Western Indian Ocean

JOURNAL OF

Marine Science

Western Indian Ocean
J O U R N A L   O F
Marine Science

Published biannually

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Nematodes as bio-indicators of physical disturbance of marine sediments following polychaete bait harvesting

Matthews Wafula[1]*, Agnes W. Muthumbi[1], Virginia Wangondu[1], Charles Kihia[2], Julius Okondo[3]

[1] School of Biological Science,
University of Nairobi,
PO Box 30197-00100 Nairobi,
Kenya

[2] Department of Biology,
Egerton University,
PO Box 536-20115, Egerton,
Kenya

[3] Kenya Marine & Fisheries
Research Institute,
PO Box 81651-001 Mombasa,
Kenya

* Corresponding author:
matthewswafula@gmail.com

Abstract

Sediment disturbance in marine environments is caused by activities including polychaete bait harvesting, trawling, dredging, sediment erosion and treading. These activities affect the benthic communities by changing the densities, community assemblage and diversity. The aim of this study was to evaluate the potential of nematodes as indicators of sediments disturbance following polychaete bait harvesting. The study was conducted in three sites experiencing different bait harvesting intensities in Mida Creek, Kenya. Sediment samples were collected from the mudflats during low tide, preserved in 5% formalin and transported to the laboratory for processing and identification of nematodes. The highly disturbed site recorded the lowest nematode genus richness while the less disturbed sites had the highest. Overall, the most abundant nematode genera in the non-disturbed (Dabaso) and less disturbed sites (Kirepwe) were selective deposit feeders (*Spirinia* and *Terschellingia)*, while most disturbed sites (e.g. Mayonda) had predators/omnivores (*Pheronus, Aporcelaimellus*) and selected members of the genus *Spirinia*. The disturbed site was characterised by low nematode diversity (H') and low dominance (D) while the non-disturbed and less disturbed sites had higher diversity and dominance. Clearly, nematode community assemblage, diversity and feeding guilds changed following disturbance to a low diversity that favoured higher proportions of predator/omnivore taxa.

Keywords: bait harvesting, meiofauna, nematodes, biomonitoring, Mida Creek, Kenya

Introduction

Mangrove forests occur within the intertidal zones and are economically and ecologically important ecosystems especially to coastal communities in developing countries. The forests provide building materials, fuel wood, herbal medicines, carbon sequestration, coastal protection and reduce sediment erosion (Lee *et al*, 2014). Ecologically, the ecosystem is important as nursery (Gajdzik *et al.,* 2014; Sheaves *et al,* 2015) and feeding grounds for many offshore fish (Lugendo *et al.,* 2007; Fry and Ewel, 2010). Mangrove ecosystems are also important fishing grounds (Kihia *et al.,* 2015), especially for artisanal fishers as the forest provides food and shelter for fish (Hutchison *et al.,*

2014). However, being close to the shoreline and easily accessible to humans, the ecosystem is rendered vulnerable to anthropogenic impacts such as poor harvesting methods and overexploitation of these coastal resources (Glaser *et al.,* 2003). In addition, no regulations exist on the harvesting of non-woody products such as crabs, shrimps, fishing baits, ornamental fish etc. (Linneweber, 2002).

Harvesting fishing bait from the mangrove forests and the adjacent mudflats is a common practice among artisanal hook and line and trap fishers that provides cheap and readily available bait. Bait harvesting, though very important and prevalent in coastal

areas, is unregulated and uncontrolled (Watson *et al.,* 2016). Most fishery stakeholders consider the bait fishery as less harmful compared to net fishing (personal observation). Nevertheless, bait harvesting that involves collection of invertebrates such as gastropods and crabs from the mangrove forest floor or digging of various polychaete worms from sediments may be equally harmful because of its effects on target and non-target organisms (Watson *et al.,* 2007). Digging for worms using a stave (*jembe*) within the intertidal mud flats causes continuous disturbance of the sediments and the benthic fauna community. Due to a lack of studies elucidating impacts of the practice on benthic epi- and in-fauna and the consequence to the coastal ecosystem integrity, regulations controlling the bait fishery are difficult to develop. Thus, the focus of this study was to collect data and information that could inform policy development on this type of fishery and in particular polychaete bait harvesting.

Meiobenthos are normally very diverse and abundant in mangrove sediments due to the complexity of the habitat (Pinto *et al.,* 2013) and the densities can reach up to 2000 ind.10cm^{-2} (Xuan *et al.,* 2007). Physical disturbance of the sediments is known to interfere with the assemblages because of the permanent association of the community with the substrate (Sun *et al.,* 2014). Nematodes are normally the most abundant meiofauna taxon and have been recognised as the best candidate for ecological health assessment (Semprucci *et al.,* 2015). Schratzberger and Warwick (1998) demonstrated that nematodes are sensitive to physical disturbance where diversity varied depending on level of disturbance. This study was carried out to investigate the potential of nematodes as an indicator of disturbance following polychaete bait harvesting on an intertidal mud flat. The information will inform policy development related to the bait fishery and in particular harvesting of polychaetes from the sediments.

Mida Creek in Kenya was selected for the study because the fishery (bait collection and fishing) was intense. The creek supports the local human communities by providing a livelihood in the form of the fishery, building material, medicine, and fuel wood, among other mangrove forest resources. The creek and the larger Watamu Marine National Park are an important tourist destination for local and international tourists due to the rich biodiversity, wonderful beaches and warm temperatures. This rich biodiversity is however threatened by the excessive bait collection from the forest floor and the mud flat. Bait in the

form of hermit crabs (*Clibanarius spp*) and gastropods (*Terebralia palustris*) are collected from the mangrove forest while polychaetes (*Marphysa mosambica*) are dug out from the mud flats (Kihia *et al.,* 2015, 2016). Digging of polychaetes entails churning of sediments continuously and thus interfering with the benthic fauna including nematodes.

Materials and methods
Study area
The study was carried out at Mida Creek in Kilifi County, Kenya. The creek is located 100 km north east of Mombasa and about 15 km from Malindi town. It is a mangrove-forested creek covering an area of 32 km² bordered by Arabuko Sokoke forest landwards and Watamu Marine Park towards the sea. The area is gazetted as a nature reserve and a UNESCO-MAB reserve managed as a national reserve by the local communities. The creek has mangrove forests composed majorly of *Rhizophora mucronata* and *Ceriops tagal* (Alemayehu *et al.,* 2014) and other species in lower abundances. Where mangrove zonation is present, the landward species is mainly *Avicennia marina* followed by a mixed *Ceriops tagal*, a mixed *Rhizophora mucronata* and *Bruguiera gymnorrhiza* zone, and finally *R. mucronata* and *Sonneratia alba* zones of pure stands (Dahdouh-Guebas *et al.,* 2002). The creek is one of the most important bird areas in Kenya supporting at least 60 % of the total numbers of birds along the Kenya Coast (Seys *et al.,* 1995). There is also high diversity of crabs associated with the diversity of mangrove species (Dahdouh-Guebas *et al.,* 2002). Benthic fauna such as crabs and molluscs form the major diet of birds in this area and a resource for the local human community either as food or fishing bait.

Three sampling sites (Dabaso, Kirepwe, Mayonda) were identified for this study based on the level of bait harvesting as a proxy of disturbance; that is, low, moderate and high harvesting effort coinciding with low, moderate and high disturbance (Fig. 1).

Dabaso, considered low disturbance (low harvest), is located on the eastern edge of the creek (S 15°03 20.53´: E 039°59.23´). It has a zone with large mature mangrove forest of *Rhizophora mucronata* next to a zone of mixed forest of *R. mucronata*, *C. tagal* and *B. gymnorrhiza*. There was bait (hermit crabs and mangrove whelks) collection on the forest floor but no digging for polychaetes on the mudflat was observed. This zone enjoys some form of Participatory Forest

Management (Frank *et al.,* 2017) which helps in the control of the activities that take place in the mangrove, unlike the other two sites. Therefore, the station was selected as a control site and sampling was done on the mudflat next to the mixed forest.

Kirepwe, considered moderately disturbed (moderate harvesting), is an island within the creek off Dabaso (S03*°27.28': E039°58.490'*). It is characterized by a narrow fringe of mangrove forest mainly *C. targal* on the

creek (S03°19.274': E039°59.098'). In Mayonda the mangrove forest is limited to the high intertidal zone and mainly composed of large trees of *A. marina*. The intertidal mudflat zone was at least 60 m in length and many bait harvesters (7-10 fishermen) could be spotted during the low tide period each day.

Sampling design

Sampling was conducted during spring low tide in November, 2013. Sediment samples were collected
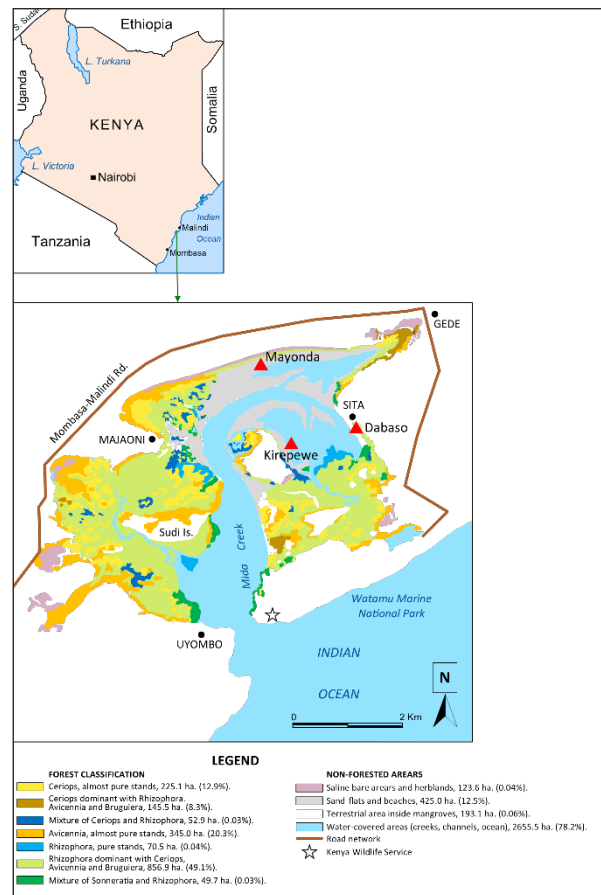

Figure 1. The Kenyan coast and Mida Creek showing the sampling sites of Kirepwe, Dabaso, and Mayonda.

eastern side, and an extended mixed forest (*R. mucronata*, *C. tagal* and *B. gymnorrhiza*) on the northern side. There are single species forest stands of *R. mucronata* and *S. alba* on the southern side of the Island. The site selected for this study was the mudflat adjacent to *C. targal* mangrove forest on the eastern side. The site had bait harvesting going on within the mudflat but by only a few (2-3) fishermen per day.

Mayonda, considered high disturbance (high rate of harvesting), is located on the northern side of the

from the intertidal mudflat between the mangrove forest and the low water mark during spring low tide for nematodes, grain size and organic matter analysis. Two replicate samples for each parameter were collected from a quadrat along a transect from the mangrove-mudflat zone and every 10 m down towards the low water mark. Due to the difference in the length of the mudflat different number of quadrats were sampled in the different sites. Kirepwe had 2 quadrats (QC to QD), Dabaso had 4 quadrats (QC to QF) and Mayonda had 5 quadrats (QC to QG).

Sample collection

Two replicate sediment samples were collected using a perspex hand corer of 3.6 cm diameter to a depth of 10 cm for each analysis (nematodes, grain size and organic matter). Samples for nematode analysis were immediately preserved in 5 % formaldehyde solution. Samples for sediment organic matter were placed in ziplock bags, carried in a cooler box and put in the freezer on arrival in the laboratory. Samples for sediment grain size analysis were carried in plastic bottles without preservation. All samples were clearly labelled with the date, station, transect and replicate.

Sediment grain analysis

Sediment samples were dried in the oven at 70 °C until no further loss of weight was recorded. The dried samples were gently crushed to loosen the particles and a sub-sample of 100 g from each replicate weighed out for grain size analysis. The samples were sieved using a mechanical shaker through a series of sieves as follows: very coarse sand (2.00 mm); coarse sand (1.00 mm); medium sand (0.5 mm); fine sand (0.25 mm); very fine sand (0.125 mm); and silt (0.063 mm). The proportion of sediment collected on each sieve was weighed and calculated as a percentage of the total sub-sample sieved.

Determination of sediment organic matter

Sediment samples for organic matter analysis were dried in the oven at 70 °C. A sub-sample of 10 g was weighed and burned at 600 °C using a muffle furnace for six hours. The ash-free dry weight was used to calculate the percentage proportion of sediment organic matter in each sample.

Nematode analysis

Sediment samples for nematode analysis were rinsed with tap water over a 1 mm sieve to exclude macrofauna and any other debris, and collected on a 38 μm sieve. The samples were centrifuged three times at 6000 rpms using Magnesium Sulphate ($MgSO_4$) (1.28 g/cm^3 specific density). The supernatant was then rinsed thoroughly with water and put back into labelled sample bottles using 4 % formaldehyde solution and stained with Rose Bengal overnight before sorting. The nematodes were counted with a dissecting microscope at 10 X magnification and 100-200 individuals picked out for identification to genus level. The selected nematodes were processed through step-wise transfer into anhydrous glycerol in order to make permanent slides of the specimens. Identification of the nematodes

to the genus level was carried out under a stereo microscope using the key by Platt and Warwick (1988) and Warwick *et al.* (1998). Genera composition and diversity was compared between sites. Nematode feeding guilds by Wieser (1953) that identifies four feeding guilds as selective (1A) and non-selective (1B) deposit feeders, epistrate feeders (2A) and predator-omnivore feeders (2B) were used to analyse the nematode trophic distribution.

Nematode community analysis was carried out using PRIMER version 5 to produce the cluster and MDS for nematode assemblages. The species richness S, Simpson's reciprocal for dominance (1/D), Shannon-Wiener (H') and Pielou's evenness (J) were derived from PRIMER which was also used for community analysis. Analysis of Variance (ANOVA) was carried out using STATA version 15 to check for differences in densities and diversities between sites. Significant difference was considered at $p < 0.05$.

Results

Grain size (granulometric) analysis and sediment organic matter

Six sediment grain size categories were encountered in the three sites. The most common sediment grain size was fine sand in all three sites. The median grain size was medium sand in Dabaso and Kirepwe while it was coarse sand in Mayonda. The largest proportion (35 %) of medium sand and the lowest proportion of very fine sand and silt (<5 %) was recorded in Mayonda. Kirepwe had 29 % medium sand, 5 % of very fine sand and silt while Dabaso had the lowest proportion of medium sand (22 %) and the highest proportion of very fine sand and silt (10 %). Consequently, the proportion of the finer grain size (fine sand, very fine sand and silt) was highest in Dabaso (57 %), followed by Kirepwe (53 %), and was much lower in Mayonda (43 %) (Fig. 2).

Sediment organic matter was highest in Dabaso (8.1±7.01 %) followed by Kirepwe 4.1±2.48 % and Mayonda which had 2.6±0.64 %, but the differences were not significant ($F_{2, 23} = 4.00$ P=0.13) between the sites.

Nematode density

Nematode densities (Fig. 3) ranged between 900±250 ind.10cm^{-2} in Dabaso, 710±210 ind.10cm^{-2} in Mayonda and Kirepwe with 680±240 ind.10cm^{-2}. Although the nematode mean density was slightly higher in Dabaso compared to the other sites the difference was not significant ($F_{2, 23} = 1.15$; p=0.33).
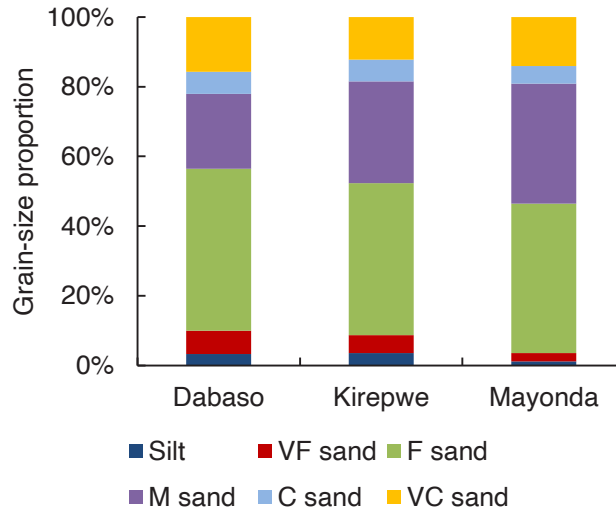
Figure 2. Grain size composition (%) at sites (Kirepwe, Dabaso, and Mayonda) in Mida Creek, Kenya.

Nematode family distribution

A total of 3985 nematode individuals identified yielded 31 families from Mida Creek (Table1). Seven of the families (Comesomatidae, Chromadoridae, Cyatholaimidae, Desmodoridae, Linhomoeiidae, Selachinematidae and Xyalidae) were represented by more than two genera and were present in all the three sites (Dabaso, Kirepwe and Mayonda). The remaining families were represented by one or two genera and were encountered in either one or two sites but not all three, except Anoplostomatidae, Ethmolaimidae, Enchelididae, Haliplectidae and Oncholaimidae. Thus, there were 12 families that were common in all three sites and four to five families that were restricted to only one site.

Most of the families represented by a single genus and restricted to only one site had low abundances except Aporcelaimidae in Mayonda that was the second most abundant family in that site.

Nematode genera distribution

A total of 83 putative nematode genera were encountered in Mida Creek. The distribution of nematode genera differed across the stations with Kirepwe (58) having the highest number, followed by Dabaso (46) and lastly Mayonda (34) (Table 1). Only a few genera had relative abundances above 1 % in any of the sites with 12 genera in Kirepwe, 16 genera in Dabaso and 18 genera in Mayonda (Table 1).
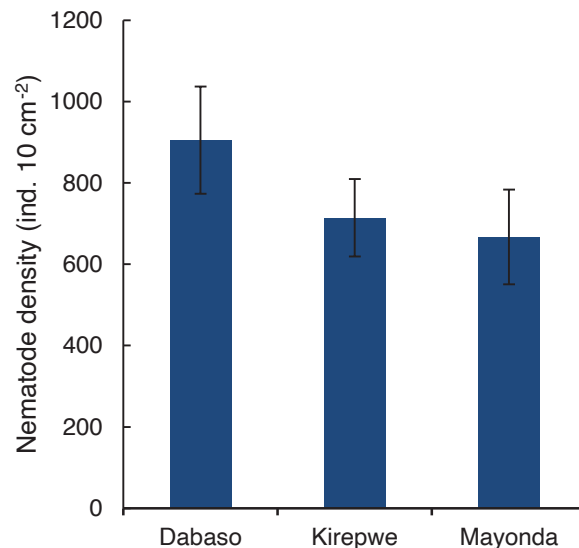

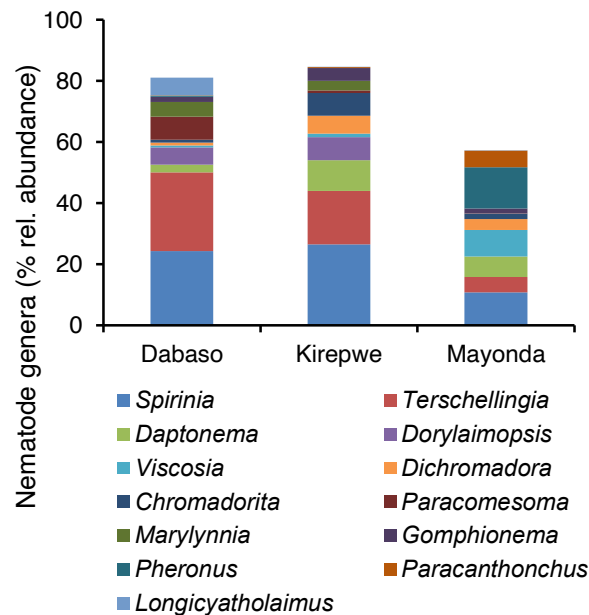**Figure 3.** Nematode densities (ind. 10cm⁻²) at sites in Mida Creek.

Figure 4. Distribution of the overall most dominant nematode genera in Mida Creek.

The thirteen most abundant nematode genera across all the three stations contributed to 80 % of the total nematode population in Kirepwe and Dabaso and less than 60 % in Mayonda (Fig. 4) indicating a low nematode dominance in Mayonda. Both Dabaso and Kirepwe were characterised by relatively high abundances (>18 %) of the two overall most common mangrove nematode genera (*Spirinia* and *Terschellingia*) and *Dorylaimopsis* at 7.6 % and 5.7 % respectively (Fig. 4). Dabaso however, differed from Kirepwe in having high proportions of *Paracomesoma* (7.5 %) and *Paralongicyatholaimus* (5.8 %). Kirepwe had high proportions of *Daptonema* (10 %) *Dichromadora* (5.9 %) and *Chromadorita* (7.5 %). Mayonda on the other hand, had relatively lower abundances of the overall most common genera, that is, *Spirinia* (10.7 %) and *Terschellingia* (5 %), but high relative abundances of *Daptonema* (6.7 %), similar to Kirepwe (10 %). Clearly, the overall most abundant genera at Dabaso and Kirepwe were relatively lower in Mayonda (Fig. 4).

A comparison of the most abundant genera in each site independent of the other sites showed that Mayonda was dominated by a unique combination of nematode genera; *Pheronus* (13 %) and *Aporcelaimellus* (11.2 %) (Table 1). *Spirinia* (10.7 %) that was highly abundant in the other two sites was only third most abundant in Mayonda. *Aporcelaimellus* (11.2 %) *Pontonema* (8.8 %), *Viscosia* (8.7 %), *Synonchium* (7.4 %), *Haliplectus* (6.8 %) and *Parachanthochus* (5.4 %) had

relatively high abundances in Mayonda while they were either totally missing in the other two sites (Dabaso and Kirepwe) or were in very low abundances. Dabaso and Kirepwe were not only similar in having high relative abundance of the overall most abundant genera (*Terschellingia* and *Spirinia*) but they also shared many other genera in common, though at different relative abundances, demonstrating high similarity between the sites (Table 1).

Cluster analysis showed a low similarity (20 %) between nematode communities in the lower intertidal zone in Mayonda (quadrats QE, QF and QG) on one the hand and that in Dabaso and Kirepwe on the other (Fig. 5a). The nematode community in Dabaso and Kirepwe had between 50 % and 70 % similarity. The nematode community from the high intertidal zone (quadrats QC and QD) in Mayonda had a slightly higher similarity (40 %) with the community from Dabaso and Kirepwe. In general, nematode communities from Dabaso and Kirepwe had higher similarity between them (50 % and 70 %) compared to their similarity with Mayonda, at 20 % for the low intertidal zone community and 40 % for the high intertidal zone (Fig. 5a). Among the nematode community in Mayonda high dissimilarity was observed between the different intertidal zones sampled but also between the replicates as they are placed far from each in the nMDS (Fig. 5b). This confirms the relationship observed in the TWINSPAN analysis.

Table 1. Relative abundances (%) and feeding guilds of nematodes at Mida Creek.

Family	Genus	Feeding guild	Dabaso (Low)	Kirepwe (Medium)	Mayonda (Heavy)
Anoplostomatidae	*Anoplostoma*	1B	0.6	0.1	1.3
Anticomidae	*Paranticoma*	1B	-	0.1	-
Aporcelaimidae	*Aporcelaimellus*	2B	-	-	11.2
Comesomatidae	*Dorylaimopsis*	2A	5.7	7.6	-
	Paracomesoma	2A	7.5	0.8	0.1
	Sabatieria	1B	0.4	3.4	-
	Pierrickia	1A	0.1	1.3	-
	Comesoma	1B	-	0.9	0.3
	Metacomesoma	2A	-	0.3	-
	Actarjania	2A	-	0.1	-
	Laimella	1B	-	0.1	-
	Hopperia	2A	-	0.1	-
	Paramesonchium	2A	-	0.1	-
Chromadoridae	*Dichromadora*	2A	0.9	5.9	3.6
	Chromadorita	2A	1.0	7.5	1.7
	Spilophorella	2A	1.7	0.8	1.0
	Chromadorella	2A	-	-	1.0
	Chromadorina	2A	-	0.3	-
	Neochromadora	2A	-	0.2	-
	Chromadora	2A	-	0.1	-
	Graphonema	2A	-	0.1	-
	Trochamus	2A	-	0.1	-
	Marylynnia	2A	4.9	3.1	-
Cyatholaimidae	*Paracanthonchus*	2A	0.1	0.3	5.4
	Longicyatholaimus	2A	5.8	0.1	0.1
	Paralongicytholaimus	2A	-	0.9	-
	Metacyatholaimus	2A	0.5	0.2	-
	Cyatholaimus	2A	0.3	-	-
	Paracyatholaimus	2A	-	0.1	-
	Pomponema	2B	-	0.1	-
Desmodoridae	*Spirinia*	1A	24.3	26.5	10.7
	Desmodora	2A	0.6	0.4	1.1
	Chromaspirina	2A	0.2	-	0.5
	Molgolaimus	2A	0.1	-	-
	Stygodesmodora	2A	-	0.1	-
	Eubostrichus	1A	0.1	-	-
Diplopeltidae	*Campylaimus*	1A	-	0.1	-
Desmoscolecidae	*Desmoscolecidae*	1A	-	-	0.2
Draconematidae	*Draconema*	1A	-	-	0.2
Ethmolaimidae	*Gomphionema*	2A	1.6	4.2	1.5
	Comesa	2A	-	0.4	-

| Family	Genus	Feeding guild	Dabaso (Low)	Kirepwe (Medium)	Mayonda (Heavy)
Enchelidiidae	*Eurystomina*	2A	0.4	-	1.0
	Pareurystomina	2B	0.5	0.1	0.1
Haliplectidae	*Haliplectus*	1A	0.2	0.1	**6.8**
Ironidae	*Pheronus*	2B	0.5	-	**13.5**
	Dolicholaimus	2B	0.1	-	-
	Terschellingia	1A	25.8	17.5	5.0
	Megadesmolaimus	2A	3.4	-	0.2
	Paralinhomoeus	1B	1.8	0.7	0.1
Linhomoeidae	*Metalinhomoeus*	1B	0.1	0.3	-
	Desmolaimus	1B	0.1	-	-
	Didelta	1B	-	0.1	-
	Eleutherolaimus	1B	-	0.1	-
Leptosomatidae	*Metacylicolaimus*	2B	0.3	-	-
Leptolaimidae	*Procamacolaimus*	2A	-	-	0.3
	Cricolaimus	2A	0.1	-	-
Microlaimidae	*Microlaimus*	2A	-	-	0.2
Monoposthiidae	*Monoposthia*	2A	-	0.1	-
	Nudora	2A	-	-	0.1
Monhysteridae	*Monhystera*	1B	-	1.5	-
Oncholaimidae	*Viscosia*	2B	0.7	1.1	**8.7**
	Pontonema	2B	-	-	**8.8**
Oxystomatidae	*Oxystomina*	1A	-	0.2	-
Pandolaimidae	*Pandolaimus*	1B	0.1	-	-
Pharnodermatidae	*Crenopharynx*	2B	0.1	0.1	-
Rhabdonemaniidae	*Rhabdodemania*	2A	0.1	-	-
	Synonchium	2B	0.3	0.1	**7.4**
	Demonema	2B	0.2	-	-
Selachnematidae	*Gammanema*	2B	-	-	0.1
	Halichoanolaimus	2B	-	0.1	-
Siphonolaimidae	*Siphonolaimus*	1A	0.1	-	-
Tripyloididae	*Bathylaimus*	2B	1.3	0.1	-
	Tripyloides	2B	1.1	0.1	-
Trefusiidae	*Rhabdocoma*	1A	-	0.2	-
Tarvaiidae	*Tarvaia*	1A	-	-	0.1
	Daptonema	1B	2.5	**10.0**	6.7
	Stylotheristus	1B	2.8	0.1	0.8
	Promonhystera	1B	1.0	0.4	-
Xyalidae	*Theristus*	1B	0.1	0.8	-
	Linhystera	1A	0.1	0.3	-
	Paramonohystera	1B	0.3	0.1	0.1
	Valvaelaimus	2A	-	0.1	-
No. of Genera	Total: 83		46	57	34
No. of Families	Total: 31		20	20	20
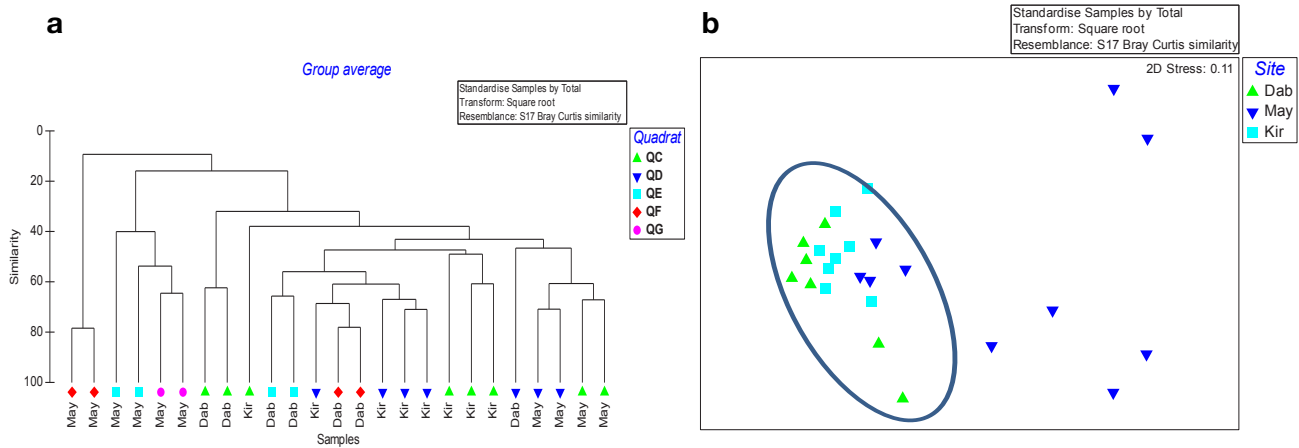
Figure 5. a) Cluster analysis b) nMDS for nematodes showing community assemblages in Mida Creek, Kenya.

Nematode diversity

Nematode diversity based on average number of genera (S) was significantly different between sites ($F_{2, 22}$= 6.97, P<0.01) being highest in Kirepwe (17.8±2.2) followed by Dabaso (16.9±1.5) and finally Mayonda (9.8±1.3). The average number of genera in Mayonda was significantly different from that in Dabaso (P=0.022) and Kirepwe (P=0.007). Similarly, Shannon diversity H' was also significantly different between sites ($F_{2, 22}$= 6.91, P=0.01). It was significantly lower in Mayonda compared to Dabaso (P=0.017) and Kirepwe (P=0.009). Equally, species dominance was also significantly different between sites ($F_{2, 22}$= 7.70, P<0.01) being lower in Mayonda compared to Dabaso (P=0.015) and Kirepwe (P=0.005). On the other hand, the nematode genus evenness was not different between the three sites ($F_{2, 22}$= 0.17, P=0.8427) (Table 2). Mayonda displayed generally lower nematode genus diversity compared to Dabaso and Kirepwe.

Nematode feeding guilds

The nematode feeding guilds distribution in Mida Creek was more or less similar in Dabaso and Kirepwe (Fig. 6). The feeding type was dominated by selective deposit feeders at 50 % and 44 %, (in Dabaso and Kirepwe respectively) that was composed mainly of the genus *Terschellingia* and *Spirinia* (Table 1). The epistrate feeders were the next most abundant being 27.4 % and 29.5 % of the community in Dabaso and Kirepwe, respectively, being contributed by the families Comesomatidae (*Dorylaimopsis* and *Paracomesoma*), Chromadoridae (*Dichromadora*) and Cyatholaimiade (*Longicyatholaimus* and *Marylynnia*). The non-selective deposit feeders contributed 2.9 % and 10 % in Dabaso and Kirepwe respectively, with the main genus being *Daptonema* in the family Xyalidae. The predator-omnivores were very low at 1.1 % and 1.2% of the nematode community, respectively. In Mayonda the distribution was different with predator-omnivores being the most dominant feeding guild at 49.8 % of the community and represented by the families Ironidae (*Pheronus)*, Selachnematidae (*Synonchium*), Aporcelaimidae (*Aporcelaimellus*) and Oncholaimidae (*Pontonema* and *Viscosia*). The epistrate feeders composed of 17.8 % of the nematode community being represented by the families Cyatholaimidae (*Paracanthochus*) and Chromadoridae (*Dichromadora*). The non-selective deposit feeders contributed 23.1 % of the community being represented mainly by the family Xyalidae (*Daptonema*). Selective deposit feeders had the lowest proportion of 9.3 % in this site being made up of the families Desmodoridae (*Sprinia*), Haliplectidae *Haliplectus*) and Linhomoeidae (*Terschellingia*) (Table 1).

Table 2. Nematode diversity indices among the sites in Mida Creek.

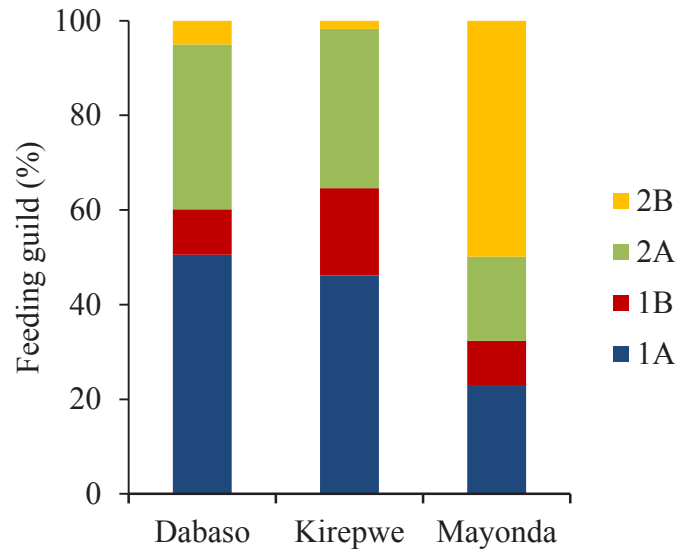| Indices	S	H'	D	J
Dabaso	16.9±1.5	2.6±010	4.5±0.40	0.91±0.01
Kirepwe	17.8±2.2	2.6±0.11	4.7±0.60	0.91±0.01
Mayonda	9.8±1.3	2.0±0.15	2.7±0.34	0.91±0.01

Figure 6. Nematode feeding guilds in Mida Creek.

Discussion

Sediment grain size distribution is a reflection of sedimentary activity that is prone to either erosion or deposition of fine sediments (Yang *et al.,* 2008). Fine sediments tend to get eroded through natural activity like wave action influenced by the set-up of the coastline, or due to human interference involving sediment disturbance (Paik *et al.,* 2008). Presence of cover such as mangrove forest or seagrass bed helps to reduce the sediment erosion by water. A relatively higher proportion of medium sand grain observed in the highly disturbed site, could be an indication of sediment erosion as a consequence of disturbance. Mutua *et al.* (2013) observed that natural and reforested sites in Gazi Bay were rich in silt and clay compared to the degraded site that had higher levels of larger grain sizes. The continuous churning of sediments in the highly disturbed site may have led to continuous removal of very fine sand and silt and retention of medium sand grains. In the moderately disturbed site, there was a lower proportion of medium sand and a higher proportion of very fine sand and silt, while in the low disturbed site there was a high proportion of very fine sand and silt sediments and the lowest proportion of coarse sand recorded. It can be concluded therefore, that disturbance of sediment through bait harvesting has led to change of sediment grain size distribution that favours larger sediment grain size (medium sand, coarse sand and very coarse sand) over the finer grain size (very fine sand and silt).

Although the area under study was a mudflat adjacent to mangrove forests, the lowest sediment organic matter was observed in Mayonda and the highest in Dabaso, while Kirepwe had intermediate values. Continuous sediment disturbance leads to exposure of sediments to oxygen leading to mineralization of organic matter from the sediments. In nature, bioturbation and bio-irrigation by benthic organisms has been shown to cause organic matter mineralization and nutrient recycling (Martinez-Garcia *et al.*, 2015), thus reducing the sediment organic matter. Secrieru and Oaie (2009) modelled total organic carbon (TOC) against grain size and found that presence of TOC was dependent on the presence of fine sediments (very fine sand, silt and clay). It follows therefore, that the presence of a high proportion of large sediment grain size (medium sand) that was observed in the highly disturbed site was associated with low sediment organic matter, perhaps as a result of a high organic matter (OM) mineralization rate. The high rate of mineralization may be influenced by the fact that the highest proportion of sediment organic carbon is found in the top 5 cm of sediment (Chaikaew and Chavanich, 2017) which is being churned continuously and exposing the OM to the air. The high rate of OM mineralization compromises the capacity of the sediments to retain sequestered carbon (Lee *et al.*, 2014). This has serious implications in the face of climate change and associated ocean acidification in the long run.

Nematode densities vary widely in mangrove ecosystems in the world as a response to ecosystem status and other physico-chemical conditions. In a tropical mangrove forest, Netto and Galucci (2003) recorded between 196 ind. 10cm^{-2} and 810 ind. 10cm^{-2} in Brazil, while Xuan *et al.* (2007) recorded between 960 ind 10cm^{-2} and 1758 ind10cm^{-2} in Vietnam. In Gazi Bay,

Kenya, Mutua *et al.* (2013) recorded between 800 and 1320 ind 10cm^{-2} in a natural forest and reforested site while the degraded site recorded only 320 ind 10cm^{-2}. In Mida Creek the densities of between 666 and 905 ind 10cm^{-2} observed were slightly lower than the densities observed in the natural forest in Gazi Bay but higher than the densities in the degraded forest (Mutua *et al.*, 2013). This suggests that nematode densities were not significantly affected by physical disturbance of the sediment and that nematode density changes may not be a good indicator of sediment physical disturbance.

Nematode families and genera encountered in most habitats range between 20 and 30 and between 70 and 90 genera in most mangrove environments. Xuan *et al* (2007) recorded 24 families and 80 genera from an intertidal mudflat in a mangrove forest in Vietnam. Netto and Gallucci (2003) recorded 28 families and 86 genera in a mangrove forest in Southern Brazil. In a Northern Brazil mangrove forest Pinto *et al.* (2013) recorded 25 families and 73 genera. Mutua (2016) recorded 24 families and 76 nematode genera from a mangrove forest in Gazi Bay. In this study 31 nematode families and 83 genera were encountered from the three sites with an average number of 20 families per site. The number of families per site was lower than the number encountered in other studies while the total number was slightly higher, perhaps because a total of three spatially separated sites were studied. The total number of genera encountered from the study was within the range of the number encountered in other mangrove sites. However, the highly disturbed site, Mayonda, had less than half (34) the average number of genera from the mangrove environments and this could indicate sensitivity of most genera to sediment disturbance. Indeed, Schratzberger and Warwick (1998) demonstrated that nematode community changed following disturbance.

The potential of nematode as a bioindicator of environmental disturbance is based on the high genus diversity where different assemblages are encountered depending on the prevailing environmental conditions. In nature, nematode community assemblages are driven mainly by nature and availability of food and sediment granulometry (van der Heijden *et al.*, 2018). *Terschellingia* has been encountered in biotopes characterised by the presence of fine sediments (Nanajker *et al.*, 2011) but they easily disappear where there is physical disturbance (Schratzberger and Warwick, 1998). Biological disturbance due to macrofauna

activity in the sediments resulted in reduction of both *Terschellingia* and *Spirinia* (Austen *et al.*, 1998). In degraded mangrove sites (deforested), *Haliplectus* and *Terschellingia* were almost absent, but increased in natural and reforested sites (Mutua *et al.*, 2013). In the current study the abundances of selective deposit feeders, *Terschellingia* and *Spirinia*, reduced in the highly disturbed site, while that of *Haliplectus* increased relative to the other sites. In organically enriched muddy sediments *Terschellingia* increased in relative abundances (Moreno *et al.*, 2008) while *Spirinia* has been observed to dominate sediments with high sediment organic matter (Hourston *et al.*, 2009). This suggests that the two genera may be sensitive to sediment disturbance (which resulted in high levels of medium grain size relative to fine sand and silt) while *Haliplectus* may be adapted to physical sediment disturbance but not to ecosystem alteration such as the clear-cutting of the mangrove forest. For the low disturbed and medium disturbed sites, the presence of very fine sand and silt may explain the presence of the two selective deposit feeders in relatively high abundance.

In the sediment disturbed site, the selective deposit feeding nematode community was replaced by omnivore/predator genera that included *Aporcelaimellus*, *Pheronus*, *Viscosia*, *Pontonema* and *Synonchium*. *Pheronus* is in the order Enoplida, and family Ironidae. It is characterized by having two large dorsal teeth and two smaller sub-ventral ones (Smol *et al.*, 2014) that qualify it as a predator known to depend on other nematodes and other small organisms for food (Yeates *et al.*, 1993). The genus *Aporcelaimellus* is in the order Dorylaimida and Family Aporcelaimidae (Santiago *et al.,* 2014). The genus is characterized by a short, thick odontostyle with a wide aperture and feeds on algae, nematodes, nematode eggs, and rotifers (Wood, 1973), and is thus categorized as a predator/omnivore (Yeates *et al.,* 1993). The other genera (*Pontonema*, *Viscosia* and *Synonchium*) are categorized as predators based on buccal morphology and the presence of large teeth. It seems therefore that the nematode community in the disturbed site was characterized by a shift to more predator/ominivore genera (and less selective deposit feeders like *Spirinia*) than the less disturbed and non-disturbed sites. The genus *Viscosia* has been shown to increase in abundance in environments with continuous physical disturbance (Schratzberger and Warwick, 1998), which may be comparable to the continuous disturbance experienced as a result of bait harvesting in this study. It is however, not clear what the driving force may be that caused the increase of the

predator/omnivore feeding guild in the disturbed site. The presence and high abundance of an otherwise terrestrial nematode, *Aporcelaimellus*, is also not clear.

The epistrate, non-selective and selective deposit feeders had much lower relative abundance in the highly disturbed site. Schratzberger and Warwick (1999) observed that mud dwelling nematodes tend to be more affected by physical disturbance than the sand dwelling nematodes. Disturbance in this case led to the reduction of the fine sediment and organic matter which may be the reason why deposit feeders were reduced in abundance in the disturbed site. Disturbance which leads to continuous churning of sediments is likely to interfere with growth of benthic algae and diatoms, the main food source for epistrate feeders, and thus leading to their lower abundance. It is however, not clear how predators survived in such high abundances while the likely source of their food (lower trophic feeding nematodes) was in lower abundances. This needs to be researched further.

The nematode community changed from a high number of taxa and high dominance in the less disturbed site to a low number of taxa, low dominance and low taxa diversity in the disturbed sites. The less disturbed site had the highest number of taxa. Intermediate disturbance hypothesis suggests that medium disturbance promotes high diversity as opposed to a relatively stable or highly disturbed community (Weithoff *et al.*, 2001) where refugia exist within a disturbed area and recolonization is faster and diversity is improved (Townsend and Scarsbrook, 1997). Schratzberger and Warwick (1998) observed that intermediate physical disturbance on nematode communities resulted in the highest diversity. This could explain why the site with intermediate disturbance had the highest nematode genus richness. However, increased physical disturbance led to generally low diversity as was observed in the most disturbed site.

Conclusion

Bait harvesting and continuous disturbance of the sediment led to changes in sediment grain size distribution where the proportion of larger grain size increased over the finer ones. Sediment organic matter also reduced in the disturbed station relative to the undisturbed station and a consequent change in the nematode community was observed. There was no difference in the total meiofauna community distribution between the stations suggesting that total meiofauna may not be a good indicator of sediment disturbance.

In terms of nematode community, not only did the diversity differ between the stations but also the assemblage of the genera. Low diversity was observed in the disturbed station that also recorded a different nematode community; thus, nematode community structure can be used as an indicator of sediment disturbance.

It is recommended that the impacts of bait harvesting are investigated further (different baits, different sites) in order to obtain data that can inform policy development to guide coastal resource management.

Acknowledgements

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