

## Zooplankton Composition and Abundance in Mida Creek, Kenya

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**MKW Osore, JM Mwaluma, F Fiers and MH Daro (2004)** Zooplankton composition and abundance in Mida Creek, Kenya. *Zoological Studies* 43(2): 415-424. In order to determine the resident assemblages of zooplankton in Mida Creek, Kenya, a survey was conducted from May 1996 to Apr. 1997 for which we studied their seasonal composition, abundance, and distribution. Twenty-seven major zooplankton taxa were identified. The order Copepoda was the most abundant taxon dominated mainly by the genera *Acartia*, *Paracalanus*, *Labidocera*, *Temora*, *Centropages*, and *Calanopia*. Other common zooplankton taxa included the Medusae, Ctenophora, Brachyura larvae, and Chaetognatha. The highest abundances ( $1961 \pm 540$  to  $2856 \pm 788$  individuals/m<sup>3</sup>) were recorded during the dry season from Feb. to Mar., while the lowest ones ( $77 \pm 21$  to  $352 \pm 98$  individuals/m<sup>3</sup>) were seen in the wet season from May to July. Vertical migration and the tidal cycle were the main factors affecting variations in diel zooplankton abundance and diversity. However, the monthly composition of the taxa varied only minimally. <http://www.sinica.edu.tw/zool/zoolstud/43.2/415.pdf>

**Key words:** Mangroves, Copepods, Tidal cycle, Diel cycle.

Mida Creek (3°23'S, 39°56'E) is unique because, unlike other creeks and bays along the Kenyan coast, it has no river inflow. It is now evident that a substantial amount of freshwater inflow into the creek is via groundwater seepage (Kitheka 1998, Tack and Polk 1999). From the literature, coastal ecosystems similar to Mida with limited drainage canals and natural streams have been documented to derive much of their freshwater input from groundwater flow (Valiela et al. 1978, Bokuniewicz 1980, Johannes 1980). However, information related to the phenomena of groundwater outflow, coastal water circulation, and their linkages in such tropical marine ecosystems is only beginning to emerge (Bokuniewicz 1980, Kjervfe 1994).

Various studies have been conducted in and around Mida Creek including some terrestrial research (Seys et al. 1995, Fassola et al. 1996, Turpie and Hockey 1997, Ouko and Manohar 1998) in the adjacent Arabuko Sokoke Forest, which is itself sustained by groundwater input

(TARDA 1983). The creek is also a marine protected area and forms part of the Watamu Marine National Park and Reserve (GOK 1989). Although much research has been conducted on the hydrology, mangroves, and the general marine ecology of Mida Creek (e.g., Gang and Agatsiva 1992, Messana et al. 1993, Hockey et al. 1995, Vezzosi et al. 1995, Ruwa 1996, Vannini et al. 1997 2001, Dahdouh-Guebas et al. 1998 1999 2000 2002, Kitheka 1998, Gherardi et al. 1999, Kitheka et al. 1999, Kairo et al. 2002), published information on zooplankton composition is completely lacking.

This paper presents results for the seasonal composition and abundance of zooplankton in Mida Creek collected during 1 yr of multidisciplinary research entitled the Mida Creek Biodiversity Research Project. The research was conducted in the framework of the Kenya Wildlife Services Wetlands Programme. The program's overall objective was to collect information on the biodiversity of Kenya's wetlands with a view to assessing natural and anthropogenic threats and their

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impacts on the wetlands. Zooplankton is an essential component of Mida Creek biodiversity since this group constitutes most crustaceans and larval stages of many larger marine animals.

## MATERIALS AND METHODS

### Study area

Mida Creek is located 20 km southwest of the town of Malindi along the Kenyan coast (Fig. 1) and occupies a total area of 32 km<sup>2</sup> including the mangrove cover. There is no river drainage into the creek, and freshwater input comes mainly from groundwater seepage and occasionally from surface runoff during the rainy season. The main channel is 11 km long. It is narrow (500 m) at the mouth of the creek, wider in its central portion (1500 to 2000 m), and narrow again further inland. Depths vary from 4 m in the shallow basin inland to 7 m in the central portions of the creek. Four sampling stations were demarcated as shown in fig 1. Sampling stations were selected to represent the oceanic water (stn. 1), the main creek water (stns. 2 and 3), and water within the sheltered mangroves and sandflats (stn. 4).

### Sampling and analysis

Monthly sampling was conducted from May 1996 to Apr. 1997 using a motorized rubber dinghy during daytime high tides. Zooplankton was collected at each station by obliquely towing a Bongo net in subsurface water; the net had a mesh size of 335  $\mu$ m and a mouth radius of 45 cm. The mouth of the net was fitted with the Hydro Bios flowmeter to estimate the volume of the water filtered through the net. Samples were immediately preserved in 5% formalin. In addition, three 24 h sampling series were conducted at stn. 3 in July, Oct., and Jan. in order to establish the diel migration patterns of zooplankton in different seasons.

Salinity and temperature were measured *in situ* at each station using an Aanderaa salinity-temperature meter (model 3315). Tidal depth and water elevations were measured using a Plastimo echosounder and a tide pole, respectively. Rainfall data were obtained from the Meteorological Department in Malindi, Kenya.

Whole zooplankton samples were first inspected under a Wild Heerbugg microscope (with a maximum magnification of 400X) in the laboratory, and the taxa present were identified and placed in their taxonomic categories. Each sample was further subsampled (1/10), and all individual taxa present were counted. Abundance was calculated as the number of individuals per cubic meter of water filtered through the net. The Shannon-Wiener index ( $H'$ ) was used to determine diversity (Magurran 1996). Statistical methods by Hampton (1994) were used for correlation and regression calculations.

## RESULTS

### Rainfall, temperature, and salinity

Monthly variations in total rainfall, surface water temperature, and salinity recorded during the sampling period are shown in figs. 2 and 3. Each monthly temperature and salinity plotted on the graphs are average readings for the 4 stations. Total annual rainfall around the Mida Creek area was 1418 mm, with most (76%) falling in Apr. and May (Fig. 2). The highest monthly rainfall recorded was 760 mm in May, and there was minimal or no rain from Dec. to Mar..

The lowest surface water temperatures (24.4~26.9°C) were recorded between July and Oct. and the highest (28.6~30.9°C) between Nov.

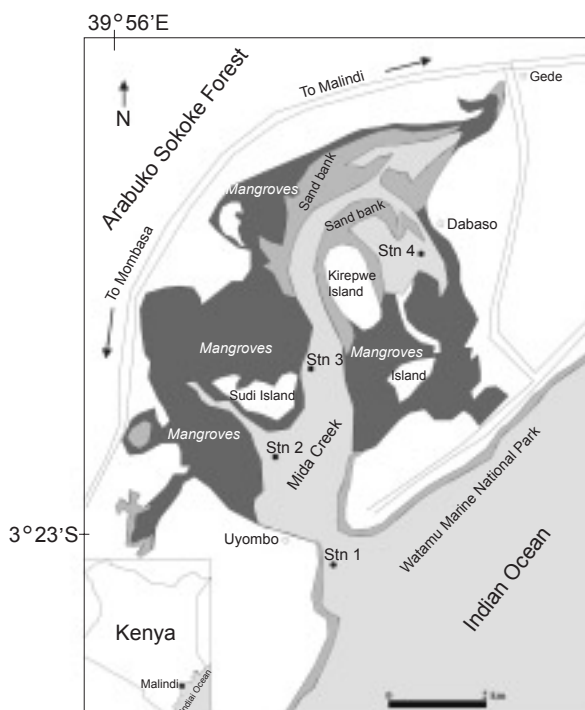


Fig. 1. Map showing the sampling stations in Mida Creek.

and Mar. (Fig. 2).

Increasing salinities (Fig. 3) were recorded in Dec. (35.23 psu), Jan. (35.91 psu), and Feb. (37.04 psu), with a peak in Mar. (37.41 psu). Values dropped in Apr. (34.15 psu) and May (32.86 psu). The lowest salinity was recorded in Aug. (25.80 psu).

### Zooplankton abundance

Variations in zooplankton collected monthly from each of the sampling stations are shown in fig. 4. The highest mean zooplankton abundances were collected in Feb. ( $2856 \pm 788$  individuals/m<sup>3</sup>) and Mar. ( $1961 \pm 540$  individuals/m<sup>3</sup>). Abundances were also quite high in Jan. ( $851 \pm 239$  individuals/m<sup>3</sup>), Apr. ( $879 \pm 242$  individuals/m<sup>3</sup>), and May ( $1029 \pm 283$  individuals/m<sup>3</sup>). Abundances were at a minimum from June to Dec.

**Table 1.** Taxa abundance at the Sampling Station 1,2,3, and 4 in Mida Creek

Taxa	Sampling Stations			
	Stn 1	Stn 2	Stn 3	Stn 4
Foraminifera	xx	x	x	
Medusae			xx	xx
Siphonophora	x	x		
Ctenophora			xx	xx
Mollusca	x	x	xxx	xx
Nematoda	x	x	x	x
Arachnida (Water mite)		x	x	
Ostracoda	x	x	x	x
Stomatopoda		x	x	
Copepoda	xx	xx	xxx	xxx
Caridea	xx	xx	x	x
Euphausiacea			x	x
Mysidacea		x		
Cirripedia			x	x
Cumacea			x	x
Isopoda			x	x
Amphipoda			xx	xx
Decapoda	x	x		
Sergestidae			xx	xx
Brachyura larvae	xx	xx	xxx	xxx
Brachyura megalopa		x	x	x
Bryozoa	x			
Chaetognatha	xx	x	xx	xx
Appendicularia		xx	xx	xx
Polychaeta			x	x
Salpa	x			
Pisces	xx	x	x	x

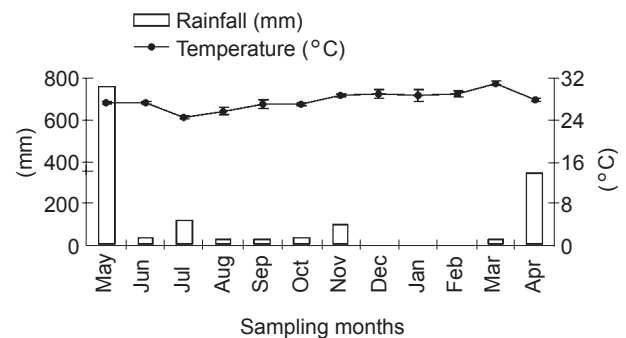
Key: x - Few (below 100 ind.m<sup>-3</sup>)  
 xx - Abundant (between 100 and 500 ind.m<sup>-3</sup>)  
 xxx - Most Abundant (500 ind.m<sup>-3</sup> and above)

(between  $77 \pm 21$  and  $352 \pm 98$  individuals/m<sup>3</sup>). Station 3 always recorded the highest zooplankton abundance, which ranged from 108 individuals/m<sup>3</sup> in June to 3998 individuals/m<sup>3</sup> in Feb.. The remaining stations recorded comparatively lower monthly abundances as follows: stn. 1 (62 to 2284 individuals/m<sup>3</sup>), stn. 2 (65 to 2398 individuals/m<sup>3</sup>), and stn. 4 (74 to 2741 individuals/m<sup>3</sup>).

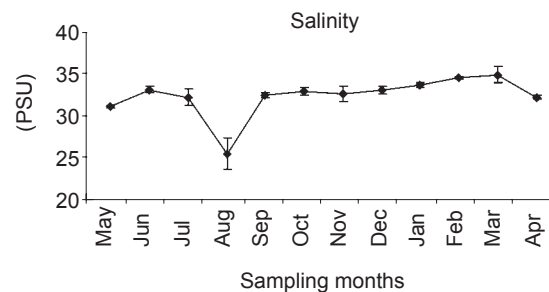
### Zooplankton composition and diversity

Table 1 shows the zooplankton taxa encountered in Mida Creek and their relative abundances at the sampled stations. Twenty-seven major zooplankton taxa were identified in this study. The Copepoda consistently occurred at all stations and was the most dominant taxon in terms of abundance and diversity. Other common taxa included the Mollusca, Caridea, Brachyura larvae, Chaetognatha, Appendicularia, and Pisces.

Monthly variations in zooplankton diversity were averaged for the 4 sampling stations and are shown in fig. 5. Generally, diversity was highest in June ( $1.27 \pm 0.12$ ) and July ( $1.33 \pm 0.15$ ), and lowest in Mar. ( $0.66 \pm 0.02$ ). However, individual stations displayed diversity gradients such that zoo-



**Fig. 2.** Surface water temperature and rainfall of the Mida Creek during the sampling period from May 1996 to Apr. 1997.



**Fig. 3.** Variations in salinity of the Mida Creek during the sampling period from May 1996 to Apr. 1997.

plankton taxa at the mouth of the creek (stn. 1) were more diverse than in the main basin upstream (stns. 2~4). Although table 1 shows that most taxa were obtained at stn. 3 followed by stns. 4, 2, and 1, the actual species richness within individual taxa (especially within the Copepoda) was higher at stn. 1 in comparison with the remaining stations.

**Zooplankton temporal distribution**

The following is a description of the temporal distribution of zooplankton taxa that contributed relative abundances of more than 100 individuals/m<sup>3</sup>.

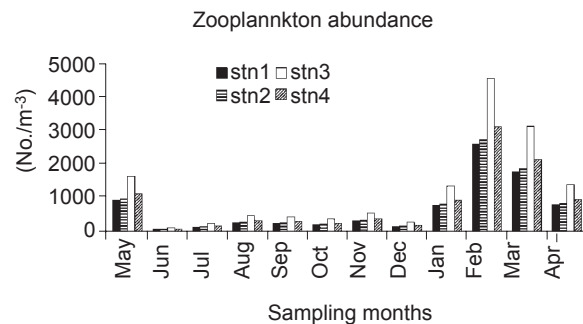
*Foraminifera*: Foraminifera were present throughout the year and peaked in Feb. with a total abundance of 314 individuals/m<sup>3</sup>. A high abundance of 184 individuals/m<sup>3</sup> was also recorded in Jan.. During the rest of the year, abundances were comparatively reduced (at between 0 and 74 individuals/m<sup>3</sup>). Foraminifera were represented mainly by *Globigerina* sp., encountered especially at stns. 1~3.

*Medusae*: Medusae were found throughout the year except in June. The highest abundance of 242 individuals/m<sup>3</sup> occurred in May during the

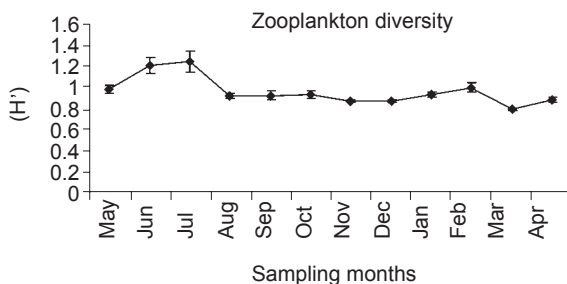
rainy season. A smaller peak of 170 individuals/m<sup>3</sup> occurred in Mar. during a dry spell. They were mostly encountered at stns. 3 and 4, and were absent from stns. 1 and 2.

*Ctenophora*: Ctenophores, like the Medusae, were found at stns. 3 and 4. They occurred throughout the year, recording a peak abundance of 296 individuals/m<sup>3</sup> in Sept. *Pleurobranchia* was the main representative genus.

*Mollusca*: These occurred at all stations throughout the year with a peak total abundance of 1530 individuals/m<sup>3</sup> in Feb. During this period, the molluscs completely dominated the zooplankton composition at stn. 3 (828 individuals/m<sup>3</sup>). They

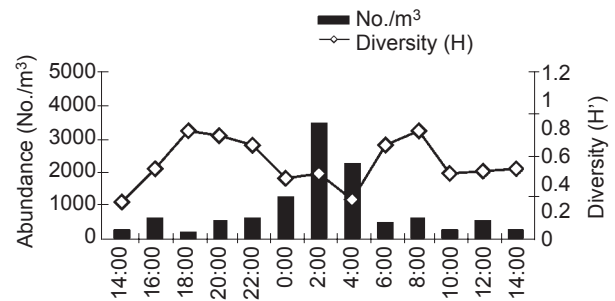


**Fig. 4.** Variations in zooplankton abundance of the Mida Creek during the sampling period from May 1996 to Apr. 1997.

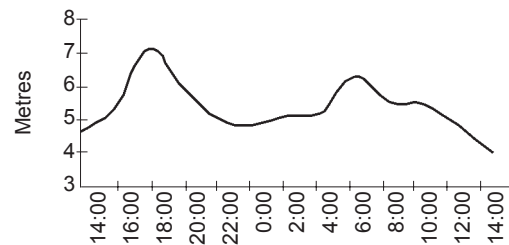


**Fig. 5.** Variations in zooplankton diversity of the Mida Creek during the sampling period from May 1996 to Apr. 1997.

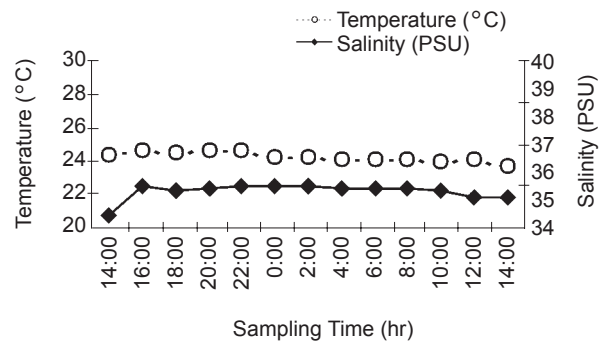
(a) Abundance (No./m<sup>3</sup>) and Diversity (H')



(b) Tidal Height (m)



(c) Temperature (°C) and Salinity (PSU)



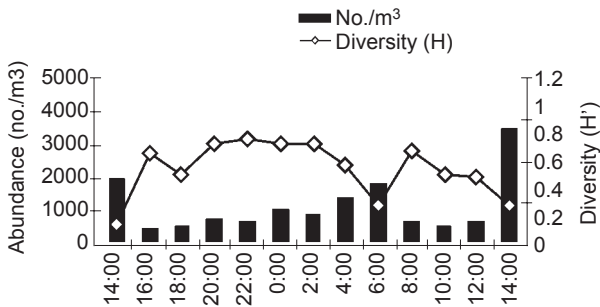
**Fig. 6.** Diurnal variations in (a) abundance and diversity, (b) tidal height, and (c) surface water temperature and salinity of the Mida Creek on 17-18 July 1996.

consisted mainly of larvae of gastropods, bivalves, heteropods, pteropods, and cephalopods. Pteropods and heteropods were mainly found at stns. 1 and 2, whereas the rest were evenly distributed in the creek.

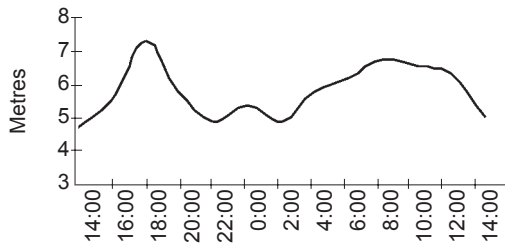
*Copepoda*: Calanoids, cyclopoids, harpacticoids, poecilostomatoids, and monstrilloids represented the copepod community. The dominant calanoids were *Acartia* sp., *Paracalanus* sp., *Centropages orsini*, and *Labidocera* sp.. *Paracalanus* sp. was always dominant at stn. 1, whereas *Acartia* sp., which occurred only scantily at stns. 1 and 2, was more abundant at stns. 3 and

4. *Acartia* sp. had a peak abundance of 1183 individuals/m<sup>3</sup> at stn. 4 during the rainy season, whereas the abundance of *Paracalanus* sp. peaked during the dry season (Feb.) with a value of 332 individuals/m<sup>3</sup>. Other notable species of copepods that occurred seasonally in the creek were *Pseudodiaptomus* sp., *Eucalanus* sp., and *Tortanus gracilis*. *Pseudodiaptomus* sp. dominated at stns. 3 and 4. *Tortanus gracilis* was also abundant here during the rainy season in May and Apr.. *Eucalanus* sp. completely dominated the copepod abundance at stn. 1 during the dry season in Feb.

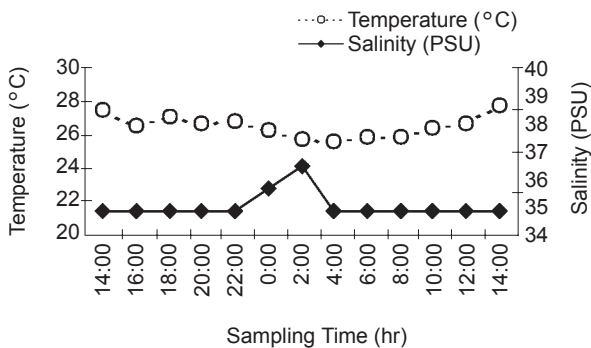
(a) Abundance (No./m<sup>3</sup>) and Diversity (H')



(b) Tidal Height (m)

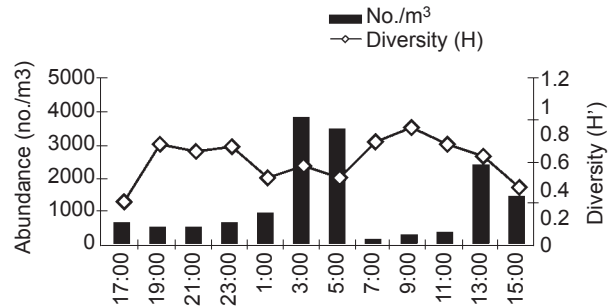


(c) Temperature (°C) and Salinity (PSU)

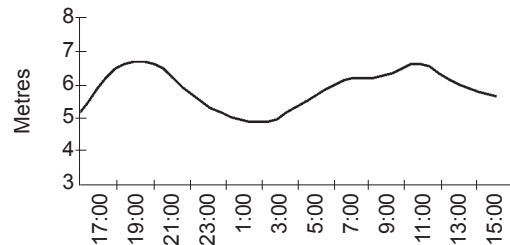


**Fig. 7.** Diurnal variations in (a) abundance and diversity, (b) tidal height, and (c) surface water temperature and salinity of the Mida Creek on 28-29 Oct. 1996.

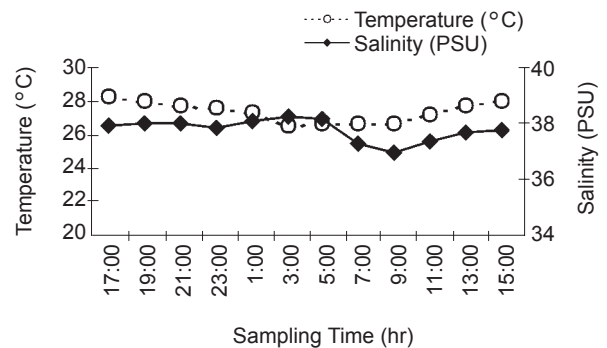
(a) Abundance (No./m<sup>3</sup>) and Diversity (H')



(b) Tidal Height (m)



(c) Temperature (°C) and Salinity (PSU)



**Fig. 8.** Diurnal variations in (a) abundance and diversity, (b) tidal height, and (c) surface water temperature and salinity of the Mida Creek on 28-29 Jan. 1997.

The majority of cyclopoids consisted of *Oithona* sp. Poecilostomatoids were represented mainly by *Oncaea venusta* and *Farranula gibbula*. Other members of this group, such as *Sapphirina* sp. and *Saphirella* sp. were found at all stations in the creek although in comparatively small numbers. *Metis* sp., *Setella* sp., and other representatives of harpacticoids were mainly found to be distributed in the inner parts of the creek especially at stns. 3 and 4.

**Caridea:** Caridean larvae were found throughout the year with a peak abundance in Feb. when high counts were recorded at stns. 1 (463 individuals/m<sup>3</sup>) and 2 (420 individuals/m<sup>3</sup>) as compared to stns. 3 (70 individuals/m<sup>3</sup>) and 4 (55 individuals/m<sup>3</sup>). During the rest of the year, Caridea were abundantly encountered at stns. 1 and 2.

**Amphipoda:** Amphipods occurred throughout the year in the inner creek (stns. 3 and 4). The highest total abundance recorded was 157 individuals/m<sup>3</sup> in Feb.. Hyperiid, gammarid, and caprellid were the main representatives. They occurred more in the upper reaches (stns. 3 and 4) of the creek.

**Sergestidae:** Sergestids were present throughout the year and experienced peak abundances in May (101 individuals/m<sup>3</sup>) and Apr. (122 individuals/m<sup>3</sup>). They were mainly composed of calyptopid larvae and adult lucifers. Other peak months were Feb. (55 individuals/m<sup>3</sup>) and Mar. (67 individuals/m<sup>3</sup>). Abundances were reduced between June and Jan. (down to 9 individuals/m<sup>3</sup>). Sergestids were commonly encountered at stns. 3 and 4.

**Brachyura larvae:** Brachyura larvae were the 2nd most abundant taxon in Mida Creek after the Copepoda. They occurred throughout the year, and a peak abundance of 2335 individuals/m<sup>3</sup> was recorded at stn. 3 during the dry season in Mar.. On many occasions, they were abundant in the upper reaches of the creek (stns. 3 and 4). However in Feb., a high abundance of 724 individuals/m<sup>3</sup> was observed at stn. 1 compared to 202 individuals/m<sup>3</sup> at stn. 2 and 685 individuals/m<sup>3</sup> at stn. 4. Larvae of portunids, porcellanids, and grapsiid crabs were the main representatives of the Brachyura.

**Chaetognatha:** Chaetognaths were found throughout the year, with a peak total abundance of 301 individuals/m<sup>3</sup> in Feb. Another observable peak occurred in May (84 individuals/m<sup>3</sup>) during the rainy season. Chaetognaths were abundant at stn. 1 (222 individuals/m<sup>3</sup>) and also at stns. 3 and

4.

**Appendicularia:** Appendicularia occurred throughout the year, with a peak abundance of 123 individuals/m<sup>3</sup> in Dec.. *Oikopleura*, *Fritillaria*, and larvae of tunicates were the main representatives. Appendicularia mainly occurred at stns. 2~4.

**Pisces:** This taxon was comprised of fish eggs and larvae. They occurred throughout the year and had a peak total abundance of 283 individuals/m<sup>3</sup> in Feb.. This peak was caused by high numbers of fish eggs at stn. 1 which amounted to 167 individuals/m<sup>3</sup> compared to 7 individuals/m<sup>3</sup> of fish larvae. Another peak was observed in Jan. (234 individuals/m<sup>3</sup>), and again this was due to the dominance of fish eggs that amounted to 122 individuals/m<sup>3</sup> as compared to 1 individual/m<sup>3</sup> of fish larvae at the same station. Fish larvae on the other hand were comparatively abundant (56 individuals/m<sup>3</sup>) at stn. 3 as compared to the other stations, which recorded between 3 and 7 individuals/m<sup>3</sup>. Fish eggs were mostly distributed at stns. 1 and 2 while fish larvae were found at stns. 3 and 4, which were predominantly mangrove and sea-grass zones.

### Zooplankton diel cycles

Zooplankton samples were collected over 3 different 24 h periods during July, Oct., and Jan. in order to study diel zooplankton variations in abundance and diversity. Samples were collected off Sudi Island (stn. 3) at 2 h intervals. Temperature, salinity, and tidal height were concurrently recorded during each zooplankton sample haul in order to relate their variations with zooplankton abundance and diversity.

17~18 July 1996: Diel variations in zooplankton abundance and diversity, tidal height, temperature, and salinity are shown in fig. 6. Sampling at stn. 3 was conducted over 24 h (17~18 July 1996). This period of sampling coincided with the spring tide and a new moon. Figure 6a shows that zooplankton abundance increased steadily with night-fall from 18:00 (173 individuals/m<sup>3</sup>) and attained a peak abundance at 02:00 (3782 individuals/m<sup>3</sup>). This peak coincided with the flooding phase just after low tide (Fig. 6b). Abundance declined slightly at 04:00 (2391 individuals/m<sup>3</sup>) and sharply thereafter (< 587 individuals/m<sup>3</sup>). The next daytime low tide occurred at 14:00 coinciding with the minimum (< 266 individuals/m<sup>3</sup>) zooplankton abundance (Fig. 6a). Temperature varied minimally (24.3~25.5°C) in rhythm with the diurnal air temperature. Salinity was quite constant (35.17~35.72

psu) except at 14:00 (34.36 psu; Fig 6c). Zooplankton abundance at night was almost 4 times higher compared to that in the daytime. This may be attributed to vertical migration of zooplankton to the surface water at night.

Spearman correlation analysis determined that there was an insignificant negative relationship between zooplankton abundance and tidal height ( $r_s = -0.15$ ;  $df = 11$ ;  $p = 0.3$ ). This suggested that no bulk lateral importation of zooplankton into stn. 3 occurred with the incoming tide. However, there was a significant positive correlation between tidal height and diversity ( $r_s = 0.64$ ;  $df = 11$ ;  $p = 0.008$ ), which may indicate that some taxa were imported by the tide during the flooding phase (Fig. 6a, b).

Dominant zooplankton taxa identified during this period were the copepods *Acartia* sp., *Paracalanus* sp., *Pseudodiaptomus* sp., *Oithona* sp., and *Temora turbinata*. Other common zooplankton included the Caridea, Brachyura larvae, Chaetognatha, Medusae, Ctenophora, and Foraminifera. These taxa peaked at different times over the 24 h sampling period. The most dominant was the copepod *Acartia* sp., which constituted between 29% and 77% of total zooplankton abundances during the 24 h cycle. *Acartia* sp. was dominant at 18:00, 22:00, 24:00, 02:00, 04:00 (with a peak abundance of 77% of total zooplankton), 10:00, 12:00, and 14:00. Other important copepod that dominated was *Oithona* sp. at 17:00 (66% of total zooplankton), 06:00 (50%), and 08:00 (38%).

28~29 Oct. 1996: Figure 7 shows diel variations in zooplankton abundance and diversity, tidal height, temperature, and salinity during the 24 h sampling conducted at stn. 3 (28~29 Oct. 1996). This sampling period coincided with the spring tide and a full moon. Figure 7a shows that zooplankton abundance displayed peaks at 14:00 (2000 and 3582 individuals/m<sup>3</sup>) and at 06:00 (1846 individuals/m<sup>3</sup>). The lowest abundance occurred at 16:00 (351 individuals/m<sup>3</sup>) when the tide was flooding in (Fig. 7b). During low tide at night between 22:00 and 06:00, the zooplankton increased albeit slightly (ranging from 593 to 1846 individuals/m<sup>3</sup>). From 08:00 to 12:00 during high tide, the abundance dropped to between 615 and 484 individuals/m<sup>3</sup>. The abundance at night was almost 1.4 times greater than that during the day.

Zooplankton abundance and tidal height were negatively but insignificantly correlated ( $r_s = -0.43$ ;  $df = 11$ ;  $p = 0.5$ ). Tidal height and zooplankton diversity also showed an insignificant negative cor-

relation ( $r_s = -0.14$ ;  $df = 11$ ;  $p = 0.3$ ) (Fig. 7a, b).

The lowest temperatures (26.36~26.76°C) were recorded between 02:00 and 08:00. They were higher (27.33~28.98°C) throughout the rest of the sampling period (Fig. 7c). Salinities sharply increased at 24:00 (35.84 psu) and 02:00 (36.82 psu); they were stable at 34.86 psu for the rest of the sampling period.

The dominant taxa on this occasion were the copepods *Temora turbinata*, *Pseudodiaptomus* sp., *Acartia* sp., and *Oncaea venusta*. Other zooplankton included Gastropoda larvae, Caridea, Foraminifera, fish eggs, and Medusae. Brachyura larvae were dominant at 14:00, comprising 72% to 95% of total zooplankton abundance. *Temora turbinata* dominated in the early morning hours at 04:00 (50%), 06:00 (86%), and 08:00 (36%) and in the early evening at 18:00 (62%). Gastropoda larvae were abundant during the daytime at 10:00 (57%), 12:00 (66%), and 16:00 (37%).

28~29 Jan. 1997: Diel variations in zooplankton abundance and diversity, tidal height, temperature, and salinity during the 24 h sampling from 28 to 29 Jan. 1997 are shown in fig. 8. Time of sampling at stn. 3 coincided with the neap tide and a full moon. Figure 8a shows that similar to the other two 24 h sampling periods, zooplankton abundance peaked only at low tide. Nighttime peaks occurred during the flood phase (Fig. 8b) at 03:00 (4025 individuals/m<sup>3</sup>) and 05:00 (3675 individuals/m<sup>3</sup>), and daytime peaks occurred during the ebb tide at 13:00 (2475 individuals/m<sup>3</sup>) and 15:00 (1450 individuals/m<sup>3</sup>). Low abundances were recorded at high tide from 19:00 to 21:00 (450~500 individuals/m<sup>3</sup>) and also during the flood phase of the next high tide from 07:00 to 11:00 (100~300 individuals/m<sup>3</sup>). Abundances at night were about twice as high as those during the day.

Zooplankton abundance showed a significant negative correlation with tidal height ( $r_s = -0.73$ ;  $df = 10$ ;  $p = 0.005$ ), whereas diversity was positively and significantly correlated ( $r_s = 0.72$ ;  $df = 10$ ;  $p = 0.004$ ) with tidal height (Fig. 8a, b).

Figure 8c shows that salinities were higher between 17:00 (37.93 psu) and 05:00 (38.27 psu) and lower thereafter (ranging between 36.6 and 37.7 psu). Temperatures gradually dropped after 17:00 (28.68°C) and reached a minimum at 03:00 (26.57°C), before increasing again. The ranges of both these parameters may be described as minimal.

Dominant zooplankton were Brachyura larvae, Chaetognatha, Gastropoda larvae, fish larvae, and Decapoda. Other important taxa were

the copepods *Acartia* sp., *Oithona* sp., *Tortanus* sp., *Pseudodiaptomus* sp., and *Labidocera acuta*.

Brachyura larvae were dominant at 17:00 (75%), 23:00 (37%), 07:00 (26%), 09:00 (41%), 11:00 (42%), and 15:00 (37%). *Acartia* sp. dominated at 01:00 (31%), 03:00 (19%), 05:00 (70%), and 13:00 (38%). Chaetognaths and *Oithona* sp. were dominant only at 19:00 (20%) and 21:00 (53%), respectively. *Acartia* sp. was dominant during the peak zooplankton abundance which occurred between 03:00 and 05:00.

## DISCUSSION

Related zooplankton data in this region appropriate for comparison with the present results are largely unavailable. Nevertheless, the present results indicate that Mida Creek is rich in zooplankton and contains at least 27 major taxa. In the present study, we have shown that the zooplankton composition is quite similar to what has been reported in other mangrove ecosystems in this region, such as Tudor Creek (Kimaro 1986, Okemwa 1990) and Gazi Bay (Mwaluma 1993, Osore 1994). However, the zooplankton community displayed a seasonality that somewhat differed from that observed in Tudor Creek and Gazi Bay. This is probably because Mida Creek experiences no direct river influence as compared to those other ecosystems. In Tudor Creek (Okemwa 1990) and Gazi Bay (Osore 1992 1994, Mwaluma 1993, Kitheka et al. 1997), estuarine species of copepods are reported to emerge due to low salinities caused by freshwater discharge from rivers. This occurs during the wet season or immediately thereafter, and it is often accompanied by peak zooplankton abundances.

In Mida Creek on the other hand, the highest zooplankton abundance occurred during the dry season in Jan., Feb., and Mar. The mean peak abundance of  $2856 \pm 786$  individuals/m<sup>3</sup> was recorded in Feb.. During the rainy season in May, the abundance was substantially reduced at  $1029 \pm 283$  individuals/m<sup>3</sup>, and thereafter in June reached the lowest value ( $77 \pm 21$  individuals/m<sup>3</sup>). In Tudor Creek, Reay and Kimaro (1984) and Okemwa (1990) reported increases in zooplankton in the rainy season due to high amounts of nutrients washed into the creek, which in turn ameliorated phytoplankton production (Kazungu et al. 1989). Osore (1994) observed a similar trend in Gazi Bay.

The highest monthly zooplankton abundance

was recorded up the creek within the main mangrove zone (stns. 3 and 4), while the lowest was at the mouth of the creek (stns. 1 and 2) adjacent to the open ocean.

During the rainy season in May and Apr., the decline in salinity in most parts of the creek was only minimal ( $32.86 \pm 0.19$  and  $34.15 \pm 0.21$  psu, respectively), since there are no draining rivers. However, underground seepage and input from surface runoff (Kitheka pers. comm.), which occurs in the inner parts of the creek (stns. 3 and 4), caused a substantial drop in salinity ( $25.8 \pm 2.28$  psu) at those stations. This change in salinity occasionally affected the zooplankton composition, attracting estuarine species like *Acartia* sp. and *Pseudodiaptomus* sp. However, this was a rare occurrence. Therefore, the absence of riverine input in Mida Creek has created a somewhat steady zooplankton population that is more or less present throughout the year.

The main zooplankton taxa recorded abundantly throughout the year included Copepoda, Medusae, Ctenophora, Brachyura larvae, and Chaetognaths. Dominant members of the Copepoda were *Acartia* sp., *Paracalanus* sp., *Temora turbinata*, *Centropages orsinii*, *Labidocera* sp., and *Calanopia thompsoni*.

Some zooplankton taxa were observed to occur at particular sampling stations. Bryozoa, fish eggs, and copepods such as *Paracalanus* sp. and *Eucalanus* sp. were mainly found at stn. 1. Ctenophores and Medusae were exclusively found at stns. 3 and 4, whereas Brachyura larvae were abundant at stn. 3. However, there were some months when a high abundance of Brachyura larvae was recorded at stn. 1. Fish larvae were predominantly found at stns. 2~4. Chaetognaths, which mostly feed on copepods, were evenly distributed in the creek and were mostly found in areas of high copepod abundance. Amphipods were abundant at stns. 3 and 4, which were areas predominantly occupied by seagrasses and mangroves.

In general, almost all zooplankton taxa attained peak abundances in Feb.. Pisces was no exception (see also Mwatha et al. 1998); fish eggs were most abundant at the mouth of Mida Creek (stn. 1) in Jan. and Feb. during the dry season. Kimaro (1986) and Okemwa (1990) reported similar observations in Tudor Creek, as did Osore (1994) in Gazi Bay. Kimaro (1986) recorded high abundances of fish eggs and larvae at the mouth of Tudor Creek between Nov. and Jan., while Okemwa (1990) reported high abundances at the



creek mouth, although they occurred during the rainy season (Mar. to June). Osore (1994) reported fish egg abundances of up to 90 individuals/m<sup>3</sup> at the mouth of Gazi Bay during the rainy season, and only 7 individuals/m<sup>3</sup> within the mangrove zone upstream.

Increased zooplankton diversity in June ( $1.29 \pm 0.12$ ) and July ( $1.33 \pm 0.15$ ) was accompanied by low abundances ( $77 \pm 21$  and  $154 \pm 42$  individuals/m<sup>3</sup>, respectively). During this period, no particular zooplankton taxon was dominant. In Feb., diversity was low ( $0.9 \pm 0.6$ ) due to the high abundance of zooplankton dominated by *Eucalanus* sp., *Brachyura* larvae, and fish eggs.

Mean zooplankton diversity among the sampled stations was highest at the oceanic stn. 1 ( $H' = 1.15 \pm 0.11$ ) and gradually dropped (down to  $H' = 0.8 \pm 0.5$ ) towards stns. 3 and 4 located in the inner parts of the creek. This observation of a zooplankton diversity gradient in bays and creeks is well documented, and it is not new in coastal Kenya. It has been reported in Tudor Creek (Okemwa 1990), Gazi Bay (Osore 1994), and further offshore (Osore et al. 1995, Mwaluma 2000).

Diel cycles of zooplankton in Mida Creek showed that the catches at night were always higher than those in the daytime. Ratios of night to day abundances were 1.98 (Jan.), 3.78 (July), and 1.39 (Oct.). The tidal cycle (tidal height and phase of the moon) significantly influenced zooplankton population structure and diversity. During high tide, zooplankton diversity was high and abundance was low, whereas at low tide, the situation was reversed. The influence was more pronounced during a neap-tide full moon than during either a spring-tide full moon or a spring-tide new moon.

During the 24 h sampling period, gelatinous zooplankton such as ctenophores (jellyfish) and medusae were mainly observed at high tide, and were absent at low tide. During low tide, large numbers of adult populations of these jellyfish could be observed around stn. 4. A possible explanation for the high abundance of medusae observed in the monthly samples from both stns. 3 and 4 is as follows: During low tide, intertidal pools which are permanently surrounded by sand banks at stns. 3 and 4 retain gelatinous zooplankton thus making these taxa typical of those stations.

The 24 h samples demonstrated that diel vertical migration (DVM) was responsible for the high zooplankton abundance at night. DVM as well as diurnal horizontal migration (DHM) are important avoidance strategies used by zooplankton to coun-

teract fish predation (Masson et al. 2001). Correlations obtained for zooplankton abundance versus tidal height on the one hand and zooplankton diversity versus tidal height on the other also suggested that few other taxa were possibly horizontally trans-located by the tide to stn. 3.

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