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Copepod composition, abundance and diversity in Makupa Creek, Mombasa, Kenya

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Abstract**—**The taxonomic composition, abundance and spatio-temporal distribution of copepods were analysed from monthly zooplankton samples collected in Makupa creek and Mombasa Harbour (Makupa creek was until recently subjected to considerable dumping of domestic and industrial waste). At least 51 copepod species belonging to 38 genera in the families Calanoida (25), Harpacticoida (5), Poecilostomatoida (7) and Cyclopoida (1) were identified. The most common genera were *Acartia*, *Acrocalanus*, *Corycaeus*, *Oncaea* and *Oithona*. Copepods bloomed in the wet months of November and April (75 to 158/m^3). Abundance was consistently high near the creek mouth and low within the creek enclosure. Copepod diversity (*H*') was slightly higher (2.00 to 2.57) during September, November, December, January, May and June and lower (1.30 to 1.95) in the remaining months. Evenness (*J*) was, however, relatively constant (0.67 to 0.84) during the entire sampling period. These results point to suppressed copepod diversity and abundance in Makupa Creek, and possible reasons for this, which may include environmental degradation caused by pollution, are presented.

INTRODUCTION

Ongoing and recently completed marine research in Kenya and on the East African coast has produced much data and information on zooplankton (e.g. Kimaro & Jaccarini, 1989; Okemwa, 1989; Osore et al., 1993; Osore et al., 1995; Kitheka et al., 1997; Mwaluma, 2000). However, information on the ecology of copepods is still scanty, and yet this taxonomic group usually comprises the major component of zooplankton in terms of abundance and diversity. Apart from preliminary observations of copepods and their role in the secondary productivity of Tudor creek (Okemwa & Revis, 1986, 1988; Revis, 1988; Okemwa, 1990, 1992), Gazi Bay (Borger, 1990) and of the upwelling waters of Somalia (Smith & Lane, 1981), very little is known about the copepods of the East African coast. The existing zooplankton literature of the region only considers copepods as a component of the plankton (Okera, 1974; Reay & Kimaro, 1984; Osore, 1992, 1994; Osore et al., 1997), and no detailed studies on the group are available.

Table 1 summarises the physical and chemical features documented for Makupa creek compiled from previous studies. The small size of the creek and its location—sandwiched between a busy harbour, a dumpsite and an electric power-generating plant—are major factors contributing to its pollution. Previous studies in the creek revealed almost complete loss of mangrove vegetation and reduced populations of fish and edible crustaceans (Munga et al., 1994; Williams et al., 1996). Kamau (2001), Mwashote (unpublished data) and Osore et al. (unpublished

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Table 1. Major physical and chemical features of Makupa creek, Mombasa, Kenya, compiled from Kamau (2001), Mwashote (Unpublished data) and Osore et al. (Unpublished data)

Location:	Northwest of Mombasa Island (4° 02' S, 39° 38' E)
Surface area (km^2):	1 (0.85 to 1.1)
Depth (m):	3 (0.7–13)
Water temperature (°C):	24.85 ± 0.50 –31.70 ±1.50
Salinity (‰):	29.90 ± 3.15 –35.80 ± 0.45
Secchi transparency (m):	0.30 –1.40
DO concentration (mg/l):	3.60 ± 0.90–5.90 ± 4.40
Heavy metal concentration (µg/g):	*In sediments:* Cu (56–114) Cd (1–13), Zn (223–1429), Fe (up to 27,718), Pb (up to 58) *In water:* Cd (nd), Pb (12) *In fish:* Cd (3.9), Pb (59)
Chlorophyll-*a* concentration (µg/l):	2.05 ± 0.60–8.00 ± 6.80
Monthly rainfall (mm):	1.9–279

DO, dissolved oxygen; nd, not detected.

data) have recently reported on aspects of heavy metal concentrations, trends of physico-chemical conditions and the general zooplankton community of Makupa creek. They concluded that although there is contamination by heavy metals in the sediments, water and some commercial fish species, it has not yet reached critical levels.

It is evident that frequent oil spillages from Mombasa Harbour into the creek have reduced the water quality and resulted in the degradation of mangroves and other habitats. The resultant poor water quality may also be detrimental to the recruitment of fish and invertebrates.

The study reported here was conducted as part of collaborative multi-institutional research by the Kenya Marine and Fisheries Research Institute (KMFRI), the Kenya Wildlife Service (KWS) and the Government Chemist Department (GCD). The overall research objective was to assess the causes and status of environmental degradation of Makupa creek. Sampling and analysis of zooplankton were fundamental to this research, as these organisms form the basis of the food chain in the aquatic ecosystem. Results of the general zooplankton survey and also a detailed description of the study area have been submitted elsewhere (Osore et al., unpublished data).

Results of the composition, abundance and distribution of copepods and their seasonal trends at four sampling locations in Makupa creek (Stns 1, 2, 3, 4) are described, and compared with a control site in Mombasa Harbour (Stn 5).

MATERIALS AND METHODS

Makupa creek connects to the Indian Ocean via Mombasa Harbour in Port Reitz creek (Fig. 1). Four sampling sites (Stn 1 to 4) were located in Makupa creek and one (Stn 5) within Mombasa Harbour. Monthly sampling of zooplankton was conducted during daytime high tide from July 1996 to June 1997. A quantitative Bongo net of mesh size 335 µm and mouth diameter of 45 cm equipped with a flowmeter, was used. The net was towed obliquely in subsurface water by a motorboat for 5 minutes and the samples were preserved in 5% formalin. Subsurface water temperature and salinity were registered using a probe (Aanderaa Display unit 3315 connected to S/T sensor 3210). Dissolved oxygen was determined in the laboratory by the modified Winkler method (Parsons et al., 1984). Chlorophyll-*a* concentration was quantified spectrophotometrically by the method described by Parsons et al. (1984). Rainfall data were obtained from the Meteorological Department, Mombasa, Kenya.

For laboratory analysis, the entire zooplankton sample was first screened under a binocular microscope to identify all the taxa present and then one-tenth of each sample was observed in detail (Osore et al., 1997). Identification keys and references were obtained from Giesbrecht (1892), Rose (1933), Owre & Foyo (1967), Wickstead (1965) and Bradford (1972). Copepods were separated from the rest of the zooplankton and abundance calculated as number of individual copepods per cubic metre (ind./m^3). The Shannon-Wiener index and Pielou index were used to calculate copepod diversity (*H'*) and homogeneity (*J*) respectively (Magurran, 1996).

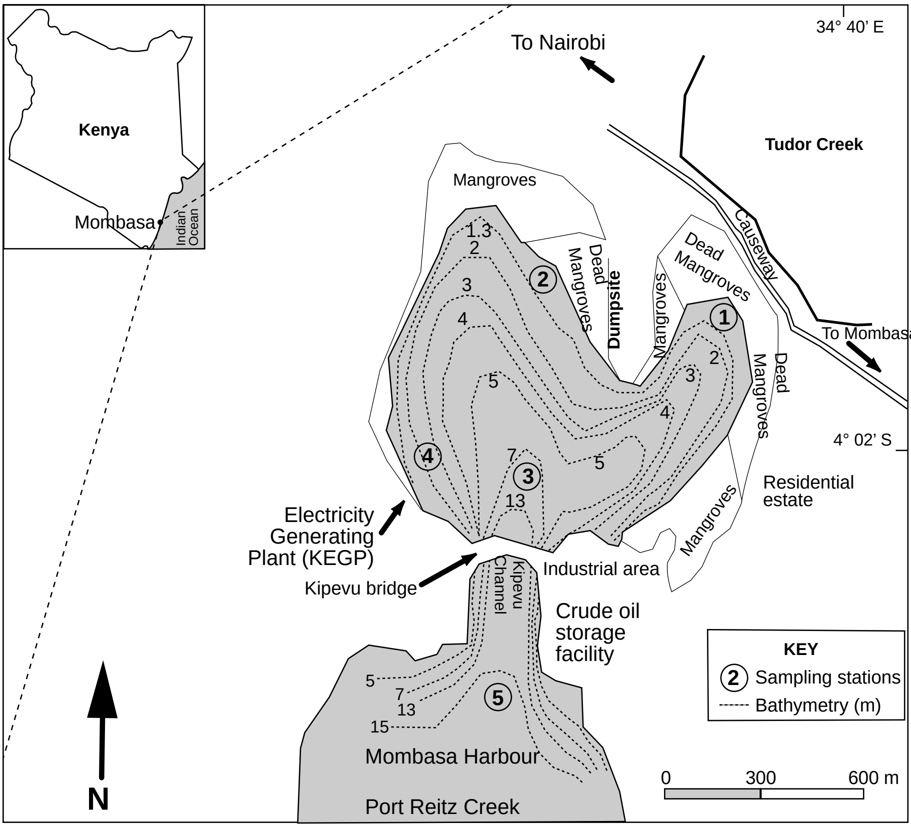

Fig. 1. Map of the study area showing sampling locations in Makupa creek (Stns 1–4) and Mombasa Harbour (Stn 5)

RESULTS AND DISCUSSION

Environmental variables

Monthly changes in average environmental variables are shown in Fig. 2a–e. Average dissolved oxygen usually ranged between 3.70 and 5.31 mg/l and increased to 10.55 mg/l in November. Chlorophyll-*a* concentration varied from 2.10 to 8.04 µg/l. These high Chlorophyll-*a* values suggest that the creek has high phytoplankton biomass due to high level of eutrophication. Surface water temperature was highest (31.0 ºC) in March and was relatively low (24.9–27.4 ºC) from April to August. There was little variation in salinity (35.0–36.0 ‰) except in August (29.9 ‰) and April (30.7 ‰), when it was low. Rainfall was high in April (268 mm), May (279 mm) and November (136 mm) during the southeast monsoon (SEM) period, but minimal or absent from December to March, the northeast monsoon (NEM) period.

Copepod abundance

Monthly variations in copepod abundance at the five sampling stations are shown in Fig. 3. Within the creek enclosure (Stns 1–4) abundance ranged from 3 to 88/m^3 (Stn 4), 23 to 78/m^3 (Stn 3), 2 to 60/m^3 (Stn 2) and 1 to 25/m^3 (Stn 1); but there was a major peak at this stn in April (638/m^3). The bloom of *Pseudodiaptomus* sp. caused the prominent peak at Stn 1 in April. Several species of this genus are documented to thrive in brackish water and often form aggregations and swarms (Walter, 1989; Mauchline, 1998). Within Mombasa Harbour (Stn 5), abundance varied between 10 and 209/m^3. Peak abundance (209/m^3) was observed in December.

Total copepod abundance for all stations was high during the NEM period, which occurred in November to March. The mean value of copepod abundance was also significantly high (P = 0.001) for the NEM compared to SEM period.

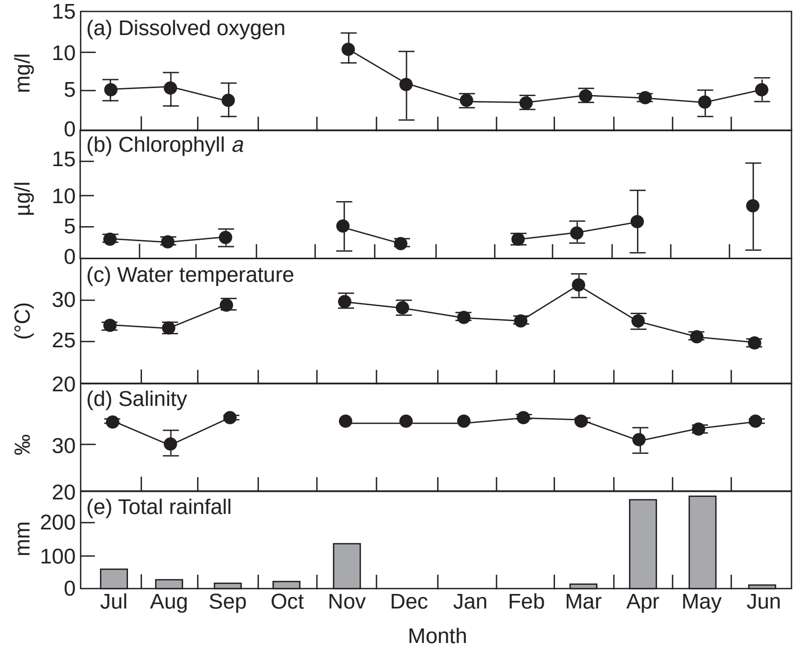

Fig. 2. Environmental variables recorded in the study area. Error bars (in a–d) represent standard deviation. Field sampling was not conducted in October; Chlorophyll-*a* was not sampled in January and May

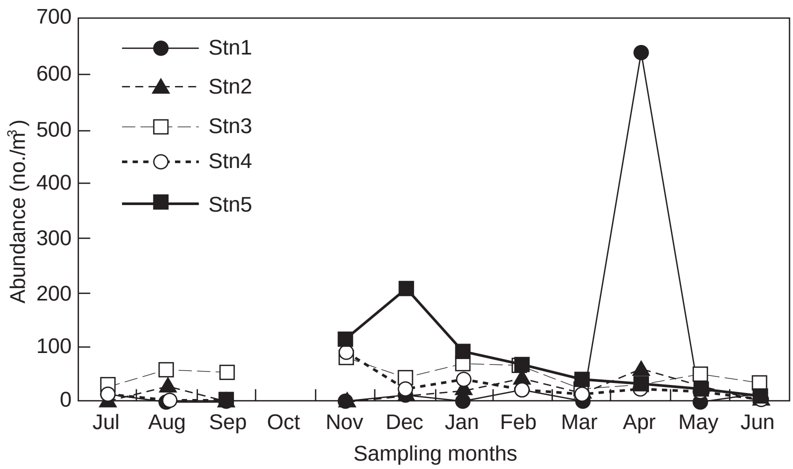

Fig. 3. Monthly abundance (no./m^3) of all the copepods counted from each sampling station in the study area from July 1996 to June 1997

Overall, copepod abundance peaked during the NEM period. Similar, high densities of copepods have been reported in the Mombasa Harbour during the NEM (Okemwa, 1992). In the present study, the highest monthly abundance (23 to 78/m^3) was recorded at Stn 3 located at the mouth of the creek and at Stn 5 (10 to 209/m^3), which is inside Mombasa Harbour and closer to the open ocean.

Species distribution

More than 51 taxa from 5 orders, 15 families and 38 genera were identified in this study. Table 2 lists the copepods identified and their mean densities averaged for all the months. Numerically, the most common orders were Calanoida, Poecilostomatoida and Cyclopoida. The Calanoida were mainly

Table 2. List of copepods identified in Makupa creek and Mombasa Harbour and their densities of occurrence (no./m^3), means for all the months of the study. The most common copepod species are shown in bold typeface and * indicates the most abundant copepod species

Species	Stn1	Stn2	Stn3	Stn4	Stn5
CALANOIDA					
Nannocalanus minor (Claus 1863)	0	0	0	0	1
Canthocalanus pauper Giesbrecht 1888	0	0	3	2	3
Cosmocalanus sp.	0	0	0	1	0
Undinula vulgaris (Dana 1849)*	0	2	7	3	24
Eucalanus attenuatus (Dana 1849)	0	1	1	1	1
Eucalanus crassus Giesbrecht 1888	0	0	1	1	1
Eucalanus mucronatus Giesbrecht 1888	0	1	0	0	1
Eucalanus spp.	1	0	5	4	4
Mecynocera sp.	0	0	0	0	1
Clausocalanus sp.*	1	1	6	2	15
Acrocalanus* sp.	**3**	**12**	**22**	**30**	**49**
Calocalanus sp.	0	0	0	1	2
Paracalanus sp.	0	1	0	1	2
Aetideus sp.	0	0	2	0	0
Euchaeta sp.	0	0	1	0	0
Scolecithrix sp.	0	0	2	0	1
Temora discaudata Giesbrecht 1889	1	0	0	0	1
Temora turbinata (Dana 1849)*	1	5	5	4	8
Centropages furcatus (Dana 1849)*	0	1	1	1	2
Centropages orsini Giesbrecht 1849	1	1	9	3	68
Candacia spp.	0	0	1	1	1
Calanopia elliptica (Dana 1849)	0	0	0	1	1
Calanopia thompsoni A. Scott 1909	3	1	0	1	0
Calanopia minor A. Scott 1902	0	0	1	0	0
Labidocera acuta (Dana 1849)	0	1	3	0	1
Labidocera minuta Giesbrecht 1889	0	0	0	0	1
Labidocera pavo Giesbrecht 1889	0	0	1	1	1
Labidocera orsini Giesbrecht 1889	0	1	3	5	1
Labidocera bipinata Tanaka 1936	0	1	0	0	10
Labidocera spp.	1	6	2	1	1
Pseudodiaptomus sp.*	629	30	3	5	0
Pontella spp.	0	1	1	1	1
Pontellina plumata (Dana 1849)	0	1	0	1	5
Pontellopsis spp.	0	1	2	1	0
Tortanus spp.*	4	24	9	3	15
Acartia* spp.	**6**	**15**	**13**	**9**	**25**
CYCLOPOIDA					
Oithona* spp.	**10**	**10**	**31**	**26**	**20**
POECILOSTOMATOIDA					
Oncaea* spp.	**1**	**2**	**10**	**3**	**12**
Pachos punctatum (Claus 1863)	0	0	0	0	1
Corycaeus* spp.	**2**	**8**	**32**	**12**	**25**
Copilia sp.	0	0	4	0	0
Saphirella sp.	3	1	0	1	0
Saphirina sp.	1	0	2	0	1
Peltidium sp.	0	1	1	0	1
HARPACTICOIDA					
Microsetella sp.	1	0	1	1	1
Macrosetella sp.	0	0	1	1	1
Clytemnestra sp.	1	1	0	0	1
Aegisthus spp.	1	0	0	0	0
Other Harpacticoida	1	1	1	3	1
MONSTRILLOIDA	0	1	0	1	1
Copepoda nauplii	1	1	1	1	1
Total no. of species	21	29	34	34	40

represented by the genera *Acrocalanus*, *Acartia*, *Centropages*, *Temora* and *Tortanus*. *Pseudodiaptomus* only bloomed occasionally at Stn1. The Poecilostomatioda were mainly represented by the genera *Corycaeus* and *Oncaea* while the Cyclopoida were represented by members of the genus *Oithona*.

Okemwa & Revis (1986) encountered nearly the same number of copepod species (52) in Tudor creek, but recorded more families (24) and fewer genera (30) compared to the present study. Time series of 24 hr surveys within Mombasa Harbour, located in the immediate neighbourhood of Makupa creek, yielded 100 species belonging to 29 families and 37 genera (Okemwa, 1992). This survey utilised smaller (180 µm) mesh size nets than ours (350 µm), and therefore captured a wider spectrum of copepods, especially Poecilostomatoida and Cyclopoida. Net filtration efficiency was also higher in both Tudor creek and Mombasa Harbour (most probably due to less clogging) since the water was less muddy and had less particulate matter as indicated by its low turbidity.

Our study identified 21 copepod species at Stn 1, 29 at Stn 2, 34 at both Stns 3 and 4 and 40 at Stn 5. The most abundant copepods in this study were *Undinula vulgaris* (Dana 1849), *Clausocalanus* sp., *Acrocalanus* sp., *Temora turbinata* (Dana 1849), *Centropages orsini* Giesbrecht 1889, *Pseudodiaptomus* sp., *Tortanus* spp., *Acartia* spp., *Oithona* spp., *Oncaea* spp. and *Corycaeus* spp. (Table 2). Their combined abundance constituted 43–90% of the entire copepod population. *Labidocera* (> 6), *Eucalanus* (> 4) and *Calanopia* (> 3) comprised the most species.

Characteristic copepod genera of the study area

The five most common copepod genera in the study area were *Acartia*, *Corycaeus*, *Oncaea*, *Acrocalanus* and *Oithona*. These five main copepod taxa constituted an average abundance of 72 % (range 45–90 %) of the total number of copepods encountered. Table 2 shows that these genera occurred in all the sampling stations at maximum monthly abundance of 6–25/m^3 (*Acartia* spp.), 2–32/m^3 (*Corycaeus* spp.), 1–12/m^3 (*Oncaea* spp.), 3–49/m^3 (*Acrocalanus* sp.) and 10–31/m^3 (*Oithona* spp.). Sampling was not conducted in October at any of the Stns, in January at Stn 1, in July at Stns 4 and 5; nor in August at Stn 5.

Copepod diversity and homogeneity

Shannon-Wiener and Pielou indices (Magurran, 1996) were used to describe the monthly diversity (*H'*) and homogeneity (*J*) of the copepod population. Figure 4 shows that whereas the diversity generally increased during the rainy season in November and May, homogeneity was relatively constant. The bloom of *Pseudodiaptomus* sp. in April significantly depressed both indices. Copepod diversity in subtropical and temperate coastal inlets and bays is documented to vary from 18 to 43 species and 14 to 26 genera (Nair et al., 1981; Kimmerer & Mickinnon, 1985; Michel & Herring, 1984; Webber & Roff, 1995). Unfortunately, data and information regarding copepod diversity for tropical creeks, especially along the East African coast, is very scarce.

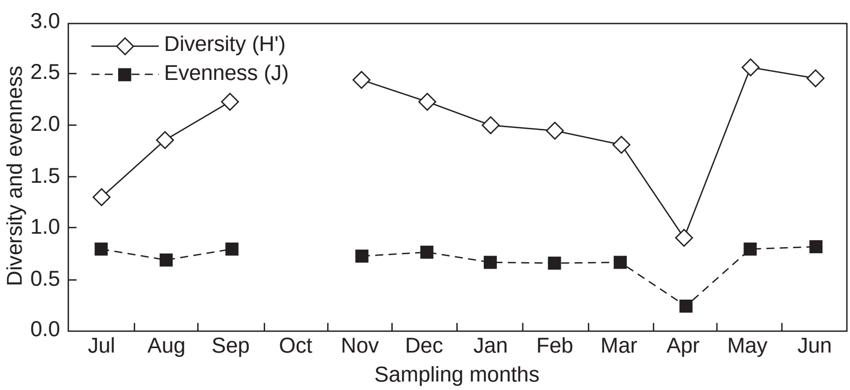

Fig. 4. Monthly variation of diversity and evenness of copepods in Makupa creek and Mombasa Harbour

CONCLUSION

Unlike other creeks of the Kenya coast, Makupa creek is effectively shielded from the open ocean due to its location and geomorphology. It is therefore considerably influenced by land runoff especially during the wet season. Due to the narrow and shallow nature of Kipevu Channel, which connects the creek to the Indian Ocean via Mombasa Harbour, flushing is poor. Thus the creek water, except during periods of extreme tides, may be expected to have extended resident time when compared to water in the neighbouring creeks, lagoons and bays.

Recent hydrodynamic studies of the creek (J. Kitheka, pers. commun.; unpublished data) reveal that it is usually completely flushed during spring tides, thus it has high rates of water exchange despite its enclosed nature. None of the physical parameters measured (mainly temperature and salinity) showed any stable condition—they varied with tidal and seasonal cycles.

The temperature and salinity ranges were very narrow all the year round, which is typical of tropical creeks. Therefore, high levels of BOD and other chemical conditions (Mwangi et al., unpublished data) were presumably the main contributing factors that caused biological and chemical instability. As a result, the factors may be responsible for the current unfavourable conditions of Makupa creek for the survival of copepods, other invertebrates and even fish.

Copepod abundance peaked during the NEM period and was usually highest at Stn 5 (up to 209/m^3) and Stn 3 (up to 78/m^3), which are the stations located close to the open ocean. At least 51 copepods species belonging to 38 genera were identified in Makupa creek and Mombasa Harbour. They were dominated by five major genera namely *Acartia*, *Acrocalanus*, *Corycaeus*, *Oithona* and *Oncaea*. These may be referred to as the characteristic copepod community of this locality. The five genera very often occurred together (co-occurred) each month at Stns 5 and 3. On the contrary, only two or at most three genera of these major copepods dominated in the other three Stns (1, 2 and 4). Station 5 was located in Mombasa Harbour close to the open ocean while Stn 3 was adjacent to it, though it was inside the creek. Results indicate that copepod species richness in Makupa creek is much less than in the adjacent waters which include Mombasa Harbour, the neighbouring creeks, bays and the neritic waters of East African coast in general. This is probably because this creek, due to its geomorphology and location, tends to accumulate contaminants derived from dumped raw municipal wastes. Mombasa residents produce an estimated 650 tonnes of industrial and domestic wastes daily (Osore, unpublished data) half of which has always been dumped at the shores of Makupa creek over the years. Additionally, routine operational activities of the Mombasa Harbour including storage (and subsequent accidental seepage) of crude oil, ship maintenance works etc., may be some of the factors contributing to environmental degradation.

Based on this and similar other research (including Abuodha & Kairo, 2001; Kamau, 2001; including various unpublished data) compared with results from adjacent locations, the authorities of the City of Mombasa have decided to relocate the dumping site from the shores of Makupa creek to a new site at Mwakirunge located to the northeast of Mombasa and further away from the coastline. Hopefully, due to the relocation of the dumping site, the fauna and flora of this degraded area will soon be restored.

This study presents a preliminary list of copepods that are associated with the kind of environmental degradation that Makupa creek has been experiencing. However, in order to effectively capture the entire representative copepod population of this creek, we recommend that sampling of zooplankton in future should employ not only the 335 µm but also the 180 µm mesh size nets. The copepod list is undoubtedly a useful contribution to the knowledge of the extant fauna in Makupa creek especially during the process of ecological recovery of this creek.

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