Hydrobiologia **356:** 117–126, 1997.

The effect of rainfall and tidal rhythm on the community structure and abundance of the zooplankton of Gazi Bay, Kenya

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Received 28 May 1996; in revised form 6 August 1997; accepted 9 September 1997

Key words: mangrove creek, zooplankton, TWINSPAN, rainfall, tides, Kenya

Abstract

Over a two year study period, zooplankton was sampled in Gazi Bay, Kenya, using a 335 μm mesh size Bongo net. Two Way Indicator Species Analysis (TWINSPAN) classification technique demonstrated that rainfall and tidal regime had substantial influence on the zooplankton community structure. Samples collected during the rainy season months clustered together when treated with TWINSPAN. Furthermore, the clustering was more pronounced for neap tide samples than for spring tide ones. Samples obtained during spring tide did not give a clear cut pattern. Canonical Correspondence Analysis (C.C.A.) confirmed these findings, a clustering together of rainy/neap tide samples; and little separation (based on environmental variables) between sampling stations.

Introduction

Few studies have been done on the community structure and seasonal variation of zooplankton of the inshore waters of East Africa. Most of these studies have been centered around major creeks and bays such as Mombasa and Dar-Es-Salaam. Reay & Kimaro (1984) studied surface zooplankton in the Port of Mombasa during the northeast monsoon. Kimaro and Jaccarini (1989) investigated the diel cycle of near-surface zooplankton abundance in Tudor Creek, Mombasa, during the southeast monsoon. Okemwa (1989) reported on 24 hours series of zooplankton sampling across Port Reitz, Mombasa. This study of Gazi bay is part of an ongoing long term campaign organized by Kenya Marine and Fisheries Research Institute Mombasa and the Free University of Brussels under the project Kenya/Belgium Cooperation in Marine Sciences. Previous related work in this bay includes a study on the diversity, density and respiration of the common Copepoda over a 24 hour cycle (Borger, 1990); and a survey of the distribution and diversity of some 22 important zooplankton taxa (Osore, 1992). The aim of the present work was to investigate zooplankton community in Gazi bay and its spatial-temporal variation.

Material and methods

Study area

Gazi Bay is situated 50 km south of Mombasa on the Kenya coast (4° 25′ S, 39° 30′ E), see Figure 1. The bay occupies an area of about 1500 ha which is divided into 661 ha of mangrove swamp, 25 ha of mangrove creeks, 300 ha of intertidal sand/mud flats and 500 ha of subtidal seagrass beds (Slim, 1993). It is well sheltered from the Indian Ocean by the Chale Peninsula and the coast fringing coral reef.

Climatic conditions in Gazi can generally be divided into two wet seasons (April–June and November–December) and two dry seasons which are dominated by north-easterly winds from November to March, and by south-easterly winds from April to October.

There is fresh water input into the bay from two seasonal rivers, Kidogoweni in the north west and Mkurumuji in the south west. There were three sampling stations in contrasting ecological zones. The coral reef zone at the mouth of the bay and adjacent to the open sea (Station 1), the mangrove dominated zone with a muddy, silty substratum near the mouth of River Kido-

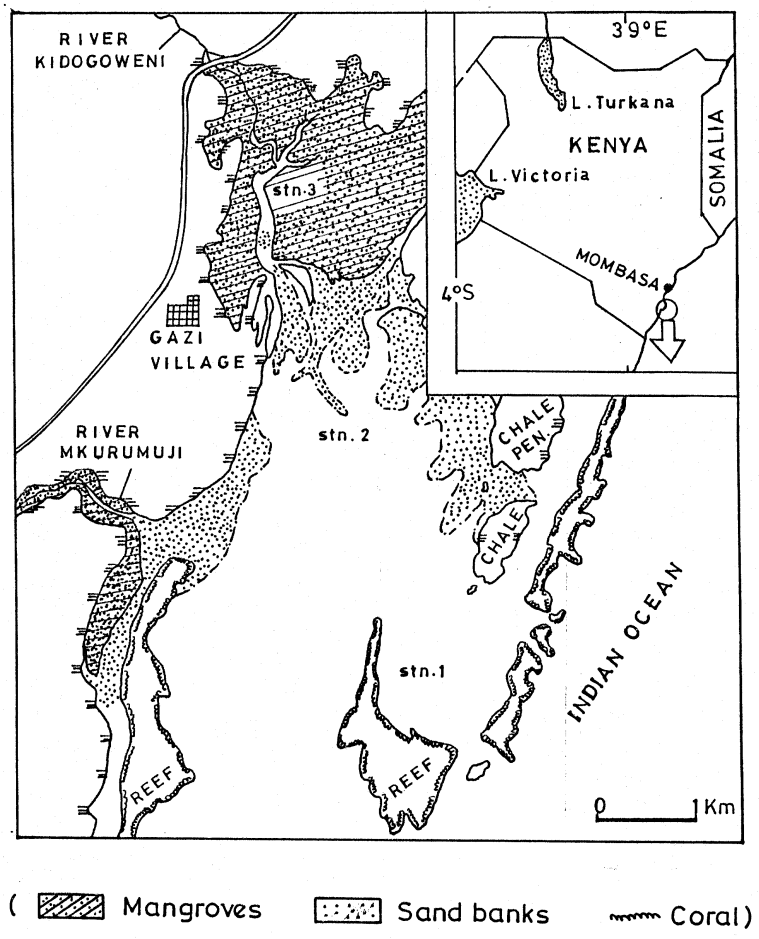


Figure 1. Map of Gazi Bay showing the sampling stations and the location of the BAY ON THE kenya coast.

goweni (Station 3) and the intermediate zone dominated by seagrass and sandbanks (Station 2).

The bay experiences the semi diurnal tidal pattern of two low waters and two high waters every 24 hour cycle. Average tidal range is 1.0 meter at neap tide and 2.5 metres at spring tide. Due to its morphology, the bay is well sheltered from strong waves.

Sampling

Sampling was carried out at Gazi between March 1990 and February 1992 and a total of 114 samples were collected. Samples were collected at least twice every month to include a spring tide and a neap tide. All samples were collected during the daytime high tide beginning from station 1 through station 2 up to station 3 (Figure 1).

A 1.5 meter long Bongo net with a mouth radius of 45 cm and mesh size 335 μm was used throughout. The volume of water filtered during each haul was measured by flowmeter. Three hauls were made at each station. The Bongo net was towed horizontally behind a rubber dinghy powered by a motor for five minutes at a constant speed of 0.5 ms^{-1}. After each haul, the catch was preserved in buffered 5% formalin. At each station environmental variables were also determined. Salinity was measured using the Artago Salinometer, pH was determined by using a digital pH meter Orion Research Model 231, transparency was measured using a secchi disc and dissolved oxygen determined by the Winkler method as described by Strickland and Parsons (1968). Temperature was measured using a mercury thermometer and rainfall data were obtained from the District Agricultural Office, Kwale District.

Laboratory and statistical analysis

Fixed samples were first filtered through a 50 μm mesh sieve. All organisms larger than 1 cm such as medusae, fish larvae etc. were then sorted out, and counted. The rest of the sample was placed in petri dishes and observed under a stereomicroscope. This initial step of scanning through the whole sample was to ensure that all the possible zooplankton groups present were exposed and accounted for qualitatively. Keys and identification references used were obtained from Giesbrecht (1892); Sars (1901); Scott (1909); Sewell (1929, 1932, 1947, 1948); Rose (1933); Tregouboff & Rose (1957); De Decker (1964); Hulsemann (1965); Brodsky (1967); Owre & Foyo (1967); Frost & Fleminger (1968); Bradford (1972); Fleminger (1973) and Greenwood (1979).

The samples were diluted to 250 ml and agitated gently. Five subsamples of 5 ml each were pipetted from each sample into counting chambers, total subsample volume being 1/10 of the total sample i.e. $(5 \times 5)/250 = 1/10$. The number of individuals in each systematic category was counted under the stereomicroscope at a magnification of $10 * 10$ for bigger organisms and $10 * 40$ for the smaller ones and in situ abundances calculated as numbers per cubic meter of water filtered (no m^{-3}).

In cases where organisms in the samples were too sparse, the entire sample was examined. Two Way Indicator Species Analysis (TWINSPAN) multivariate classification (Hill, 1974, 1979) and Canonical Correspondence Analysis (Ter Braak & Prentice, 1988) were used to analyse the abundance data.

Results

Abiotic factors

The surface water temperature was minimum (25.5 ± 2.0 °C) between the months of June and September and maximum (32.5 ± 2.5 °C) between December and February (see Figures 2a–e). Salinity was generally constant (at 35‰), however during the months of April to May it dropped considerably to as low as 20‰ in the inner bay. Dissolved oxygen varied between 4.00 mg l^{-1} and 7.00 mg l^{-1} except in February and March 1991 when it rose to over 10 mg l^{-1}. The pH of the surface water varied between 7.5 and 8.5 during most of the study period. Transparency was lowest (1.5 to 2.0 m) between April and June especially in the upper reaches of the Bay (stn 3). However, Gazi being a shallow creek, the bottom was usually visible.

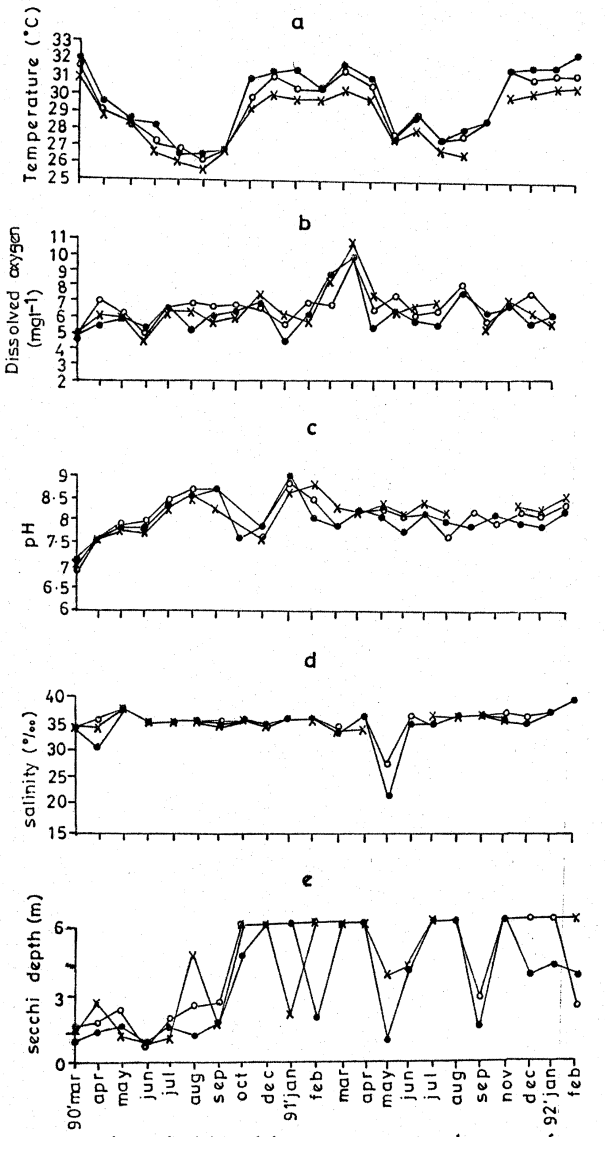


Figure 2. Monthly average values of temperature, dissolved oxygen, pH, salinity and transparency observed at gazi during the sampling period. (There was no sampling in Nov. '90 and Oct. '91)
–∗– station 1; –×– station 2; –●– station 3

Average monthly rainfall in Gazi was highest during the months of April, May and June (see Figure 3). The highest average monthly rainfall of 281 ± 103 mm was recorded during the month of May, and the lowest (26 ± 36 mm) was recorded from December to February.

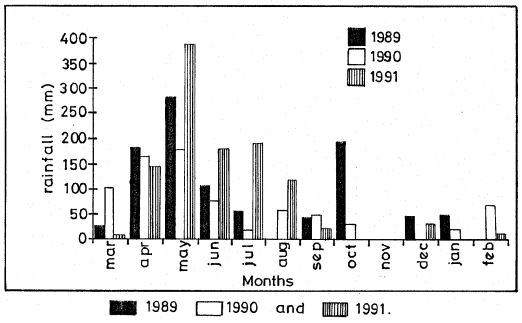


Figure 3. Monthly average rainfall data for Gazi area during ■ 1989; □ 1990; ▥ 1991.

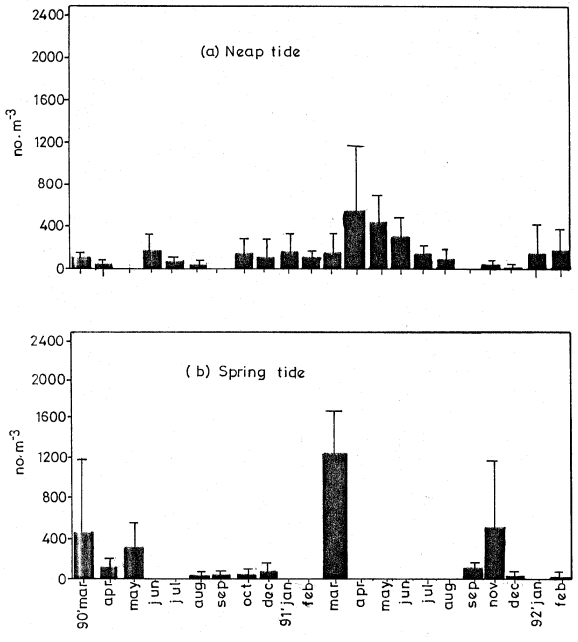


Figure 4. Monthly average zooplankton abundance for Gazi Bay during (a) neap tide samplings and (b) spring tide samplings. (There was no sampling in Nov. '90 and Oct. '91).

Zooplankton abundance

Homogeneity in different zooplankton communities at the sampling stations was observed throughout the sampling period. However, monthly average abundance varied considerably (see Figure 4). High abundance was recorded during the months of March 1990 (450 ind. m^{-3}), March 1991 (1200 ind. m^{-3}), April 1991 (550 ind. m^{-3}) May 1991 (450 ind. m^{-3}) and November 1991 (500 ind. m^{-3}).

Total dataset analysis

TWINSPAN was performed on complete data set in order to detect any pattern of classification/association that might exist. The abundance data were fourth root transformed before performing the TWINSPAN. Cut levels of 0.00, 0.32, 0.39, 0.57, 1.10, 3.30 and 10.00 were used. The results are shown in Figure 5. The outcome was a broad classification based on the tides (n-neap and s-spring as abbreviated in the dendrogram) and the months (rainy period and dry period). The first split divides the data in a cluster with a majority of neap tide samples on the right hand (with indicator species Isopoda, *Porcellidium spp.* and Polychaete larva) and a left hand cluster (with indicator species Euphausiid, Ctenophore, *Copilia spp.* and Siphonophore). This branch is further split into a left hand cluster of predominantly spring tide samples and a right hand cluster of mixed spring and neap tide samples.

The regression between the amount of rainfall for neap tide samples, not for spring tide ones, and zooplankton abundance was significantly positive ($p < 0.05$).

Neap tide and spring tide comparison

Based on the above results i.e.

i. the TWINSPAN on total data set and

ii. the difference in correlation between the amount of rainfall and zooplankton abundance for the separate tides,

TWINSPAN was further performed on neap and spring data separately.

The abundance data of the 114 samples were first converted into monthly averages. The neap tide monthly averages were separated from those of spring tide. In order to reduce the weight of the dominant species, both the neap and the spring tide samples were fourth root transformed first. The cut levels used in the analysis were 0.00, 0.67, 0.70, 0.80, 0.85, 1.30 and 1.75 for the neap tide data; and 0.00, 0.62, 0.75, 0.85, 1.05 and 1.40 for the spring tide data.

The results of the neap tide and spring tide data are illustrated in Figures 6a and 6b respectively.

For neap tide, a first split divides the year into two clusters of months: March–July and August–January (Figure 6a). The indicator species for the wet season (March–July) are *Acrocalanus spp.*, *Centropages furcatus*, *Labidocera orsinii*, *Arcartia spp.* and *Oncaea spp.* In the next division of the wet season cluster, the 'beginning-of-rain' samples (March to June) are sepa-

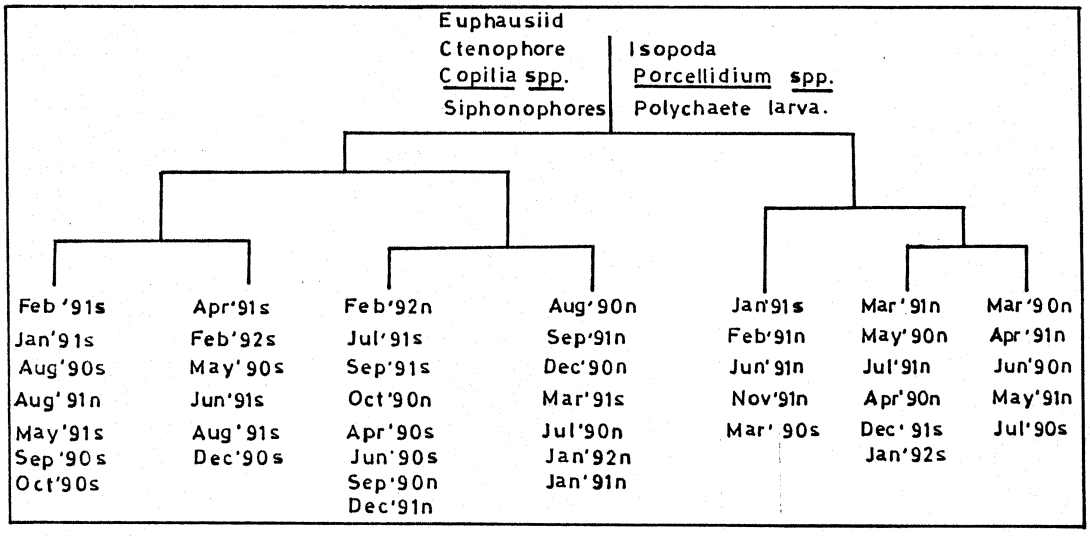


Figure 5. Dendrogram showing TWINSPAN results obtained for the total data set.

rated from the 'end-of-rain' samples (July to August) with *Sapphirina spp.* as the indicator species.

In the August–December cluster, there are several hazy splits. A first split separates the month of February 1992 from the rest (indicator species *Peltidium spp.*). Next, the January 1992 and December 1991 samples split off with *Temora turbinata* as the indicator species. The other branch containing Caridea as the indicator species splits further into a cluster of August 1990, October 1990 and December 1990 (indicator species Decapoda) and a rather overlapping cluster of January 1991, February 1991 and March 1991.

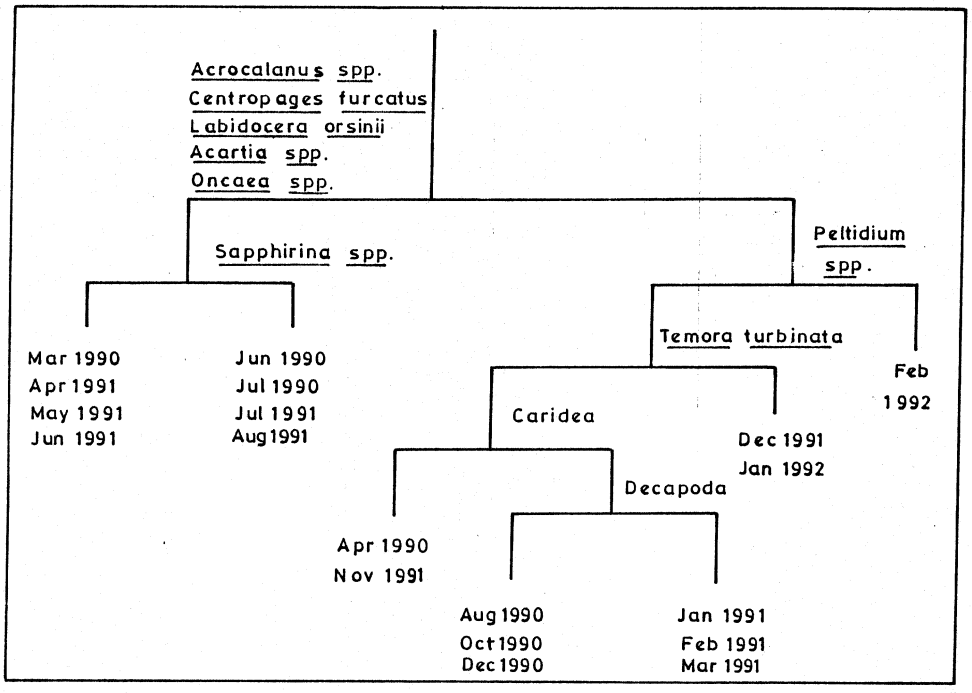
For the spring tide data, (see Figure 6b), a first split separates March 1991 and May 1990 from the rest of the group (indicator species *Centropages furcatus*). Next the cluster of September 1991, November 1991, December 1991 and January 1992 splits off with Decapoda as the indicator species; and the rest of the branch splits (indicator species Brachyura megalopa) and separates April 1990 samples from the other cluster containing samples of March 1990, August 1990, September 1990, October 1990 and December 1990 in one cluster; this group has *Lucicutia spp.* as indicator species. It is evident that the spring tide samples are not as clearly demarcated as the neap tide samples. This suggests that rainfall has a more pronounced effect on the neap tide samples than on the spring tide samples.

The interactions between environmental variables measured and the zooplankton communities were examined using Canonical Correspondence Analysis (C.C.A.). The spring and neap tide data were considered separately and subjected to fourth root transformation.

Results showed that no separation between the three stations occurred for the neap tide samples, most of the wet months (March, April and May) appeared clustered together at the top half side of the C.C.A. plot (Figure 7a). The clustering up of these months is not so evident for the spring tide samples (Figure 7b).

To determine whether the species distribution was significantly related to the environmental parameters, a Monte Carlo permutation test was done, only on the neap tide data (Figure 8). Species abundance data were significantly correlated with environmental variables (Monte Carlo, $p<0.01$) with rainfall and transparency coming out first in the favoured selection. Salinity was considered to be insignificant because it was generally constant for most of the time and only reduced drastically during the rainy season, and was as such correlated with rainfall.

Appendix I displays the average abundance (separate for wet and dry months) of common zooplankton taxa obtained at Gazi Bay during both neap and spring tides.



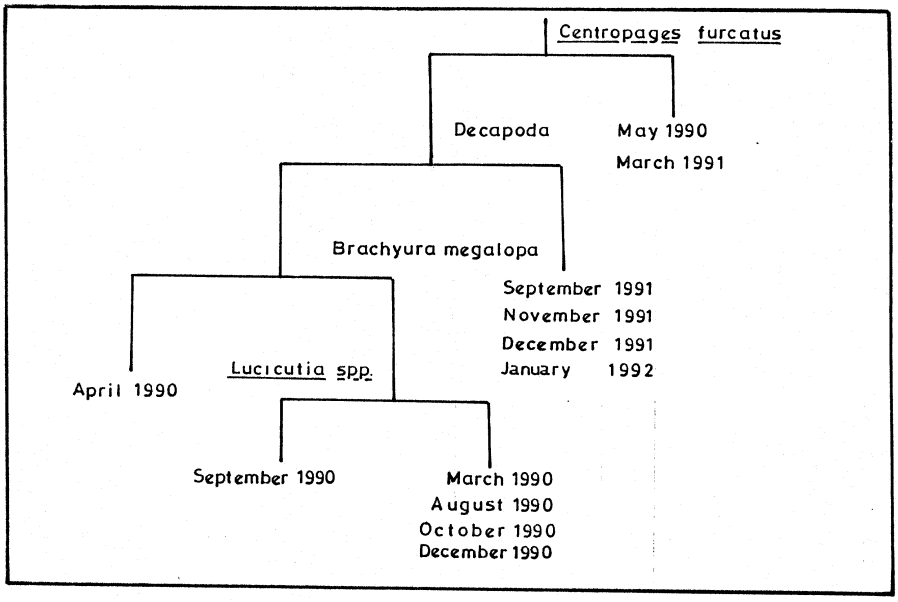


Figure 6. (*a*) Dendrogram showing TWINSPAN results obtained for the neap tide samples; (*b*) Dendrogram showing TWINSPAN results obtained for the spring tide samples.

Discussion

Gazi Bay experiences a period of low water temperature (25.5 to 28.0 °C) between the months of May to September; and a period of high temperature (29.0 to 32.0 °C) from October to April. Dissolved oxygen (at 4.5 to 7.0 mg l^{-1}) and pH (at 7.5 to 8.5) tended to resemble that of the adjacent open sea (unpublished

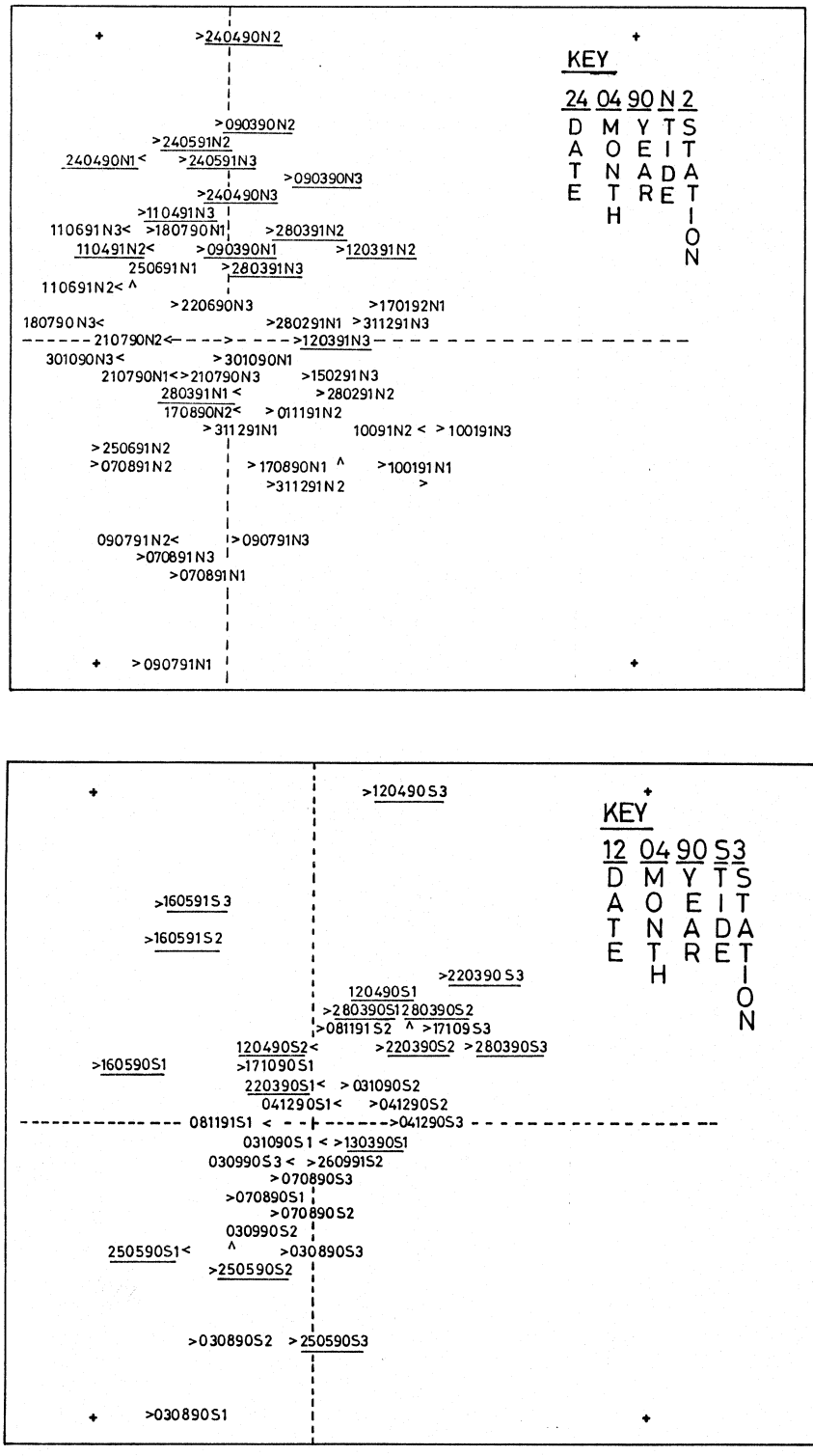


Figure 7. (a). C.C.A. biplot showing sample scores for the neap tide data. (rainy period samples are underlined) *(b).* C.C.A. biplot showing sample scores for the spring tide data (rainy period samples are underlined)

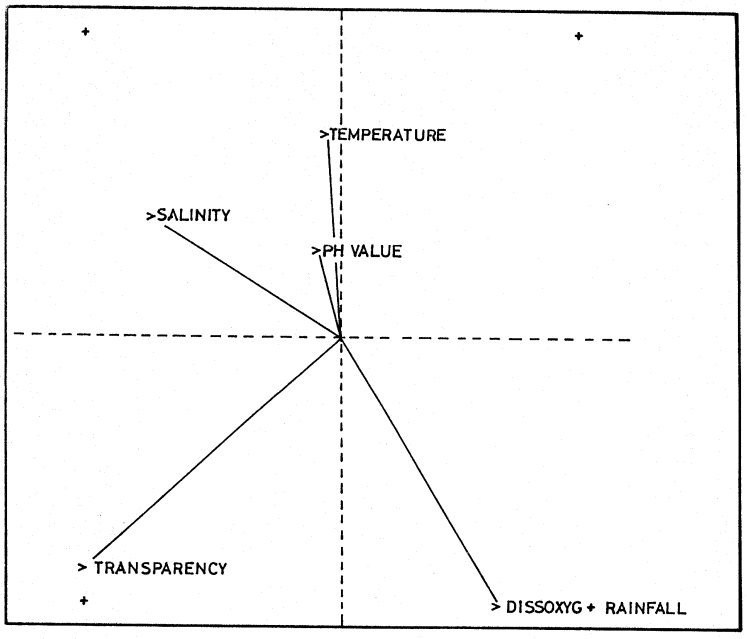


Figure 8. C.C.A. biplot of environmental variables of monthly averaged neap tide data.

data). However, in the inner parts of the bay where there is dense mangrove vegetation, lower oxygen and lower pH values were frequently observed. This is possibly due to compounds leaching from mangrove detritus and causing a drop in pH as they are oxidized (Robertson & Blabber, 1992). Transparency, used as a measure of the suspended matter in the water column, was very low in the silty, muddy and detritus rich inner parts of the bay. Low transparency in most parts of the bay usually accompanied heavy rainfall. At this time, surface run off from precipitation and the rejuvenated River Kidogoweni contributed to the importation of suspended matter into the bay thus lowering the transparency to about 1.5 m. Salinity fluctuation was also tied to the rainfall regime with values as low as 20‰ observed during the rainy period.

The rainfall regime during the study period displayed a clear pattern; there was one main wet season between March and June although the timing of the beginning and the end of the season varied from year to year. The driest season occurred in November and also around January and February when little or no rainfall was recorded. The highest zooplankton abundances were always obtained during the wet period (March–April–May) for both the neap and spring tide.

It has been demonstrated before that the tidal pattern has a considerable influence on zooplankton composition and abundance. Kimaro and Jaccarini (1989) described the influence of diel and lunar cycles on zooplankton in Tudor Creek during the N.E. monsoon. Okemwa

(1990) reported that some Copepoda species have their highest abundance during spring tide while others peak during neap tide.

Overall, little difference in species composition was observed among the three stations in Gazi Bay and the main changes in the community structure were seasonal.

Being shallow and open, Gazi Bay probably undergoes an almost total exchange of water with the adjacent open sea after every tidal cycle. This constant replenishment of water may be responsible for the minimum hydrographic variability between stations during each sampling session.

Rainfall was the most influential factor on zooplankton abundance and community structure. During the rainy season the total densities were higher (up to 1992 ind. m^{-3} in March) than during the dry period months (698 ind. m^{-3} was the highest collection obtained during January/February).

Zooplankton abundance correlated better with the amount of rainfall during neap tide than during spring tide. A possible explanation for this is that at neap tide, high water is normally lower than that of spring tide and does not penetrate considerably into the inner mangrove creeks. Thus, the flow of River Kidogoweni (then swollen up by the rain) can exceed the resistance coming from this 'weaker tide'. The effect of the river due to the rain is therefore pronounced. This effect could be in form of nutrient replenishment, change in salinity, or importation of the brackish - water zooplankton such as *Pseudodiaptomus spp*. into the bay. This phenomenon has yet to be investigated in the region and the information on it is therefore wanting. Future studies may be directed towards this observation.

Acknowledgments

We are grateful to all the staff of K.M.F.R.I., Mombasa and Laboratory of Ecology and Systematics, V.U.B., Belgium for assisting in the fieldwork and laboratory analysis that made the completion of this research possible. Thanks to Eunice Onyango for typing the manuscript.

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Appendix I . Seasonal occurrence of some common zooplankton taxa at Gazi Bay during the sampling period

Taxa	Abundance (no. m^{-3})			
	Spring tide		Neap tide	
	Wet months	Dry months	Wet months	Dry months
Copepoda				
Undinula vulgaris	5	1	5	6
Acrocalanus spp.	40	237	73	5
Paracalanus spp.	9	0	0	0
Temora turbinata	1	0	0	0
Tortanus murrayi	0	1	0	0
Tortanus sp.	1	1	1	0
Centropages furcatus	0	0	1	0
Centropages orsinii	2	1	1	0
Lucicutia spp.	0	1	0	0
Calanopia spp.	2	2	1	0
Labidocera acuta	0	1	0	0
Labidocera orsinii	0	0	1	0
Pseudodiaptomus spp.	16	120	22	17
Acartia spp.	53	84	22	2
Oithona spp.	16	120	65	93
Oncaea spp.	0	1	0	0
Corycaeus spp.	1	1	0	1
Copilia spp.	1	1	0	0
Peltidium spp.	0	1	0	0
Porcellidium spp.	0	1	1	0
Harpacticoida	2	9	1	7
Copepoda nauplii	2	15	6	20
Other zooplankton				
Foraminifera	0	0	1	3
Acantharian	0	0	0	1
Amphipoda	1	1	1	1
Oikopleura	3	3	1	3
Siphonophora	1	0	0	0
Medusae	1	0	1	1
Ctenophora	1	0	0	0
Chaetognatha	5	2	3	3
Ostracoda	1	1	0	0
Gastropoda	2	2	7	2
Euphausiaceae	1	0	0	0
Brachyuran zoea	36	4	4	6
Brachyuran megalopa	1	0	1	0
Caridea	2	1	1	1
Other decapoda	0	1	0	0
Cirripaed nauplii	1	0	0	1
Isopoda	0	1	1	1
Cladocera	1	0	0	0
Bivalve larvae	1	1	2	0
Cumacea	0	1	0	0
Fish eggs	13	2	6	2
Polychaeta	2	1	1	0
Nematoda	0	1	0	0