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Impact of pollution on the feeding, bioturbation and biomass of *Uca annulipes* in Gazi and Mikindani mangroves, Kenya

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Abstract. *Owuor MA, Aloo-Obudho P, Cannicci S, Gitundu JK. 2017. Impact of pollution on the feeding, bioturbation and biomass of Uca annulipes in Gazi and Mikindani mangroves, Kenya. Ocean Life 1: 61-68.* Marine pollution is one of the main anthropogenic factors globally recognized that affect the estuarine and coastal ecosystems. Mangroves received the pollutant since they are intercepting between land and ocean. Despite the utilization of natural mangrove as pollution buffers, how these pollutants might impact the biodiversity of the ecosystems remains a great question. Here, we aimed at determining the impact of pollution on the feeding, bioturbation, and biomass of the fiddler crab *Uca annulipes* in two regions, Gazi and Mikindani, all along the Kenya Coast. The mangroves in Mikindani on Tudor creek represented peri-urban mangroves that are heavily impacted by municipal wastewater. Meanwhile, the mangroves in Gazi Bay in the South Coast of Kenya served mangroves not affected by direct sewage input. Furthermore, Crabs *U. annulipes* are one of the most important groups of mangrove epifauna. We adopted a stratified nested design to investigate the impacts of pollution on the feeding, bioturbation, and biomass of *U. annulipes*. We applied a layered random sampling approach at each site that spanned in 2 × 2 m^2 quadrats in desert and *Avicennia* zones during July, August and October 2005. The data collection depended on each full moon springs and new moon springs. Different parameters were measured, chlorophyll *a* (*Chl a*) concentrations in the feeding pellets and unprocessed soils, amount of bioturbated clays (expressed as dry weight of excavated material and feeding pellets), and biomass (dry weight) of *U. annulipes*. Four-factor Analysis of Variance (ANOVA) tests were applied to determine whether there was a significant difference in feeding, bioturbation, and biomass of *U. annulipes* within the two sites. Our findings show substantial differences in chlorophyll *a* concentration in the feeding pellets in the *Avicennia* zone of the peri-urban mangroves. Moreover chlorophyll *a* level did not vary between the processed and unprocessed soils in the *Avicennia* zone. In Gazi, a significant difference in the bioturbated material was recorded compared to Mikindani. The results demonstrate a consistent increase in crab biomass at the peri-urban site, then the non-urban mangroves. The *Avicennia* zone of the suburban location had a higher *U. annulipes* biomass compared to the non-urban Gazi. There was no association between the mass of bioturbated material and Uca biomass. The results also show that the amount of excavated material did not relate to the Uca biomass.

Keywords: Biomass, bioturbation, feeding, fiddler crab, pollution, *Uca annulipes*

INTRODUCTION

The critical role of marine resources is known worldwide and thereby cannot demand serious attention. Coastal biodiversity, i.e., crabs and fish are essential in supporting the livelihood of the many coastal communities through among others fisheries. Over one-third of the world's population live in the coastal zone (UNEP 2006). This zone is a narrow strip constituting 4% of the total land surface (UNEP 2006; Okuku et al. 2011). However, the rapid increase in population, food production, urbanization and coastal development in most of the world's coastal regions are causing severe environmental concerns such as marine pollution (Seitzinger et al. 2005). Different kinds of marine pollutants include oil, garbage, sewage, chemicals, radioactive waste and thermal pollution (Clark et al. 2001).

Marine pollution (80%) derived from land-based sources that reach estuaries and coastal waters via several routes: non-point runoff, atmospheric fallout, and direct deposit of waste (GESAMP 1990; Vijay et al. 2008). Despite the significant contribution of land-based activities to coastal pollution, little attention has been given (UNEP 2006). In most cases, eutrophication and organic loading problems in coastal regions in the world are related to discharge of sewage effluent and removing of sewage sludge (Subramanian 1999). According to Palanisamy (2007), coastal ecosystems are known to act as receptors for industrial and municipal effluents.

Sewage can be described as a cocktail of waste from food preparation, dishwashing, garbage-grinding, baths, showers, toilets, and sinks (Okuku et al. 2011). It holds a wide variety of dissolved and suspended materials and also disease-causing microorganisms. Densely populated communities generate such large quantities of sewage that dilution by ocean waters alone cannot avert pollution incidences.

Sewage pollution is one of the most serious of all land-based threats to the marine environment (UNEP 2006). As many as 80-90% of sewage discharged into the coastal zones of many developing countries was left untreated

(UNEP 2006). This activity puts the human and wildlife as well as livelihoods (fisheries to tourism) at risk through a reduction of biodiversity and productivity (Hunter and Evans 1995; Jenssen 2003). The aesthetic and intrinsic value of the marine environment particularly when sewage discharge occurs into relatively shallow and sheltered coastal areas such as the mangrove systems as in the case of Kenya (Okuku et al. 2011).

The coastal town of Mombasa faces severe challenges of sewage pollution. The city has only one sewage treatment facility which had previously stalled for several years and is currently working at half capacity after renovation. This half capacity can barely serve even 12% of the Mombasa city population causing to volumes of sewage being discharged either untreated or minorly treated (Okuku et al. 2011).

Mangrove ecosystem is among one of the coastal ecosystems under the influence of sewage discharge. Peri-urban mangroves of Mombasa are recipients of sewage-polluted rivers and flash-flood waters.

Furthermore, it is used for sewage dumping, with possible risk to human health, fisheries, and ecosystems (De Wolf et al. 2000). Research has been performed in countries like China (Cannicci et al. 2008) which indicate that mangrove swamps have the potential for use as natural wastewater treatment areas (Wong et al. 1995). Mangrove sediments are efficient in absorbing nutrients, mainly nitrogen and phosphorus from sewage, and shrimp farming wastes (Trott et al. 2004). Nevertheless, a study on the effects of peri-urban effluents and sewage on the faunal component of shallow water ecosystems is not encouraging (Cannicci et al. 2008).

Faunal assemblages in the mangroves vary spatially. Thus, it brings confounding factors in the results (Chapman and Tolhurst 2004). Distributions of microfauna and diversity in peri-urban coastal systems are susceptible to various kinds of pollutants and impacts, such as metals (Bergey and Weiss 2008), hydrocarbons (Inglis and Kross 2000), pesticides (Garmouma et al. 1998). Fiddler crabs are one group of organisms that are exposed to sewage and pollution being strict residents of mangroves throughout their adult life (Skov et al. 2002; Fratini et al. 2004) that ingest sediment (Cannicci et al. 2008).

This study was performed based on the background of concerns that sewage disposal could result in loss of the diversity of Fiddler crab *Uca annulipes*. In this study, we investigate the impact of pollution on the feeding, bioturbation and the biomass of fiddler crab *U. annulipes* between peri-urban mangroves (Mikindani), affected by sewage disposal and non-urban sites with no evident sewage disposal (Gazi Mangroves). The status of coastal ecosystems is an essential indicator of environmental quality regarding pollution load and related issues. The information gathered from these study aspects will highlight the need for urgent planning and action in the areas studied.

The objective of this research was: (i) To determine the feeding rate of *U. annulipes* in human-impacted mangroves of Mikindani and pristine Gazi. (ii) To evaluate the rate variety of bioturbation of *U. annulipes* in Mikindani and Gazi. (iii) To determine if the biomass of *U. annulipes* differ significantly between human-impacted mangroves of Mikindani and non-impacted Gazi.

MATERIALS AND METHODS

Description of the study area

In the tropics, the government constructed cities near natural harbors or waterways that are lined by mangrove swamps (PUMPSEA 2007). Peri-urban mangroves of these towns are recipients of sewage-polluted rivers and flash-flood waters and extensively used for sewage dumping.

This study took place along the Kenyan coast in two geographically different sites; Mikindani on Tudor creek and Gazi Bay (Figure 1). Gazi Bay is located at the 47 km South of Mombasa (039.300º E, 04.220º S), in Kwale county. The Bay is protected from strong waves by the presence of Chale Peninsula to the East and fringing coral reefs to the South. Kidogoweni River drained the upper region of the Bay, while the Mkurumuji River removes its south-western part. Their combined freshwater discharge is 17.ms$^{3-1}$ and is the primary sources of dissolved inorganic nutrients (Kitheka 1996; Kitheka et al. 1996). The mangrove species usually found in this area include *Avicennia marina* (Forsks), *Ceriops tagal* (Robinson), *Bruguiera gymnorrhiz*a (Lam), *Lumnitzera racemosa* (Willd), *Rhizophora mucronata* (Lam), *Sonneratia alba* (Smith) and *Xylocarpus granatum* (Koen).

Mikindani is a mangrove system located within Tudor Creek, which surrounds the Mombasa city. Mombasa is surrounded by two main creeks namely, Port Reitz and Tudor. Mikindani has a population of 917,864, with an average population density of 3,111 persons per km^2 and an annual growth rate of 3.6% (GoK 2005). Severe anthropogenic challenges have posed the mangrove in this region. From 1893 to 1993, five tanker accidents occurred in Mombasa port and its adjacent, spilling a total of 391,680 tonnes of oil (Abuodha and Kairo 2001). In 1988, a significant spill destroyed 10 ha of mangroves in Makupa (Abuodha and Kairo 2001; FAO 2005), while 2005, 200 tons of crude oil were spilled, ruining 234 ha of mangroves in Port Reitz creek (Kairo et al. 2005). Also, the Mombasa municipal waste contributes roughly 4369 ton/year of biological oxygen demand (BOD), 622 ton/year of nitrates, 3964 ton/year of suspended solids, and 94 ton/year of phosphates into the creeks as raw sewage (Mwaguni and Munga 1997). Also, coliform and *Escherichia coli* levels raised to 1800+ per 100 ml and up to 550 CFU per 100 ml respectively (Mwaguni and Munga 1997).

The sewage flushed through the mangrove forest in canals, initially affecting the forest ecosystem that is dominated by *A. marina*, before flowing towards the sea in an ecosystem that is dominated by *R. mucronata*. Finally, it reached Tudor Creek (Figure 2). Mangroves are flooded by sewage in every tidal cycle in this creek. Nevertheless, studies show that the load reduces exponentially with distance from the source (Kitheka et al. 2003; Mohamed 2008; Mohamed et al. 2008). Every day, about 1200 kg of nitrogen and 5.5 kg of phosphorous are discharged via sewage into the Mikindani system (Mohamed et al. 2008) although this site is dominated by *A. marina* and *R. mucronata* (a typical feature of Kenyan mangrove forests), other East African mangrove species also present, except for *Heritiera littoralis* and *Pemphis acidula*.

Sampling design

To assess the impacts of pollution on the feeding, bioturbation, and biomass of fiddler crab *U. annulipes*, a stratified nested design was adopted (Underwood 1992 1994). The mangroves chosen for the sample manifested different zonation pattern in the dominance of their mangrove species maintained by associated faunal assemblages (Skov et al. 2002). Thus, a stratified random sampling approach was applied at each site. We include two belts of the *A. marina*, that is the *A. marina* zone (landward sandy belt dominated by *A. marina*) representing the region flooded only during spring tides, and desert zone (open area without any mangrove trees) flooded twice a day during high tides (Figure 3). *U. annulipes* also dominates the *A. marina* zone. They feed in the desert zone, but during low tides, they live in a burrow in the forested area during the high tides.

Sampling methods

We performed sampling after spring tides receded and intertidal flats became exposed. Two random transects (100-500 m apart) were chosen in each of the two zones (*A. marina* and desert) in both, Mikindani and Gazi. In each transect, three two by 2 m quadrats were randomly sampled to assess the feeding and bioturbation activity of the fiddler crabs. Care was taken at the peri-urban sites to locate transects adjacent to the sewage dumping channels to obtain data on areas directly affected by the wastewaters. The study took place in July, August and October 2005. The data collection depended on each full moon springs and again on the following new moon springs when spring tides come. The factor "Time" was critical since we had to wait for spring tides, inundation of the study sites depended on these factors. The whole work period at each location was spread over six weeks: Full moon springs 1, Site 1 (Gazi); New moon springs 1, Site 1; Full moon springs 2, Site 2 (Mikindani); New moon springs 2, Site 2.

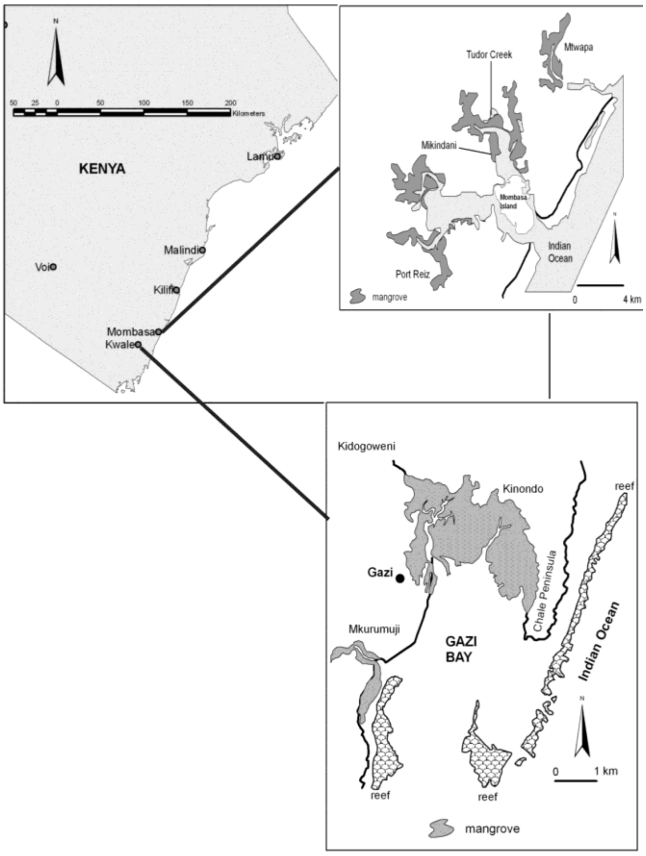

Figure 1 Map showing the study regions in Tudor Creek and Gazi bay along the Kenya coast

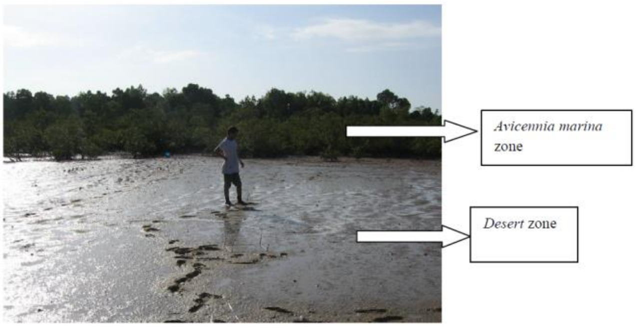

Figure 3. Forested (*A. marina* zone) and open area (desert zone) (Image by Filipo)

Figure 2 Pollutants draining to the mangroves from residential areas in Mikindani (images by Charles Mitto)

Figure 4. Image showing quadrats set in the *A. marina* and Desert zones (Image by Marco)

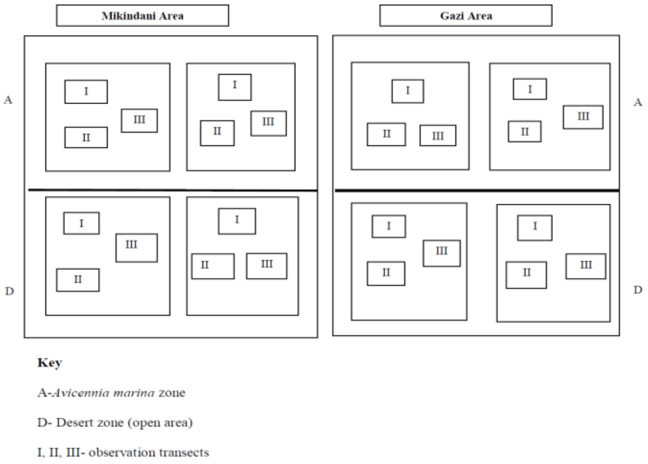

Figure 5. Sampling design showing the sampling zones and transects

Observation protocol

Guide ropes were position in two transects before inspection. In each transect, three two by 2 m quadrats were set and randomly sampled (Figure 4-5). Surface activity (feeding and bioturbation) was assessed two times for each quadrat, one hour after emersion in water during the spring high tides, and at low water. Observers standby at 3-4 m from the quadrats, there was a wait for 15 minutes to allow the regular activity of the crabs to resume. These times were found to be adequate. After the observational time was over, we proceed with the following steps (i) gathering soil samples gathered both from the feeding pellets, and unprocessed soils for chlorophyll analysis and some for bioturbation assessment (ii) counting visually the crab samples, and then samples gathered for biomass measurements.

Sediments were gathered in 10 ml vials. The vials were protected from light with an aluminum foil to avoid additional photosynthetic activities. Bioturbated soils were brought to the Kenya Marine and Fisheries Research Institute (KMFRI) Gazi Station for weighing while the rest samples were transported to KMFRI central laboratories in Mombasa for chlorophyll analysis. Below are details on the procedures which took place after the samples collection.

Chlorophyll analysis

Standard methods of measuring chlorophyll levels in the sediment (Parson et al. 1984) were used. One gram of the residue was taken from each sample of feeding pellets and unprocessed soil. One gram of sediment was then transferred in a 15 ml conical tube and added with 10 ml acetone. The tubes were left to stand for 24 hours at 20° C in the dark for extraction of chlorophyll *a*. Each tube was set in a centrifuge and spun at 200 RFC for 10 minutes briefly after the addition of acetone and after 12 to 15 hours to facilitate extraction. Fluorescence of acetone extractions of samples was calculated with a Turner Designs fluorometer, and chlorophyll *a* amount was determined. After acetone extraction, the sediment was transferred to pre-weighed aluminum pans, dried at 100°C overnight and weighed. chlorophyll *a* content was estimated per g of residue. Readings for the three cores from each replicate were pooled to obtain one value per replicate for statistical analysis.

Fluorescence of the extracts was measured at different wavelengths (630, 647, 664 and 750 nm), using spectrophotometer from their chlorophyll content was calculated using the formula below. The absorbance values at 750 nm were subtracted from the absorbance values at each of the other three wavelengths and substituted in the following equation; this is for purposes of correcting any errors incurred during Spectrophotometer readings.

Formulae:

$$[Chl.a]_{extract}=11.85A_{664}^{/I}-1.54A_{647}^{/I}-0.08A_{630}^{/I}$$

Bioturbation

Sediment from each replicate transect was collected at five cores 3.5 cm in diameter and 20 cm in depth. Standard weights (100 g) were dried at 105°C in the oven, and sediment particles were split according to grain size using a series of sieves of 2-63 mm mesh size mounted on a mechanical shaker and graded based on the Wentworth scale. The content of each sieve was weighed. Samples gathered for analysis of organic material were ignited at 550°C for three h and cooled in desiccators. The loss on ignition (LOI) was measured, and the organic material expressed as a percentage of the dry weight (Heiri et al. 2001). Sediments were gathered from the upper few millimeters of the sediment since this is where the feeding and other activities like burrowing of the fiddler crabs are confined (Dye and Lasiak 1987).

Crab biomass estimation

We gathered a total of 117 *U. annulipes* to estimate crab biomass at the different sampling sites gathered. Carapace width (CW) and length (CL) were measured using vernier calipers. Samples were dried in the oven at 100 ºC, and its weight was measured. The total biomass of each specimen was calculated by multiplying the average DW and the total number of species gathered. However, it was challenging for us to estimate the crab's weight after they were dried.

Data analysis

Cochran‟s multiple comparison tests of homogeneity was performed on all the data gathered. Datasets gathered from the feeding, bioturbation, and biomass samples were processed for normality using Shapir’s test and data transformed [Sqrt (X+1)]. A four-factor Analysis of Variance (ANOVA) was used to determine whether there were differences in feeding, bioturbation, and biomass of the fiddler crab *U. annulipes* within Mikindani and Gazi. These factors were put into consideration when utilizing the ANOVA tests: Impact vs. Control (I vs. C, asymmetrical, fixed and orthogonal), site (random and nested in I vs. C). Also, transect (random and nested in location) and time which played a very crucial role in the data analysis process since we data collection was always dependent on the spring tide season and time. Calculation of different means utilizes the statistical package MINITAB 10.

RESULTS AND DISCUSSION

Impacts of urban wastewater on the feeding rate of *Uca annulipes*

We hypothesized that chlorophyll concentration between the two locations studied is different. Results (Figure 6) show that the difference concerned about localities and zones. It means that chlorophyll levels are higher in Mikindani than in Gazi. More chlorophyll *a* concentration is found in the *Avicennia* zone than in the desert of Mikindani. *F*urthermore, there is no significant difference in the chlorophyll *a* seen in the processed and unprocessed soils *Avicennia* zone. Similarly, the desert zone recorded minimal variations in chlorophyll *a* concentration in untreated soil compared to the feeding pellets.

Effect of urban waste on the bioturbation activity of *Uca annulipes* in human-impacted Mikindani and non-urban Gazi Bay

Four ways ANOVA showed differences in bioturbation between the impacted site (Mikindani) and the control (Gazi). Table 1 shows that there were a lot more bioturbated materials in Gazi ($F_{1,\ 16}$=70.65; $p < 0.05$). In general, higher amounts of feeding material were removed in *Avicennia* zone of Gazi (162 ± 90) than in all other zones. The higher rate of bioturbation was recorded in *Avicennia* zone of Gazi than the desert zone (90 ± 60). Meanwhile, in Mikindani, a higher percentage of bioturbated material was recorded in *Avicennia* zone (36 ± 18) in comparison to the desert zone (30 ± 42) (Figure 7).

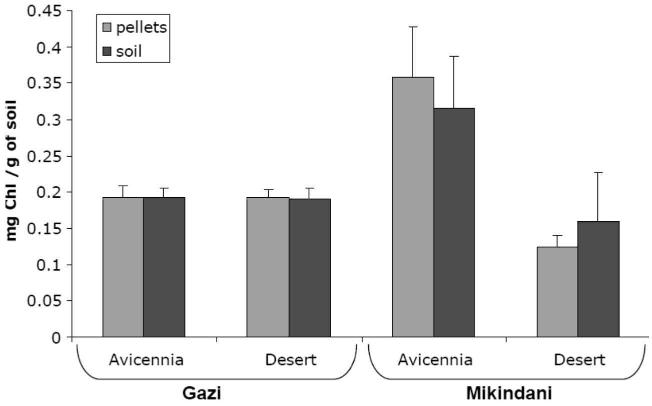

Figure 6. Mean (x ± SE) Chlorophyll *a* level in the processed and unprocessed sediments (soil) within the *A. marina* and desert zones

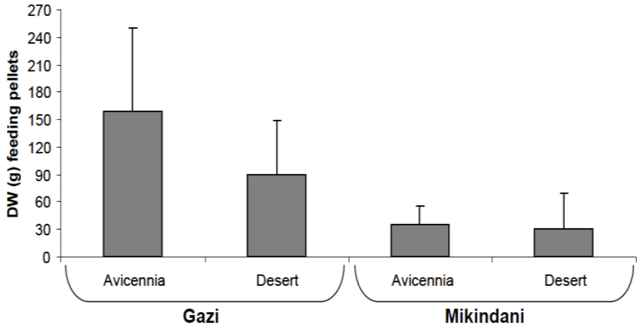

Figure 7. Average (x ± SE) dry weights (g) of feeding pellets gathered in Mikindani and Gazi within the *Avicennia marina* and desert zone

Table 1. Results of the four factor-ANOVA performed on square rooted transformed dry weight (g) of feeding pellets (used to find bioturbation data) observed from Mikindani and Gazi, Kenya

Source	DF	MS	F	*P*
Data	1	28.8854	1.51	0.3438
Impact (I) vs Control (C)	1	233.7663	70.65	0.0139*
zone (Desert Vs *Avicennia*)	1	35.9318	5.86	0.1365
Transects	2	6.1311	0.81	
(I vs C)×zone	1	6.9779	2.11	
Transect× (I vs C)	2	3.3089	0.44	
Data× (I vs C)	1	6.7724	0.58	
Data×zone	1	0.1614	0.01	
Data ×transect	2	19.0958	2.52	
Data× (I vs C)×zone	1	12.3091	1.06	
Data× (I vs C)×transect	2	11.619	1.53	
Result	16	7.5927		
Total	31			

Note: *p< 0.05

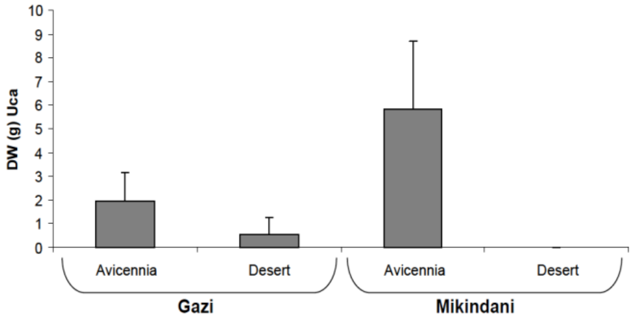

Figure 8. Average ($\bar{x}$ ± SE) dry weights (g) of *Uca annulipes* (biomass) gathered in Mikindani and Gazi, Kenya within the *Avicennia marina* and desert zone

Table 2. Results of the four factor-ANOVA performed on square rooted transformed biomass (Expressed as Dry Weight (DW) data from Mikindani and Gazi, Kenya

	DF	Dry Weight (DW)	
Source		**MS**	**F**
Time	1	0.52	6.7
Impact (I) vs Control (C)	1	0.8079	18.95
zone (Desert Vs *Avicennia*)	1	8.2322	75.28*
Transects	2	0.1094	1.72
(I vs C)×zone	1	2.3225	54.48*
Transect× (I vs C)	2	0.0426	0.67
Time× (I vs C)	1	0.2231	1.24
Time×zone	1	0.8079	10.41
Time ×transect	2	0.0776	1.22
(I vs C)×zone×Time	1	0.0868	0.48
Time× (I vs C)×transect	2	0.1793	2.82
Result	16	0.0636	
Total	31		

Note: $*p< 0.05$

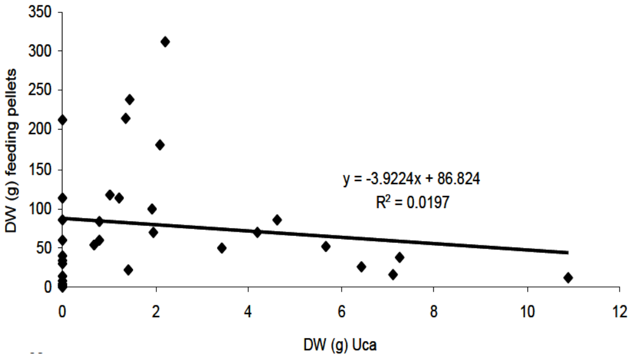

Figure 9. The dry weight of bioturbated material concerning fiddler crab *Uca annulipes* biomass

Impact of pollution on *Uca annulipes* biomass

Table 2 shows the four-way ANOVA tests of *U. annulipes* total crab biomass are shown. The total crab biomass was higher in the *Avicennia* in both locations ($F_{1,16}$=75.28, $p>0.05$) (Figure 8). The *Avicennia* of Mikindani recorded higher total biomass than in any other region of the two sites (Table 2). Further analysis was done to find out if there was any relation in the bioturbated material (both expressed as the feeding pellets and excavated materials-unprocessed soils), and the crab biomass in the two sites. However, no relationship was found between the mass of bioturbated material and *Uca* biomass. Results also show that the amount of excavated material did not relate to the *Uca* biomass (Figure 9).

Discussion

In Kenya, the coastal town of Mombasa is reported to face severe challenges of sewage pollution. Mombasa city has one individual sewage treatment facility which had previously suspended for several years and is currently running at 50% capacity after renovation (Okuku et al. 2011). This half capacity can barely serve even 12% of the Mombasa city population causing to volumes of sewage being discharged either untreated or with minor treatment (Okuku et al. 2011). In this study, we emphasized two significant points in discussing the results. First, the use of stratified sampling design that was adapted to the natural zonation of East Africa mangrove forests (Kathiresan and Bingham 2001), granted us to compare relatively homogenous area regarding vegetation cover and flooding regime. Second, there is wide variation in *Uca* crab assemblage at spatial and temporal scales, and Kenya has a higher ocypodid biomass.

Crabs able to process the surface of the most if not all of the intertidal zone in one tidal cycle (personal observation). From this study, we showed that crabs feeding at observed field densities could significantly reduce chlorophyll levels. Generally, the effect of crab feeding was pronounced in Gazi than in Mikindani. However, chlorophyll *a* level remained constant in Gazi both in *Avicennia* and Desert zones, an in the feeding pellets and unprocessed soil. In Mikindani, feeding was pronounced in the desert zone, then in the *Avicennia* zone. High levels of chlorophyll *a* was measured in the feeding pellets of the *Avicennia* zone. Fiddler crabs are known to consume benthic microalgae. Therefore, they reduce the chlorophyll content in the sediment (Reinsel 2004). The result was in line with findings from Rinsel (2004) in Rachel Estuary, North Carolina, where *Uca pugilator* foraging on sand flats reduced residue chlorophyll *a* by 20%. Reported a 70% reductions of chlorophyll *a* by *Uca pugilator* in Georgia sand flats (Robertson et al. (1980). These studies are similar to those of Reinsel whose sediment samples were mixtures of feeding pellets and unprocessed soils. Hence, this study the crabs" ability food from the sediment and processed sediments.

Kenya was reported to have higher *Uca* crab biomass (Cannicci et al. 2009). This study considered for random variability between the non-urban and peri-urban sites. Indeed, the high levels of anthropogenic nutrients and pollutants dumped in the system of Mikindani in municipal sewage did not appear to stress the crabs. The nutrient level in the two study sites has been reported in studies by Okuku et al. (2011). Nutrient levels were found to be higher in Tudor creek (averages of 0.163 mg/L Nitrate +

Nitrites and 0.11 mg/L ammonium) as compared to Gazi's (standards of 0.019 mg/L Nitrate + Nitrites and 0.018 mg/L ammonium). Different *Uca* biomass relative to control sites were found only in the *Avicennia* zone and the Desert Zone at Mikindani. These results are in a good agreement with the observation that dumping of sewage at Mikindani mostly affects the landward *Avicennia* belt which is the desert zone (Mohamed et al. 2008). The vegetation and soils of the desert zone which is more landward can assimilate the overload of nutrients (Wong et al. 1997). The desert zone at Mikindani is perhaps acting as a phytoremediation system, which is mitigating the effect of the wastewater.

Both in Gazi and Mikindani, the crab biomass was higher in the *Avicennia* zone than the desert zone, thereby confirms that *U. annulipes* are inhabitants of the *A. marina* zone as earlier indicated in this study. However, the high biomass of fiddler crab at the peri-urban site directly linked to the enhanced nutrients levels from sewage loading. The nutrients increase the number of benthic diatoms and bacteria upon which the *U. annulipes* feed (Meziane and Tsuchiya 2002). Data from this study confirms the dominance of *U. annulipes* in Kenya, found by Hartnoll et al. (2002).

Here, crab biomass was not affected by pollution stress. Thereby, we saw it necessary to find out if the number of feeding pellets and the excavated material was associated with the biomass. Results demonstrated that there was no relationship between the mass of bioturbated material and the *Uca* biomass. Besides, we did not find any connection between the excavated material and the *Uca* biomass. Reinsel (2004) observation on *Uca pugilator* found that fiddler crab activity takes place in small regions where they feed and also in the sediment they do not process during given tidal cycle making it challenging to measure the effects of their activity.

The tidal effect also plays a significant role in the renewal of crab activity in one tidal cycle. Therefore there is not enough time between feeding periods for regeneration to occur. When tides recede, the crabs did their activities of feeding and excavation of the burrows. However, where high waves come, it washes away all the sediment (Reinsel 2004).

To conclude, the present results demonstrate that the mangrove crabs are affected by pollution. We observed a consistent increase in chlorophyll *a* concentration at the suburban location. On the other hand, crab biomass was higher both in *Avicennia* zone of the impacted site and the control. Moreover, it can be concluded that the steady increase in crab biomass at the peri-urban site is not an indication that the system was healthier. This kind of changes in biomass can lead to unsustainable changes in ecosystem function (Duke et al. 2007). Therefore, data from this study are essential for management of peri-urban mangrove areas, because fiddler crabs play a crucial role in the control of algal growth in mangrove substrate. Fiddler crabs through feeding, burrowing, and ventilation activities affected microbial activity and sediment metabolism in marine sediments (Aller and Aller 1998).

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