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Trace metal pollution and its influence on the community structure of soft bottom molluscs in intertidal areas of the Dar es Salaam coast, Tanzania

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ABSTRACT

The influence of trace metal pollution on the community structure of soft bottom molluscs was investigated in intertidal areas of the Dar es Salaam coast. Significant enrichment of As, Mn, Mo, Sb, and Zn in sediments was recorded. Redundancy analysis indicated that trace metal pollution contributed 68% of the variation in community structure. Monte Carlo permutation test showed that As and Sb contributed significantly to variation in species composition. *T*-value biplots and van Dobben circles showed that the gastropods *Acteon fortis*, *Assiminea ovata*, and *Littoraria aberrans*, were negatively affected by As and Sb, while the bivalve *Semele radiata* and the gastropod *Conus litteratus* were only negatively affected by As. Bioaccumulation of As, Cd, Cu, Mo and Zn occurred in the bivalve *Mactra ovalina* and the gastropod *Polinices mammilla.* This calls for regular monitoring and management measures.

1. Introduction

Molluscs and other benthic macroinvertebrates have been used extensively in biomonitoring studies to assess the extent of anthropogenic pollution. Invertebrates are preferred, because they are diverse, highly adapted to a wide range of natural conditions and most are benthic with a limited mobility (Braccia and Voshell, 2006).

The community structure of benthic macroinvertebrates can be influenced by several physicochemical and biological factors. Due to complexity of the environment, it is difficult to identify the parameter that is affecting the invertebrates. Complexity of the environment is caused by interdependence among several environmental variables (Feld and Hering, 2007). For instance, waves and currents determine sediments particle size and organic matter content, which in turn determine the occurrence of invertebrate functional feeding groups (Lomovasky et al., 2010). Sediment particle size (Van Hoey, 2004; Jones et al., 2011), salinity (Pinder et al., 2005), availability of food and nutrients (Frost et al., 2009), anthropogenic pollution, and pH, are among the factors influencing the community structure of benthic macroinvertebrates. Pollution affects the community structure of benthic macroinvertebrates, because they exhibit species-specific responses to certain anthropogenic stressors (Goto and Wallace, 2010). Introduction of contaminants into the environment results in loss of sensitive species (Dauvin, 2008), while tolerant species may grow faster since their competitors have been eliminated by the toxicant (Connell et al., 1999). This results in a decrease of species diversity, species number, species abundance, and a shift in species composition.

Trace metals pollution is a serious problem in many developing countries, such as Tanzania. This is mainly due to poor infrastructure, use of inappropriate and insufficient technology, and failure of local authorities to act responsibly by enforcing existing laws and regulations (Linden and Lundin, 1995). Rapid expansion of coastal cities like Dar es Salaam also puts pressure on coastal ecosystems due to increase in land based activities, such as urbanisation and industrialisation, resulting in increased amount of domestic and industrial wastes. This combined with stress resulting from discharge of municipal sewage and recreational activities, puts benthic fauna like molluscs at a great risk.

Efforts have been taken to assess the concentration of trace metals in water, sediments, and fauna of the Dar es Salaam coast (De Wolf et al., 2001; Mtanga and Machiwa, 2007; Muzuka, 2007; Kruitwagen et al., 2008; De Wolf and Rashid, 2008). However, very little efforts have been made to assess the influence of these pollutants on the community structure of marine fauna, and hence very little is known about the impact of these pollutants on the community structure of sediment dwelling biota. Thus, the objective of the present study was to assess the extent of trace metal pollution and its influence on the community structure of soft bottom molluscs in intertidal areas of the Dar es Salaam coast, Tanzania.

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2. Materials and methods

2.1. Study site

This study was carried out in intertidal areas of the Dar es Salaam coast (Fig. 1). Samples were collected from Mbweni, Kunduchi, Msasani, Msimbazi, Mjimwema and Geza Ulole. Mbweni (site 1) and Kunduchi (site 2) are located 40 and 25 km north of the Dar es Salaam city centre respectively. With the exception of a few hotels built at Kunduchi (De Wolf et al., 2001) these areas are not heavily populated. The only industry located in the area is a cement factory.

Msasani (site 3) and Msimbazi (site 4) are located about 10 and 2 km north of Dar es Salaam city centre respectively. These areas have been reported to be heavily polluted, mainly by streams and rivers that drain from the city (De Wolf et al., 2001). Msimbazi river, which drains from the Dar es Salaam city centre is the main source of domestic and industrial contaminants for the Msimbazi mangroves and other areas in its vicinity. This area is also close to the Dar es Salaam harbour, which is located in the Mtoni estuary. High concentration of trace metals are reported for the Mtoni estuary which is attributed to a textile mill located on the banks of Kizinga stream (Kruitwagen et al., 2008).

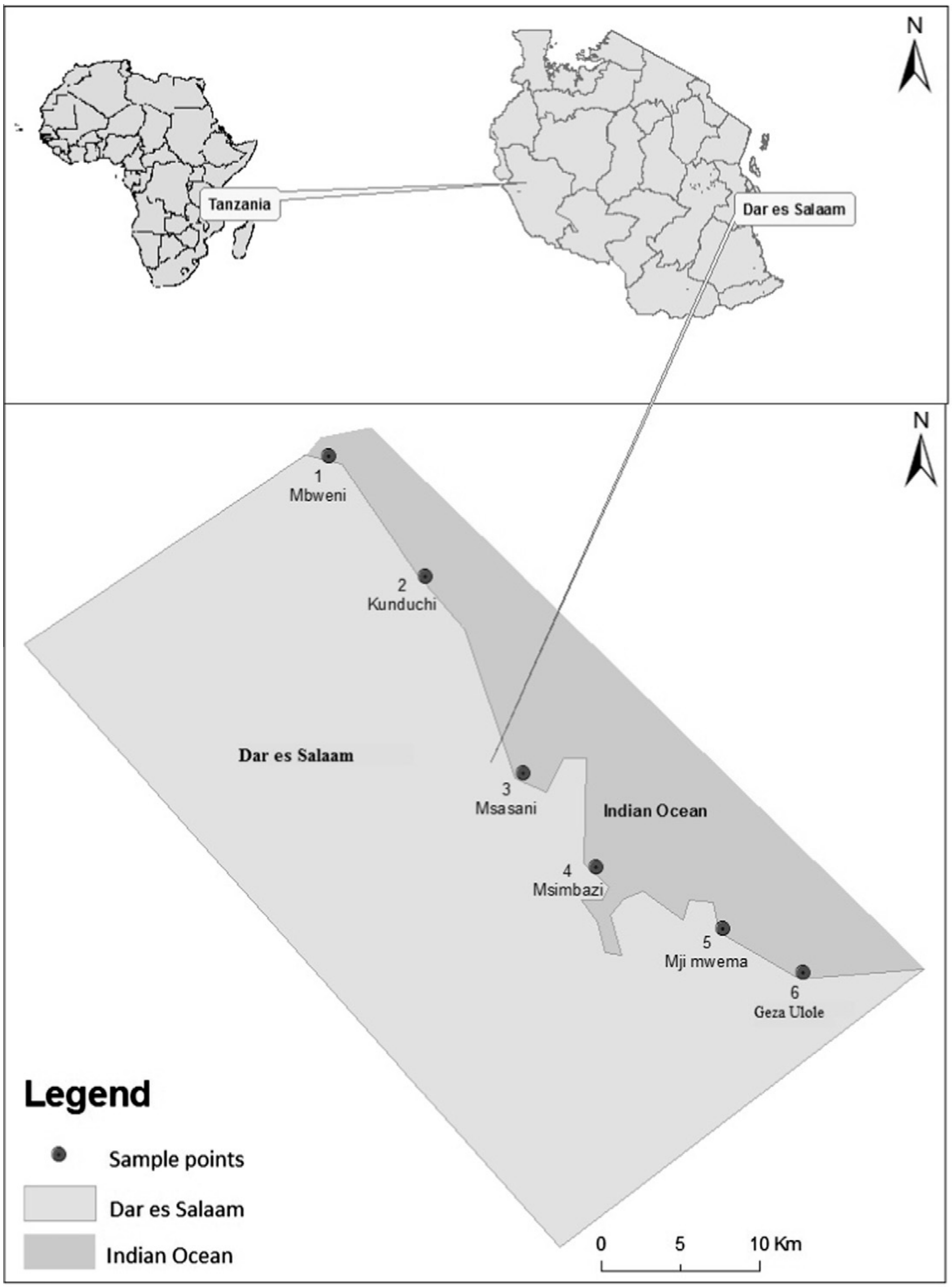

Fig. 1. Map of the Dar es Salaam coast indicating sampling sites.

Mjimwema (site 5) and Geza Ulole (site 6) are located on the south coast of Dar es salaam in a distance of about nine and 19 km from the city centre, respectively. These areas are not heavily populated but compared to other sample sites, agricultural activities are more intense in this region.

2.2. Sampling

Sampling was done at low tide in August and September 2010. Sediment samples for analysis of benthic macroinvertebrates were collected by using a rectangular corer with a surface area of 0.09625 m^2. The corer was pushed into the sediment and sediment was taken to a depth of 20 cm. At each station a total of three samples were randomly collected in the intertidal. From each sample about 200 g of sediments for analysis of trace metals was collected with a plastic spoon and placed in small polyethylene (PE) plastic bottles. The plastic bottles containing sediments were stored frozen at −20 °C. The remaining sediment was sieved through a 0.5 mm sieve and the organisms retained preserved in 75% ethanol for laboratory analysis. Salinity of the water was measured with a hand held refractometer (VWR international, Pennsylvania).

2.3. Laboratory analysis

2.3.1. Identification of macrofauna

In the laboratory, the macrofauna was sorted to separate molluscs from other macroinvertebrates. Sorted molluscs were identified to the lowest taxonomic level possible according to Richmond (2002) and counted.

2.3.2. Trace metals analysis in sediment samples

About 100 g of sediment from each sample was taken and placed in small PE bottles. The samples were then lyophilised overnight and later placed in a desiccator for 30 min. Then the samples were passed through a 1 mm sieve, homogenised and stored in sealed plastic bottles until extraction. Digestion of sediments was done with a CEM Mars 5 Microwave. From each sample, 0.2 g of sediment was weighed and placed in a digestion Teflon vessel. One analysis setup consisted of 14 Teflon vessels. Three Teflon vessels contained standard samples, two blanks (only with reagents), and nine of them contained the sediment samples. Six millilitres of highly purified concentrated hydrochloric acid (HCl) and 2 ml of nitric acid (HNO_3; 65%) were added to each Teflon vessel. Then the Teflon vessels were closed, tightened with the torquing tool, assembled, and placed in the microwave. Samples were digested at 180 °C and 200 psi (13.609 atm) maximum pressure for 15 min. After a holding time of at least 15 min, the samples were removed from the microwave, and after cooling down, the Teflon vessels were opened. Forty millilitres of deionised water were added to each sample, and the resulting mixture was transferred to PE bottles for further analysis. The samples were diluted, and the concentration of trace metals was analysed with a High Resolution Inductively Coupled Plasma Mass Spectrometer (HR-ICP-MS). Marine sediment standard reference material, MESS-2 was analysed for quality control at each extraction step. Measured and certified concentration was in good agreement. Recoveries ranging from 56.1% to 99.7% were obtained for the studied trace metals (Al = 56.1%, As = 88.2%, Cd = 99.7%, Co = 98.1%, Cr = 64.3%, Cu = 76.8%, Fe = 86.7%, Mn = 88.8%, Ni = 81%, V = 79.5%, and Zn = 97.8%).

2.3.3. Trace metals analysis in tissue samples (*Mactra ovalina* and *Polinices mammilla*)

Sampled organisms were cleaned with deionised water and air-dried. Then, shells were broken and individual soft tissue samples digested with highly purified concentrated nitric acid (HNO_3; 65%) and hydrogen peroxide (H_2O_2; 30%) in a microwave. The concentration of trace metals was analysed with a HR-ICP-MS. To verify the accuracy of the analytical method, blanks and standard reference materials were included.

2.3.4. Determination of organic matter content in sediments

Sediment organic carbon content was analysed with a CN analyser. Prior to the analyses, dried sediment samples were placed in tin cups and weighed. Then, a few drops of HCl were added to the samples to remove inorganic carbon. The samples were dried in an oven at 56 °C for 4 h and cooled in a desiccator for 30 min. The concentration of particulate organic carbon (POC) was determined with a CN analyser.

2.3.5. Determination of sediments grain size distribution

Sediment grain size distribution was analysed by using a shaker and metal sieves (2, 1, 0.5, 0.25, 0.125 and 0.063 mm). Sediments were categorised as gravel (>2 mm), very coaser sand (>1 mm), coaser sand (>0.5 mm), medium coarse sand (>0.25 mm), fine sand (>0.125 mm), very fine sand (>0.063 mm) and mud (silt and clay; <0.063 mm). Then sediment median grain size (D_{50}) in Phi scale was determined. The smaller the D_{50}, the coarse the sediments and vice versa.

2.4. Data analysis

2.4.1. Analysis of trace metals in sediments and other physicochemical parameters

One way Analysis of Variance (ANOVA) was used to test the differences between sites in salinity, trace metals concentration, sediment median grain size, and organic matter content. Whenever the assumptions for ANOVA were not fulfilled, a non parametric Kruskal–Wallis ANOVA by ranks was used. This was done by using the software R (version 2.13.1). Correlation analysis was done in order to determine the degree of association between the measured physicochemical variables. Whenever the correlation was significant, regression analysis was performed in order to determine if there is a significant relationship.

To determine whether the measured concentrations of trace metals are from anthropogenic or natural origin, an enrichment factor was calculated. The enrichment factor was calculated by using the equation;

$$Ef = \frac{\frac{CM}{CAl}(sample)}{\frac{CM}{CAl(Background)}},$$

Ef = enrichment factor; CAl = concentration of aluminium.

The concentration of trace metals (CM) was normalised to the concentration of Al, both in the background and in the sample. Normalisation accounts for the accumulation affected by the variation in the mobility of different trace metals. The background concentration was taken from Wedepohl (1995), which represents the concentration of the metals in the upper continental crust. Five contamination categories were identified based on Ef (Table 1).

The concentration of trace metals in sediments was also compared with sediment quality guidelines in order to establish if the sediments are toxic to marine fauna or not. Toxic units (TU) were calculated for each trace metal representing the proportion of metal concentration in the sample over the threshold effect level (TEL). TEL data were taken from (Macdonald et al., 1996). Generally, a TU value larger than one indicates that the sediments are potentially toxic to aquatic fauna.

2.4.2. Analysis of biological data

Density, evenness, Simpson dominance index, and Shannon–Wiener diversity index were calculated for each site by using

Table 1
Contamination categories based on the enrichment factor (Ef) (Yongming et al., 2006).

Ef	Contamination category
<2	Deficiency to minimal enrichment
2–5	Moderate enrichment
5–20	Significant enrichment
20–40	Very high enrichment
>40	Extremely high enrichment

PRIMER (version 6.1; Plymouth Routines In Multivariate Ecological Research; PRIMER-E Ltd.; Clarke and Warwick, 2001). To compare sites, a one way ANOVA was done with the software R. Whenever the assumptions for ANOVA were not fulfilled, a non-parametric Kruskal–Wallis ANOVA by ranks was used. Correlation analysis was performed to determine the degree of association between biodiversity indices and trace metals concentration, and other physicochemical parameters. Regression analysis was performed for parameters with a significant correlation.

Direct gradient analysis of the community structure was done with the software CANOCO (version 4.5; ter Braak and Šmilauer, 2002). Redundancy analysis (RDA) was performed in order to determine the relation between the measured physicochemical variables (mainly trace metals) and species. Prior to RDA, Detrended Canonical Correspondence Analysis (DCCA) was performed in order to determine the length of gradient of the dataset (extent of species turnover). In this case, a linear method was used because the length of gradient was less than 4 (Lepš and Šmilauer, 2003). Monte Carlo permutation test was performed to determine whether the relation between species abundances and the measured physicochemical variables was significant. *T*-value biplots and van Dobben circles were created in order to analyse the relation between the significant physicochemical parameters and species abundance.

2.4.3. Bioaccumulation of metals in tissues

A biota-sediment bioaccumulation factor (BSAF) was calculated for each metal in order to assess the extent by which metals occur in molluscs and associated sediments. This was calculated by using the equation,

$$BSAF = \frac{Cx}{Cs}$$

where Cx and Cs are concentrations in biota and sediments, respectively.

If the BSAF is higher than one, bioaccumulation of the contaminant is considered to occur.

3. Results

3.1. Spatial distribution of trace metals in sediments

The average concentration of trace metals in sediments is shown in Table 2. Site 1 and 3 showed high concentrations of Cu, Fe, V, and Zn compared to other sites. Highest concentration of As and Cd were recorded at site 5 and 6. Concentration of Cr, Mn, and Tl was high at site 1 and 5, while the concentration of Al, Co, Ni and Pb was high at site 1, 2, and 3. The concentration of Sb was high at site 3 and the concentration of Mo was high at site 1. Generally, the concentration of Al, As, Co, Ni, Mo, Pb, and V, increased northward and southward of site 4.

3.2. Relation between trace metals and other physicochemical variables

Iron was significantly positively correlated with Al, Co, Cr, Cu, Ni, Pb, Sn, V and Zn. Also Mn was significantly positively correlation with As, Cr, and Tl (Table 3).

Salinity at the sample sites ranged between 36.33 and 39 ppt, but significant differences were not found (Fig. 2a). In addition, the correlation between trace metals and salinity was also not significant ($P > 0.05$). Organic matter content was highest at site 5 and 6 and lowest at site 4 (Fig. 2b). The differences in organic matter content between sites were not significant. Organic matter content in sediments were significantly positively correlated with As and Tl concentration. The regression of As and organic matter was significant ($F_{(1,16)} = 6.69$, $P = 0.02$). The regression of Tl and organic matter was also significant ($F_{(1,16)} = 7.37$, $P = 0.015$).

Sediments at site 4 were coarse sand and at site 2 and 3 medium coarse sand. Sediments at sites 1, 5 and 6 were mostly fine-grained sediments (Fig. 3). The differences in sediments particle size were significant ($P < 0.05$). The correlation between sediments particle size and Al, As, Cd, Cr, Fe, Mn, Ni, Tl, and V, was also significant ($P < 0.05$). The regression of Al, Cr, Fe, Mn, Ni, and V, on sediment particle size was not significant ($P > 0.05$). However, regression of As, Cd and Tl on sediments particle size was significant ($P < 0.05$).

3.3. Sediments pollution and toxicity

3.3.1. Assessment for enrichment/anthropogenic influence

Generally, there was no enrichment of Tl at all sites except site 5. There was no significant enrichment and anthropogenic pollution of Co, Cu, Fe, Ni, Sn and V at all sites. However all sites were significantly polluted by As, Mo and Sb. Extreme high pollution of Sb was observed at site 4 and 5, while enrichment of Mo was very high at site 1. High enrichment of As was observed at site 5 and 6 (Table 4).

3.3.2. Toxicity assessment

Results indicate that the toxic units for As, Cd, Cr, Cu, Ni, Pb, and Zn were less than 1 (Fig. 4). Generally, Cd, Pb, and Zn had low TU values compared to other trace metals.

3.4. Univariate analysis of molluscs community structure

A total of 1258 individuals belonging to 84 different species were recorded during this study and most of these species were gastropods. The abundance of bivalves was high at site 4 and very low at site 1, 3 and 6.

Density of molluscs was high at site 6 and 3 and low at site 4 (Fig. 5). The differences in density between sites were significant ($P < 0.05$). Tukey multiple comparison of means indicated that the differences between site 2 and 6, 2 and 3, 4 and 1 as well as 4 and 6 were significant.

The highest diversity was recorded at site 1 and 6 and the lowest at site 4 (Fig. 6). The highest dominance index was recorded at site 3 and the lowest at site 1 and 6. The differences in diversity between sites were significant ($P < 0.05$). Tukey multiple comparison of means indicated that the differences between site 1 and 4, 2 and 6, as well as 4 and 6 were significant ($P < 0.05$). The differences in dominance between sites were also significant ($P < 0.05$). Results of Tukey multiple comparison of means indicated that differences between site 1 and 4 as well as 3 and 6 were significant.

3.4.1. Relation between density and diversity indices as well as physicochemical variables

Density was significantly positively correlated with Al and Ni ($P < 0.05$), but the regression of density on Al and Ni was not

Table 2
Average concentration (µg/g dry weight) of trace metals in intertidal sediments at the Dar es Salaam coast, Tanzania. For sample sites see Fig. 1.

Site	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sb	Sn	Tl	V	Zn
1	5128	0.9	0.01	2.57	9.6	2.1	5352	219	8.81	2.88	2.20	0.10	0.40	0.021	13.7	9.3
2	1824	0.4	0.02	0.64	3.2	0.8	1498	17	0.38	0.98	1.50	0.11	0.08	0.012	3.9	7.5
3	1737	0.3	0.02	0.65	3.9	1.0	1671	38	0.39	1.02	1.24	0.15	0.11	0.014	4.4	8.2
4	461	0.2	0.01	0.28	1.0	0.3	461	23	0.23	0.35	0.80	0.10	0.04	0.002	1.1	4.0
5	815	1.2	0.04	0.21	5.0	0.5	993	68	0.21	0.67	0.75	0.14	0.03	0.041	1.8	2.9
6	918	1.3	0.03	0.24	3.0	0.3	941	51	0.60	0.84	0.81	0.11	0.05	0.019	2.4	2.6

Table 3
Correlation between trace metals from intertidal sediments at the Dar es Salaam coast, Tanzania.

	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sb	Sn	Tl	V	Zn	Gs	O.M
As	0.3																	
Cd	0.4	0.7*																
Co	0.8*	−0.1	−0.2															
Cr	0.8*	0.6*	0.7*	0.4														
Cu	0.8*	0.1	0.1	0.9*	0.7*													
Fe	0.9*	0.3	0.2	0.9*	0.8*	0.9*												
Mn	0.3	0.6*	0.4	0.2	0.6*	0.3	0.4											
Mo	0.5*	0.1	0	0.4	0.3	0.5*	0.4	−0.2										
Ni	0.9*	0.5*	0.5*	0.5*	0.8*	0.6*	0.7*	0.3	0.5*									
Pb	0.8*	0.1	0	0.9*	0.6*	0.9*	0.9*	0.3	0.5	0.6*								
Sb	0.2	0.1	0.3	0	0.3	0.3	0.2	0.3	0.2	0.2	0.3							
Sn	0.9*	0	0	0.9*	0.6*	0.9*	0.9*	0.2	0.6*	0.7*	0.9*	0.2						
Tl	0.5*	0.7*	0.9*	0	0.8*	0.2	0.4	0.5*	0.1	0.6*	0.2	0.3	0.2					
V	0.9*	0.2	0.1	0.9*	0.7*	0.9*	1.0*	0.4	0.4	0.7*	0.9*	0.1	0.9*	0.3				
Zn	0.6*	−0.3	−0.2	0.8*	0.3	0.8*	0.7*	−0.1	0.5	0.5	0.8*	0.2	0.8*	−0.1	0.7*			
Gs	0.5*	0.8*	0.7*	0.2	0.9*	0.4	0.5*	0.8*	0.0	0.6*	0.3	0.2	0.3	0.8*	0.5	0		
O.M	0.1	0.6*	0.5	−0.3	0.4	−0.1	0.1	0.3	−0.1	0.4	−0.1	0	−0.2	0.6*	0	−0.4	0.5*	
Sal	0.2	−0.3	0.1	0.1	0.3	0.3	0.2	0.1	−0.2	0	0.2	0.3	0.1	0.2	0.2	0.4	0.1	−0.2

Gs = Median grain size, O.M = organic matter, Sal = salinity.
* Significant correlation ($P < 0.05$).

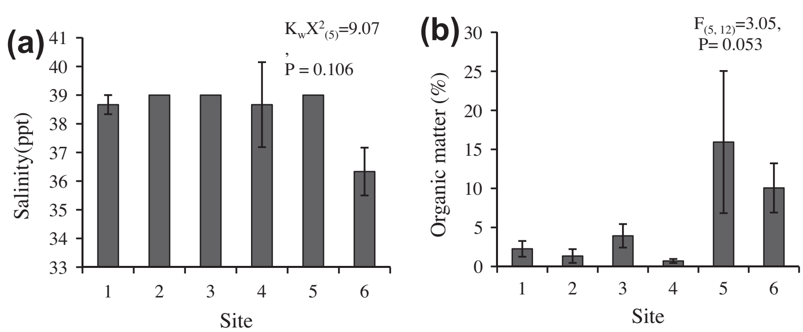

Fig. 2. Mean salinity (a) and organic matter content (b) of intertidal sediments at the Dar es Salaam coast, Tanzania (±SE). For sample sites, see Fig. 1.

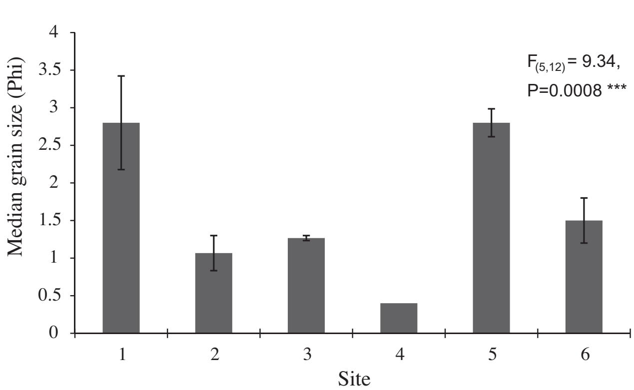

Fig. 3. Median sediment particle size (±SE) of intertidal sediments at the Dar es Salaam coast, Tanzania (±SE). For sample sites, see Fig. 1.

significant ($P > 0.05$). Diversity was significantly positively correlated with As, Mn, and Ni ($P < 0.05$). Regression of diversity on As was significant ($F_{(1,16)} = 14.28$, $P = 0.0016$), while the regression of density on Mn and Ni was not. Correlation of dominance and trace metals was not significant ($P > 0.05$) (Table 5).

Diversity was significantly correlated with sediments particle size and organic matter content ($P < 0.05$). The regression of diversity on sediments particle size was also significant ($F_{(1,16)} = 6.6$, $P = 0.02$) while regression of diversity on organic matter content was not ($P > 0.05$). The correlation of density and dominance to sediment particle size as well as salinity and organic matter content was not significant.

3.5. Multivariate analysis of mollusc community structure

Redundancy analysis (RDA) showed that site 2 and 4 were similar in terms of species composition as well as site 1 and 5. Site 3

Table 4
Enrichment factor for intertidal sediments at the Dar es Salaam coast, Tanzania (±SE). For sample sites, see Fig. 1.

Site	As	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sb	Sn	Tl	V	Zn
1	6.9*	2.2	3.2	4.1	2.3	2.6	6.3*	95.0***	2.3	2.0	5.0*	2.4	0.4	3.9	2.7
2	8.4*	6.5*	2.3	3.8	2.3	2.1	1.4	11.6*	2.2	3.7	14.9*	1.4	0.7	3.1	6.1*
3	6.9*	7.2*	2.4	4.9	3.2	2.4	3.2	12.5*	2.4	3.2	21.2**	2.0	0.8	3.7	7.0*
4	17.5*	9.0*	4.0	4.6	4.1	2.5	7.5*	27.2**	3.1	7.9*	54.3***	2.6	0.4	3.4	12.8*
5	55.6***	38.6**	1.6	13.6*	3.1	3.1	12.3*	14.3*	3.3	4.2	42.3***	1.3	5.2*	3.2	5.3*
6	56.4***	21.6**	1.7	7.1*	1.8	2.6	8.2*	36.0**	3.7	4.0	29.3**	1.5	2.1	3.8	4.2

* Significant enrichment.
** Very high enrichment.
*** Extreme high enrichment.

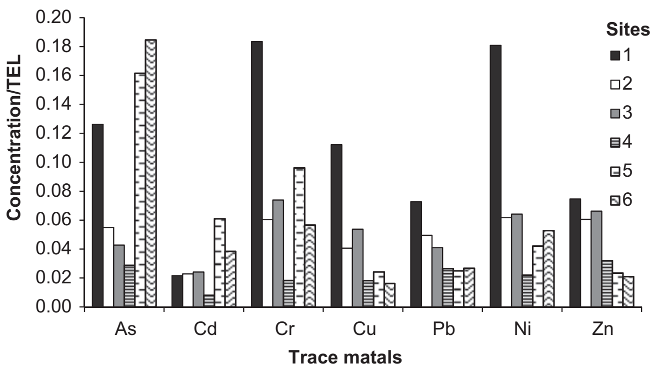

Fig. 4. Comparison of trace metals concentration with sediments quality guidelines. For sample sites, see Fig. 1.

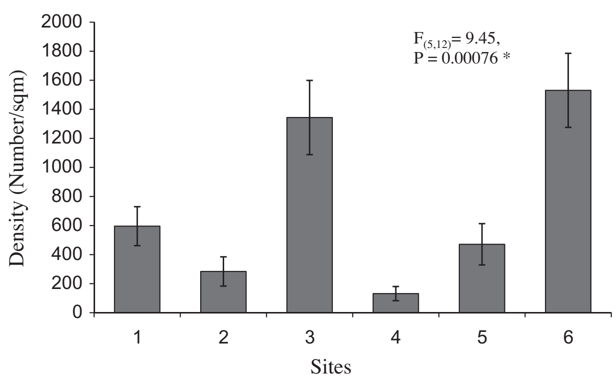

Fig. 5. Mean density of intertidal molluscs (±SE) at the Dar es Salaam coast, Tanzania. For sample sites, see Fig. 1.

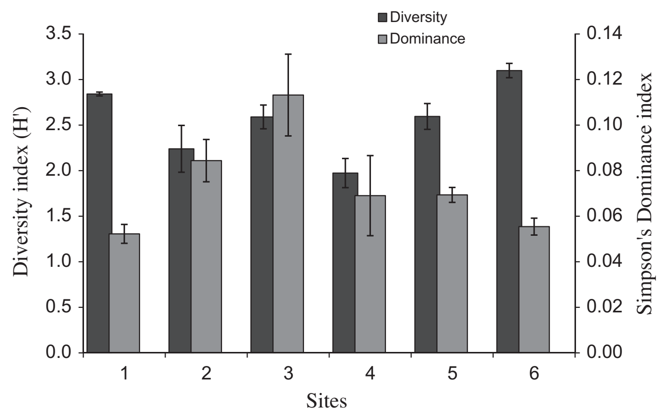

Fig. 6. Average Shannon–Wiener diversity index and Simpson's dominance index for intertidal molluscs at the Dar es Salaam coast, Tanzania (±SE). For sample sites, see Fig. 1.

and 6 were dissimilar from other samples sites. Axis 1 and 2 of the RDA explained 28.7% and 17.2% of the variations in species composition respectively. All environmental variables explained 79% of the variation in species abundance. Trace metals alone explained 68% of the variations in species composition.

RDA also showed that the gastropod *Cerithium rostratum, Cerithium sp., Mitra honkeri, Mitra sp.*, and *Nerita sp.*, were associated with high values of As, Cd, Mn, Mo, Ni, Pb, Tl, sediment grain size and organic matter. The gastropods *Akera soluta* and *Crithium citrinum* were associated with high values Sb, Zn and salinity (Fig. 7). The bivalve *Semele radiata*, and the gastropods, *Acteon fortis, Assiminea ovata, Cypraea moneta, Conus litteratus, Littoraria aberrans, Pterygia nucea*, and *Phasianella nivosa* were associated with low values of most trace metals and other physicochemical variables.

The significance of each environmental variable was tested by Monte Carlo permutation test on RDA. Arsenic explained significantly 18% and Sb 12% of the variation in species composition ($P < 0.05$). *T*-value biplots for the significant environmental variables (As and Sb) were created in order to analyse the relation between these metals and species.

Arsenic was positively correlated with the gastropods *C. rostratum*, *M. honkeri*, and *Mitra sp.* (Fig. 8). Both As and Sb were significantly negatively related with the gastropods *A. fortis*, *A. ovata*, and *L. aberrans* (Figs. 8 and 9). Arsenic was also significantly negatively related with the bivalve *S. radiata* and the gastropod *C. litteratus*.

3.6. Concentration of metals in tissues of molluscs (P. mammilla and M. ovalina)

The average concentration of Al, Cr, Fe, Mn, Ni, Pb, Sb, Sn, Tl, V, and Zn in *M. ovalina* at site 2 was at least two times higher than in *P. mammilla* (Table 6). The biota-sediments bioaccumulation factor indicated that bioaccumulation of As, Cd, Cu, Mo, and Zn occurred in both species and that there was none for Al and Fe (Table 7). All other trace metals showed bioaccumulation at some sites.

4. Discussion

4.1. Spatial distribution of trace metals in sediments

The concentration of trace metals measured during this study is slightly lower compared to other studies for the region (Table 8). This suggests that pollution decreased along the coast. The concentrations of trace metals in sediments were also low compared to concentrations reported in developed countries like Spain (Usero et al., 2005) and other developing countries such as China (Zhang et al., 2007) and Brazil (Hatje et al., 2008). The lower concentration measured at the Dar es Salaam coast could be due to the low level of industrialisation. High concentration of most trace metals in

Table 5
Correlation between trace metals and density as well as diversity indices of molluscs in intertidal sediments at the Dar es Salaam coast, Tanzania.

	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Cd	Pb	Mo	Sn	Sb	Tl
ρ	0.5*	0.33	0.40	0.4	0.35	0.11	0.6*	0.16	−0.1	0.4	0.4	0.08	0.4	0.3	0.3	0.38
H'	0.4	0.38	0.44	0.5*	0.37	0.15	0.5*	0.09	−0.3	0.7*	0.4	0.10	0.2	0.3	−0.1	0.34
λ'	0.2	−0.05	0.04	−0.5	−0.01	0.04	0.2	0.15	0.3	−0.3	0.1	−0.07	0.3	0.1	0.4	0.05

H' = Shannon–Wiener diversity index, λ' = Simpson's dominance index, ρ = density of molluscs.
* Significant correlation ($P < 0.05$).

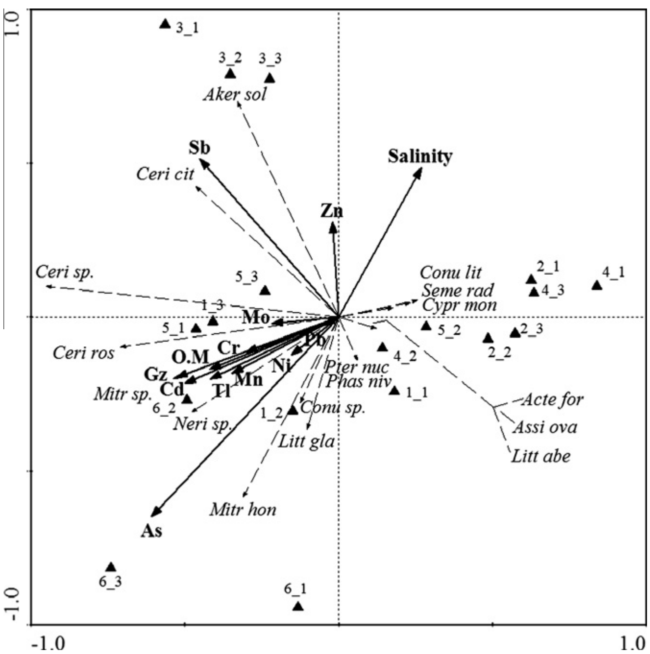

Fig. 7. Triplot representation of the redundancy analysis (RDA) ordination plot showing the relationship of intertidal mollusc abundance and environmental variables at the Dar es Salaam coast, Tanzania. Samples are represented by triangles. The distance between samples correlates to their dissimilarity in species composition, i.e. close samples in the plot are more similar than distant samples. Environmental variables are represented by solid arrows. Length of arrows represents the relative importance of that variable. Species are represented by dashed arrows. Arrows pointing in the same direction indicate a positive correlation. Gz = sediment median grain size, O.M = organic matter content, Acte for = *Acteon fortis*, Aker sol = *Akera soluta*, Assi ova = *Assiminea ovata*, Ceri cit = Cerithium citrinum, Ceri ros = *Cerithium rostratum*, Ceri sp. = *Cerithium sp.*, Conu sp = *Conus sp.*, Conus lit = *Conus litteratus*, Cypr mon = *Cypraea moneta*, Litt abe = *Littoraria aberrans*, Litt gla = *Littoraria glabrata*, Mitr hon = *Mitra honkeri*, Mitr sp = *Mitra sp.*, Neri sp. = *Nerita sp.*, Phas niv = *Phasianella nivosa*, Pter nuc = *Pterygia nucea*, Seme rad = *Semele radiata*.

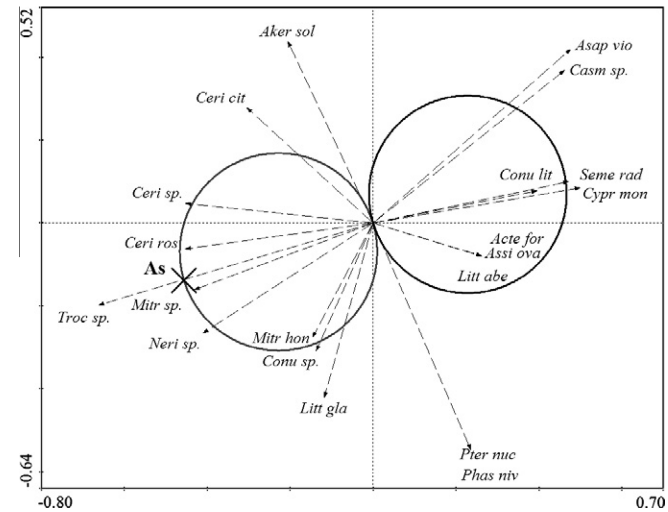

Fig. 8. *T*-value biplot showing the relationship between intertidal molluscs and the environmental variable As at the Dar es Salaam coast, Tanzania. Species are represented by dashed arrows and the environment variable by a symbol X. Species with arrow tips enclosed within the van Dobben circle adjacent to the environmental variable symbol are significantly positively related with that variable. Asap vio = *Asaphis violascens*, Acte for = *Acteon fortis*, Aker sol = *Akera soluta*, Assi ova = *Assiminea ovata*, Casm sp = *Casmaria sp.*, Ceri cit = *Cerithium citrinum*, Ceri ros = *Cerithium rostratum*, Ceri sp. = *Cerithium sp.*, Conu sp = *Conus sp.*, Conus lit = *Conus litteratus*, Cypr mon = *Cypraea moneta*, Litt abe = *Littoraria aberrans*, Litt gla = *Littoraria glabrata*, Mitr hon = *Mitra honkeri*, Mitr sp = *Mitra sp.*, Neri sp. = *Nerita sp.*, Phas niv = *Phasianella nivosa*, Pter nuc = *Pterygia nucea*, Seme rad = *Semele radiata*, Troc sp = *Trochus sp.*

Mbweni (site 1), Kunduchi (site 2), and Msasani (site 3) suggests a northward increase of trace metals from Dare s Salaam city centre. A northward increase in trace metals concentration from the Dar es Salaam harbour to the Msasani–Kunduchi area was also observed in another study (Muzuka, 2007). This indicates that most pollutants are generated in the harbour-Msimbazi area and are distributed by currents to other areas along the coast. Generally, when the South Equatorial Current (SEC) approaches the Tanzanian coast, it splits into the northward East Africa Coastal Current (EACC) and the southward Mozambique Current (MC). During the SE monsoon (April–September), the flow of the EACC is increased and its range extends further north, becoming the Somali current (Richmond, 2002). The current could be responsible for erosion and distribution of sediments and pollutants along the Dar es Salaam coast, which could explain a northward increase in trace metals distribution observed in the present study.

Positive association between various trace metals suggest that they are coming from the same anthropogenic source or their ore minerals occur in association. Positive association between Al, Co, Cr, Cu, Ni, Pb, Sn, V and Zn with Fe, and As, Cr, and Tl with Mn, suggest that these metals are transported attached to Fe or Mn oxide (Charriau et al., 2011). Significant positive association between sediments particle size and Al, As, Cd, Cr, Fe, Mn, Ni, Tl, and V (Table 3), suggests that these metals adhere to sediments particles. Significant positive relationship between sediments particle size and As, Cd and Tl indicate that the concentration of these metals in sediments increases with the decrease in sediments particle size. The positive relationship between As and organic matter content and Tl with organic matter content indicates that these metals binds to organic matter and can be transported in suspended matter. High concentration of As, Cd and Tl at Mjimwema (site 5) and Geza ulole (site 6) can then be due to the fact that sediments at these sites were finer and contained high contents of organic matter.

4.2. Sediments pollution and toxicity

Significant enrichment of As, Cd, Cr, Mn, Mo, Pb, Sb, Tl, and Zn (Table 4) suggest that these metals originate from anthropogenic sources and it indicates that the coast of Dar es Salaam is significantly polluted. These results are comparable to the findings of other researchers, reporting significant enrichment of Cd in Mzinga

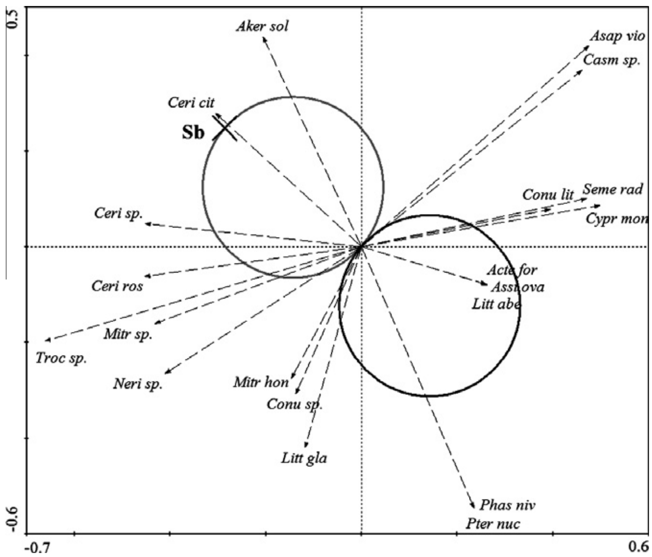

Fig. 9. *T*-value biplot showing the relationship between intertidal molluscs and the environmental variable Sb at the Dar es Salaam coast, Tanzania. Species are represented by dashed arrows and the environment variable by a symbol X. Species with arrow tips enclosed within the van Dobben circle adjacent to the environmental variable symbol are significantly positively related with that variable. Asap vio = *Asaphis violascens*, Acte for = *Acteon fortis*, Aker sol = *Akera soluta*, Assi ova = *Assiminea ovata*, Casm sp = *Casmaria sp.*, Ceri cit = *Cerithium citrinum*, Ceri ros = *Cerithium rostratum*, Ceri sp. = *Cerithium sp,*, Conu sp = *Conus sp.*, Conus lit = *Conus litteratus*, Cypr mon = *Cypraea moneta*, Litt abe = *Littoraria aberrans*, Litt gla = *Littoraria glabrata*, Mitr hon = *Mitra honkeri*, Mitr sp = *Mitra sp.*, Neri sp. = *Nerita sp.*, Phas niv = *Phasianella nivosa*, Pter nuc = *Pterygia nucea*, Seme rad = *Semele radiata*, Troc sp = *Trochus sp.*

creek (Mtanga and Machiwa, 2007), high enrichment of Zn in Msimbazi (Okuku et al., 2010), and elevated levels of Cr and other metals in Mtoni (Kruitwagen et al., 2008). Industrial and domestic discharges as well as runoff from agricultural fields are the possible sources of these contaminants from the catchment. This is because effluents from most industries are not treated before being discharged into the environment (Mmochi and Francis, 2003). It is also because only 15% of the residents of Dar es Salaam are connected to the sewage systems and most of the collected sewage is discharged untreated into the ocean (Linden and Lundin, 1995). These wastes released directly or indirectly into the ocean contain trace metals (Muzuka, 2007).

Values of toxic units for As, Cd, Cr, Cu, Pb, Ni, and Zn smaller than one, indicate that the concentration of these metals in sediments is within the recommended sediment quality standards (Fig. 4). This suggests that adverse effects will rarely occur. However, because there was significant pollution of Mn, Mo, and Sb and because TEL data for these metals were not available, it cannot be ruled out that these sediments are not toxic.

4.3. Relation between physicochemical variables and mollusc community structure

The results showed that the mollusc community assemblage in the study area is affected by physicochemical characteristics of the sediments. Differences in sediments particle size and organic matter content between sites can be due to differences in hydrodynamic conditions. Differences in organic matter content between sites can also be due to differences in anthropogenic input (Amin et al., 2008). High organic matter content at Mjimwema (site 5) and Geza Ulole (site 6) can be due to close vicinity to mangroves. The distribution of organic matter content in sediments and sediments particle size can explain why the abundance of bivalves was high in Msimbazi (site 4) but low at Mjimwema (site 5) and Geza Ulole (site 6). This is because Msimbazi sediments were coarse and contained less organic matter, which implies that more organic matter is left in suspension for the filter feeding organisms such as bivalves.

Differences in sediments particle size and organic matter content between sites could also explain the differences in density, diversity and dominance observed in the present study. Low density and diversity of molluscs at Msimbazi compared to other sites could be associated with intense flushing from waves and currents resulting in a lower abundance of macrofauna (Rodil, 2004) and retention of coarse sediments. High dominance at Msasani could be attributed to a slightly low diversity measured at that site. As diversity decrease due to unfavourable conditions, tolerant species takes advantage of the available niche (Connell et al., 1999) and they become dominant until the conditions are even too stressful for them to survive. High density and diversity of molluscs at Mbweni, Mjimwema, and Geza Ulole (Figs. 5 and 6) despite significant enrichment of trace metals can be partly explained by the fact that the concentration measured in this study were within the recommended sediment quality guidelines. This means that despite significant enrichment, the sediments were probably not toxic for the studied species. Lack of a significant negative association

Table 6
Average concentration (μg/g dry weight) of trace metals in tissues of the gastropod *Polinices mammilla* (pm) and bivalve *Mactra ovalina* (mo) from the intertidal at Dar es Salaam coast, Tanzania. For sample sites see Fig. 1.

Site	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sb	Sn	Tl	V	Zn
2^{pm}	3.6	1.5	0.4	0.3	0.08	20	205	8	2.3	0.4	0.3	0.01	0.02	0.002	0.5	82
2^{mo}	251	2.6	0.2	0.5	0.68	14	455	39	1.6	2	6.2	0.44	0.13	0.008	1.8	201
3^{mo}	1307	6.0	0.1	0.9	4.98	15	1425	20	1.7	5	4.2	0.04	0.05	0.051	4.1	65
4^{mo}	166	0.7	0.2	2.1	1.9	22	316	428	2	2.7	4.4	0.07	0.07	0.004	2.5	163

Table 7
Biota-sediments bioaccumulation factors of the gastropod *Polinices mammilla* (pm) and bivalve *Mactra ovalina* (mo) from the intertidal at Dar es Salaam coast, Tanzania. For sample sites see Fig. 1.

Site	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Sb	Sn	Tl	V	Zn
2^{pm}	0.002	4*	25*	0.5	0.03	26*	0.1	0.5	6*	0.4	0.2	0.1	0.3	0.2	0.1	11*
2^{mo}	0.14	7*	14*	0.8	0.2	19*	0.3	2.3*	4*	2*	4.2*	4*	1.5*	0.7	0.5	27*
3^{mo}	0.75	19*	7*	1.3*	1.3*	15*	0.9	0.5	4*	4.9*	3.4*	0.3	0.4	3.8*	0.9	8*
4^{mo}	0.36	4*	31*	7.6*	2*	66*	0.7	18*	9*	7.7*	5.5*	0.7	1.8*	2.2*	2.3*	41*

* Bioaccumulation.

Table 8
Comparison of trace metal concentration in sediments at the Tanzanian coast and other areas around the world.

	Dar coast, Tz (μg/g)	Kunduchi, Tz (μg/g ± SE)	Mbweni, Tz (μg/g ± SE)	Dar port, Tz (μg/g)	Camau bay, Brazil (μg/g)	Xiemen bay, China (μg/g)	Southern Spain (μg/g)	Boughrara, Tunisia (mg/L ± SE)
Al	1814	2370 ± 68	8150 ± 544	–	–	–	–	0.368 ± 0.69
As	0.7	–	–	0.47	0.24–10.9	–	3.5–102	–
Cd	0.02	1.3 ± 0.4	0.7 ± 0.3	3.6	bd-0.65	0.33	0.26–0.72	0.026 ± 0.23
Co	0.8	1.7 ± 0	3 ± 1.4	4.7	bd-9.92	–	–	–
Cr	4.3	4.5 ± 0.5	14.6	21.6	bd-30	75	10–33	0.018 ± 0.02
Cu	0.8	1 ± 0.1	2.8 ± 0.1	13.5	bd-2.5	44	6–92	7.080 ± 0.4
Fe	1819	2020 ± 141	7490 ± 1060	7255	0.02–2.33	–	–	–
Mn	70	–	–	132.6	1.5–518	–	–	–
Ni	1.1	2.7 ± 0.4	8.9 ± 0.4	15.5	bd-11.2	37.4	3–13	–
Pb	1.2	23.8 ± 12.1	13 ± 0.8	35.4	bd-24.8	50	2–46	0.173 ± 0.23
Sn	0.1	6.7 ± 0.6	6.4 ± 2	–	–	–	–	–
V	5	–	–	–	bd-23.4	–	–	–
Zn	5.7	13.1 ± 1	21.4 ± 1.4	58.4	bd-77.5	139	18–460	–
	This study	Kruitwagen et al. (2008)	Kruitwagen et al. (2008)	Muzuka (2007)	Hatje et al. (2008)	Zhang et al. (2007)	Usero et al. (2005)	Mensi et al. (2008)

Dar = Dar es Salaam, Tz = Tanzania, bd = below detection.

between trace metals and diversity or density of molluscs supports this idea. High diversity and density of molluscs at these sites can also be attributed to high amount of organic matter measured at these sites. Because organic matter tend to bind trace metals in sediments thus making them less available to macrofauna (Chariau et al., 2011). Low concentration of organic matter and significant enrichment of most trace metals at Msimbazi (site 4) can therefore explain why diversity and density of molluscs was very low at that site. Significant positive association between Ni with density and diversity and Mn with diversity may be due to the fact that these are essential trace metals. Generally, lack of essential trace metals results in physiological disorders and exposure to high dose of the trace metals results into toxic effects (Connell et al., 1999).

Results of RDA showed that the measured environmental variables explained 79% of the variation in species composition. This indicates that the measured variables are the main factors affecting the studied molluscs. Because trace metals explained 68% of the variations in species composition, they can be regarded as the main physicochemical parameter affecting the community structure of molluscs in the studied area. This is because introduction of contaminants into the environment results into loss of sensitive species (Dauvin, 2008), while the tolerant species may grow faster since their competitors have been eliminated by the toxicant (Connell et al., 1999). This affects the community structure of macrofauna, because it leads to decrease in species diversity and abundance as well as a shift in species composition. Results of RDA also showed that the gastropods *C. rostratum, Cerithium sp., M. honkeri, Mitra sp.*, and *Nerita sp.*, are associated with high levels of trace metals and organic matter (Fig. 7). This means that these species can tolerate high levels of trace metal pollution hence they can be relevant indicators of sediments contamination. It also showed that the bivalve *S. radiata*, as well as the gastropods *C. moneta, C. litteratus, A. fortis, A. ovata, L. aberrans, P. nucea*, and *P. nivosa*, are sensitive to trace metal pollution.

Results of Monte Carlo permutation test on RDA identified As and Sb as the trace metals that contribute significantly to variation in species composition. This indicates that these metals have a significant influence on the community structure of soft bottom molluscs in the studied area. Ecological effects of As on benthic macrofauna are also reported for a stream in North America (Huddleston et al., 2009). *T*-value biplot identified the gastropods *C. rostratum, M. honkeri*, and *Mitra species*, to be significantly positively related to As concentration (Fig. 8). This indicates that these species are tolerant to As contamination. The gastropods*A. fortis, A. ovata, C. litteratus* and *L. aberrans*, and the bivalve *S. radiata* were identified to be significantly negatively related with As concentration. Even though levels of As in sediments were within the recommended standards, these species were negatively impacted, showing their sensitivity to As contamination. This is probably due significant enrichment of As at all sites and because prolonged exposure to low concentration can also result in toxicity. The species were affected probably due to prolonged As exposure. The gastropods *L. aberrans, A. fortis*, and *A. ovata* were significantly negatively related with Sb, indicating that the abundance of the species decreased with increase in Sb concentration (Fig. 9). This suggests that the species were negatively affected by Sb contamination. Sites 1 and 5 as well as site 2 and 4 were similar in terms of species composition, supporting the idea that As and Sb were the main physicochemical variables affecting the studied molluscs. This is because, the composition of the two trace metals at the related sites were comparable. The composition of Sb was comparably high at site 3 and the composition of As was comparably high at site 6. This can explain why these samples were very different from each other and from other samples in terms of species composition.

4.4. Relation between metals in sediments and tissues

The concentration of Fe and Zn was comparably high in tissues of *P. mammilla* and *M. ovalina* (Table 6), where as the concentration of Al and Mn was higher in *M. ovalina*. It could be that the concentration of Fe, Mn and Zn in tissues of these organisms was high because these elements are essential. The concentration of Al, Cr, Fe, Mn, Ni, Pb, Sb, Sn, Tl, V, and Zn in *M. ovalina* at Kunduchi was at least two times higher than in *P. mammilla*, suggesting that *M. ovalina* accumulated more metals. Differences in accumulation of trace metals between species is also shown in other studies (Usero et al., 2005; Huang et al., 2007; Koné et al., 2010). These differences are probably due to different capabilities in accumulating and regulating toxicants. Results of BSAF indicate bioaccumulation of As, Cd, Cu, Mo, and Zn at Kunduchi (site 2), Msasani (site 3), and Msimbazi (site 4). This could be due to enrichment of these metals at these sites. In addition, if BSAF of *P. mammilla* and *M. ovalina* at Kunduchi (site 2) are compared, it can be shown that *M. ovalina* accumulated more metals than *P. mammilla*. It can be also shown that despite significant enrichment of Sb at Kunduchi, bioaccumualation of Sb in *P. mammilla* did not occur. This indicates that *P. mammilla* does not reflect well the conditions of the local environment, compared to *M. ovalina*. Therefore, *M. ovalina* seems to be a good bio-indicator species for monitoring programmes.

When chemical measurements of the pollutants in sediments are compared with measurements in tissues of molluscs, chemical measurement identified that the concentration of trace metals in sediments were within the recommended sediments quality standards, despite significant enrichment of most trace metals in sediments. However, a biomonitoring study showed that there was evidences of bioaccumulation of most trace metals at Kunduchi and Msasani. This supports the idea that due to fluctuation in anthropogenic input, chemical measurements and laboratory toxicity tests do not give a complete or correct picture of the pollution status of a water body. Therefore information on the real biological impact of pollutants can only be obtained by applying long-term in situ biomonitoring assays (Bervoets et al., 2004).

5. Conclusion

This study revealed that the community structure of soft bottom molluscs along the Dar es Salaam coast is influenced by trace metals pollution. Among all metals, As and Sb contributed significantly to the variations in species composition. The study also revealed that soft bottom molluscs exhibit species-specific responses to specific contaminants. For example, the gastropods *L. aberrans, A. fortis* and *A. ovata* were very sensitive to trace metals pollution, while the gastropod *M. honkeri* was tolerant to As and other trace metals. The study also indicated that the Dar es Salaam coastal sediments are polluted. High pollution of As and Sb was observed at Mjimwema and Geza Ulole. Msimbazi was also highly polluted with Sb and Mbweni with Mo. However, the concentration of metals measured in sediments was within the recommended sediment quality standards for most trace metals. Since no TEL data for comparison were available for Mo, Mn, and Sb, it can not be evaluated if these trace metals meet the recommended standards. The current study also identified that bioaccumulation of Cu, Zn, As, Cd, Pb, and Mo was occurring in *P. mammilla* and *M. ovalina* at Kunduchi, Msasani, and Msimbazi. There were also differences in concentration of metals in tissues of the two species and *M. ovalina* was identified to be a good indicator species of the local environmental quality.

6. Recommendation

Although the sampling covered almost the whole coast of Dar es Salaam, a more comprehensive spatial and temporal sampling would be desirable. It is therefore recommended that future studies should include more stations from the southern area of Dar es Salaam because the present study covered only two stations from the south. Future studies should also be conducted in the dry and wet season in order to account for seasonal variations.

It is also recommended that future studies should include other groups of marine fauna and should be conducted along the whole Tanzanian coast for a longer time period in order to account for long term fluctuations in anthropogenic input and changes in macrofauna community structure. Since the study was restricted to soft sediments of the intertidal, it is recommended that future monitoring should include rocky bottom fauna and the lower subtidal in order to get more information on trends of trace metals contamination in different coastal habitats.

Finally, yet importantly, it is recommended that the local authorities should act responsibly and enforce existing laws and regulations in order to protect biodiversity of soft bottom molluscs and other marine fauna. It is also recommended to conduct monitoring studies on organic pollutants in order to investigate if there is organic pollution along the Tanzanian coast and if it affects the community structure of the marine fauna. Nevertheless, the data of the present study provide a baseline for future investigations on trace metals pollution and its effects on the community structure of soft bottom macrofauna.

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