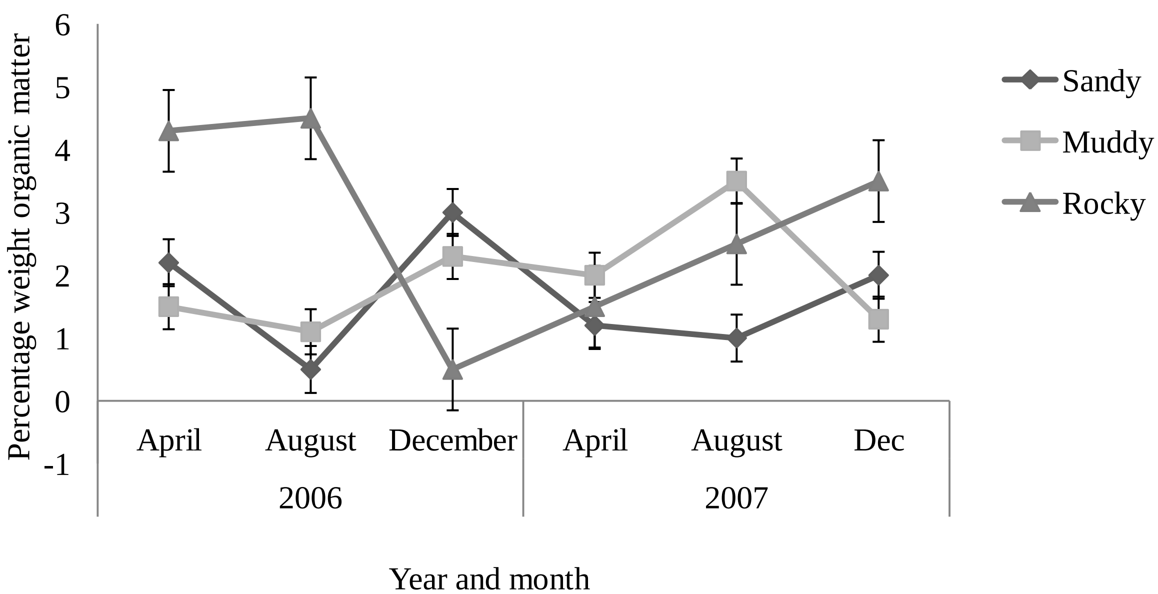

Figure 1.5 a. Seasonality in organic matter at Kunduchi substrata (Un-protected site)

Table 1.4 a. ANOVA Results for substrata at Kunduchi

Source of Variation	*Sum of square*	*df*	*Mean square*	*F-ratio*	*P-value*
Between substrata	15.78111	2	7.890556	19.4615	6.8E-05
Within substrata	6.081667	15	0.405444		
Total	21.86278	17			

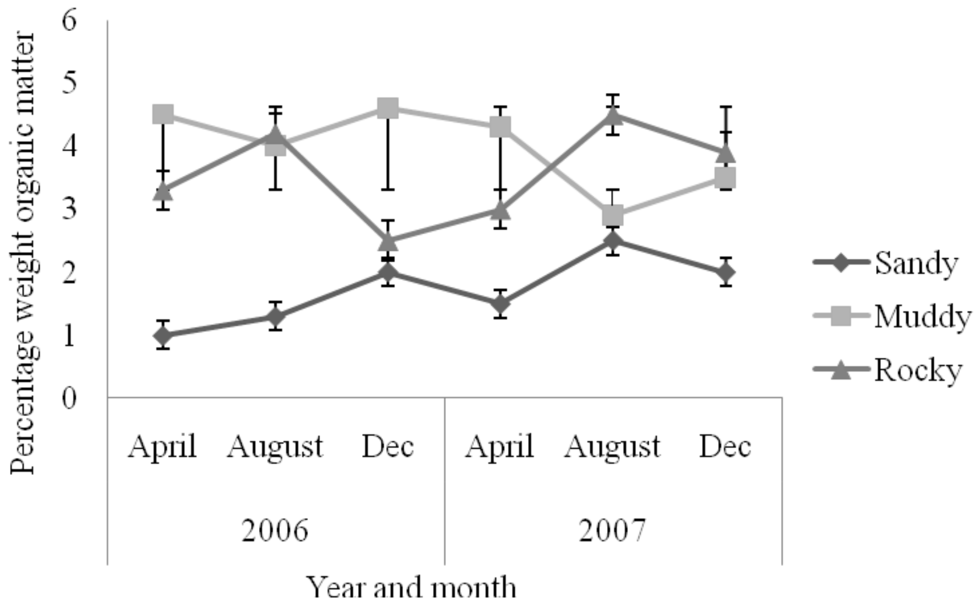

Figure 1.5 b. Seasonality in organic matter at Buyuni substrata (lowly disturbed site)

Table 1.4 b. ANOVA Results for substrata at Buyuni

Source of Variation	*Sum of square*	*df*	*Mean square*	*F-ratio*	*P-value*
Between substrata	15.78111	2	7.890556	19.4615	6.8E-05
Within substrata	6.081667	15	0.405444		
Total	21.86278	17			

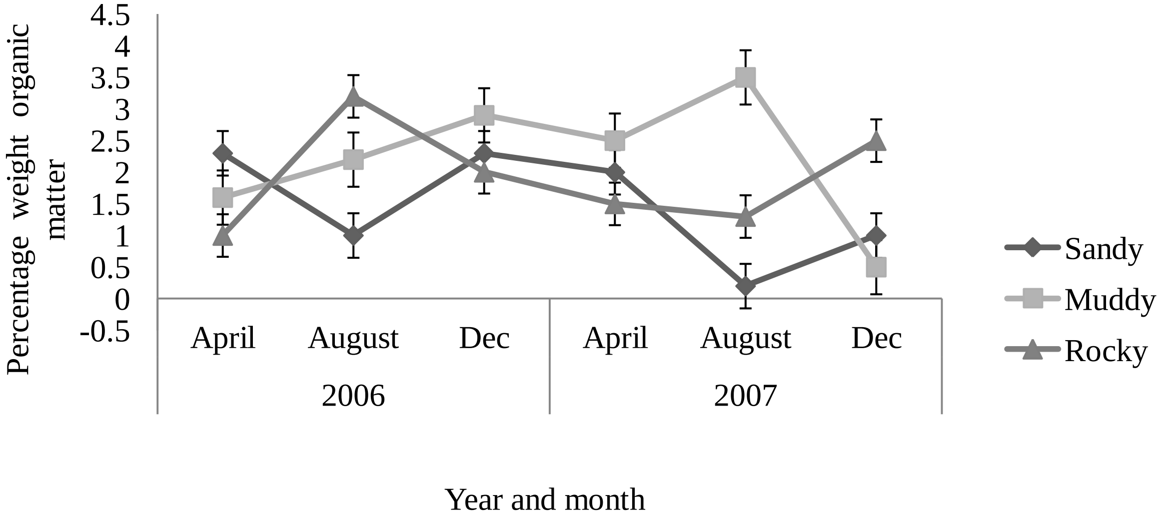

Figure 1.5 c. Seasonality in organic matter at Magemani substrata (lowly disturbed site)

Table 1.4 c. ANOVA results for substrata at Magemani

Source of Variation	*Sum of square*	*df*	*Mean square*	*F-ratio*	*P-value*
Between substrata	2.614444	2	1.307222	16.75926	0.00015
Within substrata	1.17	15	0.078		
Total	3.784444	17			

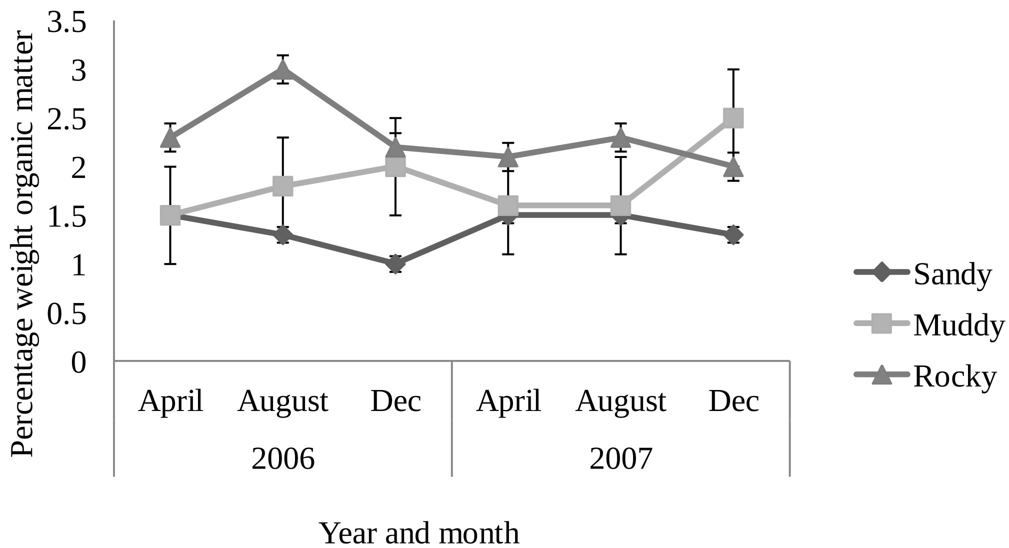

Figure 1.5 d. Seasonality in organic matter at Kitoni (Protected site)

Table 1.4 d. ANOVA Results for substrata at Kitoni

Treatment/ source of variation	*Sum of square*	*df*	*Mean square*	*F-ratio*	*P-value*
Between substrata	1.747778	2	0.873889	1.012748	0.386755
Within substrata	12.94333	15	0.862889		
Total	14.69111	17			

Immediate changes in OM % was much more observed at Kunduchi followed by Magemani and less at Buyuni and Kitoni.

Table 1.4 e. The ANOVA results for the different overall substrata in all sites

Treatment / source of Variation	*Sum of square*	*df*	*Mean Square*	*F-ratio*	*P-value*
Months	0.687361	5	0.137472	0.189525	0.965349
Sites and Substrata	42.15486	11	3.83226	5.283318	1.25E-05
Error	39.89431	55	0.725351		
Total	82.73653	71			

The results of ANOVA showed that there is no significant variation of OM season wise at Kunduchi (P=0.2139) and at Kitoni (P=0.3867). Significant variation was revealed at Buyuni (P=0.000068) and Magemani (P=0.00015).

3.4. Abundance, biomass and size structure of H. *nobilis* and H. *scabra*

The estimation of abundance (Table 1.5) is important in determining the effects of fishing and environmental disturbances as well as in estimating mortality. This is important for management authorities, investors and fishers to make some judgments on the level of fishing that should be encouraged or permitted within the fishery. Buyuni has higher absolute abundance of *H. scabra* than other sites while Kitoni (in MPA) has higher absolute abundance of *H. nobilis* than other sites.

Table 1.5. Absolute abundance of *H. scabra* and *H. nobilis* at study sites

Site	Kunduchi		Buyuni		Magemani		Kitoni	
Species	*H.scabra*	*H.nobis*	*H.scabra*	*H.nobilis*	*H.scabra*	*H.nobilis*	*H.scabra*	*H.nobilis*
Abundance	767	234.3	7567.7	767.7	1867.7	367.7	500	1133.3

The collection by biomass of *H. scabra* and *H. nobilis* was generally higher during July-December (2006) and lower during February-July (2007) and higher again during August to December (2007) (Figure 1.6). However the biomass of *H. scabra* at Kunduchi was lower compared to that at Buyuni.

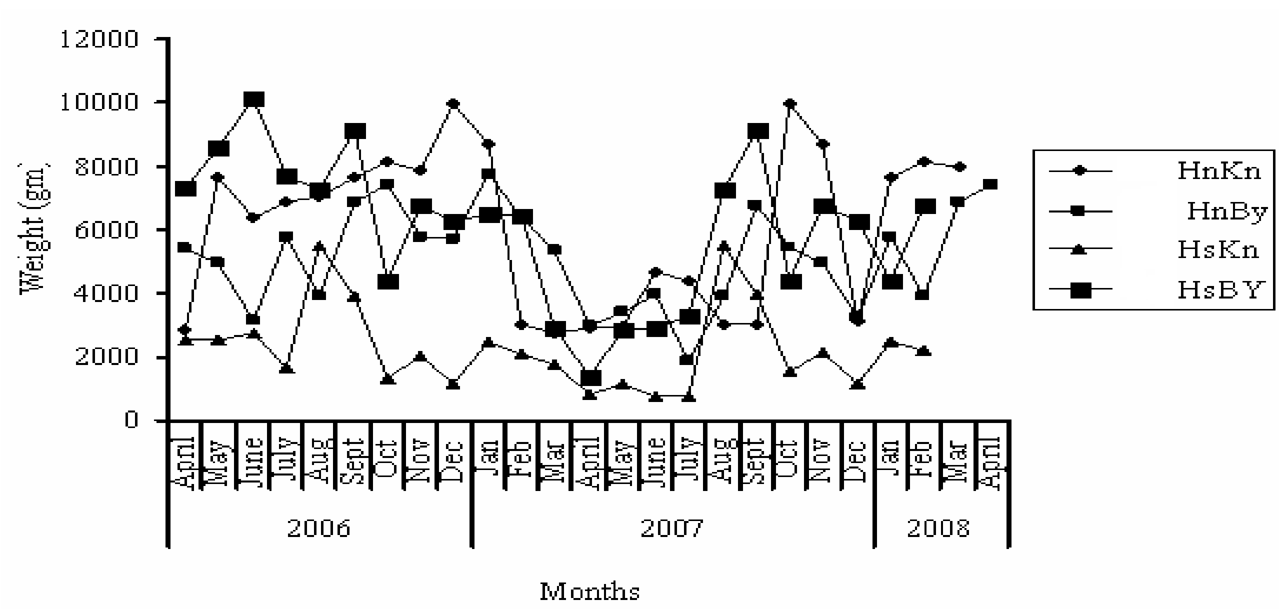

Figure 1.6. Monthly biomass (wet weight) collections for *H. scabra* and *H. nobilis* at Kunduchi and Buyuni

(Key: HnKn = *Holothuria nobilis* at Kunduchi, HnBy = *Holothuria nobilis* at Buyuni, HsKn = *Holothuria scabra* at Kunduchi and HsBy = *Holothuria scabra* at Buyuni)

Table 1.6. Degutted weight (g) comparison for *H. nobilis* and *H. scabra* as recorded at the landing sites

Sites	Buyuni		Kunduchi		Magemani		Kitoni	
Species	*H.nobilis*	*H.scabra*	*H.nobilis*	*H.scabra*	*H.nobilis*	*H.scabra*	*H.nobilis*	*H.scabra*
Mean	544.44	444.77	636.84	188.06	468	146.56	529.5	541
SD	158.28	113.85	150.28	187.4	166.01	95.517	142.3	132.39
SEM	31.139	22.77	29.472	37.479	32.558	19.103	28.08	26.479
Median	563.5	420	669	99.2	503.85	114	523	526
Mini	182	260.5	215	69.4	67	48	232	298
Max	765.5	694	911	669	678.5	412	811	811

The trend in the mean degutted weight for *H. nobilis* was in the order; Kunduchi > Buyuni > Kitoni > Magemani, in maximum value the trend was Kunduchi > Kitoni > Buyuni > Magemani but the significant difference was only between; Kunduchi – Magemani ($p < 0.05$) and Kunduchi – Kitoni ($p < 0.05$). The mean and maximum value of degutted weight trend for *H. scabra* was in the order of Kitoni > Buyuni > Kunduchi >

Magemani. The significant difference was on Kunduchi – Buyuni (p<0.01), Kunduchi – Kitoni (p<0.001), Buyuni – Magemani (p<0.001) and Magemani – Kitoni (p<0.001).

Buyuni site had a higher population of *H. nobilis* that is clearly bimodal while that of Kinduchi had one small and one prominent mode and for Kitoni had one prominent mode followed by low mode at 1601 – 1800g (Figure 1.7 a).

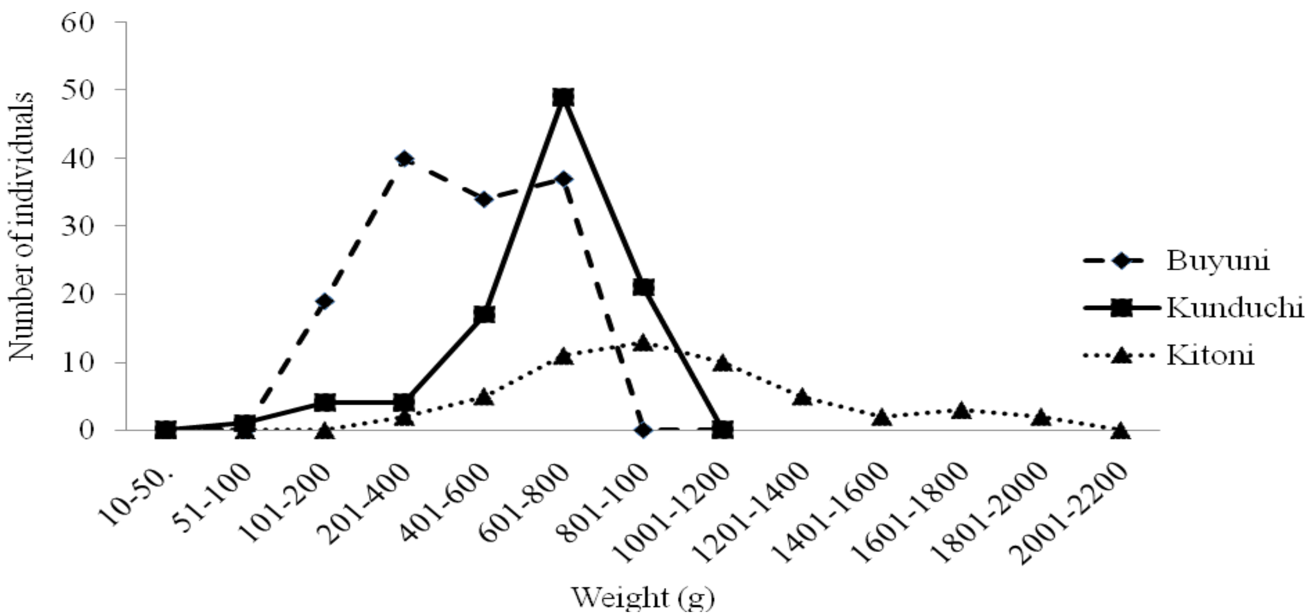

Figure 1.7 a. Population structure of *Holothuria nobilis* at Buyuni, Kunduchi and Kitoni

In the case of *H. scabra* Buyuni has higher abundance with clear multiple cohorts and bimodal while that of Kunduchi have one large mode followed by small mode. Magemani had two small modes while Kitoni have unimodal population of *H. scabra* (Figure 1.7 .b).

3.4.1. Density of H. nobilis and H. scabra in the selected sites

There was spatial variation in *H. scabra* densities within all four sites. In Kunduchi, Magemani and Kitoni, the highest mean densities were at sand substrata, whereas at Buyuni highest densities were observed at mud substrata. Densities of *H. nobilis* was significantly higher in rock sites in both Kunduchi and Kitoni than in Sand (Kunduchi: $p < 0.01$; Kitoni: $p < 0.05$) and sand sites ($p < 0.01$) respectively. Within each site, *H. scabra* and *H. nobilis* density differed significantly between substrata. Shallow water rocky substrata had a higher mean density of *H. scabra* (0.03 ± 1.2) at Magemani compared to other substrata (0) (Mann-Whitney *U*-test; $p < 0.05$), whereas for *H.nobilis*, the mean density was higher in rocky substrata (0.01 ± 0.3) than other substrata (0.0). When all depths were considered (shallow and deep water) there were higher densities of *H.*

scabra (4.3 /m^2) and *H. nobilis* (4.7/m^2) in Magemani compared to other sites, i.e. Buyuni (3.3 / m^2, and 0.05/ m^2), Kunduchi (0.5/ m^2 m and 4.6/ m^2) and Kitoni (3.9/ m^2 m and 4.6 / m^2) respectively.

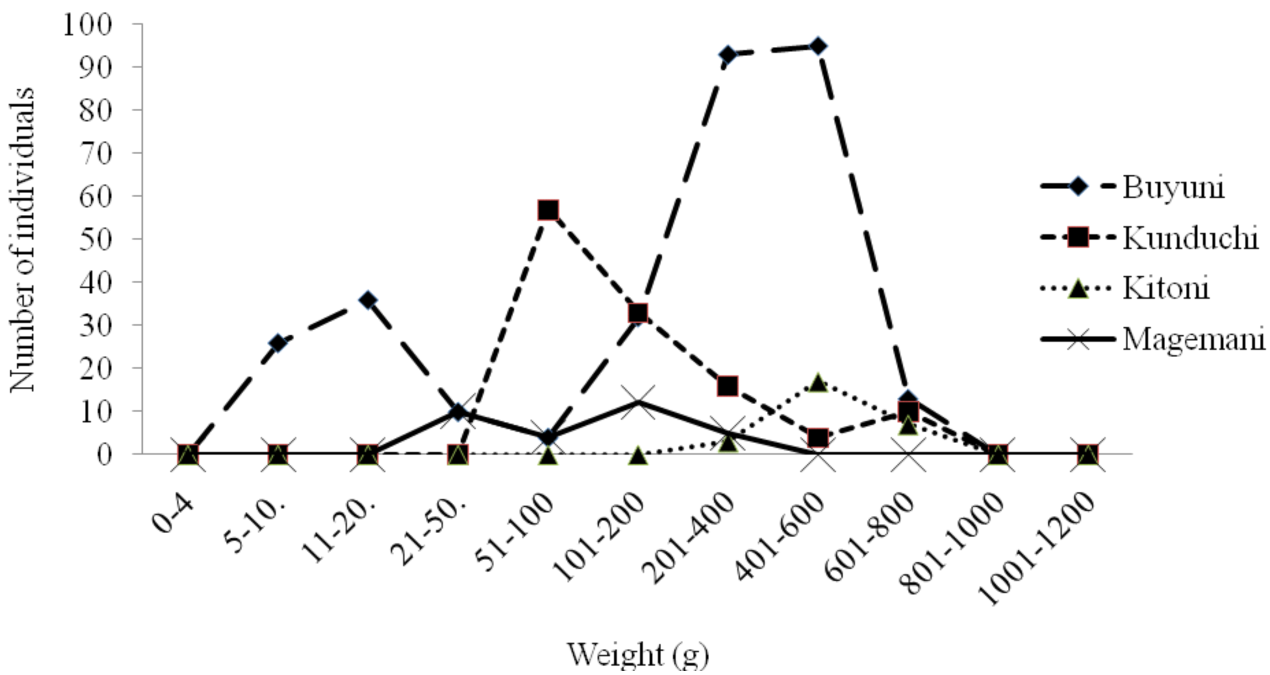

Figure 1.7 b. Population structure of *H. scabra* at Buyuni, Kunduchi, Kitoni and Magemani

Seasonal patterns in *H. scabra* and *H. nobilis* density were generally obscured by the high monthly variability within each season. However, there was significantly higher density during the rainy season in muddy (t-test; df = 18, $p < 0.05$) and sandy sites (*t*-test; df = 18, $p < 0.001$) at Buyuni.

Table 1.7. Pearson correlation index between density and salinity, temperature, organic matter and bio-cover in the study sites

Environmental factors	Species	Correlation r			
		Buyuni	Kunduchi	Kitoni	Magemani
Salinity	*Holothuria scabra*	0.066	0.05	0.12	0.11
	Holothuria nobilis	-0.176	0.01	0.001	0.21
Temperature	*Holothuria scabra*	0.211	0.03	0.001	0.05
	Holothuria nobilis	-0.183	-0.1	-0.01	0.12
Organic matter	*Holothuria scabra*	0.103	0.12	0.11	0.001
	Holothuria nobilis	-0.401	0.001	0.05	0.002
Biocover	*Holothuria scabra*	0.125	0.01	0.02	0.013
	Holothuria nobilis	0.006	0.05	0.04	0.01

3.5. Threats intensity on sea cucumber and habitats of selected sites

The level of habitat and resources destruction was indicated by the number of people operating their activities with vessels and methods (Table 1.8) of doing their activities. Threats magnitude (number of fishing vessels, fishers, and destructive fishing techniques) was higher at Kunduchi compared to other sites while in the case of fishing intensity and CPUE, Magemani scored higher value compared to other sites. SCUBA diving to collect sea cucumber was observed at Kunduchi only.

Table 1.8. Fishing activities and intensity indicators

	Kunduchi	Buyuni	Magemani	Kitoni
Number of fishing vessels	40	10	18	2
Number of fishers	20	4	12	6
Fishing area	Deep water	Shallow	Shallow & Deep	Deep &specific
Fishing methods	SCUBA & Hand	Snorkeling & hand	Skin diving & Hand	Skin diving & hand
CPUE(g/diver/hour)	0.5	0.4	0.6	0.3
Fishing intensity (Fishers/m^2)	3.54	2.55	8.67	0.82

4. Discussion

4.1. Species composition

The surveys registered few species in shallow water as compared to deep water and more in thorough sampling (11 species were recorded in shallow water survey and 24 species with inclusion of deep water with thorough sampling including searching). Low species recorded at Kunduchi can be linked with negative effects of beach seine. Other areas in Indian Ocean e.g. Madagascar have much higher species composition e.g. Cherbonnier (1988) described 122 species, and Conand (1998) listed 28 exploited species (i.e. only those which are both large in size and whose populations are dense and readily accessible). Richmond, (2002) presented 26 species in East African coasts and islands. In New Caledonia, Conand (1989) recorded some 49 aspidochirote sea cucumber species and Guille et al. (1986) described 54 species of various orders in Papua New Guinea. The difference in species composition can be linked to fishing intensity at shallow water as reported elsewhere e.g. Hassan (2004) at Abu Rhamada Island, and Khalfan et al. (2007) in Mahout Bay. Species composition can also be linked with the nature of bottom sediments, degree of tolerance during exposure at low tide time, benthic communities' distribution (e.g. algae cover and coral reefs), food availability and perhaps the degree of pollution (Abdel-Razek et al., 2006). In some cases substratum can support some sea grasses, seaweeds, and sea cucumber species compared to another, due to sediment stability e.g. at Kitoni and some parts of Buyuni whereas at the more loose habitats like in Kunduchi and in Magemani had varied species composition due to intermediate levels of sediment shifting. Although Kitoni is in MPA, it might not necessarily be the best for some commercial sea cucumbers as compared to Buyuni which is protected by being remote but has mixed substrata which favors most species of sea cucumbers. In this study it was not abnormal for example to find different sea cucumber species sharing a habitat for quite long in one site or substrata at Buyuni even during different seasons (SE and NE) as compared to Kitoni. Another factor affecting species composition of echinoderms is surface area (MacArthur and Wilson, 1967). This has also been observed for fish (Galzin et al., 1994). MPA can be one factor for species assemblage but other associated factors like physical, biological and chemical environmental conditions may contribute to more or less species composition. The least species composition noted at Magemani and Kunduchi perhaps is due to habitat degradation because most microhabitats have been destroyed by fishing and other human activities (like beach seining, coral mining and cutting of mangroves). Gutt (2006) adhere the dynamic environment to low species composition pointing that species are eliminated by intense disturbance and, as a consequence, only few survivors or pioneers shape the assemblage. Bottom trawling has been proven to cause mortality of invertebrates, reducing their overall biomass and lower organic matter as well as reducing number of taxa (Prantoni et al., 2012). Complexity of benthic substratum is positively correlated with species composition, density and abundance of holothurians as observed at Buyuni. In some areas there is niche differentiation as a result of seasonal segregation of species by life-history differentiation and spatial segregation of species caused by the physiological responses to temperature and salinity.

Buyuni was identified to have unique habitat favoring *H. scabra* as it was the only site with multiple cohorts, habitats, substrata and environmental parameters favoring all stages of sea cucumber from spawning, pelagic larvae and settlement, development and growth of juveniles. Although no method was used to characterize the habitat, field observation reveals the unique arrangement of rock on the south (which calm down the incoming energetic water during high tides), a large tidal pool with dense sea grasses and sea weeds (*Thalassia hemrichii, Enhalus acoroides*, *Cymodocea* sp., *Thalassodendron ciliatum*) which allow for settlement of larvae. Tidal pool close to mangroves cool down the water to 28^0 C hence favoring which then disperse as they grow to the mixed substratum characteristics of the Buyuni shore. Relatively sedentary life of holothurians reflects the local conditions of a habitat better than organisms with high dispersal capacity such as fish.

4.2. Effects of habitats and environmental parameters on species composition

There were significant differences between abundances, bio-mass and density among sites and substrata but not in temperature, salinity and organic matter among sites except when a special identified site with juvenile hotspot in Buyuni. There was more temporal fluctuation of sea grass, seaweeds and organic matter in Kunduchi and Magemani compared to Buyuni and Kitoni. The influxes of organic matter from the surface productivity to the seafloor exert considerable control on benthic standing stocks (Soltwedel, 2000). The energy content of sediment organic matter generally decreases with water depth because of degradation process within the water column (Soltwedel, 2000). In the present study there were different levels of fluctuations in amount of organic matter with time and substrata among study sites which can be associated with the level of habitat degradation. Frequent and easiness of shifting of OM in Kunduchi was due to lack of stable substrate given destroyed sea grasses and sea weeds by human compared to other sites. Other factors which may affect quantity and localization of OM can be the sea grass abundance, monsoon, and looseness of the main component on the substrata and shape of the shore. Disturbed sites like Kunduchi and Magemani generally showed lowest bio-cover especially in sand and mud hence great and sharp variations of OM quantity within substrata as a result of water movement.

However there are some factors which dominate over other factors and are likely to influence the animals' way of survival e.g. temperature which correlated with number of animals collected. According to Dar and Ahmad (2006) during the spawning period (early summer to autumn), some sea cucumber species (e.g. *Holothuria atra* and *Bohadschia vitiensis)* tend to assimilate fine sediments more than coarse sediments, perhaps due to their increasing need for organic matter. Probably such phenomena made other researchers' (e.g. Conand and Chardy, 1985; Conand, 1990) to associate difference in density to larval sources larval source, supply and delivery (supply side ecology) and the complex tidal hydrological system (Barkai, 1991) and Zhou and Shirley, (1996) experienced in different shores. *H. nobilis* in particular are usually found in deep water reef passes that have oceanic influence, therefore factors like suitable depth (Preston and Lokani 1990; Lokani et al*.,* 1996), small number of natural enemies (Hassan, 2003; 2005) may favor the existence of *H. nobilis* than *H. scabra*.

Variations in tentacle morphology (peltate or branched digitate), particle types and size of food, level and strength of protein-based mucus secreted from tentacles, conditions in different depth (pressure, temperature) related to metabolic rates may favor the survival of some species selectively (Roberts et al., 2000; Roberts and Moore, 1997; Khripounoff and Sibuet, 1980; Hudson et al. 2004). If deep sea animals are brought to shallow water the effects of temperature and change in pressure may change metabolic rates ultimately resulting to death of animal (Hudson et al., 2004). Other factors explained by researchers include the availability of food, suitable substrata (Mercier et al., 1999), and high variety of niches (Clark and Rowe, 1971). My results suggest the importance of stable substrate to localized sea cucumber abundance. Long term monitoring research is required to study the effect of exogenous environmental factors on the seasonal sea cucumbers population patterns regardless its expense in sampling costs.

4.2.1. OM, Salinity and Temperature and Densities of H. scabra and H. nobilis

Density of *H. scabra* was higher in the area adjacent to MPA Magemani 4.3 ind/m^2 followed by MPA 3.9, Buyuni 3.3 ind/m^2 and intensive long fished areas Kunduchi 0.5 ind/m^2. In terms of substrate shallow water rocky substrata had a higher mean density of *H. scabra* (0.03 ± 1.2) whereas for *H.nobilis*, the mean density was higher in rock substrata (0.01 ± 0.3). When depth is considered (shallow and deep water) there were higher densities of *H. scabra* and *H. nobilis* in Magemani compared to other studied sites Buyuni, Kunduchi and Kitoni. The density of *H. scabra* recorded in Tanzania is similar to the reduced densities measured in other places: e.g. in Indonesia *H. scabra* density ranged from 0.0025 to 0.39 individuals m^{-2} (Mangawe and Daud, 1988) and in Papua New Guinea it was 0.01 to 0.02 individuals m^{-2} (Lokani et al*.,* 1996). The comparable trend was observed by Hassan (2005) as a result of exploitation pressure (73.2-60.1 ind./100 m^2) at the sandy habitat. *H. nobilis* showed much higher densities in Papua New Guinea in 1981 (0.29 to 0.37 individuals m^{-2}) (Shelley, 1981). Sea cucumbers are broadcast spawners and need a threshold population density for fertilization success. The highest and lowest recorded density of *H. scabra* at Sultanate of Oman was 4000 ind./ha in Ras-Knasah and 1770 /ha in Al Eigah respectively (Khalfan et al., 2007) , > 600 individuals per meter (Preston, 1993) and the lowest was 0.0 (Kinch, 2002) while for *H. nobilis* was > 13 and 0.18 individuals per meter respectively. Observations showed that overexploited sea cucumber populations may take several decades to recover (Battaglene and Bell, 2004).

The correlation of OM with density of *H. scabra* was positively significant (r = 0.103) but negative (r =-0.401) with *H. nobilis*. There was low correlation between habitat type and abundances of both *H.scabra* and *H. nobilis* (Pearson's r = 0.41 – 0.43). Observation showed that *H. scabra* are selective for sediment types hence influx and shift of OM observed in this study reflect what was recorded by Mercier et al. (2000) i.e. in equally distributed organic matter no movements of *H. scabra* to search for food; this might be the case of *H. nobilis* at its depth. Bulteel et al. (1992) postulated that factors such as water movement and food availability could affect the distribution of species. Bulteel et al. (1992) and Mercier et al. (2000) found that small individuals up to 150 mm favored sea grass beds (probably because OM does not shift to other places quickly compared to areas with sporadic and scattered sea grass beds) and larger animals were found close to sea grass beds due to increased ability to access food. This might affect spatial distribution of larvae, juveniles and adult sea cucumber species feeding on organic matter. Some researchers have established a relation between the organic enrichment level of the sites as a result of tides and holothurian densities (Conand and Mangion, 2002) and Conand and Frouin, (2007).

In the case of temperature and salinity; the density of *H. scabra* was positively correlated (Pearson's correlation coefficient) with temperature and salinity (r = 0.211, and 0.066) while *H. nobilis* showed low and negative correlation. This might be due to patchiness and difference in feeding behavior. Generally different species and ages do not behave in the same way in different places. Far from being holothurians, the sea exhibits variability in illumination, temperature, depth, species food and predators which according to King (2007), may vary daily and seasonally as well as spatially. In view of this diversity, it is unlikely that one habitat will be suitable for all species or all stages of a sea cucumber species lifecycle. *H. nobilis* was always seen scrubbing surfaces (biofilms) of rubles and not the sediments.

Work using a DNA fingerprinting technique shows that black teatfish (*H. nobilis*) migrated 90 m between study sites during one year (Uthicke et al*.,* 2004) while field measurements of various sized animals and subsequent modeling suggest that sandfish (*H. scabra*) will mostly remain within a few hundred meters of their settlement locations over a 10–year time span (Purcell and Kirby, 2006).

Therefore although there was some significant correlation between *H. scabra* and *H. nobilis* density and salinity, temperature and organic matter, presence of bio-cover seem to affect rate of movement of sediment grains hence holothurians juveniles, adult sea cucumbers as well as larvae. In Kunduchi beach seining have probably removed many epifauna organisms causing mortality of invertebrate species related to holothurians and reduced their abundance. Other sites do not experience beach seining due to overlap or mixed substrata e.g. sand-mud with rocks at Buyuni which in turn act as refuges of many species. The distribution patterns of several tropical species are also explained by hydrodynamic factors (Uthicke, 1994; Thorne et al., 2012).

In the case of Kunduchi, Magemani and Kitoni, the populations seem to be open due to the shape and nature of the shores and given holothurians pelagic larval duration, larvae might be oceanographically advected from one natal population to the other site by ambient currents and their dispersal potential. For the case of Buyuni, the population can be said to be closed due to the shape of the shore and water circulation in the shore such that there is little or no exchange of larvae with other populations. The presence of juveniles throughout the time of the year supports the point of closed population. Combination of factors e.g. bio-cover variations and diel rhythm activities of holothurians in deferent stages of development and growth may also determine density and distributions as a result of massive displacements and migrations of sea cucumbers within substrata or between depth zones.

Density and distribution results may also be affected by sampling time because juvenile and adult *H.scabra* respond to low salinities and sunlight by variable times burrowing into the sediment and stop feeding until conditions return to normal (Mercier et al., 2000). Giraspy and Ivy (2005) opined that salinity ranging from 33 to 37 ppt is good for successful larval and juvenile of *H. scabra*.

In the present study, the highest number of individuals was obtained with increased water depth. Other animals in different stages might be migrating to the favorable salinity for growth. According to Asha et al. (2011) the highest growth rate in length and weight of the juveniles was obtained at 30 ppt. Liu et al. (2004) indicated that salinity tolerance varied with respect to the size of juvenile holothurians. Perhaps there are also chemical cues for various adult holothurian species, juveniles and larvae to select the host sea grass or macro algae species for settlement or cue for predator identification as observed in sea urchin (Swanson et al., 2006).

4.2.1.1. Population structure of H. *scabra* and H. *nobilis*

With regards to the population structure of the focused species (*H. scabra* and *H. nobilis*), there was a difference in live weight distributions for *H. scabra* between the sites (modal weights variations). The results indicated that there were important differences in the size structure of the population of *H. scabra* and *H. nobilis* fished in MIMP versus IFA sites. These differences are most easily explained in terms of fishing pressure; sea cucumbers in Kunduchi and Magemani have been fished un-discriminatively for a longer period than MIMP. The cause of difference in size at different sites could be linked to diet and disturbances from human activities including intensive fishing. The size structure of the population at Kitoni was relatively stable, (with wet weight from 201g to 2200g) and no smaller size classes were found. The absence of juveniles in the Kitoni site suggests different habitat preferences between juveniles and adults. The size frequency distribution of some population in some sites became disrupted and shifted to have unequal cohort's amplitudes, large animals disappeared and low recruits to no recruits were seen in some sites (*Old collectors; personal communication*). The situation has been observed in other places e.g. Hassan (2004, 2005), observed the shifting of modal classes such that the size frequency distribution of the population became unimodal, large animals disappeared and no recruits were seen.

Settlement of larvae and recruitment of new individuals into marine habitats are fundamental ecological processes for population structure and community dynamics in benthic ecosystem (Underwood and Keough, 2000; Swanson et al., 2006).

Although no past data for comparison, old sea cucumbers collectors reported robust population with tri-modal size frequency distribution, high densities (especially at sand habitat for *H. scabra* and rocky habitat for *H. nobilis),* and high biomass (an indicator of low exploitation and destruction of ecosystems). Although some sites were far apart, sea cucumber cohorts within substrata in the same sites differed much such that causes of difference may not be due to the different levels of exploitation but cohort's habitat preferences. This was portrayed by small individuals and juveniles mostly observed at Buyuni (hotspot for juveniles) as compared to other substrata of Buyuni. Observation of juveniles or immature individuals during some months, in different sites may be due to habitat complexity and degree of cryptic behavior that diminishes with size.

According to Mercier et al*.* (1999), smaller specimens of *H. scabra* (>10-40 mm) are reported to remain hidden for the majority of day light hours. Although Mercier et al. (1999) observed larger *H. scabra* juveniles (>40-140 mm) emerging from sediment in the middle of the day, most of them emerged during the evening suggesting nocturnal behavior.

Other works on marine organism has revealed two broad classes of processes that shape local patterns of abundance; those processes that affect the input of plankton dispersed young to an area (physical transport, larvae behavior, and availability of settling habitat) and those that subsequently modify settlement patterns (physical oceanographic feature e.g. currents which creates variability in the delivery of propagules (Leis and Carson-Ewart, 1997; Schimitt and Holbrook, 1999).

4.3. Threats intensity on habitats of H. *nobilis* and H. *scabra*

Habitat destruction is the process in which natural habitat is rendered functionally unable to support the species present (NRC, 2001). The use of destructive fishing activities have a long history and been reported by several researchers (e.g. Alexander, 1964; Bryceson, 1978; Horrill et al. 2000). The prevalence of destructive techniques e.g. poisons is probably more on relative sedentary benthic organisms as every poison used ends up in the sea bottom. Both sea grasses and coral sites are targeted by sea cucumber e.g. *H. scabra* and *H. nobilis,* hence impacted by these destructive techniques. Although it was difficult to assess the magnitude of impacts associated with each destructive technique due to difficulty of isolating human effects from natural spatial and temporal variability, habitat destruction by human activity mainly for the purpose of harvesting marine natural resources and production is currently ranked as the most important cause of species depletion in Tanzania. The more the human activities in the area, the more the variation of bio-cover, particle sizes and the organic matter retention which in turn affect the spatial and temporal assemblage of sea cucumbers. Habitat alteration in most of the study sites was due to boat anchoring and fishing intensity. These activities affect corals, algae and sea grass beds (GCRMN, 2000). Other important causes of habitat destruction include coral mining, trawling and seining. Decrease of habitat diversity has been reported also to be followed by decrease of variability in marine animal communities (GCRMN, 2000). The negative systemic effects of bottom seining may induce changes in predator-prey relationships (Prantoni et al., 2012). Similarly low differences in sea cucumber community structure in this study appear to be related to among other factors, trawling effects which have caused low habitat diversity as compared to Buyuni.

In this study the threats (clearing habitats, coral mining, seining, transportation, bait digging, tourist hotel construction, dredging and organic pollutants) intensity was in trend of Magemani > Kunduchi > Buyuni > Kitoni while in terms of general number of fishers is in the order of; Kunduchi > Magemani > Kitoni >Buyuni. The number of vessels was in the order of; Kunduchi > Magemani > Buyuni > Kitoni. The reasons for less intensity or more intensity of sea cucumber collection in different areas sampled was due to the stage at which the fishery is (boom and bust cycle) in that particular area, presence of other lucrative fishery and other socio-economic factors). The collection intensity can be very high on low spring tides with opportunists observed on occasion who collect even juveniles. While sea cucumbers are collected by all fishers, it seems that changes in the balance of the benthos, particularly the loss of coral reefs and sea grass beds attributed to over-fishing and tourist vessels damage, beach seine (Benno, 1992) and dynamite fishing (Wagner, 2004) which has been practiced for more than 30 years (Bryceson, 1978; Horril et al., 2000) have occurred in Kunduchi as compared to other study sites.

5. Conclusion

This study has shown some correlations between environmental factors and densities more on *H.scabra* than *H. nobilis* as well as effects of exploitation between exploited sites and relatively low exploited sites. However being bipartite in life cycle of benthic, relatively sedentary and with pelagic larvae, sea cucumbers local patterns of abundance and density probably can be shaped by processes that affect the input of planktonic larvae to a habitat and settlement modifying factors such as physical oceanographic features. Oceanographic features can cause a population to be closed or open hence affecting positively or negatively significant exchange among populations. Being sedentary it is apparent that MPA and overlapping substrata with rocks contribute to a large extent the conservation of sea cucumbers than any other options. Sea cucumbers are protected from collection in areas with sea grass cover, less disturbed sites mixed with rocks and low energy waves. It is also apparent that the studied commercial species *H. scabra* and *H. nobilis* suffered local exploitation. Evaluation of causes of variation in abundance and densities of sea cucumber can be achieved using unexploited stock by designing a study that simultaneously consider multiple life stages and processes across spatial scales so as to draw conclusions about the roles various factors play in shaping patterns of abundance.

It is therefore recommended that; 1. Government should designate areas spotted with abundant juveniles e.g. Buyuni has no take zone for sea cucumbers, 2. Catch size and minimum size limits should be introduced and enforced in areas with high abundance of commercial species and 3. Collection of sea cucumbers using scuba equipment should be prohibited and enforced from areas with local depletion. Government through MPA should establish specific regulation or legislation regarding different species of sea cucumbers based on their ecology and behavior.

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