AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS
Aquatic Conserv: Mar. Freshw. Ecosyst. **19**: S19–S26 (2009)
Published online 8 May 2009 in Wiley InterScience
(www.interscience.wiley.com). DOI: 10.1002/aqc.1041

Seagrass–sea urchin interaction in shallow littoral zones of Dar es Salaam, Tanzania

FLORENCE MAMBOYA[a], CHARLES LUGOMELA[b], ESTHER MVUNGI[c,d], MARIAM HAMISI[d,e], ALBOGAST T. KAMUKURU[b] and THOMAS J. LYIMO[e,*]

[a]*Dar es Salaam Institute of Technology, Department of Science and Laboratory Technology, Box 2958 Dar es Salaam, Tanzania*
[b]*Faculty of Aquatic Sciences and Technology, University of Dar es Salaam, P.O. Box 35064 Dar es Salaam, Tanzania*
[c]*Department of Botany, University of Dar es Salaam, P.O. Box 35060 Dar es Salaam, Tanzania*
[d]*Department of Botany, Stockholm University, SE-10691 Stockholm, Sweden*
[e]*Department of Molecular Biology and Biotechnology, University of Dar es Salaam, P.O. Box 35179 Dar es Salaam, Tanzania*

ABSTRACT

1. Seagrasses biomass, canopy height, shoot density, percentage cover, and sea urchin abundance were intermittently (between July and November 2007) studied at four littoral sites in the Dar es Salaam area (Mjimwema, Mbweni, Bongoyo Island and Mbudya Island) in order to investigate the seagrass–sea urchin association.

2. Seagrass biomass ranged from $126.7 \pm 65.62\,g\,dwt\,m^{-2}$ in the upper sub-tidal area at Bongoyo Island to $508.1 \pm 133.4\,g\,dwt\,m^{-2}$ in the upper sub-littoral area at Mbudya Island. Canopy height ranged from 6.51 ± 2.76 cm in the mid-littoral zone at Mjimwema to 23.8 ± 8.93 cm in the upper sub-littoral zone at Mbudya Island. Shoot densities ranged from 363.6 ± 268.9 shoots m^{-2} in the mid-littoral zone at Mjimwema to 744.0 ± 466.9 shoots m^{-2} in the lower littoral zone at Mbudya Island.

3. Seagrass biomass, canopy height and percentage cover differed significantly among study sites ($P = 0.001$, 0.0001, 0.008 respectively). However, there was no significant difference in shoot density among the sites ($P = 0.376$).

4. Ten species of sea urchins were recorded, *Echinometra mathaei* being the most abundant followed by *Tripneustes gratilla*. Total sea urchin abundance was significantly different among the study sites ($P = 0.001$). Seagrass–sea urchin interaction was depicted by significant negative correlations between sea urchin densities with seagrass biomass, canopy height, shoot density and percentage cover. This suggests that grazing by sea urchins might have contributed to the reduction of above ground seagrass biomass in locations with higher sea urchin densities. However, further studies are required to corroborate the present results and assess effects of other factors (e.g. light, nutrients and currents), which also influence seagrass growth.
Copyright © 2009 John Wiley & Sons, Ltd.

Received 14 February 2009; Accepted 1 March 2009

KEY WORDS: seagrass biomass; canopy height; shoot density; sea urchin abundance; Tanzania

INTRODUCTION

Seagrasses play a major role in ecological services and functions in the marine environment (Hemminga and Duarte, 2000). They are among the major primary producers in the near shore marine environment and act as home, feeding and nursery ground for different species of fish and other fauna and flora (Heck *et al.*, 2003; Heck and Valentine, 2006). Seagrasses play an important role in nutrient recycling in coastal areas and in reducing coastal erosion through absorbing wave and current energy (Costanza *et al.*, 1997; Rose *et al.*, 1999). Most importantly, seagrass beds host more diverse and abundant animal communities than non-vegetated areas in both temperate (Pihl, 1986; Boström and Bonsdorff, 1997) and tropical areas (Coles *et al.*, 1993; Arrivillaga and

*Correspondence to: T. J. Lyimo, Department of Molecular Biology and Biotechnology, University of Dar es Salaam, P.O. Box 35179 Dar es Salaam, Tanzania. E-mail: lyimo@amu.udsm.ac.tz

Copyright © 2009 John Wiley & Sons, Ltd.

Balz, 1999). Many of the animals residing in seagrass beds, e.g. fish and sea urchins, are directly utilised by humans, and are thus of economic importance (Lynne *et al.*, 2000; Jackson *et al.*, 2001).

Direct herbivory on seagrass leaves constitutes a natural and common process in tropical seagrass beds (Klumpp *et al.*, 1989; Valentine and Heck, 1999), and hundreds of species are known to graze on living seagrass tissues. In the Western Indian Ocean (WIO) region, the most well known grazers include the sea urchins (primarily *Tripneustes gratilla*), fish (*Leptoscarus vaigiensis*), green turtles (*Chelonia midas*) and dugongs (*Dugong dugon*) (Richmond, 2002; Eklöf *et al.*, 2008). In many parts of the world, sea urchins have become the most abundant seagrass herbivore and rapid population outbreaks (with up to 500–600 individuals m^{-2}) can cause extensive loss of seagrass biomass, sometimes even clearing entire seagrass beds (Heck and Valentine, 1995; Rose *et al.*, 1999; Peterson *et al.*, 2002). This causes erosion of the seabed, which increases resuspension of fine sediment particles resulting in increased turbidity, alters coastal geomorphology, and makes recovery of seagrasses a complicated and slow process (Peterson *et al.*, 2002). Sediment characteristics are also known to influence the distribution and growth of seagrasses (Eklof *et al.*, 2005). In a study to assess the herbivory of fish and sea urchins in the Indo-Pacific area, fish herbivory was restricted to unfished seagrass meadows, while sea urchin herbivory took place in fished as well as unfished areas, where fish appeared not to be effective sea urchin predators. This confirmed that grazing by sea urchins is important in tropical seagrass ecosystems and indicated that herbivorous fish graze, and probably consume, substantial amounts of seagrass in fishing-protected habitats (Alcoverro and Mariani, 2004).

Reports from coastal areas of several countries in the WIO region have indicated an increase in sea urchin densities and simultaneous rapid seagrass decline (Alcoverro and Mariani, 2002; de la Torre Castro and Jiddawi, 2005). It has been suggested that such declines in seagrass have been caused by overgrazing of seagrass meadows by sea urchins; in particular *T. gratilla*. This is one of the most common sea urchins in seagrass beds in the region, and is known to graze primarily on *Thalassodendron ciliatum* in Zanzibar (Herring, 1972). Few sea urchin studies have been done in Tanzanian coastal waters and then limited to the coral reef–sea urchin association (McClanahan and Arthur, 2001).

The aim of this study was to correlate the seagrass biomass, canopy height, shoot density and percentage cover with sea urchin abundance at four littoral sites in the Dar es Salaam area. It was hypothesized that sea urchin abundance impacts negatively on the above mentioned seagrass parameters due to grazing. This background information on the status of seagrass and sea urchins forms a basis for monitoring to inform better management and conservation of the rather fragile seagrass ecosystems.

MATERIALS AND METHODS

Study sites

The study was conducted at four sites, namely: Mjimwema and Mbweni off the mainland and Bongoyo and Mbudya which are small uninhabited islands near Dar es Salaam city (Figure 1). Three sets of samples were taken at each site between July and November 2007 during spring low tides. A total of nine quadrats (0.5 m × 0.5 m) were thrown haphazardly in the mid- and lower littoral zones as well as in the upper sub-littoral zone on each occasion at Mjimwema and Mbweni. At the Mbudya and Bongoyo islands sites, samples were taken in the lower littoral and upper sub-littoral zones only. The tidal regime in Dar es Salaam has a mixed semi-diurnal periodicity with a tidal range of about 4 m during spring tide.

Determination of seagrass composition, cover, shoot density, biomass and canopy height

Determination of the seagrass composition, canopy height and percentage cover was done in a total of nine quadrats at each tidal zone as described by Duarte and Kirkman (2001). Shoot density was determined by counting individual shoots in a quarter (i.e. 0.25 m × 0.25 m) of the quadrat. Thereafter, the seagrass was harvested for biomass estimation by digging with a shovel, making sure that the whole plant biomass was recovered (Duarte and Kirkman, 2001). In the laboratory, seagrass samples for biomass determination were sorted and rinsed with tap water and then treated with dilute (1%) hydrochloric acid to remove epiphytes. Dry weight was determined by drying the plant material in an oven at 60°C to constant weight.

Determination of sea urchin abundance and species composition

Sea urchin abundance and species composition were determined for each sampling zone as described by McClanahan and Shafir (1990). At each zone, a total of 18 round quadrats (10 m^2 per quadrat) were thrown haphazardly for counting sea urchin species.

Determination of sediment grain size and percentage organic matter

Sediment samples for grain size and organic matter analysis were collected in five quadrats at each station using a plastic corer (7 cm in diameter) inserted into the sediment down to about 10 cm deep. In the laboratory, 30 g wet weight of the sediment samples was sieved and analysed for grain size as described by Erftermeijer and Koch (2001). The proportion of silt/clay (< 0.063 mm), sand (0.063–2 mm) and coarse sand (> 2 mm) was calculated according to Eklöf *et al.* (2005). The remaining portion of the sediment samples was used for organic matter content calculated as the difference in weight between dry weight (60°C until a constant weight is attained) and ash weight (500°C for 4 h).

Statistical analysis

Differences between zones and the four sites for the aforementioned variables were statistically tested using a *t*-test or two-way analysis of variance with Tukey HDS post hoc test, using STATISTICA 6.0 software. To compare the relationship between the variables measured in seagrass and the sea urchin abundance at different study sites, a Pearson correlation test was performed. In all cases, significance was determined at the 95% confidence level.

Copyright © 2009 John Wiley & Sons, Ltd.

DOI: 10.1002/aqc

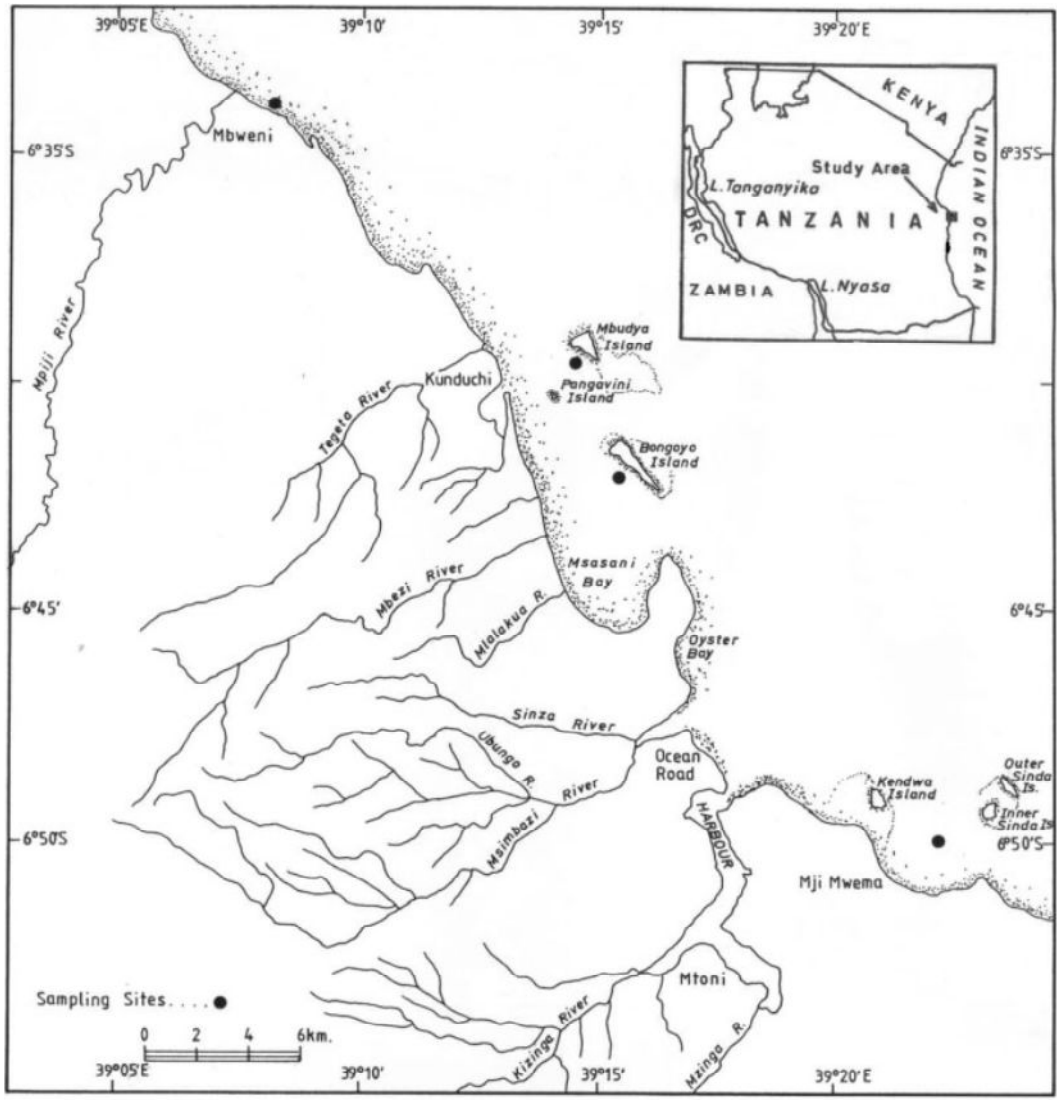


Figure 1. Map of Dar es Salaam area showing the study sites (Inset: map of Tanzania showing study area).

RESULTS

Seagrass composition

Six species of seagrasses were encountered during the study (Table 1). Seagrass meadows were dominated by one particular species but comprised at least three species. *Thalassia hemprichii* dominated in the study sites contributing 32.4% of all shoots counted followed by *Syringodium isoetifolium* (27.3%), *Cymodocea rotundata* (23.3%), *Halodule univervis* (7.4%), *Thalassodendron ciliatum* (7.3%), and *Halophila ovalis*, which contributed 2.3% (Table 1). In general, quadrats dominated by *Cymodocea* spp. and *S. isoetifolium* species had higher shoot density and percentage cover compared with quadrats dominated by other species. Furthermore, quadrats dominated by *T. ciliatum* had higher canopy heights than other species.

Seagrass cover, shoot density, canopy height and biomass

The mean seagrass percentage cover ranged from $41.67 \pm 15.21\%$ in the mid-littoral zones at Mjimwema to $84.56 \pm 21.75\%$ in the upper sub-littoral zone at Mbweni (Figure 2(a)). There were significant differences in the seagrass percentage cover between the four study sites ($F = 4.682$, $P = 0.008$) with Tukey HDS test showing the significant differences in sites to be between Mbweni and Mjimwema, and between Mbweni and Bongoyo ($P < 0.05$). However, there were no significant differences in seagrass percentage cover among tidal zones. In addition, interaction between the two factors (sites and zones) did not show a significant effect ($P > 0.05$) on the percentage cover.

Shoot density ranged from a mean value of 363.6 ± 268.9 shoot m^{-2} in the mid-littoral zone at Mjimwema to 744.0 ± 466.9 shoots m^{-2} in the lower littoral zone at Mbudya Island (Figure 2(b)). There was no significant

Copyright © 2009 John Wiley & Sons, Ltd.

DOI: 10.1002/aqc

Table 1. Percentage composition of seagrass species based on shoot densities at different study stations in Dar es Salaam intertidal area (Mid = mid-tide zone, Low = lower tide zone, Sub = sub-tidal zone)

Seagrass species	Mjimwema			Mbweni			Bongoyo Isl.		Mbudya Isl.		Average
	Mid	Low	Sub	Mid	Low	Sub	Low	Sub	Low	Sub	
Halophila ovalis	0.0	0.2	0.0	5.4	0.0	0.0	0.0	9.5	8.1	0.0	2.3
Halodule univervis	0.0	0.0	0.0	23.2	0.0	0.0	2.1	0.0	25.7	23.4	7.4
Cymodocea rotundata	43.8	24.1	55.9	21.6	2.8	2.8	24.1	10.9	45.8	1.4	23.3
Thalassia hemprichii	41.8	68.2	35.5	30.4	12.3	12.3	68.5	34.0	12.1	9.2	32.4
Syringodium isoetifolium	14.4	7.6	0.0	19.5	73.6	73.6	5.4	27.7	4.5	46.5	27.3
Thalassodendron ciliatum	0.0	0.0	8.6	0.0	11.3	11.3	0.0	18.0	3.8	19.6	7.3

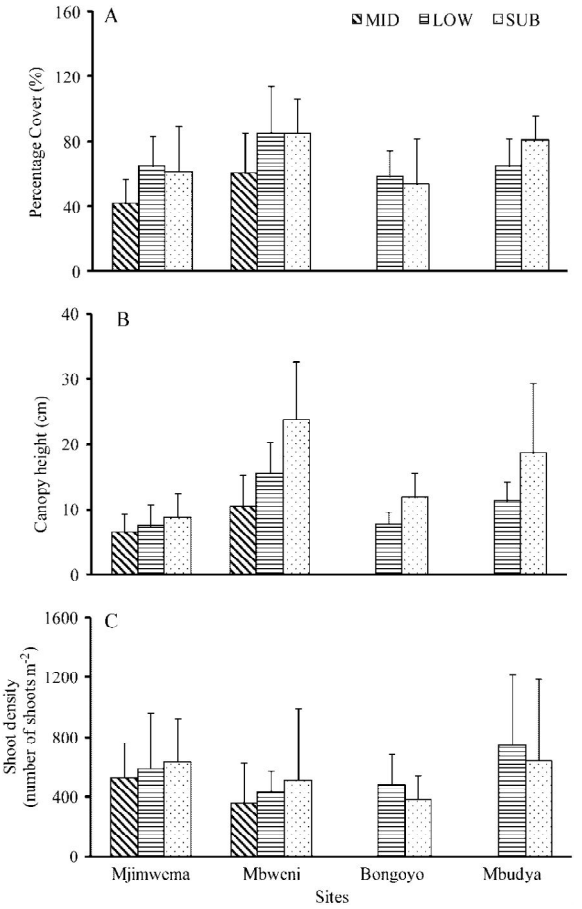


Figure 2. Variations in seagrass characteristics in the study sites (A = percentage cover; B = canopy height; C = shoot density).

difference in shoot density among sites and zones ($F = 1.071$, $P = 0.376$ and $F = 0.363$, $P = 0.551$, respectively). Also, the interaction between sites and zones did not show a significant effect on shoot density.

Canopy height in the study area ranged from a mean value of 6.51 ± 2.76 cm in the mid-littoral zone at Mjimwema to 23.8 ± 8.93 cm in the upper sub-littoral zone at Mbudya Island (Figure 2(c)). There was a significant difference in canopy height among the sampling sites and zones ($F = 17.105$, $P < 0.0001$ and $F = 17.015$, $P = 0.0002$, respectively). Tukey HDS multiple comparison tests showed that the differences were among all study sites ($P < 0.05$). However, there was no significant interaction between zones and sites on seagrass canopy height.

Mean above ground biomass ranged from 62.67 ± 44.08 g dwt m^{-2} in the upper sub-tidal areas at Bongoyo to 508.1 ± 133.4 g dwt m^{-2} in the upper sub-tidal areas at Mbudya (Figure 3). Below ground biomass ranged from an average value of 64.0 ± 33.7 g dwt m^{-2}, also as recorded in the upper sub-tidal areas at Bongoyo, to 270.4 ± 173.2 g dwt m^{-2} in the upper sub-tidal area at Mbudya Island. Similarly, the lowest total biomass (126.7 ± 65.62 g dwt m^{-2}) was found in the upper sub-tidal area at Bongoyo but the highest (508.1 ± 133.4 g dwt m^{-2}) was in the upper sub-tidal area at Mbudya. Total biomass was significantly different among study sites ($F = 6.594$, $P = 0.001$) with Tukey HDS multiple comparison test showing the differences to be only between Mjimwema and Mbudya Island ($P < 0.05$) and between Mbweni and Mjimwema ($P < 0.05$). There was no significant difference in seagrass total biomass among zones ($F = 0.139$, $P = 0.712$) and there was no significant interaction between sites and zones on seagrass total biomass.

Sea urchin abundance and species composition

Ten species of sea urchins were recorded during the current study: *Asthenosoma varium*, *Diadema savignyi*, *D. setosum*, *Echinometra mathaei*, *Echinostrephus molaris*, *Echinothrix diadema*, *Salmacis bicolour*, *Salmaciella dussumoeri erythracis*, *Stomopneustes valioralis*, and *Tripneustes gratilla* (Table 2). In general, *E. mathaei* and *T. gratilla* were the most abundant species in the studied sites. *Echinometra mathaei* was dominant at Mjimwema site reaching a maximum abundance of 17.2 individuals m^{-2} while the rest of the sites were dominated by *T. gratilla*, reaching a maximum abundance of 1.75 individuals m^{-2} in the sub-littoral zone at Bongoyo. There was a significant difference in the total sea urchin abundance among the sites ($F = 6.997$, $P = 0.001$). However, there was no significant difference ($F = 0.33$, $P = 0.56$) in sea urchin abundance among zones.

Total seagrass biomass, above ground biomass, canopy height, percentage cover and shoot density showed significant negative correlations ($r = -0.666$, $P = 0.044$; $r = -0.770$, $P = 0.013$; $r = -0.758$, $P = 0.015$; $r = -0.733$, $P = 0.020$; $r = -0.818$, $P = 0.006$, respectively), with total sea urchin abundance. However, density of *T. gratilla* had no significant correlation with any of the above seagrass parameters.

Sediment characteristics

The mean percentage organic matter content in the sediment differed among study sites and among zones, as indicated in Table 3. In the sub-littoral zone, Bongoyo Island had the

Copyright © 2009 John Wiley & Sons, Ltd.

DOI: 10.1002/aqc

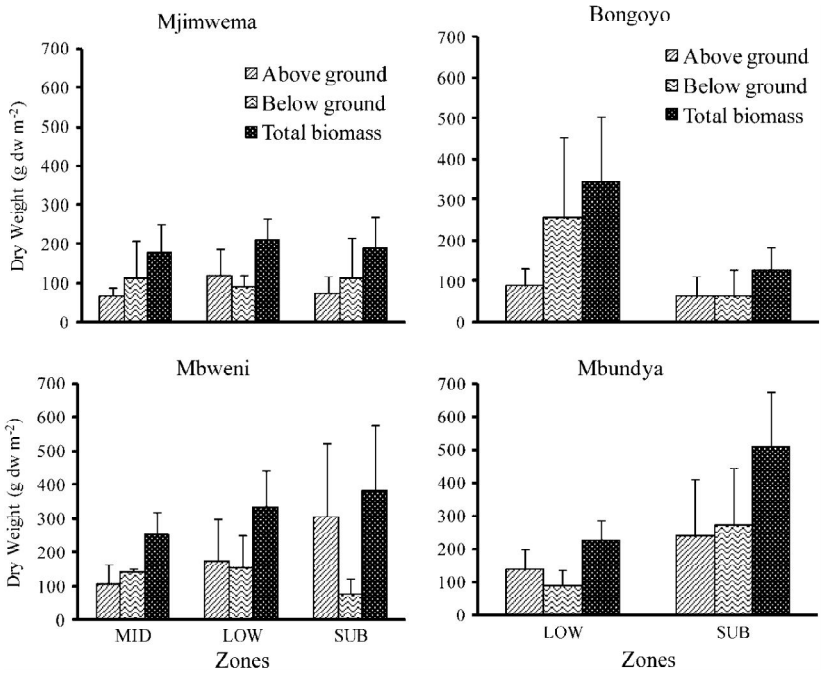


Figure 3. Variations in seagrass biomass in the study site.

highest (4.46%) while Mbweni was found to have the least (0.78%) mean percentage organic matter content. Generally, mean percentage organic matter content in Bongoyo and Mbudya Islands were higher than those recorded from Mbweni and Mjimwema.

Sandy sediment was dominant in all study sites (Table 3), with Mjimwema showing a smaller mean grain size than the other sites. The largest mean grain size was found at Mbweni sub-littoral zone (2.93 μm), while the smallest mean grain size was recorded at Mjimwema sub-littoral zone (1.50 μm). In general, sediment from littoral zones in the study sites showed a negative skewness. Mbweni mid-littoral zone was more strongly negatively skewed (–0.887) compared with other stations while the lower littoral zone at Mbudya Island had the weakest negative skewness (–0.101) indicating that it was a more muddy area compared with the rest of the study sites.

There were no significant correlations between percentage organic matter and total seagrass biomass or between percentage organic matter and sea urchin abundance. Also the mean sediment grain size did not significantly correlate with the total seagrass biomass, although a significant correlation was found between the sediment mean grain size with total sea urchin abundance ($r = 0.676$, $P = 0.032$).

DISCUSSION

Seagrass shoot density, canopy height and percentage cover obtained in this study were within the range of other findings in the WIO region and other tropical areas (Lanyon, 1986; Erftemeijer *et al.*, 1993; Lin and Shao, 1998; Agawin *et al.*, 2001; Rollon *et al.*, 2001; de la Torre-Castro and Rönnbäck, 2004; Uku and Björk, 2005; Lyimo *et al.*, 2006). The variation in the measured seagrass parameters was influenced by the respective species composition. For example, areas dominated by *Syringodium* and *Cymodocea* species had higher shoot density and percentage cover than quadrats dominated by other species. Also, areas dominated by *T. ciliatum* had higher canopy heights compared with other species.

Seagrass biomass values were within the range of other reports in the region (Martin and Bandeira, 2001; Eklof *et al.*, 2005; Lyimo *et al.*, 2006). Generally, the above-ground biomass was lower than below-ground biomass (Figure 3). Similar observations were reported by Lyimo *et al.* (2006) in Zanzibar seagrass meadows. The authors postulated that this is a survival strategy of seagrasses to minimize anthropogenic pressure, exposure to desiccation at low tide and to increase stability when exposed to high tides. Grazing by herbivores such as sea urchins also contributes to the reduction of above ground biomass. Other studies, however, report that grazing has no negative effect on seagrass biomass (Cebrian and Duarte, 1994) and may actually stimulate production in some instances (Tomasko and Dawes, 1989; Cebrián *et al.*, 1997). Below-ground material losses are negligible for most seagrass species and is less prone to losses derived from other disturbances. Seagrass biomass might also be influenced by the species composition of a locality. For example, Mbudya Island, which was dominated by large-sized *T. ciliatum,* had higher biomass than other sites that were dominated by smaller-sized seagrass species.

The values for total sea urchin abundance were also within the range reported from other tropical seagrass beds (Heck and Valentine, 1995; Rose *et al.*, 1999; Alcoverro and Mariani, 2002; Peterson *et al.*, 2002). Alcoverro and Mariani (2002) reported average sea urchin density of 1.6 individuals m^{-2} in Mombasa Marine Park lagoon. Sea urchin population outbreaks with up to 500–600 individuals m^{-2} have been reported in some areas, resulting in extensive loss of seagrass

Copyright © 2009 John Wiley & Sons, Ltd.

DOI: 10.1002/aqc

Table 2. Abundance (individuals m^{-2}) of different sea urchin species in different study sites in the intertidal areas of Dar es Salaam (Mid = mid-tide zone, Low = lower tide zone, Sub = sub-tidal zone)

Species	Mjimwema			Mbweni			Bongoyo		Mbudya	
	Mid	Low	Sub	Mid	Low	Sub	Low	Sub	Low	Sub
Tripneustis gratilla	0.00±0.0	0.133±0.2	1.18±1.7	0.50±1.0	0.21±0.3	0.00±0.0	0.95±2.3	1.75±2.1	0.14±1.7	0.89±0.3
Echnometra mathaei	17.15±6.1	6.62±1.5	2.58±1.9	0.00±0.0	0.00±0.0	0.00±0.0	1.34±0.3	0.94±0.2	0.00±0.0	0.00±0.0
Diadema spp.	0.02±0.1	0.23±0.5	0.71±1.2	0.00±0.0	0.00±0.0	0.00±0.0	0.00±0.0	0.00±0.0	0.00±0.0	0.04±0.2
Stomopneustis varioralis	0.00±0.0	0.09±0.1	3.16±4.5	0.01±0.0	0.00±0.0	0.00±0.0	0.00±0.0	0.02±0.04	0.00±0.0	0.00±0.0
Echinatrix diadema	0.00±0.0	0.00±0.0	0.08±0.2	0.11±0.4	0.01±0.0	0.00±0.0	0.00±0.0	0.01±0.1	0.00±0.0	0.00±0.0
Asnethosoma varium	0.00±0.0	0.00±0.0	0.00±0.0	0.00±0.0	0.00±0.0	0.00±0.0	0.02±0.1	0.01±0.0	0.00±0.0	0.00±0.0
Salmacis bicolor	0.00±0.0	0.00±0.0	0.00±0.0	0.01±0.0	0.00±0.0	0.00±0.0	0.00±0.0	0.02±0.0	0.00±0.0	0.00±0.0
Salmaciella dussumoeri erythracis	0.00±0.0	0.00±0.0	0.09±0.1	0.00±0.0	0.00±0.0	0.00±0.0	0.00±0.0	0.04±0.0	0.00±0.0	0.00±0.0
Echinostrephus molaris	0.07±0.1	0.05±0.1	0.00±0.0	0.00±0.0	0.00±0.0	0.00±0.0	0.02±0.1	0.01±0.0	0.00±0.0	0.00±0.0
Total, m^{-2}	17.2±5.71	7.12±2.19	7.79±1.21	0.65±0.16	0.21±0.07	0.00±0.00	2.31±0.51	2.81±0.62	0.14±0.05	0.93±0.3

Table 3. Sediment grain size analysis in the studied sites (Mid = mid-tide zone, Low = lower tide zone, Sub = sub-tidal zone)

Type	Mjimwema			Mbweni			Bongoyo		Mbudya	
	Mid	Low	Sub	Mid	Low	Sub	Low	Sub	Low	Sub
Coarse sand (%)	16.20±11.4	15.16±13.2	15.32±8.5	1.86±1.7	3.89±2.4	5.40±4.8	8.99±6.6	15.16±13.2	2.36±1.3	5.50±4.4
Sand (%)	78.85±10.6	77.44±12.9	80.11±7.7	96.62±0.9	91.82±4.2	93.07±5.2	84.49±5.6	77.44±12.9	90.36±2.9	89.85±4.0
Silt/clay (%)	4.95±2.3	7.39±2.7	4.57±1.4	1.53±0.8	4.29±2.2	1.53±0.6	6.52±3.1	7.39±2.7	7.10±2.6	4.65±2.6
Mean grain size (μm)	1.633	1.600	1.500	2.333	2.400	2.933	1.620	1.833	2.650	2.267
Skewness (phi)	−0.418	−0.277	−0.400	−0.887	−0.324	−0.325	−0.484	−0.289	−0.101	−0.253
Organic matter (%)	2.031	2.989	3.489	0.878	0.779	1.779	4.103	3.486	4.359	3.470

Copyright © 2009 John Wiley & Sons, Ltd.

DOI: 10.1002/aqc

biomass (Heck and Valentine, 1995; Rose *et al.*, 1999; Peterson *et al.*, 2002). At Watamu in Kenya, aggregations of 37 *T. gratilla* individuals were recently recorded in an area of about 1 m square (Zanre and Kithi, 2004). The current study recorded aggregations of *T. gratilla* of up to 17.24 individuals m^{-2} at Mbweni, which is lower than the outbreaks reported above. The observed significant negative correlations between the total sea urchin density and total seagrass biomass, as well as above-ground biomass, canopy height, shoot density and percentage cover suggests a grazing effect by sea urchins on seagrasses. However, there were no significant correlations between the density of *T. gratilla,* which is known to be the main sea urchin grazer of seagrasses (Ecklof *et al.*, 2008), with seagrass biomass, shoot density, canopy height and percentage cover, suggesting that the effects on seagrass were due to collective sea urchin species densities rather than one particular species. This may be due to the observed low densities of *T. gratilla*. In addition, the type of sea urchin can have a net influence on seagrasses due to species specific feeding modes, as previously reported by (McClanahan, 1995) in Kenya coral reefs.

The data for sediment characteristics were within the range reported in other seagrass meadows in Tanzania (Eklöf *et al.*, 2005). However, values of percentage organic matter content in the sediment were slightly lower than those reported by Eklöf *et al.* (2005) from Chwaka Bay, Zanzibar, seagrass meadows. In all of the study sites the sediment grain size was negatively skewed indicating that sandy sediment predominated. The strongest negative skewness was found at Mbweni while the weakest was at Mbudya Island, suggesting a higher percentage proportion of finer particles at Mbudya Island, which have the ability to retain more nutrients. Similarly, Mbudya Island had the highest organic matter content compared with other sites which might have contributed to the observed high seagrass biomass in Mbudya Island compared with other sites.

The lack of significant correlation between percentage organic matter and total seagrass biomass, between percentage organic matter and total sea urchin abundance as well as between sediment grain size and total seagrass biomass may be due to the fact that there was not much variation in sediment characteristics in the study area. Sediment grain size is known to be a good indicator of the variety of the physical and geochemical characteristics in seagrass habitats. As grain size distribution becomes skewed towards silt and clay, the pore water exchange with the overlying water column decreases (Huettel and Rusch, 2000), which may result in increased nutrient concentrations.

This study documents the characteristics of seagrass and sea urchin in the intertidal and subtidal areas in the Dar-es-Salaam coast. The data indicate a plant (seagrass) and herbivore (sea urchin) interaction by depicting significant negative correlations between total sea urchin density with seagrass biomass canopy height shoot density and percentage cover, suggesting that grazing by sea urchins contributed to the reduction of above-ground biomass in locations with higher sea urchin density. However, other parameters (e.g. light intensity, concentration of inorganic nutrients and water currents) not considered in this study may have contributed to the observed seagrass growth characteristics. During the current study, there seems to be a balance between the seagrass and sea urchins in the area, however, should there be a population outbreak of sea urchins there is a high risk that overgrazing could occur. Monitoring sea urchin populations in seagrass meadows in the area and evaluation of the interaction of other factors is recommended.

ACKNOWLEDGEMENTS

This study was supported by the Marine Science for Management (MASMA) grant for 'Seagrass and Sea urchin interactions: overgrazing and resource use in the WIO region' project. We thank Dr Yohanna Shaghude and Mr Alhaji Kombo for their technical assistance in sediment analysis and map digitization, respectively. We thank the University of Dar es Salaam for availing time to researchers to conduct field work and provision of logistical support including laboratory space, equipment and transport.

REFERENCES

Agawin NSR, Duarte CM, Fortes MD, Uri JS, Vermaat JE. 2001. Temporal changes in the abundance leaf growth and photosynthesis of three co-occurring Philippine seagrasses. *Journal of Experimental Marine Biology Ecology* **260**: 217–239.

Alcoverro T, Mariani S. 2002. Effects of sea urchin grazing on seagrass (*Thalassodendron ciliatum*) beds of a Kenyan lagoon. *Marine Ecology Progress Series* **226**: 255–263.

Alcoverro T, Mariani S. 2004. Patterns of fish and sea urchin grazing on tropical Indo-Pacific seagrass beds. *Ecography* **27**: 361–365.

Arrivillaga A, Balz DM. 1999. Comparison of fishes and macro invertebrates on seagrass and bare-sand sites on Guatemala's Atlantic coast. *Bulletin of Marine Science* **65**: 301–319.

Boström C, Bonsdorff E. 1997. Community structure and spatial variation of benthic invertebrates associated with *Zostera marina* (L.) beds in the northern Baltic Sea. *Journal of Sea Research* **37**: 153–166.

Cebrian J, Duarte CM. 1994. The dependence of herbivory on growth rate in natural plant communities. *Functional Ecology* **8**: 518–525.

Cebrian J, Duarte CM, Marba N, Enriquez S. 1997. The magnitude and fate of production of four co-occurring Western Mediterranean seagrass species. *Marine Ecology Progress Series* **155**: 29–44.

Coles RG, Lee Long WJ, Watson RA. 1993. Distribution of seagrasses, and their fish and Penaid prawns communities, in Cairns Harbour, a tropical estuary, Northern Queensland, Australia. *Australian Journal of Marine and Freshwater Research* **44**: 193–210.

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, *et al.* 1997. The value of the world's ecosystem services and natural capital. *Nature* **387**: 253–260.

de la Torre Castro M, Jiddawi NS. 2005. Seagrass-related research and community participation: 'Fishermen, fisheries and seagrasses'. *Participatory workshop. Chwaka Bay, Zanzibar, Tanzania*, 6–11 September, 2004. WIOMSA book series no. 3, WIOMSA.

de la Torre Castro M, Rönnbäck P. 2004. Links between humans and seagrasses. *An example from tropical East Africa. Ocean Coastal Management* **47**: 361–387.

Copyright © 2009 John Wiley & Sons, Ltd.

Duarte CM, Kirkman H. 2001. Methods for measurement of seagrass abundance and depth distribution. In *Global Seagrass Research Methods*, Short FT, Coles RG (eds) Elsevier Science B.V., Amsterdam, The Netherlands; 141–153.

Eklöf JS, de la Torre-Castro M, Adelsköld L, Kautsky N, Jiddawi NS. 2005. Differences in macrofauna and seagrass assemblages in seagrass beds with and without seaweed farms. *Estuarine, Coastal and Shelf Science* **63**: 385–396.

Eklöf JS, de la Torre-Castro M, Gullström M, Uku J, Muthiga N, Lyimo T, Bandeira SO. 2008. Sea urchin overgrazing of seagrasses: a review of current knowledge on causes, consequences and management. *Estuarine, Coastal and Shelf Science* **79**: 569–580.

Erftemeijer PLA, Koch EW. 2001. Sediment geology methods for seagrass habitat. In *Global Seagrass Research Methods*, Short FT, Coles RG (eds), Elsevier Science B.V., Amsterdam, The Netherlands; 344–367.

Erftemeijer PLA, Osinga R, Mars AE. 1993. Primary production of seagrass beds in South Sulawesi (Indonesia): a comparison of habitats, methods, and species. *Aquatic Botany* **46**: 67–90.

Heck KL, Valentine JF. 1995. Sea-urchin herbivory — evidence for long-lasting effects in subtropical seagrass meadows. *Journal of Experimental Marine Biology and Ecology* **189**: 205–217.

Heck KL, Valentine JF. 2006. Plant-herbivore interactions in seagrass meadows. *Journal of Experimental Marine Biology and Ecology* **330**: 420–436.

Heck KL, Hays CG, Orth RJ. 2003. Critical evaluation of the nursery hypothesis for seagrass meadows. *Marine Ecology Progress Series* **253**: 123–136.

Hemminga MA, Duarte CM. 2000. *Seagrass Ecology*. Cambridge University Press.

Herring PJJ. 1972. Observations on the distribution and feeding habits of some littoral echinoids from Zanzibar. *Journal of Natural History of London* **6**: 169–175.

Huettel M, Rusch A. 2000. Transport and degradation of phytoplankton in permeable sediment. *Limnology and Oceanography* **45**: 534–549.

Jackson JL, Rowden AA, Attril MJ, Bossey SJ, Jones MB. 2001. The importance of seagrass beds as habitats for fishery species. *Oceanography and Marine Biology* **39**: 269–303.

Klumpp DW, Howard RK, Pollard DA. 1989. Trophodynamics and nutritional ecology of seagrass communities. In *Biology of Seagrasses*: *a Treatise*, Larkum AWD, McComb AJ, Shephard SA (eds). Elsevier Science.

Lanyon, J. 1986. Seagrasses of the Great Barrier Reef. Great Barrier Reef Marine Park Authority, Special Publication Series 3, Townsville, Australia.

Lin H, Shao KT. 1998. Temporal changes in the abundance and growth of intertidal *Thalassia hemprichii* seagrass beds in southern Taiwan. *Botanical Buletin of Academia Sinica* **39**: 191–198.

Lyimo TJ, Mvungi EF, Lugomela C, Björk M. 2006. Seagrass biomass and productivity in seaweed and non-seaweed farming areas in the East Coast of Zanzibar, Tanzania. *Western Indian Ocean Journal of Marine Science* **5**: 141–152.

Lynne CS, Boland JW, Edyvane KS, Jones GK. 2000. Development of seagrass residency index for economically important species. *Environmentrics* **11**: 541–552.

Martin ARO, Bandeira SO. 2001. Biomass distribution and leaf nutrient concentrations and resorption of *Thalassia hemprichii* at Inhaca Island, Mozambique. *South African Journal of Botany* **67**: 439–442.

McClanahan TR. 1995. Fish predators and scavengers of the sea urchin *Echinometra mathaei* in Kenya coral reef marine parks. *Environmental Biology of Fishes* **43**: 187–193.

McClanahan TR, Arthur R. 2001. The effect of marine reserves and habitat on populations of East African coral reef fishes. *Ecological Applications* **11**: 559–569.

McClanahan TR, Shafir SH. 1990. Causes and consequences of sea urchin abundance and diversity in Kenyan coral-reef lagoons. *Oecologia* **83**: 362–370.

Peterson BJ, Rose CD, Leanne LM, Fourqurean JW. 2002. Disturbance and recovery following catastrophic grazing: studies of successional chronosequence in a seagrass bed. *Oikos* **97**: 361–370.

Pihl L. 1986. Exposure, vegetation and sediment as primary factors for mobile epibenthic faunal community and production in shallow marine soft bottom areas. *Netherlands Journal of Sea Research* **20**: 75–83.

Richmond M. 2002. A field guide to the Seashores of Eastern Africa and the Western Indian Ocean Islands. *Sida/SAREC–UDSM. ISBN* 91-586-8783-1.

Rollon RN, Cayabyab NM, Fortes MD. 2001. Vegetative dynamics and sexual reproduction of monospecific *Thalassia hemprichii* meadows in the Kalayaan Island group. *Aquatic Botany* **71**: 239–246.

Rose CD, Sharp WC, Kenworthy WJ. 1999. Overgrazing of a large seagrass bed by the sea urchin *Lytechinus ariegatus* in Outer Florida Bay. *Marine Ecology Progress Series* **190**: 211–222.

Tomasko DA, Dawes C. 1989. Effects of partial defoliation on remaining intact leaves in the seagrass *Thalassia testudinum* Banks ex König. *Botanica Marina* **32**: 235–240.

Uku J, Björk M. 2005. Productivity aspects of three tropical seagrass species in areas of different nutrient levels in Kenya. *Estuarine Coastal and Shelf Science* **63**: 407–420.

Valentine JF, Heck KL. 1999. Seagrass herbivory: evidence for the continued grazing of marine grasses. *Marine Ecology Progress Series* **176**: 291–302.

Zanre R, Kithi E. 2004. Preliminary sea urchin study and kill report, Watamu. Report for the Local Ocean Trust, Watamu, Kenya.

Copyright © 2009 John Wiley & Sons, Ltd.

DOI: 10.1002/aqc