Assessment of vertical and horizontal distribution of meiobenthos along a salinity gradient in the Tana and Sabaki Estuaries, north coast Kenya

Joel Amisi[1, 2]*, Cosmas Munga[2], Nina Wambiji[1], Edward Kimani[1]

[1] Kenya Marine and Fisheries
Research Institute,
PO Box 81651-80100
Mombasa,
Kenya

[2] Department of Environment
and Health Sciences,
Marine and Fisheries Programme,
Technical University of Mombasa,
PO Box 90420 - 80100 Mombasa,
Kenya

* corresponding author:
amisi2012@gmail.com

Abstract

Meiobenthos respond to variability in salinity gradients in estuarine habitats and are thus suitable organisms for ecological studies. The vertical and horizontal distribution of the meiofauna community structure of two major estuaries (Sabaki and Tana) on the north coast of Kenya were compared. The aim was to draw a meiofaunal dataset inventory of the two estuaries and to examine how salinity gradient, seasonality and sediment characteristics influence their structure. Replicate samples were collected from three sampling stations along the salinity gradient of each estuary. A total of 3,556 individuals belonging to 26 taxa were recorded. Based on seasons and across stations, the upper surface (0-5 cm) layer recorded the highest meiobenthic density (90 ± 42 ind.10 cm^{-2}), followed by 46 ± 23 ind.10 cm^{-2} (5-10 cm) and 30 ± 8 ind.10 cm^{-2} in the deepest sediment layer (10-15 cm) studied. The southeast monsoon season recorded the highest mean density (160 ± 22 ind.10 cm^{-2}) compared to the northeast monsoon season (22 ± 12 ind.10 cm^{-2}) for both estuaries. Results of the non-Metric Multidimensional Scaling technique revealed distinct seasonal composition in meiobenthos but not between the estuaries. Results of the 2-way ANOSIM test confirmed no significant differences in meiobenthic composition between the estuaries ($p = 0.712$). However, seasonal difference was significant ($p = 0.001$) with higher densities for nematoda (166 ± 99 ind.10 cm^{-2} and 56 ± 29 ind.10 cm^{-2}) recorded in Tana and Sabaki, respectively during the southeast monsoon season. At least 7 taxa out of a total of 26 were present in both estuaries. Salinity gradient, season and sediment depth were found to influence the meiobenthic densities and taxa composition.

Keywords: meiobenthos, vertical and horizontal distribution, salinity gradient, river estuary, north coast of Kenya

Introduction

Meiobenthos (benthic fauna with a size range of between 32 and 1,000 µm) characterize sedimentary matter in estuarine habitats where they not only serve as diet to macrofauna but also play a key role in the ecological functioning of the ecosystem (Schratzberger *et al.,* 2017). The vertical and horizontal distributions of meiobenthos in the river estuaries are influenced by upstream anthropogenic activities coupled with a number of natural processes from the sea. Considering the extensive catchment areas of the Sabaki and Tana rivers on the north coast of Kenya, runoff from agricultural lands containing organic, inorganic and mineral matter influence water transparency, primary production and sediment loads whereas tidal movements regulate estuarine salinities. Consequently, this induces enormous variations in community composition and abundance in the estuaries (Kotwicki *et al.,* 2005).

http://dx.doi.org/10.4314/wiojms.v21i1.6

Naturally, meiobenthos occur in high densities in estuarine sediments (Coull, 1999; Dauer *et al.*, 2000) and their abundance, species composition and diversity depends largely on sediment grain size among other abiotic factors (Alongi, 1987a, b; Vanhove *et al.*, 1992; Mutua *et al.,* 2013). Since estuarine ecosystems are known to be globally stressed by anthropogenic activities (Dauer *et al.*, 2000), the integral role of meiobenthos in food webs and the ecological balance is threatened (Vincx and Heip, 1987; Coull, 1999; Dauer *et al.*, 2000; Costa *et al.,* 2016). These habitats are very productive despite the threats from upstream anthropogenic activities. Land use patterns within the watershed modify the receiving waters through inflow of nutrients, contaminants and tons of sediment (Dauer *et al.*, 2000; Burton and Thurman, 2001). The resultant increase in nutrients comes from extensive runoff from agricultural land and town wastes (Chapman and Wang, 2001), eventually influencing the biological and ecological structure of meiobenthos at the river mouths.

Previous studies on meiobenthos have mostly concentrated on temperate regions (Higgins and Thiel, 1988; Bongers and Ferris, 1999; Cryer *et al.*, 2002; Ingels *et al.*, 2009; Williams *et al.*, 2010; Dannheim *et al.*, 2014) focusing on various benthic environments and depths. In the Western Indian Ocean (WIO) region, literature on meiobenthos is very scanty or limited to bays (Annapurna *et al.,* 2015). No published work is available on the characterization of inter-estuary meiobenthos specifically on the rivers Sabaki and Tana on the north coast of Kenya except for a few studies in tropical habitats such as the tidal mangrove forests on the south coast of Kenya (Alongi, 1987a, b; Mutua *et al.*, 2013). Vanhove *et al.* (1992) described a total of 17 meiobenthic taxa from Gazi Bay on the south coast with nematodes accounting for 95 % of the total densities, and copepoda, turbellaria, oligochaeta, polychaeta, ostracoda and rotifera recording decreasing densities in that order.

The present study is therefore the first of its kind to describe the inter-estuary meiofaunal community structure, their vertical distribution and the influence of salinity gradient on taxa composition and diversity. The study also emphasizes the role of sediment characteristics on meiobenthic densities.

Materials and methods

The study area

The Sabaki (Kenya's second longest river) estuary is the point of entry of the river into the Indian Ocean. It is located on the north coast of Kenya at 03°09'S and 40°08'E, at distance of 5 km north of Malindi town (Figure 1). It is a relatively small estuary covering an area of about 6 km^2 and consists of sand and mud banks, dunes and seasonal and permanent freshwater pools, mangroves and scrubs (McClanahan, 1988; Marwick *et al.,* 2014). The river drains a basin area of approximately 70,000 km^2 where extensive human activities are undertaken including livestock keeping, growing of drought resistant crops, irrigated horticulture, fisheries and sand harvesting. The river rises at 1° 42' S as River Athi and empties into the Indian Ocean as River Sabaki. River Tana (2° 35′ 56.42″ S, 40° 20′ 19.04″ E), Kenya's longest river (with an estuarine area of 27 km^2) drains into the Indian Ocean at Formosa Bay, Kipini, from its headwaters in the Aberdare Ranges and Mount Kenya region (Manyenze *et al.*, 2021). The river discharge varies with the season. During the southeast monsoon (SEM) season the river discharge is higher at 750 m^{3}s^{-1} and lower during the northeast monsoon (NEM) at 350 m^{3}s^{-1} (Kitheka *et al.,* 2005). Higher discharge occurs during the rainy SEM season in the months of May and November. This consequently results in daily variations in sediment load from 2,796 tons/day during the dry NEM season to 24,322 tons/day during the rainy SEM season (Kitheka *et al.,* 2005). Annually, the Tana estuary records a sediment load of 6.8 × 10^6 tons, though this is slightly lower than that recorded before the construction of the upper Tana Basin dams (Kitheka *et al.,* 2005). Numerous anthropogenic activities contribute to the structuring of meiobenthic biodiversity downstream.

Field sample collection and treatment

Sampling was carried out twice (14th and 15th) monthly for October and November 2016 (NEM season) and on 27th and 28th for May and June 2017 (SEM season). For each sampling site, three independent replicate sediment samples were collected across the salinity gradient (i.e., stations A, B & C) at each river estuary using a Plexiglas® corer tube (6.5 cm inner diameter) that was softly and slowly pushed into the sediment by hand up to a depth of 15 cm. Each sediment core obtained was divided into 2 halves longitudinally. One half was then sliced into three layers: 0 – 5 cm, 5 – 10 cm and 10 - 15 cm and taken for analysis of vertical distribution of meiobenthos. These samples were immediately treated with 70 % ethanol and taken for further laboratory analyses. The other longitudinal half samples were taken for the analysis of total organic carbon (TOC) and granulometry under refrigerated conditions in the laboratory. Processing of both meiobenthos, TOC and grain size sediment samples followed the procedures described in Heip *et al.* (1985), Higgins and Thiel (1988), EPA (2001), and Foti *et al.* (2014). Sediment temperature and salinity were measured *in situ*. Temperature was measured using the field thermometer (analogical thermometer, 0.1°C) whereas salinity was measured using a field hand-held refractometer (0 – 35 ‰).

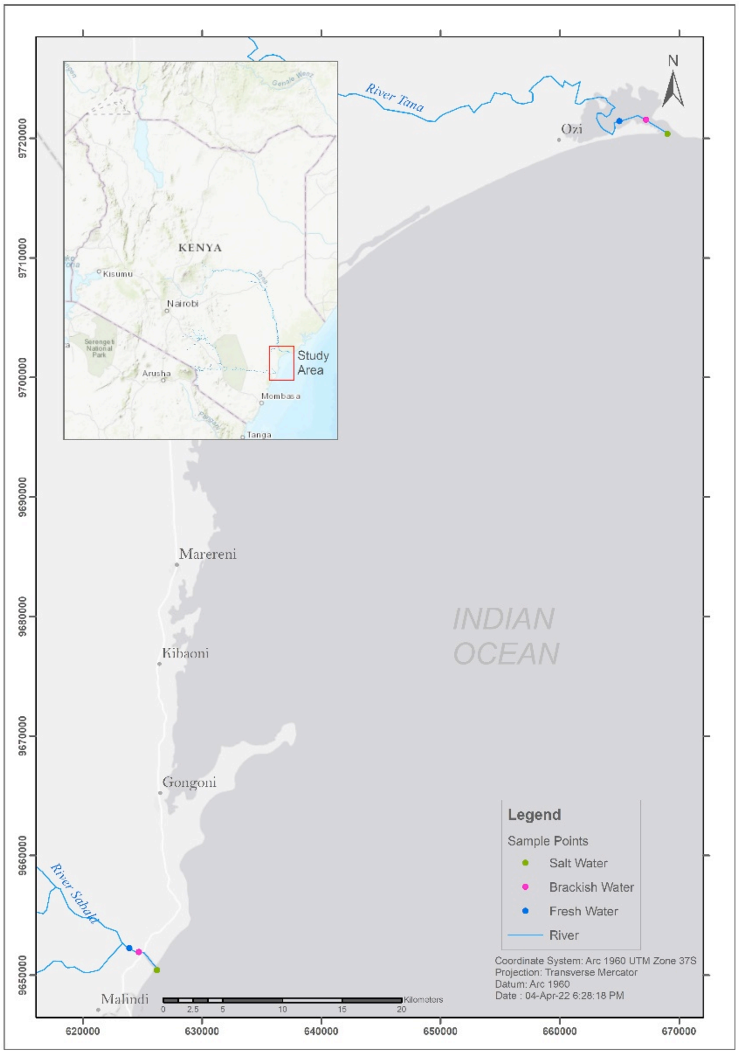

Figure 1. Map of the study area showing the location of the estuaries of rivers Sabaki and Tana and sampling stations indicated in blue, red and green circles along a salinity gradient.

Meiobenthic analysis

Sediment samples were washed through a top 1,000 µm sieve and a bottom 38 µm sieve. The collected fraction was put in a centrifugation tube (Heip *et al.*, 1985; Danovaro *et al.,* 2004) in which magnesium sulphate ($MgSO_4$) with specific density of 1.28 g/cm³ was added and centrifuged three times at 6,000 rpm for 10 minutes. For every centrifugation cycle, the supernatant was retained and collected in a 38 µm mesh sieve. The supernatant was carefully washed and rinsed to remove $MgSO_4$, after which rose Bengal was added to stain the organisms for 24 hours. Meiobenthos were extracted and stored in 70 % ethanol and were then identified, counted and classified at higher taxa using a binocular microscope (Leica S6E stereomicroscope, x50 magnification) following the Higgins and Thiel (1988) protocol. Meiobenthic taxa diversity and composition was analyzed by river estuary (Sabaki or Tana), salinity gradient and season.

Granulometric and total organic carbon (TOC) analysis

Refrigerated sediment samples were analyzed for both granulometry and TOC in the laboratory. Grain size (range 0.04 – 1600 mm) was determined following the

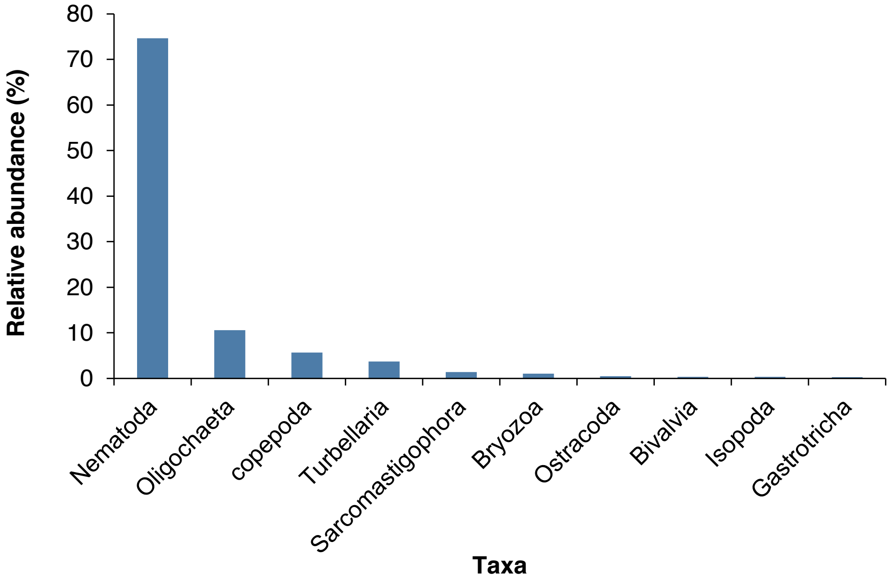

Figure 2. Relative abundance (%) of the ten most abundant meiobenthic taxa sampled during the study period for Tana estuary.

procedures described by Buchanan and Kain (1971), and the Wenthworth (1922) scale was applied to characterize sediment type. Thereafter, samples for TOC were put in an oven and dried at 90 °C for 24 hours to ensure moisture was removed. 5 g of the TOC sample was then taken from the oven and ashed at 600°C for six hours to attain ash free weight. TOC was determined as % of ashed content.

Data and statistical analyses

Descriptive statistics were conducted in Excel while multivariate analyses were performed using PRIMER v. 6.0 software and PERMANOVA+ for PRIMER (Clarke and Gorley, 2006; Anderson, 2005; Anderson *et al.*, 2008), and STATISTICA v.7.0 was used for all univariate analyses. Meiobenthic density was expressed as ind.10 cm^{-2}. For meiobenthos composition, data was initially standardized into relative abundance to minimize variations caused by the most abundant/dominant species and then similarities between pairs of their samples determined using the Bray-Curtis resemblance matrix (Clark and Warwick, 2001). A non-Metric Multidimensional Scaling (nMDS) technique was then used to visualize cluster

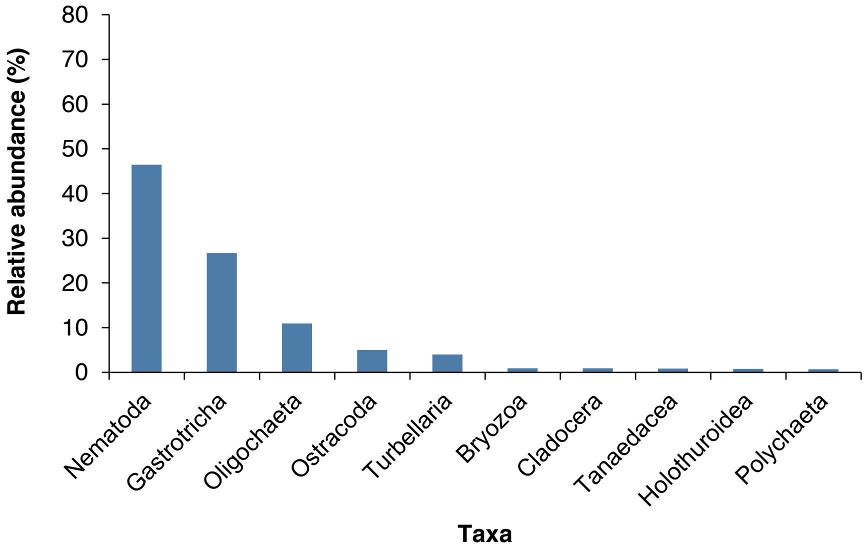

Figure 3. Relative abundance (%) of the ten most abundant meiobenthic taxa sampled during the study period for Sabaki estuary.

Table 1. Results of mean environmental variables for all stations sampled. Sediment grain size description (after Wentworth, 1922). SF = Sabaki fresh; SB = Sabaki brackish; SSA = Sabaki saline, TF = Tana fresh; TSA = Tana saline.

Season	Station	Clay%	Silt%	Very Fine Sand %	Fine Sand%	Medium Sand%	Coarse Sand%	Very Coarse Sand%	TOC%	Salinity (‰)	Temperature (°C)
SEM	SF-Station C	1.76	20.26	47.28	17.04	2.13	2.63	6.41	2.79	0.02	30.00
	SB-Station B	0.92	3.72	29.60	52.07	8.39	0.79	1.01	2.20	19.00	28.38
	SSA-Station A	0.02	2.60	39.08	45.54	6.43	0.88	1.52	0.48	30.33	27.11
	TF-Station C	2.16	52.96	31.06	2.80	1.81	2.79	2.78	4.22	0.01	26.11
	TB-Station B	1.18	11.11	43.53	13.16	4.27	8.26	10.98	6.39	9.86	26.06
	TSA-Station A	0.60	13.24	61.68	14.55	2.16	1.70	2.90	2.15	32.67	25.67
NEM	SF-Station C	9.95	47.00	20.03	6.14	7.08	4.48	1.70	1.15	0.03	31.15
	SB-Station B	7.64	36.59	15.36	12.27	13.56	8.06	2.30	2.27	17.50	29.00
	SSA-Station A	2.66	20.94	31.13	37.67	4.99	1.02	0.55	0.44	33.50	29.00
	TF-Station C	3.12	5.78	22.76	15.92	12.12	15.23	8.45	0.57	0.02	27.00
	TB-Station B	0.31	2.60	11.00	39.36	27.01	8.70	5.17	0.39	11.25	27.50
	TSA-Station A	0.01	1.16	16.82	57.75	20.72	1.93	0.66	0.76	34.30	28.15

(spatial differences in the composition of meiobenthic assemblages) groups by river estuary, salinity gradient, and season. Significant differences in the meiobenthic community composition between variables were tested by Analysis of Similarity (ANOSIM) for the nMDS assemblages. Complimentarily, a SIMPER analysis (cut-off of 50 %) was performed to unravel the percentage contribution of each taxon to the observed (dis)similarities between estuary, sampling station and season. Differences in taxa diversity (Shannon-Wiener diversity index) were tested using a 2-way ANOVA. Before the ANOVA test was performed, the normality and homoscedasticity of variances were checked using the Levene's test and accepted at $p > 0.05$. To meet the ANOVA assumptions, data were appropriately transformed and all significant differences were assigned at $p < 0.05$. Tukey HSD pair-wise comparison tests were performed for confirmation of differences between variables.

Results

Environmental factors

Sediment mean salinity varied across sampling stations between the two river estuaries. In the Sabaki, station C (upper estuary) recorded the lowest salinity of 0.02 ± 0.003 ‰, followed by Station B (19.00 ± 0.00 ‰) and the lower Station A (30.33 ± 0.83 ‰) had highest salinity level. In the Tana estuary, Station C recorded the lowest salinity of 0.01 ± 0.00 ‰, followed by Station B (9.86 ± 0.34 ‰) and the lower Station A (32.67 ± 0.44 ‰) had the highest salinity.

Sediment temperature varied between the estuaries and across sampling stations. For Sabaki, Station C recorded a highest mean of 30.0 ± 0.3 ^{0}C followed by Station B (28.4 ± 0.2 ^{0}C) and Station A (27.1 ± 0.2 ^{0}C). Sediment temperature across stations for the Tana estuary showed little variation where Station C recorded 26.1 ± 0.5 ^{0}C, Station B (26.1 ± 0.3 ^{0}C) and Station A (25.7 ± 0.2 ^{0}C). Silt and very fine sand proportions were higher in the sediment samples whereas TOC was generally higher during the SEM season (Table 1).

Meiofaunal composition

A total of 3,556 meiobenthic individuals belonging to 26 taxa were recorded. Overall, Nematoda was the most abundant taxon (62.1 %) followed by Gastrotricha (12.04 %) and Oligochaeta (10.74 %). The remaining 23 taxa recorded lower abundances of between 0.03 and 3.82 % (Table 2). By river estuary, Nematoda contributed 75 % in the Tana and 46 % in the Sabaki. Gastrotricha in Tana accounted for 0.4 % and 27 % in Sabaki (Figures 2 & 3). Oligochaeta on the other hand recorded 11 % in both the Tana and Sabaki. The rest of the 23 taxa were found in smaller abundances in both estuaries.

Densities of meiobenthos ranged from 1.0 ± 0.6 to 90 ± 42 and 1.2 ± 0.6 to 54 ± 42 ind.10 cm^{-2} for the NEM and SEM season, respectively (Figures 4 & 5). Meiobenthic total densities decreased with increase in sediment depth in both estuaries (Fig. 4 & 5) with highest densities recorded in the surface layers (0-5 cm), whereas the lowest density was recorded in the bottom-most layer (10-15 cm). The converse was true for taxa diversity in the aforementioned sediment depths. Generally, seasonal mean densities were higher in the

Table 2. Meiofauna densities (10 ind/cm²) of all the taxa sampled during the study period for Tana, Sabaki and Tana and Sabaki estuaries combined.

Meiobenthic Taxa	Sabaki	Tana	Sabaki&Tana	Meiobenthic Taxa	Sabaki	Tana	Sabaki&Tana
Polychaeta	0	0	0	Rotifera	1	0	1
Oligochaeta	2	18	10	Tardigrada	0	0	0
Nematoda	56	166	111	Bryozoa	3	4	4
Sarcomastigophora	0	0	0	Priapulida	0	0	0
Turbellaria	11	9	10	Aplacophora	0	1	1
Cumacea	0	0	0	Holothuroidea	2	0	1
Ostracoda	16	1	8	Cladocera	3	1	2
Copepoda	1	15	8	Insecta	1	0	1
Bivalve	0	0	0	Tunicata	0	0	0
Isopoda	0	0	0	Cnidaria	1	0	0
Tanaedacea	0	0	0	Laptoscala	0	0	0
Gastrotricha	0	1	1	Ciliophora	0	0	0
Amphipoda	0	1	0	Syncarida	0	0	0

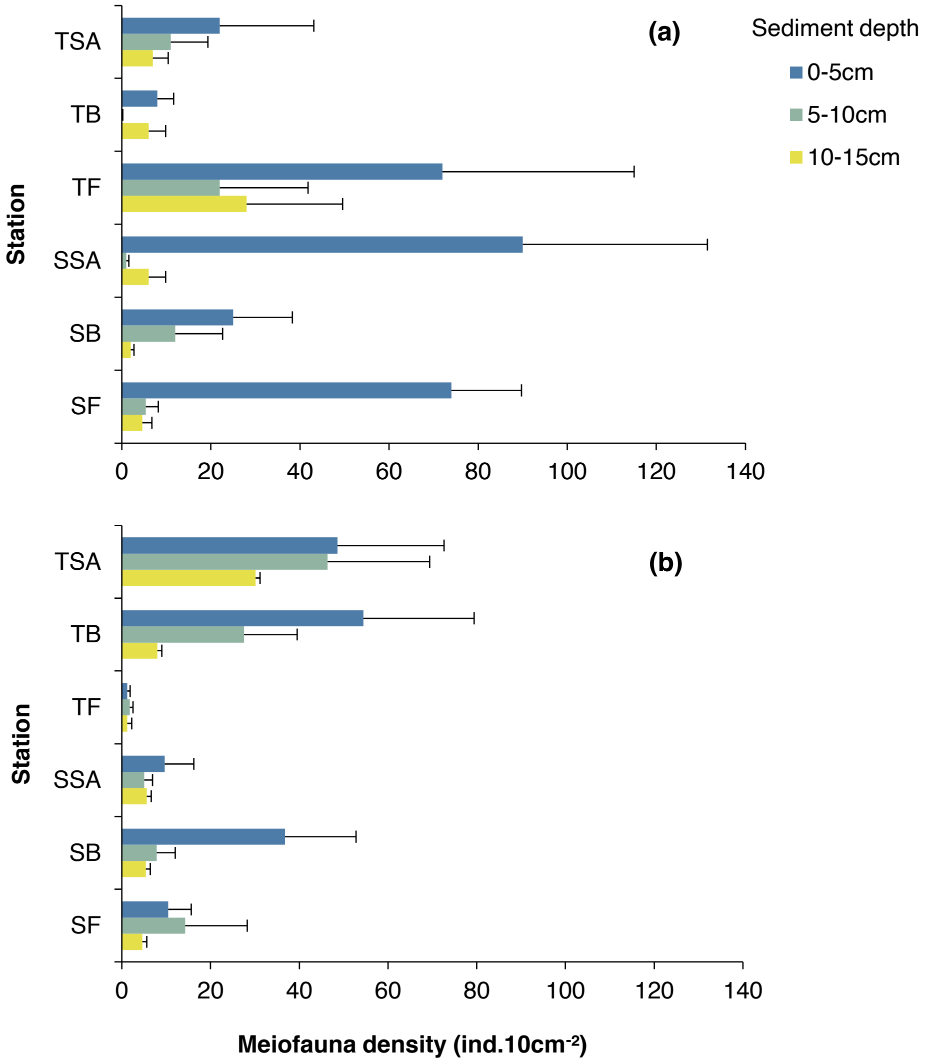

Figure 4. Mean ±SE meiobenthic density (ind/10cm²) distribution along the salinity gradient with sediment depths during the (a) north east monsoon and (b) south east monsoon season. TSA = Tana saline; TB = Tana brackish; TF = Tana fresh; SSA = Sabaki saline; SB = Sabaki brackish and SF = Sabaki fresh.

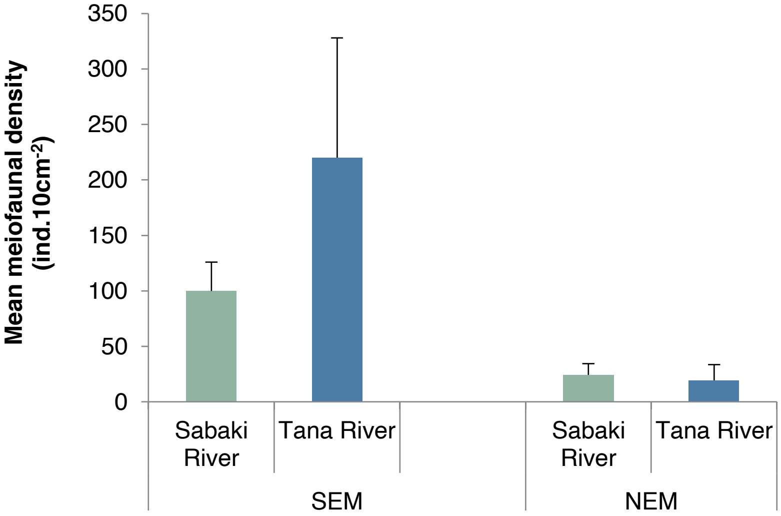

Figure 5. Comparison of mean meiobenthos density (ind/10cm^2) between estuaries with seasons. SEM = south east monsoon; NEM = north east monsoon.

Tana estuary (220 ± 108 ind. 10 cm^{-2}) compared to the Sabaki (100 ± 26 ind.10 cm^{-2}) during the SEM season. Results of non-Metric Multidimensional Scaling (nMDS) of the metazoan meiobenthic densities and structural composition showed distinct separation of meiobenthos composition between river estuaries with season combination (Figure 6). However, no distinct separation was observed for meiobenthos composition between river estuaries with habitat and with sediment depths. Results of the 1-way ANOSIM test confirmed a significant distinct meiobenthos composition between river estuaries with season combination (R = 0.043; p = 0.004). Results of the 1-way SIMPER analysis revealed that the dissimilarities observed in meiobenthos composition between river estuaries with season combination were attributed to more abundant Oligochaeta, Turbellaria, Ostracoda, Gastrotricha and Bivalvia (Table 2).

In terms of salinity gradient, meiobenthic densities were generally higher in Tana Station A, at 75 ind.10 cm^{-2} in the topmost (0-5 cm) sediment layer followed by Tana Station C and lastly Tana Station B. In the Sabaki, only surface layers recorded higher densities in all the stations with highest densities recorded in Station A followed by Station C and Station B in that order. In

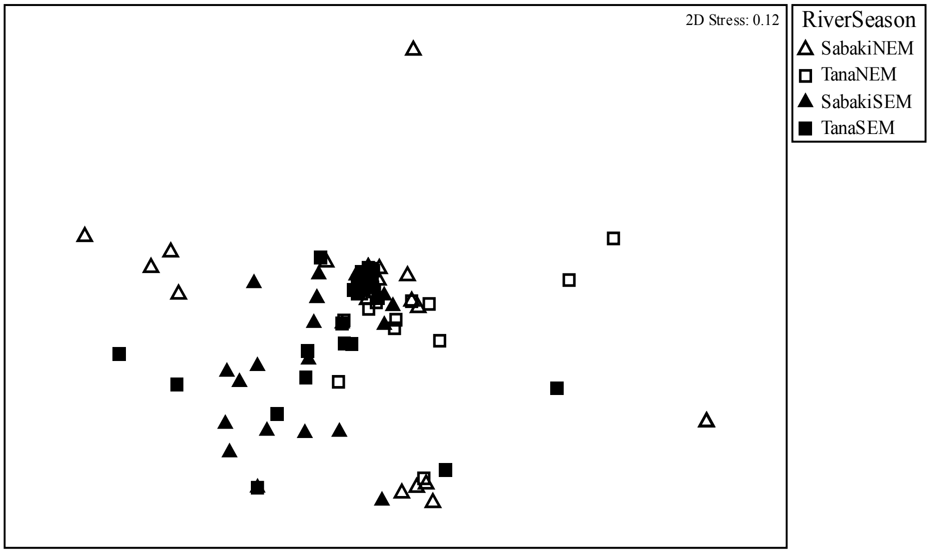

Figure 6. Non-metric multi-dimensional scaling plots on meiobenthos assemblages showing distinct clusters for both Sabaki and Tana rivers during southeast monsoon season.

Table 3. Results of 1-way SIMPER analysis: Sabaki river estuary showing meiobenthos taxa contributing to dissimilarity in terms of abundance (%) with river-season combination and an average dissimilarity of 73.20 %.

Taxa	Sabaki-NEM average abundance	Sabaki-SEM Average abundance	Av. Diss	% Contribution
Nematoda	50.65	43.81	22.6	30.86
Oligochaeta	14.37	6.65	9.21	12.57
Turbellaria	1.26	**16.03**	7.98	10.89
Ostracoda	0.00	**15.22**	7.61	10.39
Gastrotricha	14.92	0.00	7.46	10.19
Bivalvia	**8.74**	0.00	4.37	5.97
Polychaeta	4.36	0.79	2.5	3.42
Copepoda	3.10	0.62	1.79	2.45
Cladocera	0.00	3.18	1.59	2.17
Bryozoa	0.00	2.93	1.46	2.00

the same estuary the mid (5-10 cm) and lower (10-15 cm) sediment layers recorded low to moderate densities. Overall, both river estuaries showed higher densities in surface sediment layers designated as Station A for both estuaries (Fig. 4). Stations A and B of the Tana estuary recorded the highest mean meiobenthic densities in their surface sediment layers whereas station B in Sabaki recorded the highest density in the 0-5 cm sediment layer during the SEM season. Low to moderate densities were recorded in stations A and C along the Sabaki estuary (Figure 5). The nMDS plots revealed seasonal cluster separation for meiobenthic densities and taxa composition in both river estuaries with seasons (Figure 6).

Results of 1-way SIMPER analysis for the Sabaki meiobenthic taxa composition showed an average dissimilarity of 73.2 % between the seasons, with Nematoda (30.86 %) contributing most to the observed dissimilarities, followed by Oligochaeta (12.57 %), Turbellaria (10.89 %), Ostracoda (10.39 %), Gastrotricha (10.19 %) and Bivalvia (5.97 %) making up the meiobenthic genera responsible for the dissimilarities observed (Table 3). For the Tana estuary, 1-way SIMPER analysis for meiobenthos composition showed an average dissimilarity of 55.77 % between the seasons with Turbellaria (16.31 %) contributing the highest to the observed dissimilarities, followed by Copepoda (10.15 %), Isopoda (8.42 %) and Bryozoa (3.65 %) as the dominant meiobenthic taxa responsible for the observed dissimilarities (Table 4). By salinity gradient, Station B recorded the highest taxa diversity followed by Station C and A in that order (Figure 7). However, results of 2-way ANOVA indicated no significant difference in taxa diversity between river estuaries and across salinity gradient (df = 1; f = 0.018; p = 0.895 and df = 2; f = 1.837; p = 0.165, respectively). The same test indicated no significant effect due to estuary and station interaction (df = 2; f = 0.338; p = 0.714). By depth, lower sediment layers (10-15 cm) recorded the highest taxa diversity followed by the middle layers (5-10 cm) and surface layers (0-5 cm) (Figure 8). Results of the 2-way

Table 4. Results of 1-way SIMPER analysis: Tana river estuary showing meiobenthos taxa contributing to dissimilarity in terms of abundance (%) with river-season combination and an average dissimilarity of 55.77 %.

Taxa	Tana-NEM Average abundance	Tana-SEM Average abundance	Av.Diss	% Contribution
Nematoda	61.37	58.05	19.46	34.89
Turbellaria	8.44	14.41	9.1	16.31
Copepoda	4.55	8.39	5.66	10.15
Oligochaeta	7.73	4.38	5.27	9.46
Isopoda	**9.39**	0.00	4.70	8.42
Bryozoa	0.00	4.07	2.03	3.65
Bivalvia	3.32	0.00	1.66	2.97
Sarcomastigophora	3.24	0.00	1.62	2.91
Gastrotricha	0.00	3.11	1.56	2.79

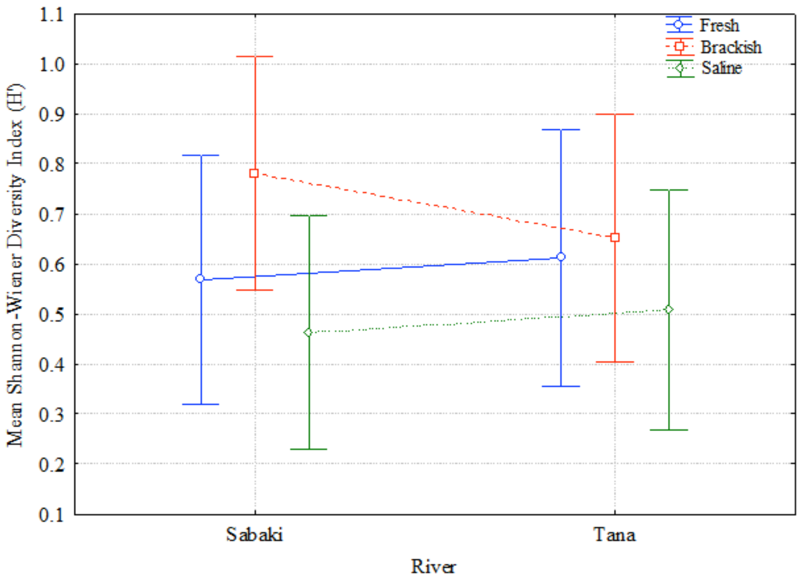

Figure 7. Mean ± SE Shannon-Wiener diversity index (H') of meiobenthos between rivers with habitat types sampled during the study period.

ANOVA test showed no significant difference in taxa diversity between river estuaries and across sediment depths (df = 1; f = 0.01; p = 0.922 and df = 2; f = 1.225; p = 0.299, respectively). The same test indicated no significant effect due to river estuary and sediment depth interaction (df = 2; f = 0.236; p = 0.791).

Discussion

Salinity gradient

Salinity gradient is a common phenomenon influencing the distribution and profiling of meiobenthic fauna. In the present study, salinity played a key role in community structuring for both fresh (Station C, brackish; Station B), and marine (Station A) habitats along the river estuaries as demonstrated by Montagna *et al.* (2002), Olafsson *et al.* (2000) and Merryl (2002). Salinity along the estuaries constantly keep changing with season and tidal influence. During the southeast monsoon (SEM) season, large volumes of fresh water with an influx of organic and inorganic materials enter the ocean resulting into reduced salinity levels in the estuarine ecosystem. Tidal movements also contribute to changes in salinity levels, where marine water pushes upstream during

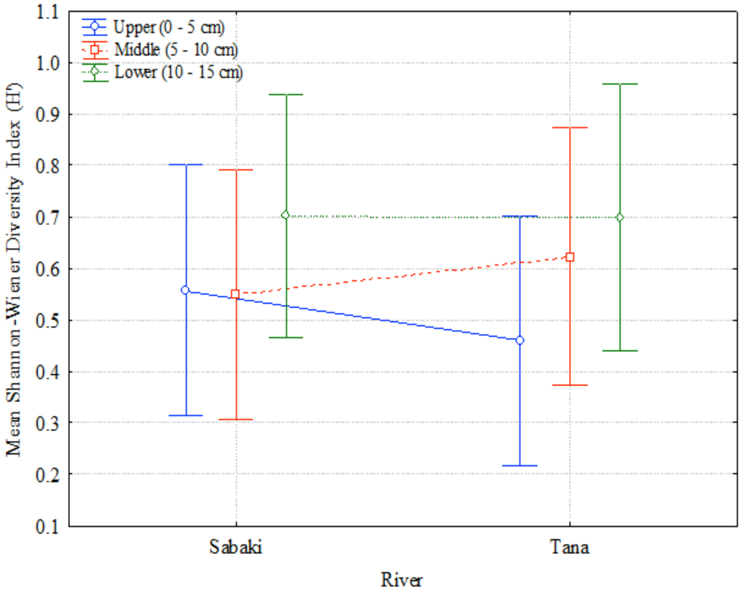

Figure 8. Mean ± SE Shannon-Wiener diversity index (H') of meiobenthos between rivers with sediment depths sampled during the study period.

high tide changing the salinity level (Olafsson *et al.* 2000). The Tana and Sabaki river estuaries exhibited this daily, and the seasonal dynamism in salinity levels influenced the diversity of taxa recorded.

Meiofaunal composition and structural assemblages

The Sabaki and Tana estuaries have continuously undergone upstream human pressure; particularly from agricultural activities, building and construction, mining and waste disposal, to mention a few. Determination of meiobenthic biodiversity trends from the present study provides a basis for describing their distribution along the salinity gradient. Meiofaunal structural composition and densities was aligned with the results from similar habitats across tropical zones (Guo *et al.,* 2008; Semprucci *et al.,* 2013; Costa *et al.,* 2016) and this study was the first of its kind in the WIO region. The results revealed relatively low densities and diversity in the two river estuaries. This observation can be accounted for by the fact that surface sediments (0-5cm) harbored higher abundance of meiobenthos with lower diversity whereas lower sediment depths (10-15 cm) harbored higher diversity with lower abundances (Vincx and Heip, 1987). Alongi and Pichon (1988) associated similar observations with inverse trend between meiobenthos abundance with depth. Vanhove *et al.* (1992) illustrated a declining pattern from the marine to freshwater habitat which is in accordance with the principle that abundance and diversity decreases from the marine zone towards the freshwater habitats. This scenario concurs with the study by Coull (1999) which further reveals that euryhaline estuarine species are rare, whereas euryhaline freshwater species do not exist. Alongi, (1987b) noted that physical characteristics, estuarine forest cover and productivity in addition to food availability determines meiobenthos community structure and densities.

In the findings from this study, it has been demonstrated that the WIO region does not have sufficient data on estuarine meiobenthos. It is therefore difficult to theorize on the elaborate mechanisms that shape their structure and composition. In fact, the current study established that salinity due to tidal action was the key factor in determining the community composition and structure (Fig. 4 & 5) which show the habitat prevalence of meiobenthos. More so, Annapurna *et al.* (2015) noted through a Canonical Correspondent Analysis (CCA) that community composition and structure was largely dependent on salinity and sediment texture. Other factors contributing to the observed patterns include seasonality, competition and predation, though the latter were not tested in this study. Tropical estuarine habitats incur severe physical stresses which can be reflected in the low numbers of species (5 to 13) living in these habitats. Similar trends have been recorded by others (Alongi, 1987b; Coull, 1999) citing low rates of organic matter deposition, speedy detritus utilization and enormous upstream to downstream disturbances as factors behind this scenario. In comparison, species richness and diversity across European and North American river mouths are much higher (Alongi, 1987a, b, c) than what the present study has revealed.

Nematodes were the most abundant meiobenthos in both river estuaries accounting for over 62.05 % of all the meiobenthic taxa identified. The other most dominant taxa were Gastrotricha, followed by Oligochaeta, Turbellaria, Copepoda, Ostracoda and Bryozoa in that order. These taxa are cosmopolitan with capabilities of being resilient to a wide range of environmental conditions (Alongi, 1987b; Ngo *et al.* 2013). This dominance pattern concurs with the structural assemblages for meiobenthic animals on the eastern African coast and other tropical estuaries (Vanhove *et al*., 1992; Schrijvers *et al*., 1997; Olaffson *et al*., 2000; Mwonjoria, 2007). Vertical distribution of nematodes in sediment was biased with surface layers recording the highest densities where clay and silt dominated with a division of copepods occupying the medium and course sands. This finding agrees with that of Vanaverbeke *et al.* (2002), Mutua (2013) and Semprucci *et al. (*2013) on the ecology of nematodes and their preferred sediments to inhabit. De Troch *et al.* (2008) found that copepods preferred coarser and well oxygenated sediments. The current study yielded similar findings for both nematodes and copepods. Additionally, surface sediment layers possess higher total organic matter (TOM) which forms detritus and other food substances, thus supporting higher meiobenthos and especially high nematode densities (Mutua *et al.,* 2013).

Meiobenthic mean densities were higher in the Tana estuary during the SEM season as compared to the Sabaki, possibly due to enhanced riverine forest canopy in this estuary which implied that there was minimal environmental disturbance to meiobenthos (Mutua *et al.,* 2013). Additionally, this is associated with riverine productivity and hence food availability (Alongi, 1987b). The converse was true for the Sabaki estuary. Mutua *et al.,* (2013) further noted that sediment salinity and temperature increases with exposure, hence influencing the benthic microphytobenthos which form the primary food source for meiobenthos. This is indeed true and was confirmed by the present study where salinity and temperature values for the Sabaki estuary were higher compared to those of the Tana, hence moderate meiofauna densities and species diversity. This study, the first of its kind in estuarine meiobenthic community profiling on the east African coastline, has contributed to the body of scientific information on meiobenthic assemblages in these major river estuaries on north coast of Kenya. It has clearly shown that salinity gradient, coupled with temperature, sediment grain size and depth, TOC, and season control the community structure for meiofaunal assemblages which are known to be reliable biological indicators.

Conclusions

This study showed that meiobenthos densities and structural composition across the river estuaries were generally relatively low. The differences observed in densities and diversity could be attributed to the influence of salinity gradient, sediment depth and seasons. Unlike nematodes which are ubiquitous, all other meiofaunal groups identified clearly revealed that the variations in environmental factors and habitat heterogeneity in estuaries were responsible for the observed patterns. In the opinion of the authors, this implies that meiobenthos are good indicators of the environmental variations in river estuaries, though the relatively low densities and diversity signified high intensity stress levels both from river inflows and ocean tidal influences. It is recommended that similar studies are conducted across other estuarine systems within the WIO region to confirm the present findings. Including estuaries with minimal tidal actions may be necessary for comparison. Focused attention should be given to a taxon of interest such as the nematoda, which is not only useful for impact studies but also as a good indicator of habitat health.

Acknowledgements

Financial support was provided through the Marine Research Grant (MARG I) program of WIOMSA [MARG 1_2016_04]. We thank the Kenya Marine and Fisheries Research Institute for providing logistical field support and laboratory space during the entire project period. Much appreciation to Alfred Katana, Gladys Mwaka and Bernard Kimathi for their technical assistance both in the field and in the laboratory. Thanks to Mr Steven Odhiambo for designing the study area map. Finally, the authors are grateful to the anonymous reviewers for their valuable comments and suggestions which improved the quality of this publication.

References

Alongi DM (1987a) Intertidal zonation and seasonality of meiobenthos in tropical mangrove estuaries. Marine Biology 95 (3): 447-458 [doi.org/10.1007/BF00409574]

Alongi DM (1987b) Inter-estuary variation and intertidal zonation of free-living nematode communities in tropical mangrove systems. Marine Ecology Progress Series 40: 103-114 [doi.org/10.3354/meps040103]

Anderson MJ (2005) PERMANOVA Permutational multivariate analysis of variance. Austral Ecology: 1-24

Anderson M, Gorley RN, Clarke RK (2008) Permanova+ for Primer: Guide to Software and Statistical Methods. 218 pp

Annapurna C, Rao MS, Bhanu CV (2015) Distribution of meiobenthos off Kakinada

Bay, Gaderu and Coringa estuarine complex. Journal of Marine Biological Association of India 57 (2): 17-26 [doi.org/10.6024/jmbai.2015.57.2.1841-03]

Bongers T, Ferris H (1999) Nematode community structure as a bio-indicator in environmental monitoring. Trends in Ecology & Evolution 14 (6): 224-228

Buchanan JB, Kain JM (1971) Measurement of the physical and chemical environment. In: Holme NA, McIntyre AD (eds) Methods for the study of marine benthos. IBP Handbook (16). Blackwell Scientific Publishers, Oxford. pp 30-58

Burton EA, Thurman HV (2001) Introductory oceanography: 9th Edition. Prentice Hall, New Jersey. 554 pp

Chapman PM, Wang, F (2001) Assessing sediment contamination in estuaries. Environmental Toxicology and Chemistry. SETAC Press [doi.org/10.1002/etc.5620200102]

Costa ABHP, Valença APMC, Santos PJP (2016) Is meiofauna community structure in artificial substrate units a good tool to assess anthropogenic impact in estuaries? Marine Pollution Bulletin 110 (1): 354-361 [doi.org/10.1016/j.marpolbul.2016.06.041]

Coull BC (1999) Role of meiofauna in estuarine soft-bottom habitats. Australian Journal of Ecology 24 (4): 327-343

Clark KR, Warwick RM (2001) Change in marine communities. An approach to statistical analysis and interpretation, 2nd ed. PRIMER-E, Plymouth, UK. 174 pp

Clarke KR, Gorley RN (2006) PRIMER v6: User manual/tutorial. PRIMER-E, Plymouth, UK. 192 pp [doi.org/10.1111/j.1442-9993. 1993.tb00438.x]

Cryer M, Hartill B, O'shea S (2002) Modification of marine benthos by trawling: Toward a generalization for the deep ocean. Ecological Applications 12 (6): 1824-1839

Dannheim J, Brey T, Schröder A, Mintenbeck K, Knust R, Arntz WE (2014) Trophic look at soft-bottom communities – Short-term effects of trawling cessation on benthos. Journal of Sea Research 85: 18-28

Danovaro R, Gambi MC, Mirto S, Sandulli R, Ceccherelli VU (2004) Meiofauna. Biologia Marina Mediterranea 11: 55-97

Dauer DM, Ranasinghe JA, Weisberg SB (2000) Relationships between benthic community condition, water quality, sediment quality, nutrient loads, and land use patterns in Chesapeake Bay. Estuaries 23 (1): 80-96

De Troch M, Melgo JL, Angsinco-Jimenez L, Gheerardyn H, Vincx M (2008) Diversity and habitat selectivity of harpacticoid copepods from seagrass beds in Pujada Bay, the Philippines. Journal of the Marine Biological Association of the United Kingdom: 88: 515-526

EPA (2001) National coastal assessment: Field operations manual. National Health and Environmental Effects Research Laboratory, Gulf Ecology Division, Gulf Breeze, FL. EPA 620/R-01/003. 72 pp

Foti A, Fenzi G, Di Pippo F, Gravina MF, Magni P (2014) Testing the saprobity hypothesis in a Mediterranean lagoon: Effects of confinement and organic enrichment on benthic communities. Marine. Environmental Research 99: 85-94

Guo Y, Helleouet MN, Boucher G (2008) Spatial patterns of meiofauna and diversity of nematode species assemblages in the Uvea lagoon (Loyalty Islands, South Pacific). Journal of the Marine Biological Association of the United Kingdom 88 (5): 931-940[doi.org/10.1017/S002531540800146X]

Heip CHR, Vincx M, Vranken G (1985) The ecology of marine nematodes. Oceanography and Marine Biology 23: 399-489

Higgins RP, Thiel H (1988) Introduction to the study of meiofauna. Smithsonian Institution Press, London. 488 pp

Ingels J, Kiriakoulakis K, Wolff GA, Vanreusel A (2009) Nematode diversity and its relation to the quantity and quality of sedimentary organic matter in the deep Nazaré Canyon, Western Iberian Margin. Deep Sea Research Part I: Oceanographic Research Papers 56 (9): 1521-539

Kitheka JU, Obiero M, Nthenge P (2005) River discharge, sediment transport and exchange in the Tana Estuary, Kenya. Estuarine, Coastal and Shelf Science: 455-468 [doi.org/10.1016/j.ecss.2004.11.011]

Kotwicki L, De Troch M, Urban-Malinga B, Gheskiere T, Weslawski J M (2005) Horizontal and vertical distribution of meiofauna on sandy beaches of the North Sea (The Netherlands, Belgium, France). Helgoland Marine Research 59 (4): 255-264 [doi.org/10.1007/s10152- 05-0001-8]

Manyenze F, Munga CN, Mwatete C, Mwamlavya H, Groeneveld JC (2021) Small-scale fisheries of the Tana Estuary in Kenya. Western Indian Ocean Journal of Marine Science, Special Issue 1: 93-114

Marwick T R, Tamooh F, Ogwoka B, Teodoru C, Borges AV, Darchambeau F, Bouillon S (2014) Dynamic seasonal nitrogen cycling in response to anthropogenic N loading in a tropical catchment, Athi-Galana-Sabaki River, Kenya. Biogeosciences 11 (2): 443-460 [doi.org/10.5194/bg-11-443-2014]

McClanahan T (1988) Seasonality in East Africa's coastal waters. Marine Ecology Progress Series 44: 191-199 [doi.org/10.3354/meps044191]

Merryl A (2002) A conceptual model of estuarine freshwater inflow management. Estuaries 25 (6): 1246-1261

Montagna PA, Richard DK, Christine R (2002) Effect of restored freshwater inflow on macrofauna and meiofauna in upper Rincon Bayou, Texas, USA. Estuaries 25 (6): 1436-1447

Mutua AK, Muthumbi A, Ntiba MJ. Vanreusel A (2013) Patterns of meiofaunal colonisation as an indicator of reforested *Rhizophora mucronata* mangrove recovery in Gazi Bay, Kenya. Western Indian Ocean Journal of Marine Science: 25-35

Mwonjoria FM (2007) Fish and benthic communities as indicators of mangrove ecosystem recovery in Gazi Bay, Kenya. MSc Thesis, University of Nairobi, Kenya. 128 pp

Ngo XQ, Smol N, Vanreusel A (2013) The meiofauna distribution in correlation with environmental characteristics in 5 Mekong estuaries, Vietnam. Cahiers de Biologie Marine 54 (1): 71-83

Olafsson E, Carlstrom S, Ndaro SGM (2000) Meiobenthos of hypersaline tropical mangrove sediment in relation to spring tide inundation. Hydrobiologia 426: 57-64

Schratzberger M, Ingels J (2017) Meiofauna matters: The roles of meiofauna in benthic ecosystems. Journal of Experimental Marine Biology and Ecology 502: 12-25

Schrijvers J, Schallier R, Silence J, Okondo JP, Vincx M (1997) Interactions between epibenthos and meiobenthos in a high intertidal *Avicennia marina* mangrove forest. Mangroves and Salt Marshes 1: 137-154

Semprucci F, Colantoni P, Sbrocca C, Baldelli G, Balsamo M (2014) Spatial patterns of distribution of meiofaunal and nematode assemblages in the Huvadhoo lagoon (Maldives, Indian Ocean). Journal of the Marine Biological Association of the United Kingdom 94 (7): 1377-1385 [doi: 10.1017/S002531541400068X]

Vanaverbeke J, Gheskiere T, Steyaert M, Vincx M (2002) Nematode assemblages from subtidal sandbanks in the Southern Bight of the North Sea: effect of small sedimentological differences. Journal of Sea Research 48 (3): 197-207

Vanhove S, Vincx M, Van Gansbeke D, Gijselinck W, Schram D (1992) The meiobenthos of five mangrove vegetation types in Gazi Bay, Kenya. In: The ecology of mangrove and related ecosystems. Springer Netherlands. pp 99-108

Vincx M, Heip CHR (1987) The use of meiobenthos in pollution monitoring studies: a review. ICES Techniques in Marine Environmental Sciences 16: 50-67

Wenthworth CK (1922) The Wenthworth scale of grain size for sediments. Journal of Geology. 30: 381

Williams A, Schlacher TA, Rowden AA, Althaus F, Clark MR, Bowden DA, Kloser RJ (2010) Seamount megabenthic assemblages fail to recover from trawling impacts. Marine Ecology 31 (s1): 183-199