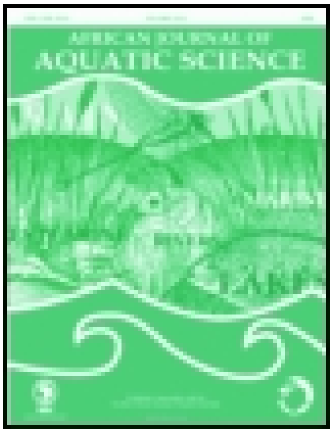

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Benthic macroinvertebrate assemblages in mangroves and open intertidal areas on the Dar es Salaam coast, Tanzania

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The assemblages of benthic macroinvertebrates in mangroves and open intertidal areas of the Dar es Salaam coast, Tanzania, was investigated in 2013–2014, revealing 56 species. Higher density, species richness and diversity were recorded in open intertidal areas, compared to nearby mangrove forests. Non-metric multidimensional scaling indicated differences in assemblages between mangrove and open intertidal samples. These differences were confirmed by analysis of similarity. SIMPER identified an average dissimilarity of 97.24% between mangroves and open intertidal samples, most of which were due to the malacostracan *Uca annulipes* and the gastropod *Cerithidea decollata*. PRIMER RELATE indicated significant correlation between macroinvertebrate assemblages and the measured physico-chemical parameters salinity, pH, redox potential and sediment particle size, whereas BIOENV and the Monte Carlo permutation test indicated that redox potential, sediment particle size and pH contributed significantly to variation in species composition. Mangroves were dominated by the gastropod *C. decollata*, and by the malacostracans *Neosarmatium africanum* and *U. annulipes*, and open intertidal areas by the bivalves *Dosinia hepatica* and *Eumarcia paupercula*. Due to the rich biodiversity in open intertidal ecosystems, it is recommended that conservation efforts along the Tanzanian coast should focus here.

Keywords: benthic macrofauna, community structure, littoral zone, Tanganyika, Western Indian Ocean

Introduction

The 800 km-long Tanzanian coastline is characterised by coastal plains and a narrow continental shelf. It includes three large islands, Unguja, Pemba and Mafia, as well as numerous small islands (Agrawala et al. 2003). The coastal shore is characterised by mangrove forests, fringing coral reefs, sandy beach lagoons, seagrass beds, algal communities and estuaries. Mangrove forests grow along sheltered sedimentary shores, especially in bays and estuaries. The most extensive forests are found in the estuaries of large rivers such as the Rufiji and around Mafia Island, although narrow strips of fringing mangroves are also common along the shore where rivers are absent (Richmond 2002; Oliveira et al. 2003). Whereas mangroves survive at the sea–land interface, seaweeds and seagrasses occupy the intertidal to subtidal zone down to depths of 50 m or more, depending on water transparency. Extensive seagrass meadows are often found between mangroves and coral reefs (Oliveira et al. 2003).

Mangrove forests are among the world's most productive ecosystems, enriching coastal waters, yielding commercial forest products, protecting coastlines and supporting coastal fisheries (Kathiresan and Bingham 2001). These forests harbour a wealth of animals such as annelids, arthropods, molluscs, fish, amphibians, reptiles, birds and mammals (Taylor et al. 2003; Faridah-Hanum et al. 2014). Mangroves and other sheltered ecosystems are generally well supplied with benthic macroinvertebrates. Because these ecosystems are used as breeding, nursery and feeding grounds for both resident and migratory species (Taylor et al. 2003; Nagelkerken and van der Velde 2004; Muhando and Rumisha 2008), high diversity is expected in healthy ecosystems.

Habitat destruction, through human activities such as the diversion of fresh water for irrigation, land reclamation and aquaculture, has been the primary cause of mangrove ecosystem loss. These impacts are likely to continue, and to worsen, as human populations expand further into mangrove forests (Kathiresan and Bingham 2001). In growing coastal cities like Dar es Salaam, these impacts are largely attributed to a high rate of population growth (Taylor et al. 2003). Signs of pollution in mangrove ecosystems along the Dar es Salaam coast have also been reported (De Wolf et al. 2001; Muzuka 2007; Rumisha et al. 2012) and the expanding coastal populations are likely to elevate the rate of pollution.

Degradation of intertidal ecosystems, due either to overexploitation, pollution or any other human activity, would compromise their ability to perform several important ecological functions. Because mangrove forests provide shelter, and are used as feeding and breeding grounds for marine fauna, most conservation efforts are usually focused on these ecosystems in the understanding that they are rich in terms of biodiversity. However Alfaro (2006) reported low abundance of benthic macroinvertebrates in mangrove forests compared to other intertidal ecosystems. Alfaro (2010) also reported less total abundance and fewer taxa of benthic macroinvertebrates in habitats with mature mangroves compared to other intertidal habitats. Thilagavathi et al. (2011) reported low abundance of meiofauna in mangrove areas compared to adjacent open intertidal areas.

Therefore, the objective of the present study was to investigate the assemblages of benthic macroinvertebrates in mangrove forests and nearby open intertidal areas of the Dar es Salaam coast, Tanzania.

Materials and methods

Study area

The climatic conditions of the Tanzanian coast near Dar es Salaam are generally hot and humid throughout the year with an average daily temperature of about 26 °C, rising to 35 °C during the hottest season in October–March. The average rainfall is 1 000 mm and the climate is often influenced by monsoon winds (Richmond 2002).

Six sampling sites were selected along the Dar es Salaam coast (Figure 1), based on the nature of the bottom substrate, the availability of mangrove forests and the distance between mangrove forests. Forests at least 10 km apart were selected. Site 1 was located in the Mtoni mangrove forest (6°52′30″ S, 39°17′30″ E). The forest occurs on both sides of the Mtoni River over a distance of about 5 km (Mlay et al. 2001). Site 2 was located at a beach in the Mtoni Estuary. Site 3 was located in a mangrove forest at the entrance of the Msimbazi River. Mangroves in this area cover an area of approximately 0.5 ha and are dominated by *Avicennia marina* (Mremi and Machiwa 2003). Site 4 was located at the Msimbazi beach (6°47′50″ S, 39°17′00″ E) on the northern side of the Dar es Salaam harbour extending northwards from the harbour mouth to the mouth of the Msimbazi River (Mlay et al. 2001). Sites 5 and 6 were located in the Mbweni fishing village 30 km north of the Dar es Salaam city centre. The mangrove forest in this area is located around 6°34′35″ S, 39°08′30″ E (Mremi and Machiwa 2003) and it has been severely affected by overexploitation. Currently, the forest is dominated by a mixture of *Ceriops tagal*, *Rhizophora mucronata* and *Avicennia marina* species. The communities living at Mbweni fishing village depend largely or wholly upon marine and coastal resources (Wagner et al. 2001).

Sampling

Sampling of sediments and benthic macroinvertebrates was conducted in February–March 2013 and August–September 2014. Samples were collected at low tide within a 40 cm × 30 cm rectangular metal frame. In the first (2013) sampling campaign, three sediment samples were randomly collected from each site. The frame was pressed into sediments up to a depth of 20 cm and all sediments within the frame were collected. About 250 g of sediments were collected from each sample for analysis of sediment particle size. The remaining sediments were sieved through a 0.5 mm metal sieve. Macroinvertebrates retained on the sieve were sorted and preserved in plastic bags with 75% ethanol. In the second (2014) sampling campaign, six sediment samples were collected from each site. Collected sediments were also sieved and macroinvertebrates were preserved in ethanol for further analysis. Redox potential and pH were measured with a portable field meter (Hanna HI 98204 pH/ORP/EC/°C meter), and salinity with an Eijkelkamp Agrisearch meter.

Laboratory analysis

Sampled macroinvertebrates were identified to species level using keys by Richmond (2002), Fernando and Fernando (2002) and Ragionieri et al. (2012). Scientific names of the identified macroinvertebrates were checked for synonyms on WoRMS (World Register of Marine Species) and GBIF (Global Biodiversity Information Facility) and edited accordingly. Analysis of sediment particle size was done by using metal sieves of 2, 1, 0.5, 0.25, 0.125 and 0.063 mm mesh. About 100 g of dry sediment was sieved through a series of metal sieves arranged in order of decreasing size from top to bottom. Sediments retained on each sieve were weighed and median sediment grain size (D_{50}) in phi scale (phi = $-\log_2$[size of a metal sieve in mm]) was determined. The sediments were categorised as

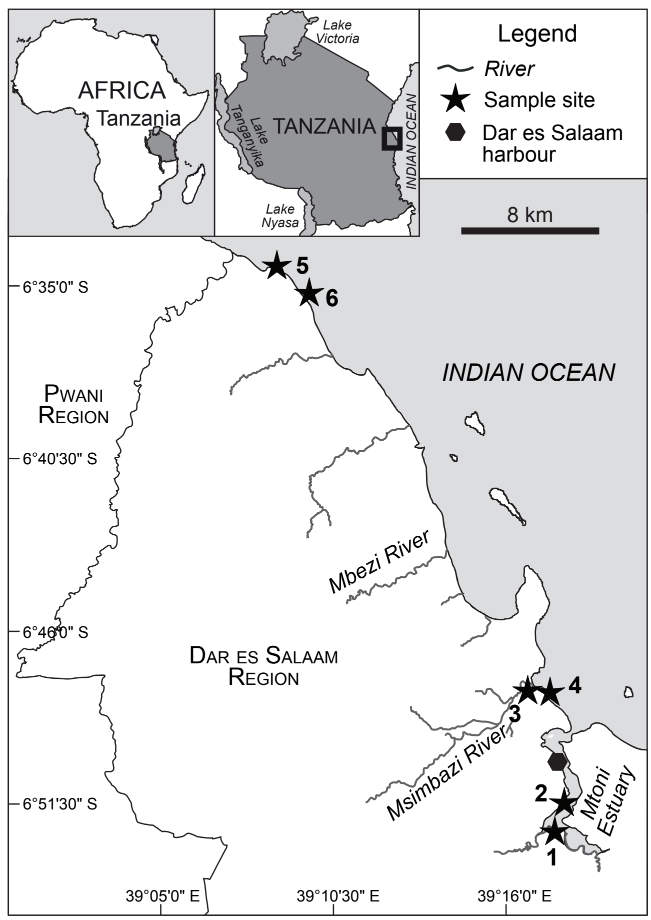

Figure 1: Map of the Dar es Salaam coast showing locations of sampling sites**.** Sites 1, 3 and 5 were located in mangrove forests, and Sites 2, 4 and 6 in open intertidal areas

coarse sand (D_{50} ≤ 1 phi), medium coarse (1 < D_{50} ≤ 2 phi) and fine sand (D_{50} > 2 phi). Small D_{50} values indicate that sediments have large particles and vice versa.

Data analysis

Shannon–Wiener diversity index, Margalef's species richness index, Pielou's evenness index and Simpson's dominance index for the collected macroinvertebrates were determined with PRIMER v. 6.1 (Clarke and Warwick 2001). Because the assumptions for parametric ANOVA were not fulfilled, variations in density, richness and diversity between open intertidal and mangrove samples were tested with the Kruskal–Wallis rank test. The same test was applied to test for variation in the measured physico-chemical parameters. This was done by using R software v. 3.1.1. Multivariate analysis of patterns in physico-chemical parameters and macroinvertebrate assemblages were performed using PRIMER and CANOCO v. 4.5, (CANOCO for Windows; ter Braak and Šmilauer 2002). One-way analysis of similarity (ANOSIM) was performed to test whether the variations in physico-chemical parameters between mangroves and open intertidal samples were significant. Differences in composition of macroinvertebrate assemblages between mangroves and the open intertidal areas were determined using non-metric multidimensional scaling (n-MDS). Abundance data were square root-transformed to reduce the influence of dominant species, and the Bray–Curtis similarity matrix was generated. ANOSIM was performed to test for differences in macroinvertebrate assemblages between mangroves and open intertidal samples. The SIMPER (similarity percentage) routine was used to determine species accounting for most of the dissimilarity between mangroves and open intertidal samples. Similarity between patterns in physico-chemical parameters and macroinvertebrate assemblages were determined using the PRIMER RELATE routine. To determine which physico-chemical parameters best explained variations in macroinvertebrate assemblages, the BIOENV procedure was performed. Canonical correspondence analysis (CCA) was performed to determine the correlation between species abundance and the measured physico-chemical parameters. Prior to this, detrended canonical correspondence analysis (DCCA) was performed to determine the length of the gradient. Canonical correspondence analysis was used because the longest gradient was larger than 4 (Lepš and Šmilauer 2003). To determine the proportion of variation explained by each physico-chemical parameter, a Monte Carlo permutation test was performed.

Results

Physico-chemical parameters

The mean pH ranged between 7.4 and 8.4, with the highest and lowest mean values being recorded at Sites 4 and 1, respectively (Table 1). Differences in pH between mangroves and open intertidal sites were not significant (Kruskal–Wallis χ^2 = 1.14, df = 1, p = 0.29). The mean redox potential of the sediments ranged between 73.5 and −254.8 mV. Differences in redox potential between open intertidal and mangrove samples were significant (Kruskal–Wallis χ^2 = 6.02, df = 1, p = 0.01). In general, mangrove sediments were associated with low redox potential. The mean sediment particle size ranged between 1.2 and 1.6 phi. Mangrove forests were associated with sediments of low particle size, and the variations in sediment particle size between open intertidal and mangrove samples were significant (Kruskal–Wallis χ^2 = 20.9, df = 1, p = 4.88E−06). The highest mean salinity was recorded at Msimbazi and the lowest at Mtoni. Variation in salinity between mangroves and open intertidal sites was not significant (Kruskal–Wallis χ^2 = 0, df = 1, p = 1). ANOSIM indicated significant differences between mangrove and open intertidal samples (Global R = 0.45, p = 0.001; number of permutations = 999).

Macroinvertebrate density and diversity

Fifty-six species of benthic macroinvertebrates were recorded during this study (Table 2). In general, density of benthic macroinvertebrates was high in open intertidal areas. Polychaetes were observed only in mangrove forest at Sites 1 and 3. Bivalves were not observed in mangrove forests, but were dominant in the open intertidal areas. Gastropods and malacostracans appeared in both habitats. With the exception of the gastropod *Amaea acuminata* and the malacostracans *Chiromantes eulimene*, *Uca annulipes* and *Uca urvillei*, malacostracan and gastropod species that occurred in the open intertidal areas did not occur in mangrove forests and vice versa. Mangrove forests were dominated by the gastropod *Cerithidea decollata* and the malacostracan *Uca annulipes.* The open intertidal areas were dominated by the bivalves *Dosinia hepatica*, *Eumarcia paupercula* and *Mactrotoma ovalina* and by the malacostracan *Uca annulipes.*

Highest richness and evenness of benthic macroinvertebrates were recorded in the open intertidal areas (Figure 2). Differences in richness and evenness between mangroves and the open intertidal areas were significant (richness: Kruskal–Wallis χ^2 = 6.46, df = 1, p = 0.01; evenness: Kruskal–Wallis χ^2 = 4.51, df = 1, p = 0.03). At

Table 1: Mean (± SE) of physico-chemical parameter values of intertidal water and sediments from the Dar es Salaam coast in 2013 and 2014

Site	pH	Redox potential (mV)	Median sediment particle size (phi)	Salinity
1	7.4 ± 0.34	−254.8	1.6 ± 0.03	38.6 ± 0.2
2	7.7 ± 0.26	−145.3	1.3 ± 0.02	38.2 ± 0.4
3	8.1 ± 0.29	73.5 ± 1.1	1.6 ± 0.01	40.4 ± 0.2
4	8.4 ± 0.04	49.8 ± 0.6	1.2 ± 0.14	40.4 ± 0.2
5	7.7 ± 0.32	−236.9	1.6 ± 0.06	39.2 ± 0.2
6	8.2 ± 0.06	59.1 ± 0.7	1.5 ± 0.03	39.4 ± 0.2

Table 2: Average density per macroinvertebrate species at sample sites on the Dar es Salaam coast, Tanzania, in 2013 and 2014

Macroinvertebrate species	Average density (ind. m^{-2})							
	Mangrove sites				Open intertidal sites			
	1	3	5	Average	2	4	6	Average
Bivalvia								
Anadara antiquata	0	0	0	0	0	32	0	11
Dosinia hepatica	0	0	0	0	3 550	0	0	1 183
Eumarcia paupercula	0	0	0	0	833	0	0	278
Gryphaeidae	0	0	0	0	0	0	13	4
Mactra cuneata	0	0	0	0	0	7	0	2
Mactra glabrata	0	0	0	0	0	20	26	15
Mactrotoma ovalina	0	0	0	0	200	33	39	91
Maoricardium pseudolima	0	0	0	0	0	32	0	11
Meropesta nicobarica	0	0	0	0	0	7	13	7
Pinna muricata	0	0	0	0	0	7	0	2
Siliqua radiata	0	0	0	0	33	0	25	19
Subtotal				0				1 623
Gastropoda								
Afrolittorina africana	0	0	0	0	0	25	0	8
Agagus agagus	0	0	0	0	0	13	0	4
Akera soluta	0	0	0	0	0	0	13	4
Amaea acuminata	0	4	74	26	0	0	39	13
Amaea sp.	0	0	0	0	0	0	188	63
Architectonica perspectiva	0	0	0	0	0	25	0	8
Bulla ampulla	0	0	0	0	0	13	0	4
Cerithidea decollata	49	0	556	201	0	0	0	0
Cerithium caeruleum	0	0	0	0	0	250	0	83
Cerithium nodulosum	0	0	0	0	0	75	0	25
Conus catus	0	0	0	0	0	13	0	4
Conus generalis	0	0	0	0	0	7	0	2
Conus litoglyphus	0	0	0	0	0	7	0	2
Conus lividus	0	0	0	0	0	13	0	4
Conus sp.	0	4	0	1	0	0	0	0
Diala sp.	0	0	0	0	0	0	25	8
Gibberulus gibberulus	0	0	0	0	0	0	13	4
Hastula lanceata	0	0	0	0	0	13	0	4
Janthina janthina	0	0	0	0	0	13	0	4
Littoraria coccinea glabrata	0	0	0	0	0	0	13	4
Mitra chrysalis	0	0	0	0	0	25	13	13
Mitra sp.	0	0	0	0	0	13	13	8
Monetaria annulus	0	0	0	0	0	13	0	4
Nerita albicilla	0	0	0	0	0	13	0	4
Notocochlis gualteriana	0	0	0	0	17	75	26	39
Oliva bulbosa	0	0	0	0	0	13	13	9
Oliva caerulea	0	0	0	0	0	38	13	17
Polinices mammilla	0	0	0	0	50	13	19	27
Tectus mauritianus	0	0	0	0	0	25	0	8
Tectus virgatus	0	0	0	0	0	13	0	4
Terebralia palustris	4	0	7	4	0	0	0	0
Volema paradisiaca	0	0	0	0	0	25	0	8
Subtotal				232				389
Malacostraca								
Chiromantes eulimene	0	0	17	6	0	25	0	8
Coenobita violascens	0	0	7	2	0	0	0	0
Metopograpsus messor	7	0	0	2	0	0	0	0
Metopograpsus thukuhar	19	0	0	6	0	0	0	0
Neosarmatium africanum	33	20	46	33	0	0	0	0
Paratylodiplax derijardi	0	0	0	0	0	13	0	4
Selatium elongatum	0	0	0	0	0	4	0	1
Sesarmops impressus	50	0	0	17	0	0	0	0
Uca annulipes	25	799	0	275	653	0	0	218
Uca urvillei	39	0	0	13	10	0	0	3
Subtotal				354				234
Polychaeta								
Glycera tesselata	0	38	0	13	0	0	0	0
Nephtys tulearensis	39	0	0	13	0	0	0	0
Subtotal				26				0
Sipunculidea								
Siphonosoma cumanense	0	13	0	4	0	0	0	0
Total	265	878	707	616	5 346	913	504	2 246

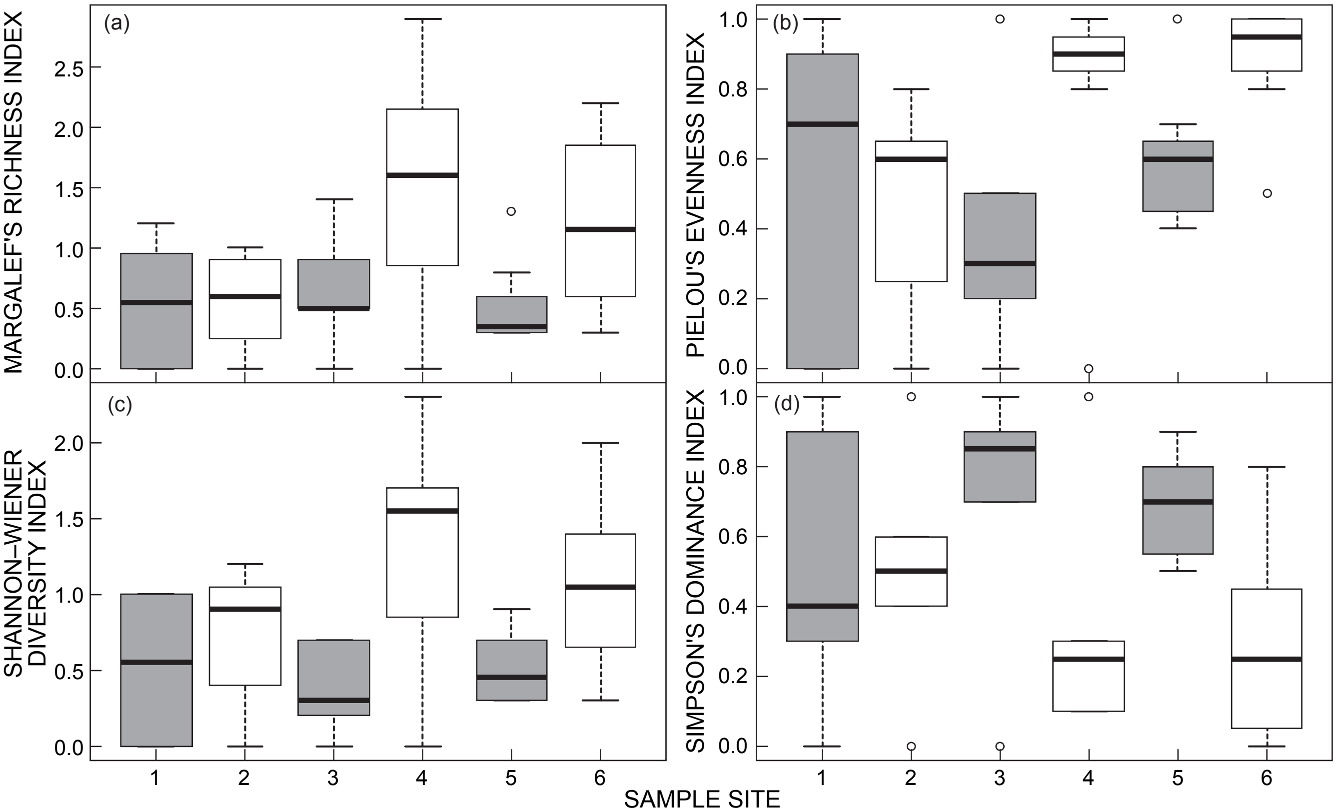

Figure 2: Box-and-whisker plots of (a) species richness, (b) evenness, (c) Shannon–Wiener diversity index and (d) Simpson's dominance index of macroinvertebrates in intertidal areas of the Dar es Salaam coast, Tanzania, in 2013 and 2014. The horizontal lines that form the bottom and the top of the boxes = 25th and the 75th percentiles, respectively. The bold horizontal line intersecting each box is the median. Whiskers represent the minimum and maximum values, respectively. Open circles represent the outliers. Grey boxes = mangrove sites, white boxes = intertidal sites

all sites, diversity was high in the open intertidal areas (Figure 2). Differences in diversity and dominance between mangroves and the open intertidal areas were significant at the 5% significance level (diversity: Kruskal–Wallis $\chi^2 = 10.88$, df = 1, $p = 0.001$; dominance: Kruskal–Wallis $\chi^2 = 8.2$, df = 1, $p = 0.004$).

Multivariate analysis of the macroinvertebrate assemblages

Non-metric multidimensional scaling identified two main groups of samples at a similarity level of 1.2% (Figure 3). While Group A contained most mangrove samples from Sites 1 and 5, Group B contained almost all open intertidal samples and some mangrove samples from Site 3. At a similarity level of 20%, more subgroups were observed in both Groups A and B. Of the five subgroups observed in Group A, one subgroup contained two samples from Site 1 and one from Site 2, another subgroup contained several samples from Sites 1 and 5, while the remaining subgroups contained samples from the same sites. Six subgroups were also observed in Group B. Of these, one subgroup contained samples from Sites 4 and 6, another subgroup contained samples from Sites 2 and 3, and the remaining subgroups contained samples from the same sites. Differences in assemblages between mangroves and open intertidal samples were confirmed by ANOSIM (Global $R = 0.274$, $p = 0.001$; number of permutations = 999). SIMPER revealed that *U. annulipes*, *C. decollata* and *Neosarmatium africanum* were responsible for similarity between mangrove samples, and *Mactrotoma ovalina*, *D. hepatica*, *E. paupercula* and *Amaea* sp. for similarity between open intertidal samples. An average dissimilarity of 97.24% between mangroves and open intertidal samples was detected. The malacostracan *U. annulipes* and the gastropod *C. decollata* contributed most of the dissimilarity (13.15% and 12.53% respectively). Other macroinvertebrates which contributed at least 4% of the dissimilarity included the bivalves *D. hepatica*, *E. paupercula* and *Mactrotoma ovalina*, the malacostracan *N. africanum* and the gastropod *Amaea* sp. (Table 3). Results from the RELATE routine indicated significant correlation between the measured physico-chemical parameters and macroinvertebrate assemblages (rho [ρ] = 0.29, p = 0.001; number of permutations = 999). BIOENV indicated that variations in the macroinvertebrate assemblages are best matched with a combination of redox potential and sediment particle size ($\rho = 0.26$, $p = 0.001$; number of permutations = 999). Monte Carlo permutation test results indicated that sediment particle size and redox potential accounted for 36.6% and 35.2% of the variation in the

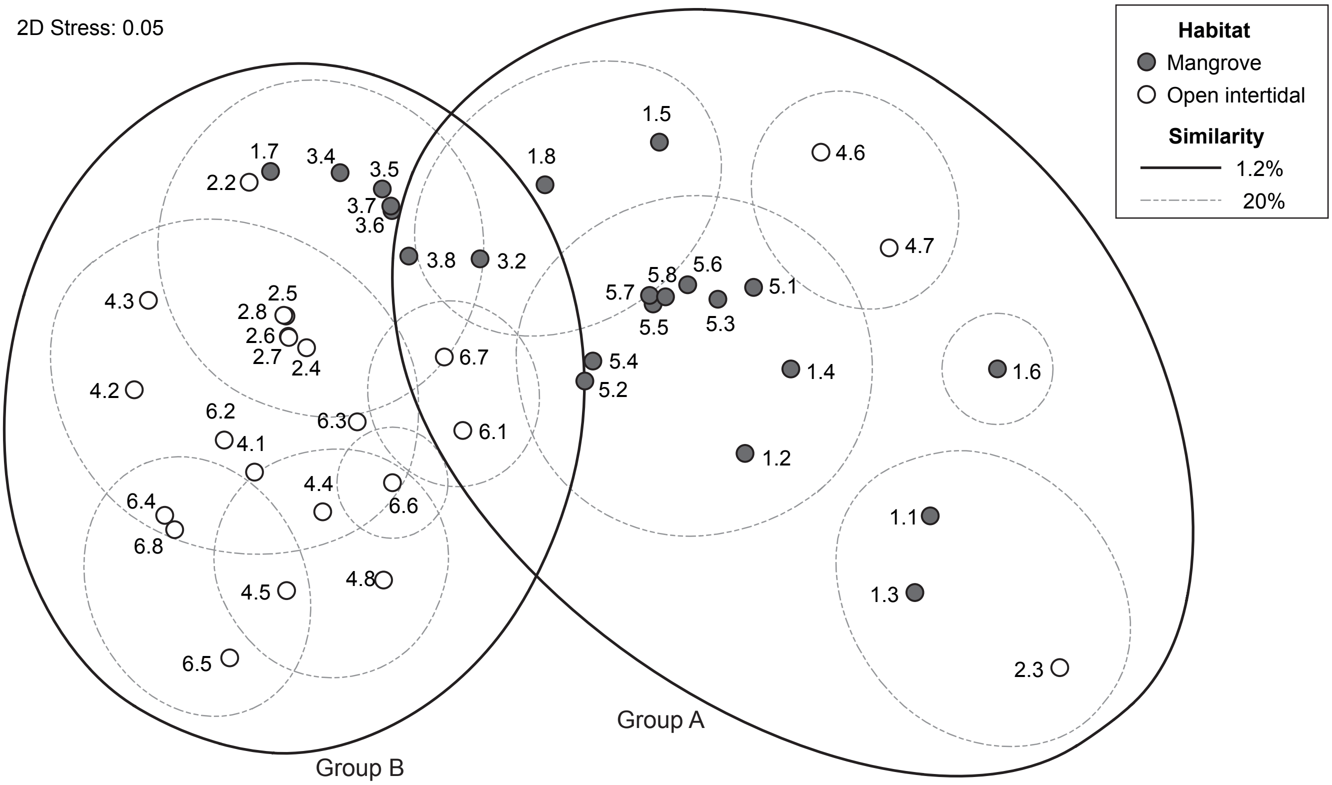

Figure 3: Two-dimensional non-metric multidimensional scaling of macroinvertebrate samples collected on the Dar es Salaam coast in 2013 and 2014. Numeric values comprise the site number followed by the sample number after the point

Table 3: Average abundance of the most important macroinvertebrate species found in mangroves and on open intertidal areas on the Dar es Salaam coast in 2013 and 2014, and percentage dissimilarity between the two habitats. Species contributing at least 4% of dissimilarity between mangroves and open intertidal areas are shown

Species	Average abundance		Average dissimilarity	Dissimilarity/SD	% Dissimilarity	Cumulative % dissimilarity
	In mangroves	In open intertidal areas				
Uca annulipes	1.52	1.19	12.79	0.70	13.15	13.15
Cerithidea decollata	1.55	0	12.18	0.72	12.53	25.68
Dosinia hepatica	0	2.81	8.03	0.52	8.26	33.94
Mactrotoma ovalina	0	0.96	5.00	0.76	5.15	39.09
Neosarmatium africanum	0.51	0	4.75	0.51	4.88	43.97
Amaea sp.	0	0.54	4.67	0.40	4.80	48.78
Eumarcia paupercula	0	1.36	3.90	0.52	4.01	52.79

macroinvertebrate assemblages, respectively. Results of the CCA showed that mangrove forests were associated with relatively low redox potential values and fine sediments (Figure 4). Canonical correspondence analysis also showed that the bivalves *D. hepatica*, *E. paupercula* and *M. ovalina* were associated with coarse sediments (low phi values).

Discussion

Macroinvertebrate density and diversity

Density of benthic macroinvertebrates in intertidal areas of the Dar es Salaam coast ranged between 504 and 5 346 ind. m^{-2} (Table 2). This is slightly lower than that reported by Lyimo et al. (2008) in intertidal areas on the east coast of Zanzibar, but slightly higher than reported by Rumisha et al. (2012) at Msimbazi and Mbweni. The density of macroinvertebrates in mangrove forests of the Dar es Salaam coast ranged between 265 and 878 ind. m^{-2}. Results of the distribution of macroinvertebrates along the Dar es Salaam coast suggest that different macroinvertebrate species have different habitat preferences. Polychaetes were observed only in mangrove forests while bivalves dominated the open intertidal areas. Gastropods and malacostracans were found in both habitats, but with the exception of the gastropod *A. acuminata* and the malacostracans *U. annulipes*, *C. eulimene* and *U. urvillei*, species that occurred in open intertidal areas did not occur in mangrove forests. Like other Epitoniidae, *A. acuminata* is a carnivorous

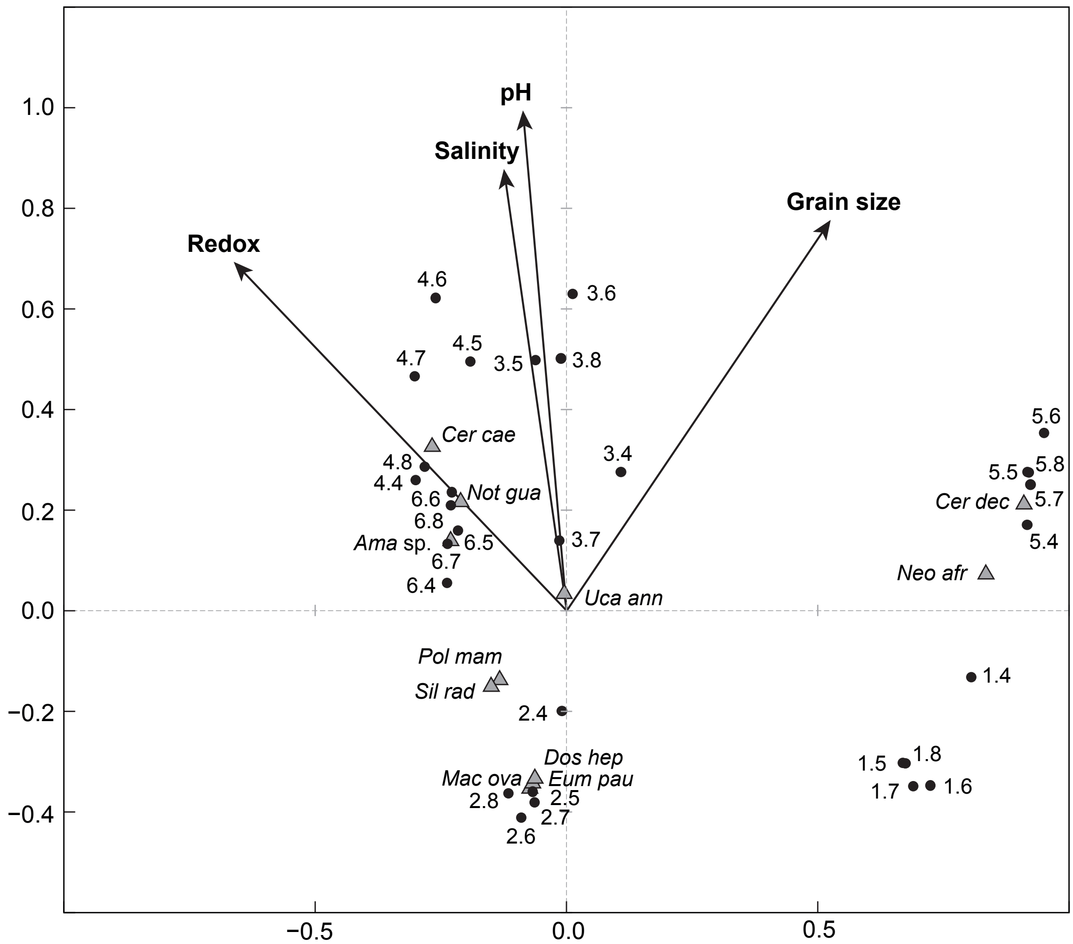

Figure 4: Triplot representation of canonical correspondence analysis showing the relationship between intertidal macroinvertebrates and measured physico-chemical parameters along the Dar es Salaam coast in 2013 and 2014. Samples are represented by filled circles (numeric values represent the site number followed by the sample number after the point); the distance between them represents their dissimilarity in species composition. Environmental variables are represented by arrows; the angle between one arrow and another represents the correlation between them. Species are represented by triangles; the distance between them represents the dissimilarity of distribution of such species across samples. Grain size = sediment particle size, Redox = redox potential, *Ama* sp. = *Amaea* sp., *Cer cae* = *Cerithium caeruleum*, *Cer dec* = *Cerithidea decollata*, *Dos hep* = *Dosinia hepatica*, *Eum pau* = *Eumarcia paupercula*, *Mac ova* = *Mactrotoma ovalina*, *Neo afr* = *Neosarmatium africanum*, *Not gua* = *Notocochlis gualteriana*, *Pol mam* = *Polinices mammilla*, *Sil rad* = *Siliqua radiata*, *Uca ann* = *Uca annulipes*

marine gastropod that occurs on a variety of substrata and feeds mainly on anthozoans, annelids, and other invertebrates (Lima et al. 2012).

Sediment texture is known to be a prime factor controlling the distribution of benthic macroinvertebrates. Bivalves are known to be associated with sand-dominated textures and polychaetes with fine sand sediments (Jayaraj et al. 2008). Sediment grain size was generally low in mangrove forests compared to that in open intertidal areas (Table 1). This is due to the fact that vegetation slows water currents and allows relatively fine sediments to settle (Granata et al. 2001; van Katwijk et al. 2010), leaving a small amount of organic matter in suspension to be used as food for filter-feeding animals. This can explain the dominance of filter-feeding bivalves such as *D. hepatica*, *E. paupercula*, *M. ovalina*, *Siliqua radiata* and *Mactra glabrata* in the open intertidal areas. Dominance of the gastropod *C. decollata* and the malacostracan *U. annulipes* in mangrove forests can also be attributed to the fact that they are detritus feeders, feeding on decaying organic matter which is generally abundant in mangrove forests. The presence of *A. accuminata* in both habitats can be explained by the fact that its distribution is not controlled by sediment texture because it is carnivorous. The presence of the fiddler crab *U. annulipes* in the open intertidal areas and mangrove forests was also reported by Richmond (2002). The species is often seen foraging from burrows in mangroves and open intertidal areas near mangroves, and it is usually dominant in *Avicennia* zones.

Species richness, evenness and diversity were generally low in mangrove forests compared to the nearby open intertidal areas (Figure 2). Low diversity of benthic macroinvertebrates in mangrove forests, compared to seagrass beds and sand flats, was also reported by Alfaro (2006). Differences in diversity and richness between mangroves and open intertidal samples could be attributed to the observed patterns in physico-chemical variables. The Kruskal–Wallis test and ANOSIM indicated significant differences in physico-chemical parameters between mangroves and open intertidal samples. This indicates that mangrove forests and open intertidal areas are quite different environments with different physical and chemical dynamics.

Multivariate analysis of the macroinvertebrate assemblages

The results of n-MDS showed two main groups of samples at an arbitrary similarity level of 1.2% (Figure 3). Group A contained most mangrove samples from Sites 1 and 5, and Group B a mixture of open intertidal samples and mangrove samples from Site 3. When the similarity level was increased to 20%, several subgroups were revealed. In Group A, one subgroup contained several samples from Sites 1 and 5. This suggests that these sites had similar species compositions. Non-metric multidimensional scaling also clustered together samples from Sites 4 and 6, and from Sites 2 and 3. Similarity in species composition between Sites 4 and 6 could be attributed to the fact that they were both located in the open intertidal, with relatively similar physico-chemical characteristics. In general, differences in assemblages between mangroves and open intertidal areas were significant (ANOSIM: Global $R = 0.27$, $p = 0.001$, number of permutations = 999). SIMPER identified an average dissimilarity of 97.24% between mangroves and open intertidal samples. The gastropod *C. decollata* and the malacostracan *U. annulipes* contributed most of the dissimilarity (Table 3). The former is a detritus feeder, feeding on decomposing organic matter in mangroves (Richmond 2002) and it was also found on mangrove tree trunks. The absence of this species from the open intertidal areas, and its dominance in mangrove forests, could be attributed to its feeding habit. The latter contributed most of the dissimilarity because it was the most abundant animal in mangrove forests, although it was also found in open intertidal areas near mangrove forests (Table 2). Other macroinvertebrates which contributed at least 4% of the dissimilarity included the bivalves *D. hepatica*, *E. paupercula* and *M. ovalina*, the malacostracan *N. africanum* and the gastropod *Amaea* sp. *Neosarmatium africanum* was found only in mangrove forests, and *Amaea* sp. only in the open intertidal areas. The bivalves contributed at least 4% of the dissimilarity because they did not occur in mangrove forests. Dominance of filter-feeding bivalves in the open intertidal and detritus feeders in mangrove forests indicates the influence of sediment texture on the feeding behaviour of benthic macroinvertebrates. This was also reported by Jayaraj et al. (2008) on the south-western coast of India and by Alfaro (2010) at Mangawhai Harbour, New Zealand. Sediment particle size in the studied area was generally low in mangrove forests compared to open intertidal areas (Table 1). Results from the RELATE routine showed that variations in species composition between mangrove and open intertidal samples were significantly associated with the measured physico-chemical parameters ($\rho = 0.29$, $p = 0.001$, number of permutations = 999). BEST/BIOENV indicated that variations in macroinvertebrate assemblages were best correlated with sediment particle size and redox potential ($\rho = 0.26$, $p = 0.001$, number of permutations = 999). Results of the Monte Carlo permutation test showed that, among the measured physico-chemical parameters, sediment particle size, redox potential and pH contributed significantly to variations in species composition ($p < 0.05$). Sediment particle size, redox potential and pH accounted for 36.6%, 35.2% and 22.07% of the variations in macroinvertebrate assemblages, respectively. Canonical correspondence analysis indicated that mangrove samples from Mtoni (Site 1) and Mbweni (Site 5) were associated with relatively low sediment particle size and redox potential (Figure 4). This can account for the observed similarities in species composition between these sites. Canonical correspondence analysis also showed that the gastropod *C. decollata*, which accounted for most of the dissimilarity between mangrove and open intertidal areas (Table 3), was dominant in mangrove forests. This gastropod can withstand low redox potential in mangrove sediments because it can climb mangrove trees (Vannini et al. 2008). This could be an additional reason for its dominance in the mangrove forests. The CCA also showed that the malacostracan *N. africanum* was also dominant in mangrove forests. This species is usually restricted to the landward *Avicennia marina* zone (Dahdouh-Guebas et al. 2002), where redox potential of sediments might not be very low. The CCA also showed that the open intertidal areas were characterised by relatively high pH and redox potential. This could be a reflection of well-oxygenated conditions resulting from regular tidal influence, and it could account for similarities in species composition between open intertidal samples. The preference of the bivalves *D. hepatica*, *E. paupercula*, *M. ovalina*, *M. glabrata* and *S. radiata* for relatively high pH and redox potential explains their dominance in open intertidal areas (Figure 4). These bivalves were also associated with coarse sediments and they were very abundant in the open intertidal area at Mtoni (Site 2). Generally, shellfish-gathering activities are quite intense in open intertidal areas at Msimbazi (Site 4) and Mbweni (Site 6) compared to Mtoni (Site 2). This can account for the low abundance of bivalves at Msimbazi and Mbweni and the dominance of *D. hepatica* and *E. paupercula* at Mtoni.

This study revealed that density, species richness, evenness and diversity of benthic macroinvertebrates along the Dar es Salaam coast is low in mangrove forests compared to that in the nearby open intertidal areas. While conservation efforts are focused on mangrove forests, open intertidal ecosystems should also be taken into consideration due to their rich biodiversity. Because the present study was restricted to intertidal areas of the Dar es Salaam coast, it is recommended that a similar study be conducted along the entire Tanzanian coast, to give a broader picture. It is also recommended that future studies should employ other sampling tools such as grabs or pitfall traps, because the metal frame used in the present study was not very effective against fast-crawling animals such as crabs. The present study provides baseline information on the assemblages of benthic macroinvertebrates along the Dar es Salaam coast.

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