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Effects of Sewage Discharge on Polychaete Communities in East African Peri-urban Equatorial and Subtropical Mangroves

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Abstract—Mangrove ecosystems are of great socioeconomic and ecological importance but are adversely affected by anthropogenic activities. Benthic infaunal community studies, particularly of polychaetes, are useful indicators of the health of an ecosystem. An unbalanced After Control/Impact (ACI) design was used to compare the polychaete infaunal community in polluted peri-urban mangrove swamps with nearby mangroves unaffected by sewage in Kenya and Mozambique. Differences were detected in the polychaete community between the peri-urban and un-impacted mangroves in both countries. In Kenya, the results showed that peri-urban mangroves are subjected to more severe human impact, leading to a decrease in polychaete diversity and a shift to more opportunistic species. In contrast, in Mozambique, the polluted peri-urban system had higher polychaete diversity when compared with the control sites. This was probably due to domestic sewage making more organic matter available in the foodweb. Among the polychaete families found in this study, the most tolerant to sewage were the Nereididae and Capitellidae, with *Dendronereides zululandica*, *Perinereis vancaurica* and a *Mediomastus* sp. the main representatives.

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INTRODUCTION

Mangrove ecosystems are of great socioeconomic and environmental importance (Nagelkerken *et al*., 2008; Walters *et al*., 2008) but have been adversely affected by anthropogenic activities including deforestation and disposal activities, particularly of wastewater (Duke *et al*., 2007; Kruitwagen *et al*., 2008). East African peri-urban mangroves are subject to significant pressures caused by human activity, such as the disposal of large amounts of untreated sewage (Kruitwagen *et al*., 2008; Mohammed, 2002). The disposal of such effluent is considered one of the most common anthropogenic disturbances of marine benthic communities, and has long been recognized as one of the main causes of faunal change in estuarine and coastal environments (Pearson & Rosenberg, 1978). Moreover, sewage effluent can lead to severe habitat degradation in marine environments (Diaz & Rosenberg, 2008; Savage *et al*., 2002; Wu, 2002). Considerable work has been undertaken on organic enrichment in aquatic systems and its temporal and spatial effects on benthic community dynamics (Chambers *et al*., 2006; Frouin, 2000; Morris & Keough, 2001; Pearson & Rosenberg, 1978). Studies on polluted peri-urban East African mangrove systems (compared to mangroves in rural areas) have shown that sewage can have significant (Cannicci *et al*., 2009; Machiwa & Hallberg, 1995; Penha-Lopes *et al*., in submitted; Penha-Lopes *et al*., 2010a; Penha-Lopes *et al*., 2010b) or no effect (Yu *et al*., 1997) on faunal diversity and biomass.

Polychaetes are amongst the most useful marine organisms for the detection of pollution and are considered as the taxonomic group with the highest level of sensitivity to perturbation of the soft substrata (Markert *et al*., 2004). The presence, absence or relative biomass of specific polychaetes in marine sediments may provide an excellent indication of the condition or health of the benthic environment.

The present study formed part of the PUMPSEA Project (Peri-urban mangrove forests as filters and potential phytoremediators of domestic sewage in East Africa; funded by European Commission: FP6, INCO-CT2004-510863), the global aim of which was to demonstrate the potential ecosystem service of mangroves in filtering discharged wastewater to limit coastal sewage pollution. This study aimed to investigate possible differences in the polychaete community between mangroves affected by sewage (peri-urban sites) and mangroves unaffected by sewage (non-urban sites), in East Africa, using basic metrics that can be adopted by developing countries. The study was intended to provide baseline information for the future development of biological indicators to monitor and manage mangrove environments.

MATERIALS and METHODS

Study area and sampling design

The mangrove sites and sampling design were described by Cannicci *et al*. (2009) but will again be briefly covered here. Three sampling sites were chosen along the Kenya coast (Fig. 1): Mikindani (impacted site), Gazi Bay and Shirazi Creek (sites unaffected by sewage). The Mikindani mangrove system is located within Tudor Creek, which surrounds the city of Mombasa. This mangrove stand has been exposed to sewage effluent for more than a decade, primarily from Mikindani residential estate and also the city of Mombasa (Mohammed, 2008). The sewage runs through the upper mangrove fringes in canals and is discharged directly into the mangrove forest at Mikindani in Tudor Creek. The mangroves receive sewage every tidal cycle, the loading being exponentially diluted with distance from the source (PUMPSEA, 2008).

Appropriately replicated before/after sampling designs are perhaps the most reliable method to detect environmental impact (Underwood, 1992; 1994). However, in the absence of previous impact data, it is still possible to assess differences between disturbed and control locations after a "disturbance" with appropriate spatial and temporal replication (Chapman *et al*., 1995).

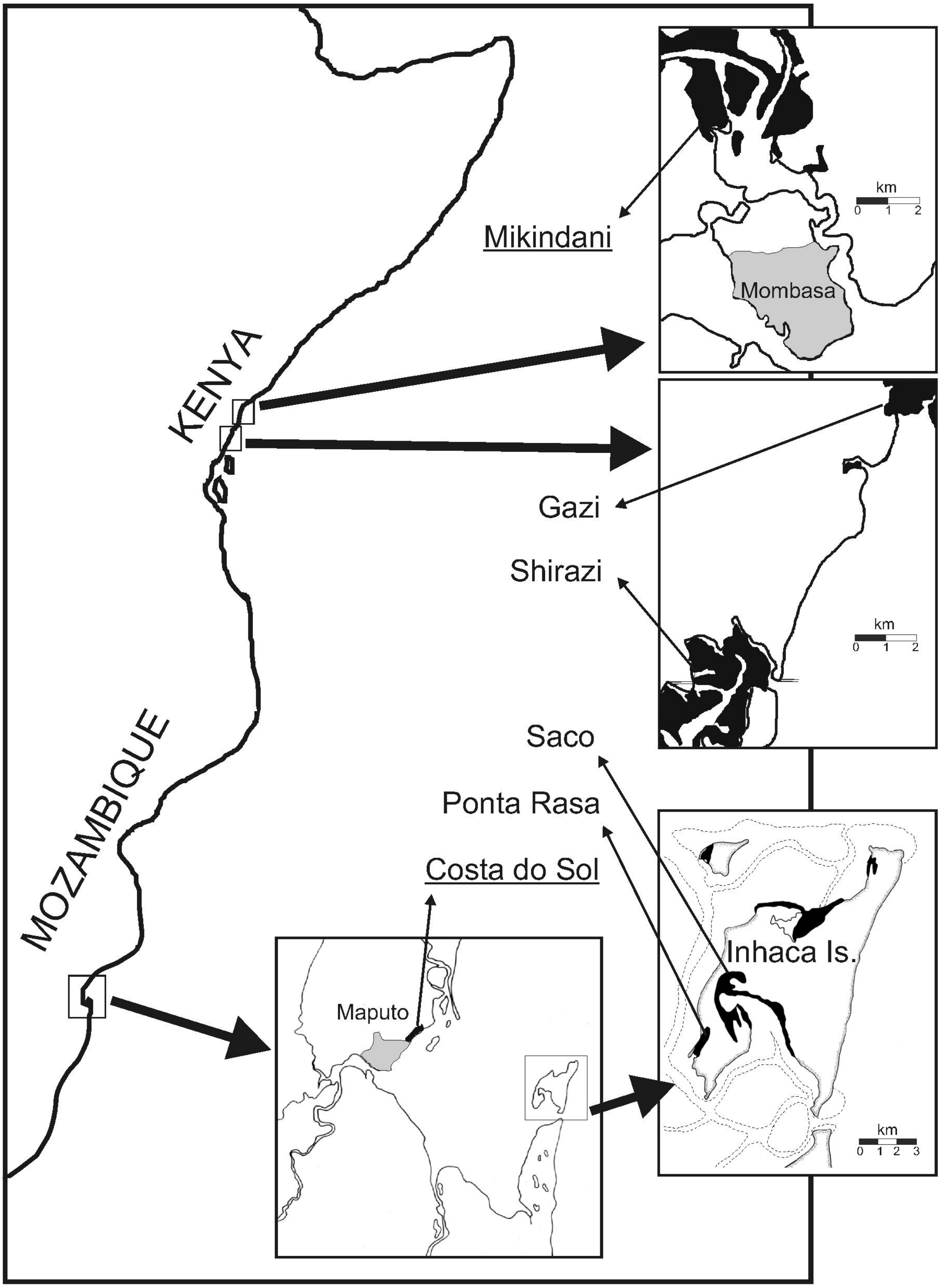

Figure 1. Map of sampling sites in Kenya and Mozambique.

For this reason, we followed an unbalanced After Control/Impact (ACI) design, comparing the ecological features recorded in an contaminated mangrove swamp with those characteristic of nearby mangroves with similar ecological traits but unaffected by sewage, in Kenya and Mozambique.

In Mozambique, sampling was conducted in three mangrove ecosystems: a peri-urban mangrove at Costa do Sol and two unpolluted mangroves, the Saco and Ponta Rasa, at Inhaca Island (Fig. 1). Costa do Sol mangrove lies about 7 km north of Maputo city in Maputo Bay. Quinhenganine River discharges seasonally into the swamp after passing through the city. The mangrove is bordered by a residential area, and has been receiving domestic sewage, aquaculture effluent and solid waste from various sources over the past few decades (PUMPSEA, 2008). Costa do Sol has higher concentrations of nutrients, especially nitrites and nitrates, relative to the Saco and Ponta Rasa mangroves (PUMPSEA, 2008).

A stratified random sampling approach was used at each site since the mangroves under study manifested clear zonation, with obvious vegetation belts that are known to be characterized by ecologically different and, thus, colonized by different faunal assemblages (Hogarth, 2007; Macnae, 1968). The belts under consideration were a landward sandy belt dominated by *Avicennia marina* (Forssk.) Vierh. in a zone flooded only at spring tides (hereafter referred to as the *Avicennia* belt), and a seaward muddy belt dominated by *Rhizophora mucronata* Lam. trees, flooded twice daily at high tide (hereafter referred to as the *Rhizophora* belt). Only a wide *Avicennia* belt was present at Costa do Sol and we concentrated our efforts here, comparing it with the corresponding landward *Avicennia* belts at the Mozambican control sites.

Sampling

Two *A. marina* and two *R. mucronata* study areas were selected (50 m apart) at each Kenyan sampling site. Two sub-areas (1 m of diameter) were delineated in each area, separated by more than 5 m. In each sub-area, three macrofauna samples were collected using a 15 cm Ø corer driven to a depth of 20 cm. Macrofauna were extracted from the sediment by passing through a 500 µm sieve. They were preserved in 10% buffered formalin. Polychaetes were identified in the laboratory to species level and counted. Temporal replicates were collected during the dry season in the months of July and August 2005 at the Mozambican locations and October 2005 at the Kenyan locations, and during the wet season, in February 2006 in Mozambique and April 2006 in Kenya.

Data analysis

The data were analysed using univariate and non-parametric multivariate techniques contained in the PRIMER 6 package (Clarke & Gorley, 2006a) and Prism 5 software. Generic diversity was assessed using the Shannon-Wiener diversity index (H'), Pielou's evenness index (R'), and Margalef's species richness index (d). These indices were generated using two-way ANOVA. ANOSIM (analysis of similarities) randomization tests were performed to assess differences in assemblage structure derived from MDS ordination. If the global value of R calculated from the ANOSIM was significant, pairwise comparisons were made between treatment levels. ANOSIM generates a global value of R which is scaled to lie between -1 and +1, a value of zero representing the null hypothesis (no difference between a set of samples). A comparison of pair-wise R values ensued, measuring the extent of separation between groups on a scale of 0 (indistinguishable) to 1 (similarities within groups are less than the similarity between groups), providing an interpretable number reflecting the difference between groups. R-values >0.75 were interpreted as being indicative of well-separated groups, R>0.5 as overlapping but clearly different, and R<0.25 as barely separable (Clarke & Gorley, 2006b).

RESULTS

Polychaeta

A list of all polychaete species found in both Kenya and Mozambique is presented in the Appendix. Species diversity was much higher in the *Rhizophora* belt in Kenya, followed by the *Avicennia* belt in the same country. Very few species were found in Mozambique. In terms of abundance (Figs 2-4), there was a clear distinction in the polychaete communities between rural and peri-urban mangroves. In Kenya, Gazi had the highest species diversity in the *Rhizophora* belt (Table 1) but the highest abundance of the most dominant species in the *Avicennia* belt (Fig. 2). Polychaete species were less abundant at Mikindani and, in the *Rhizophora* belt (Fig. 3), only two species were encountered, *Dendronereides zululandica* and *Perinereis vancaurica*. These occurred in greater abundance in the peri-urban mangrove than the rural mangroves. All other species tended to decrease in abundance or even disappear from the peri-urban mangroves.

In Mozambique, a much lower polychaete diversity and abundance was encountered at all locations in the *Avicennia* belt. While *Dendronereides zululandica* was found at Ponta Rasa and Costa do Sol, *Phyllodoce* sp. was only observed at Costa do Sol.

The diversity indices calculated for both the *Avicennia* and *Rhizophora* belts in Kenya (Table 1) indicated that the peri-urban mangrove site (Mikindani – the grey lines) had null species richness, and lower species evenness and diversity than the rural mangroves. In Mozambique, the number of species and their abundance was very low, and many of the samples lacked polychaetes, precluding any meaningful diversity index comparison.

K-dominance plots (Fig. 5) were calculated for the *Rhizophora* belt in Kenya due to the low abundance and diversity of polychaetes species in the *Avicennia* belts in both countries. The dominance-plots showed that the Mikindani mangrove sediment had very few species in this belt (*Rhizophora*), and only one of them occurred with more than

Table 1. Comparison of average polychaete species (±SE) richness (d), evenness (J') and diversity (H') in peri-urban and rural *Avicennia* and *Rhizophora* mangroves in the dry and wet seasons in Kenya ($p < 0.05$). Different superscript letters indicate significant differences between seasons for the same site (vertical comparison); different superscript numbers indicate significant differences between sites for the same season (horizontal comparison).

Avicennia marina	Season	Margalef's index (d)	Pielou's evenness index (J')	Shannon diversity index (H')
Mikindani	Dry	---	---	---
	Wet	---	---	---
Shirazi	Dry	0.11±0.122,a	0.21±0.212	0.15±0.152
	Wet	0.00±0.001,b	0.25±0.252	0.17±0.172
Gazi	Dry	1.70±0.632	0.64±0.222	0.71±0.242
	Wet	0.76±0.462	0.32±0.212	0.36±0.232

Rhizophora mucronata	Season	Margalef's index (d)	Pielou's evenness index (J')	Shannon diversity index (H')
Mikindani	Dry	0.78±0.161	0.26±0.051	0.27±0.061
	Wet	0.55±0.391	0.44±0.101	0.21±0.151
Shirazi	Dry	2.24±0.572	0.69±0.082	1.03±0.252
	Wet	2.59±0.212	0.72±0.082	1.41±0.222
Gazi	Dry	3.30±0.322	0.78±0.042	1.73±0.092
	Wet	2.99±0.722	0.72±0.102	1.23±0.322

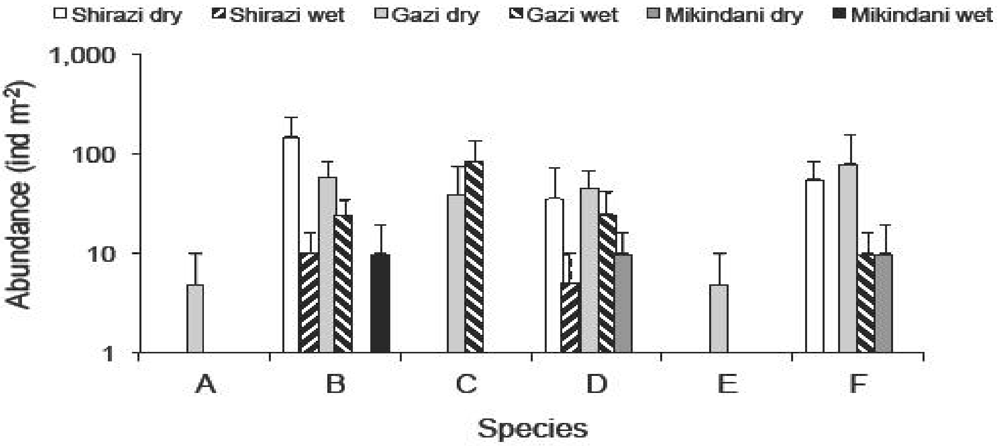

Figure 2. Abundance (log n) of the most dominant polychaetes recorded in the *Avicennia* belt in peri-urban and rural mangroves in Kenya. Species: A – *Armandia* sp.; B - *Dendronereides zululandica*; C – *Exogone* sp.; D – *Fabriciola mossambica*; E – *Namlycastis* sp.; F – *Nematonereis* cf. *Unicornis*.

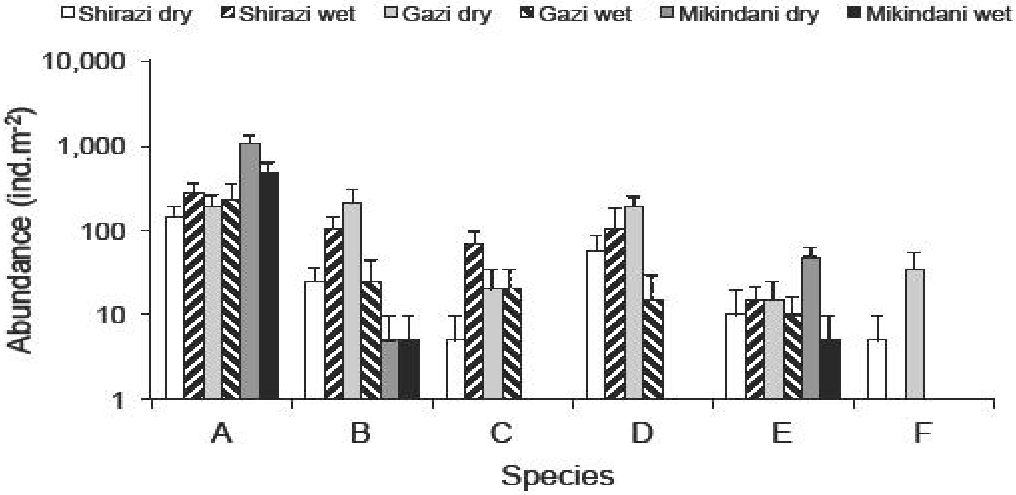

Figure 3. Abundance (log n) of the most dominant polychaetes recorded in the *Rhizophora* belt in peri-urban and rural mangroves mangroves in Kenya. A - *Dendronereides zululandica*; B – *Mediomastus* sp.; C – *Melinna* sp.; D – *Notomastus* sp.; E – *Parinereis vancaurica*; F – *Schyphoproctus* sp.

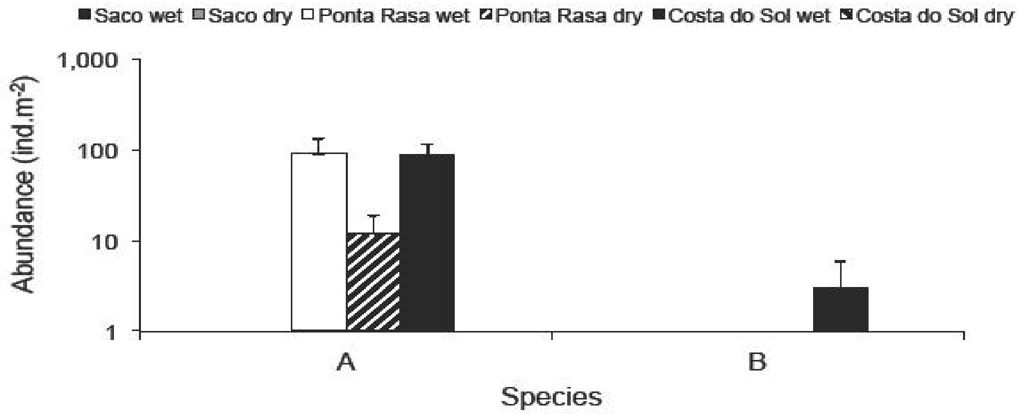

Figure 4. Abundance (log n) of the most dominant polychaetes recorded in the *Avicennia* belt in peri-urban and rural mangroves mangroves in Mozambique. Species: A – *Dendronereides zululandica*; B – *Phyllodoce* sp.

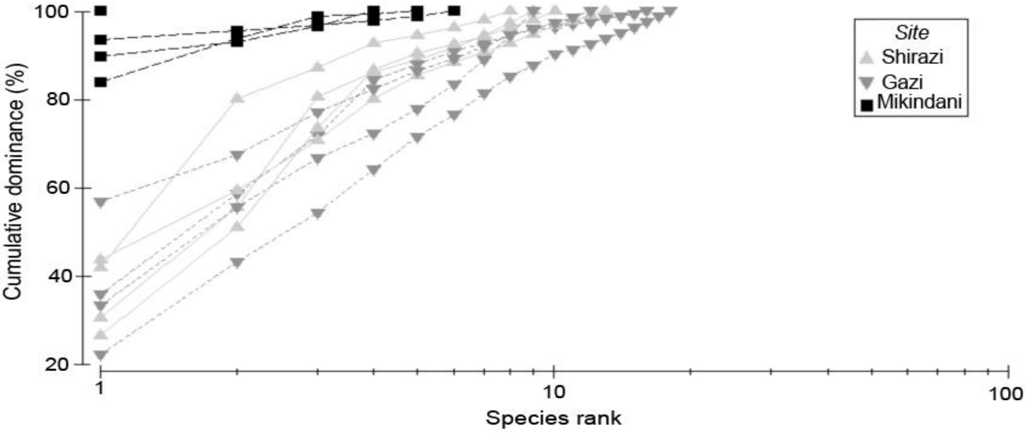

Figure 5. K-dominance curves for species number and relative abundance of polychaetes in the *Rhizophora* belt in Kenyan mangroves (data for both seasons pooled).

80% relative frequency. At the rural locations, the number of species was much higher and the most abundant had a relative frequency of below 60%.

Data for the different seasons were pooled (within each country and belt type) for the multivariate analyses, as no significant differences were found between seasons in either Kenya or Mozambique. In Mozambique, multivariate analysis revealed higher differences between the rural sites than between Costa do Sol and both rural locations (Table 2 - A). In Kenya a similar result was observed but was less pronounced (Table 2 - B).

Table 2. Results of global ANOSIM and pair-wise tests using Bray–Curtis, comparing polychaetes in A) the Mozambican *Avicennia* belt and B) the Kenyan *Rhizophora* and *Avicennia* belts.

A)

Mozambique	*Avicennia* Between seasons Global R=0.286 (P= 0.044)
Pair-wise	*Avicennia* Both seasons Global R=0.47 (P= 0.002)
Saco vs Ponta Rasa	R=0.750 (P= 0.005)
Saco vs Costa do Sol	R=0.000 (P= 0.148)
Costa do Sol vs Ponta Rasa	R=0.206 (P= 0.119)

B)

Kenya	*Rhizophora* Between seasons Global R=0.11	*Avicennia* Between seasons Global R=0.15
Pair-wise	*Rhizophora* Between seasons Global R=0.11 (P= 0.130)	*Avicennia* Between seasons Global R=0.15 (P= 0.084)
Gazi vs Mikindani	*Rhizophora* Both seasons Global R=0.24 (P= 0.023)	*Avicennia* Both seasons Global R=0.39 (P= 0.001)
Mikindani vs Shirazi	R=0.373 (P= 0.001)	R= 0.453 (P= 0.007)
Gazi vs Shirazi	R=0.264 (P= 0.084)	R= 0.544 (P= 0.007)

DISCUSSION

Macrobenthos comprise a target component for ecosystem health assessment and polychaetes are widely used for this purpose (Giangrande *et al*., 2005). Effects of stress on this group include, amongst others, an increase in production, especially linked to eutrophication and reduced diversity with increased dominance by opportunistic species. Since opportunistic forms are typically small-sized species with short life cycles, the biomass also decreases (Giangrande *et al*., 2005). The present study was intended to provide baseline information to answer the question: "Are polychaete communities similar between peri-urban and less anthropogenically impacted mangroves?" Although the results were different in each country, it was observed that polychaete communities inhabiting peri-urban mangroves had a species composition, diversity and abundance different from the control sites which were considered relatively pristine and distant from urban development. In general, the *Avicennia* belt in Gazi had the highest polychaete species diversity. This was followed by Shirazi, Mikindani, Costa do Sol and Ponta Rasa. No polychaetes were found in the Saco. Overall, a much more diverse polychaete community was found in the

Rhizophora belt, there being more than 26 taxa at Gazi, 17 at Shirazi and 8 at Mikindani.

The discrepancy between the species diversity in the belts can be explained by differences in their biotic and abiotic properties (Metcalfe & Glasby, 2008). *Rhizophora* belts usually have a higher number of polychaete species, reflecting the frequency of tidal effects providing more food and, in consequence, new recruits (Metcalfe & Glasby, 2008). Differences between locations may also be due to many other factors, including local sediment and hydrological conditions, local ecological food-webs and anthropogenic pressure, ranging from pollution to intensive fisheries and mangrove extraction. However, determination of these parameters fell beyond the scope of this study. Nevertheless, examination of polychaete populations to species level in peri-urban and rural areas may allow identification of the types of human pressure in mangrove ecosystems, by monitoring the disappearance or profusion of indicator species (potential indicators).

Polychaete species diversity (regardless of diversity index) was lower with a much higher abundance of certain species (reaching more than 1000 ind.m^{-2}, such as *Dendronereides zululandica*) in the peri-urban mangroves of Kenya (Mikindani) when compared with the control ecosystems (Gazi and Shirazi). In the Kenyan *Rhizophora* belt, good separation was demonstrated between the peri-urban and non-urban polychaete communities in the dominance-plots (Figure 5), with all the Mikindani samples appearing at the top left, indicating low diversity and evenness. A clear reduction in diversity has been noted by other authors in the *Rhizophora* belt at ecologically stressed locations (Cardell *et al*., 1999; Giangrande *et al*., 2005; Nordhaus *et al*., 2009), with an increase in dominance by resistant species belonging to the families Nereididae and Capitellidae. Capitellid polychaetes are reported to increase in abundance and promote organic matter decomposition in eutrophic sediments (Cardell *et al*., 1999; Chareonpanich *et al*., 1993; Nordhaus *et al*., 2009). Nereid polychaetes manifest high physiological tolerance to extreme variations in environmental factors, and can grow and reproduce in different sediment types and also in stressed environments (Bartel-Hardege & Zeeck, 1990; Cheggour *et al*., 1990; Miron & Kristensen, 1993; Scaps, 2002; Zubillaga & Salina, 1997).

As indicated in Table 1, seven of the eight species present in Mikindani were also present at the rural locations (*Dendronereides zululandica*, *Lepidonotus tenuisetosus*, *Marphysa* cf. *mossambica*, *Mediomastus* sp., *Perinereis* cf. *vancaurica*, *Potamilla* sp. and *Sigambra* sp.), showing that they are tolerant species instead of opportunistic. These species comprised about 25% of the total polychaete population in the rural locations. On the other hand, nine species present in both the rural *Rhizophora* controls were absent from Mikindani (*Armandia* sp., *Capitella* sp., *Fabriciinae* sp., *Melinna* sp., *Micronephthys* sp., *Namlycastis* sp., *Notomastus* sp., *Scyphoproctus* sp. and *Syllis* sp.). These species may be indicators of pristine environment, however further studies are needed to elucidate the biology of these species and possible cause-effect relationships.

In Mozambique we found a different situation, where factors other than urban sewage apparently have more influence on the distribution and abundance of the polychaetes. A species additional to those present at Ponta Rasa was found at the peri-urban site (Costa do Sol) but the abundances were otherwise similar. No polychaetes were found in the Saco, in contrast with results recorded more than a decade ago (Guerreiro *et al*., 1996), possibly indicating degradation in this area due to recent increases in population and infrastructure. These last contrasting results may be attributable to sampling limitations.

Studies on other mangrove macrofauna in the PUMPSEA Project yielded similar results (Penha-Lopes *et al*., 2010b). An increase in the diversity, abundance/biomass and productivity of organisms was encountered at anthropogenically impacted sites in Mozambique (Costa do Sol), and a decrease of all faunal parameters in Kenyan peri-urban locations (Mikindani), when compared with the regional controls. In considering the macro-epifauna in Mozambique, fiddler and sesarmid crab community analysis also indicated that Costa do Sol was richer than the unpolluted mangroves due to a higher abundance of benthic microalgae and bacteria on the substratum and leaf litter (Cannicci *et al.*, 2009). Crustacea (crabs and shrimps) were bigger, more fertile and produced more viable embryos at Mozambican peri-urban sites when compared with control sites, probably for the same reason (Penha-Lopes *et al.*, 2010a; Penha-Lopes *et al.*, 2009). In Kenya, mangrove macro-infauna abundance decreased, mainly in the following groups: Oligochaeta, Polychaeta, Halacaroidea and Turbellaria (Penha-Lopes *et al.*, 2010b), which was probably indicative of higher organic loading and other anthropogenic pollution known to affect these communities (e.g. Danovaro *et al.*, 1995; Gillet *et al.*, 2008).

This study thus contributed to the knowledge on the polychaete community in several peri-urban and non-urban mangroves in East Africa. Mangroves in the different belts and at the levels of perturbation examined in this study could be differentiated using a variety of univariate, multivariate and diversity analyses, although the polychaete community response differed in each country. While the sites chosen were deemed typical in terms of their biotic and abiotic variables, it is known that mangrove ecosystems are patchy and dynamic and manifest a high degree of temporal and spatial variability at different scales (Chapman & Tolhurst, 2004). This may account for some of the differences between the Mozambican and Kenyan mangroves, as well as between some of the systems within each country. However, a clear distinction between the infaunal communities (using diversity and multivariate indexes) at peri-urban and rural sites was indicative of perturbation, discernible at species or a higher taxonomic level. While in Kenya it was possible to state that peri-urban mangroves undergo a decrease in polychaete diversity and a shift to more resistant species, it seems that domestic sewage discharged into the peri-urban system in Mozambique had no effect on polychaete diversity when compared with the control sites. Further research is needed to elaborate on these findings.

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Appendix. List of polychaete species (or higher taxonomic level) found at mangrove sampling locations in Kenya and Mozambique.

Kenya					
	Avicennia			*Rhizophora*	
Gazi	**Shirazi**	**Mikindani**	**Gazi**	**Shirazi**	**Mikindani**
Armandia. sp.	*Dendronereides zululandica*	*Dendronereides zululandica*	*cf. Aphelochaeta.* sp.	*Armandia.* sp.	*Dendronereides zululandica*
Dendronereides zululandica	*Namlycastis.* sp.	*Namlycastis* sp.	*Armandia* sp.	*Capitella sp.* sp.	*Lepidonotus tenuisetosus*
Fabriciola mossambica			*Branchiocapitella* sp.	*Dendronereides zululandica*	*Marphysa cf. mossambica*
Namlycastis sp.			*Capitella* sp.	*FABRICIINAE* sp.	*Mediomastus.* sp.
Nematonereis cf. unicornis			*Dendronereides zululandica*	*cf. Genetyllis sp.*	*Perinereis cf. vancaurica*
Perinereis cf. vancaurica			*Exogone. (Exogone)* sp	*cf. Kefersteinia sp.*	*cf. Potamilla* sp.
			FABRICIINAE sp. sp.	*Mediomastus.* sp.	*SABELLIDAE* sp.
			Fabriciola mossambica	*Melinna* sp.	*Sigambra* sp.
			Heteromastus sp.	*Micronephthys* sp.	
			Lepidonotus tenuisetosus	*Namlycastis* sp.	
			Leiocapitellides sp.	*Neanthes* sp.	
			Leiochrides sp.	*Notomastus* sp.	
			Marphysa cf. mossambica	*Perinereis cf. vancaurica*	
			Mediomastus sp.	*cf. Potamilla* sp.	
			Melinna sp.	*Scyphoproctus* sp.	
			Micronephthys sp.	*Syllis* sp.	
			Namlycastis sp.	*TEREBELLIDAE* sp.	
			Nematonereis cf. unicornis		
			Notomastus sp.		
			Odontosyllis sp.		
			Perinereis cf. vancaurica		
			Phyllodoce sp.		
			cf. Potamilla sp.		
			Scyphoproctus sp.		
			Sigambra sp.		
			Syllis sp.		

Mozambique		
Avicennia		
Saco	**Ponta Rasa**	**Costa do Sol**
	Dendronereides zululandica	*Dendronereides zululandica*
		Phyllodoce sp.

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